Dairy Intake Is Protective against Bone Loss in Older Vitamin D Supplement Users: The Framingham Study1–3

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Abstract

Background: Previous studies showed beneficial effects of specific dairy foods on bone health in middle-aged adults. Objective: We examined the association of milk, yogurt, cheese, cream, fluid dairy (milk + yogurt), and milk + yogurt + cheese intakes with bone mineral density (BMD) and Δ%BMD; femoral neck, trochanter, and lumbar spine (LS), and %BMD. Dairy-food intakes (servings per week) were converted to energy-adjusted residuals, and linear regression was used, adjusting for covariates. These associations were further examined by vitamin D supplement use.

Methods: Food-frequency questionnaire responses, baseline BMD (hip and spine, n = 862 in 1988–1989), and follow-up BMD (n = 628 in 1992–1993) were measured in the Framingham study, a prospective cohort study of older Caucasian men and women aged 67–93 y. Outcomes included baseline BMD and Δ%BMD. Dairy-food intakes (servings per week) were converted to energy-adjusted residuals, and linear regression was used, adjusting for covariates. These associations were further examined by vitamin D supplement use.

Results: The mean age of the participants was 75 y. In the full sample, dairy-food items were not associated with BMD (P = 0.11–0.99) or with Δ%BMD (P = 0.29–0.96). Among vitamin D supplement users, but not among nonusers, higher milk, fluid dairy, and milk + yogurt + cheese intakes were associated with higher LS BMD (P = 0.011–0.009). Among vitamin D supplement users, but not among nonusers, higher milk + yogurt + cheese intakes were protective against trochanter BMD loss (P = 0.009).

Conclusions: In this population of older adults, higher intakes of milk, fluid dairy, and milk + yogurt + cheese were associated with higher LS BMD, and a higher intake of milk + yogurt + cheese was protective against trochanter BMD loss among vitamin D supplement users but not among nonusers. These findings underscore that the benefits of dairy intake on the skeleton may be dependent on vitamin D intake. J Nutr 2017;147:645–52.

Keywords: dairy food, milk, bone mineral density, osteoporosis, older adults, bone loss, observational studies, vitamin D

Introduction

It is estimated that 10 million Americans >50 y old have osteoporosis (1), a disease characterized by low bone mass and progressive deterioration of bone tissue (2). The consequences of osteoporosis include increased risk of fracture, loss of physical function, increased mortality and morbidity, and decreased quality of life (3). Osteoporosis prevention includes regular physical exercise and adequate intakes of calcium and vitamin D (1). Dairy foods are good sources of calcium and vitamin D and provide more protein, calcium, magnesium, potassium, and phosphorus than any other food (4, 5). Yet, >80% of the US population does not meet the recommended dairy intake (6) of 3 servings/d (7).

Our previous research and that of others have suggested a positive link between milk intake and bone mineral density (BMD)8 (8–12). Although previous studies of BMD have...
focused primarily on young, premenopausal women (13–16), most evaluated milk intake and did not consider other dairy foods with different nutritional profiles or total vitamin D intake. Under normal dietary conditions, ~30–40% of the calcium contained in milk and cheese is absorbed in the gut through vitamin D–dependent transport across the duodenum, facilitated diffusion, or under the influence of lactose in the distal small intestine via the paracellular route (4). Vitamin D stimulates calcium absorption, which is beneficial for building bones and preventing bone loss over time, and a recent study showed that there was no threshold of calcium absorption with increased vitamin D intakes (17). However, recent data evaluating the effect of vitamin D on BMD have been inconsistent. A meta-analysis (18) and a randomized controlled trial (RCT) (19) concluded that there was no evidence of an overall benefit of vitamin D supplementation on BMD, yet there was a small but relevant effect on calcium absorption. It thus remains unclear whether the effect of vitamin D on calcium absorption is substantial enough to translate into beneficial effects on BMD, especially in older, calcium-replete women who are represented in the recent clinical trial (19). Additionally, recommended intakes of vitamin D are difficult to achieve without fortified foods or supplements (20). Further, RCTs to date have focused almost exclusively on calcium and vitamin D supplement use and not on dairy intake, which is a concentrated source of both calcium and vitamin D (in vitamin D–fortified dairy foods).

This prospective cohort study examined the association of dairy-food intake [servings per week of milk, yogurt, cheese, cream, fluid dairy (milk + yogurt) and milk + yogurt + cheese] with BMD and bone loss and if these associations were modified by additional vitamin D intake via supplements in older adults from the Framingham Original Cohort. Our hypothesis was that higher intake of all dairy foods except cream would be associated with higher BMD and lower BMD loss in this older population of men and women but that vitamin D supplement users would realize greater benefits than nonusers.

**Methods**

**Study population.** The sample included participants in the Framingham Osteoporosis Study, an ancillary study of the Framingham Heart Study. This population-based cohort study began in 1948 to examine risk factors for heart disease. The original participants (5209 men and women, aged 28–74 y) were selected as a population-based random sample of households in Framingham, Massachusetts (21). Of 5209 men and women who formed the original cohort, 1164 cohort members participated in the Framingham Osteoporosis Study, when BMD measurements were taken in 1988–1989. Of these participants, we excluded men and women with incomplete FFQ information (based on the criteria of >12 food items left blank in the FFQ), energy intakes <2.51 or >16.74 MJ (<600 or >4000 kcal/d), or missing covariate information [BMI (in kg/m²), n = 1; milk and yogurt intake, n = 1]. The final analytic sample for the cross-sectional study of dairy intake and BMD included 862 men and women with a valid FFQ in 1988–1989 and ≥1 baseline bone site measured in 1988–1989. The final sample for the longitudinal cohort study of dairy intake and bone loss included 628 men and women with a valid FFQ in 1988–1989 and ≥1 longitudinal bone site measured at the 4-y follow-up examination in 1992–1993.

**Outcome ascertainment.** BMD was measured in the original cohort in 1988–1989 and in 1992–1993 at the femur, spine, and radius, as previously described (22). BMD of the proximal right femur [femoral neck (FN) and trochanter] and lumbar spine (Ls; average L2-L4) were measured in gram per square centimeter by using a Lunar DP3 dual-photon absorptiometer at baseline. At the 4-y follow-up examination, BMD was measured by using DXA (DPX-L; Lunar Radiation Corporation). There were strong correlations between measures taken with dual photon absorptiometry and DXA; however, because of a small but consistent shift in BMD values between the 2 methods, FN BMDs were adjusted for a change from DP3 to DPX-L technology by using published corrections (23). BMD at the radial shaft was measured in gram per square centimeter with a Lunar SP2 single-photon absorptiometer (Lunar Radiation Corporation) at both examinations.

**Dietary assessment.** Usual dietary intake was assessed with the semiquantitative, 126-item Willett FFQ at the baseline examination for this study in 1988–1989 (24). This FFQ has been validated against four 7-d dietary records in the Nurses’ Health Study (25) and against multiple diet records and blood measurements for many nutrients, including protein, in several populations (26, 27). The corrected correlation coefficients ranged from 0.57 to 0.94 for dairy products. Questionnaires were mailed to the study participants before their scheduled clinic visit. They were asked to complete the questionnaires based on their intake over the previous year and bring them to the clinic examination, where the questionnaires were reviewed with participants by clinic staff. Intake of dairy exposure variables was assessed in servings per week by using the food-list section of the FFQ. Willett’s questionnaire specifies the serving size for each dairy food as follows: milk, skim or low-fat or whole (8-ounce glass or 237 mL); ice milk (1/2 cup or 118 mL); cottage or ricotta cheese (1/2 cup or 118 g); other cheese (1 slice, 1-ounce serving, or 30 g); cream (1 tablespoon or 15 g); sour cream (1 tablespoon or 15 g); ice cream (1/2 cup or 118 g); cream cheese (1 ounce or 30 g); and yogurt (1 cup or 237 g). Milk intake was calculated as the sum of intake of skim milk, low-fat milk, whole milk, and ice milk. Cheese intake was calculated as the sum of intake of cottage and ricotta cheese and other cheeses. Cream intake was calculated as the sum intake of cream, sour cream, ice cream, and cream cheese. Yogurt intake was also estimated in servings per week (fat-free, reduced fat, and full fat combined). A variable for fluid dairy intake was created, which included milk and yogurt in servings per week. A variable for total dairy intake was created, which included intake of milk, yogurt, and cheese in servings per week. Intakes of dietary calcium (expressed as mg/d), dietary vitamin D (expressed as IU/d), calcium supplement use (expressed as mg/d), vitamin D supplement use (yes or no), calcium (expressed as mg/d), protein (expressed as g/d) intake from nondairy-food sources, and total energy (expressed as kcal/d) were assessed by using the food-list section of the FFQ.

**Potential confounding factors.** Sex, age (years), height (meters), weight (kilograms), smoking (current or noncurrent), physical activity, total energy (expressed as MJ/d), alcohol (expressed as g/d), caffeine (expressed as mg/d), calcium supplement use (expressed as mg/d), vitamin D supplement use (yes or no), and current estrogen use (yes or no) in women only were measured at the baseline examination for this study in 1988–1998. The dietary intakes and supplement use were assessed by using the FFQ. Furthermore, intake of total energy and total intake of dairy-specific nutrients (from dairy and other sources), such as dietary calcium, and vitamin D were measured by using the food-list section of the FFQ.

Height at examination 1 (1948–1949) was measured without shoes, in inches (converted to meters), and measurements of weight were taken at the 20th examination in pounds (converted to kilograms) with a standardized balance-beam scale. Smoking status was assessed via the questionnaire in 1988–1989 as current cigarette smoker (smoked regularly in the past year), former smoker, or never smoked. Physical activity was measured with the Framingham physical activity index, which asked about the number of hours spent in heavy, moderate, light, or sedentary activity and the number of hours spent sleeping during a typical day (28). Physical activity index scores at the baseline examination (1988–1989) were used unless missing; if an individual was missing data, the physical activity index from 2 y earlier was used. To adjust for current estrogen use, participants were divided into 3 groups: 1) men, 2) women who never used estrogen or used it formerly, and 3) women currently using estrogen (>1 y).
Statistics analysis. The primary exposure variables included intake of milk, yogurt, cheese, cream, and a combination of milk + yogurt + cheese. Study outcomes included baseline and 4-yr percentage of change in BMD at the FN, trochanter, and LS. We tested for interaction by sex by including an interaction term of individual dairy-food intake and sex in the adjusted models. Similarly, we also tested for interaction by vitamin D supplement use by including an interaction term of individual dairy-food intake and vitamin D supplement use in the adjusted models. Finally, we tested interactions for 4 dairy-food groups, only interactions that were significant at $P < 0.0125$ were examined to avoid false-positive results. All dairy exposures were adjusted for total energy intake by using the residual method (29). Dairy intakes were regressed on total energy intake to create residuals, which were then added to the predicted dairy intake for the mean energy intake of the study population.

To determine the cross-sectional association between dairy intake variables (modeled as continuous variables, in servings per week) and BMD at each site, we used multivariable linear regression to calculate regression coefficients ($\beta$) estimating the difference in BMD associated with a 1-unit increase in dairy intake (i.e., an increase of 1 serving/wk). Analyses of 4-yr percentage of change in BMD from baseline (1988–1989) to the follow-up (1992–1993) were first calculated as $[(BMD \text{ at follow-up} - BMD \text{ at baseline}) / BMD \text{ at baseline}] \times 100$. The 4-yr percentage of change in BMD was regressed onto the continuous form of energy-adjusted dairy-food intake variables, adjusting for potential confounders and covariates. To examine if the cross-sectional and longitudinal associations between dairy intake variables and bone measures were modified by vitamin D supplement use, we stratified the cross-sectional and longitudinal analyses by vitamin D supplement use (yes or no).

The models were initially adjusted for sex, total energy intake, age, height, and weight. Subsequent models were further adjusted for current cigarette smoking and calcium supplement use. Longitudinal models examining 4-yr percentage of change in BMD were further adjusted for baseline BMD. Starting with a full model, we performed sequential regression models, removing variables one at a time, such that any covariate that changed the $\beta$ coefficient of the primary exposure by >10% was included in the final parsimonious model. Based on this method, estrogen use (in women alone), physical activity, alcohol, and caffeine did not contribute to the final parsimonious models. Final parsimonious models were further adjusted sequentially for nondairy calcium intake (expressed as mg/d) and nondairy protein intake (expressed as g/d). Student’s $t$ test (for normally distributed variables) and the chi-square test (for categorical variables) were used to compare participants with baseline BMD assessments alone with those who also had a follow-up BMD assessment.

All analyses were performed by using SAS statistical software (version 9.1; SAS Institute Inc.). A nominal 2-sided $P$ value of <0.05 was considered statistically significant for all the analyses. For interactions with sex, nominal 2-sided $P$ values <0.002 were considered statistically significant.

Results

One thousand one hundred sixty-four cohort members had BMD measured at the baseline examination in 1988–1989. At the same examination, 976 participants had complete, usable FFQs. Of these, 864 participants had ≥1 BMD measure and a complete, usable FFQ. After excluding 1 participant with missing information on BMI and 1 participant with missing information on milk and yogurt, the final analytic sample for the cross-sectional study of dairy intake and BMD included 862 men and women. The final sample for the longitudinal cohort study of dairy intake and bone loss included 628 men and women. Mean follow-up time between the 2 BMD measurements was 3.9 y (range: 2.1–5.1 y). The mean age was 75 y (range: 69–96 y) at the baseline examination (Table 1). Of the 863 total participants, 38% were men, and 27% used vitamin D supplements. Among vitamin D supplement users, total milk intake was 6.3 servings/wk (1538 mL/wk), total calcium intake was 966 mg/d, and vitamin D intake was 591 IU/d. In this group, 44% of participants used calcium supplements. Among those who did not use vitamin D supplements, total milk intake was 5.8 servings/wk (1372 mL/wk), total calcium intake was 745 mg/d, and vitamin D intake was 184 IU/d. In this group 8% of participants used calcium supplements.

Interaction by sex. After adjusting for testing multiple interactions at the $P$ level of 0.0125, no significant interactions were observed by sex (cross-sectional analyses: $P$-interaction = 0.013–0.99; longitudinal analyses: $P$-interaction = 0.18–0.96). Therefore, all analyses were conducted with both men and women combined.

After adjusting for testing multiple interactions at the $P$ level of 0.0125, in cross-sectional analyses significant interactions were observed by vitamin D supplement use for LS BMD ($P$-interaction with milk = 0.004, fluid dairy = 0.005, and total dairy = 0.010). No significant interactions were observed by vitamin D supplement use for other bone sites or other dairy foods ($P$-interaction = 0.13–0.94). For longitudinal analyses, significant interactions were observed by vitamin D supplement use for trochanter bone loss ($P$-interaction with total dairy = 0.011) and LS bone loss ($P$-interaction with cheese = 0.009). No significant interactions were observed by vitamin D supplement use for other bone sites or other dairy foods ($P$-interaction = 0.032–0.83). Therefore, all analyses were conducted stratified by vitamin D supplement use.

Cross-sectional association with BMD. Dairy intake in servings per week was not associated with BMD in the multivariate-adjusted models ($P = 0.11–0.99$) with the full sample. Adjusted models were then stratified by vitamin D supplement use (yes or no, Table 2). Among vitamin D supplement users, but not among nonusers ($P = 0.09–0.41$), higher intakes of milk ($P = 0.011$), fluid dairy ($P = 0.009$), and milk + yogurt + cheese ($P = 0.005$) were associated with higher LS BMD. Among vitamin D supplement users, there was a 0.006-g/cm² difference in LS BMD for an increase of 1 serving milk/wk. These associations did not change significantly after further adjustment for calcium and protein from nondairy-food sources except for milk intake, which became negatively associated with LS BMD ($P = 0.030$) among nonsupplement users (data not shown). No significant associations were observed at the trochanter or FN among vitamin D supplement users or nonusers ($P = 0.11–0.97$). These associations did not change significantly after further adjustment for calcium and protein from nondairy-food sources, except for cream intake, which became negatively associated with FN BMD among vitamin D supplement users ($P = 0.050$) (data not shown).

Longitudinal association with percentage of change in BMD over 4 y. In the combined sample of vitamin D supplement users and non-users, no significant associations were observed between any type of dairy food and percentage of change in BMD over 4 y at any site ($P = 0.29–0.96$) in the multivariate-adjusted model. However, when stratified by vitamin D supplement use, among vitamin D supplement users, but not among nonusers ($P = 0.10–0.59$), milk + yogurt + cheese...
intakes \((P = 0.009)\) were protective against trochanter-BMD loss (Table 3). There was a 0.23% increase in trochanter-BMD over 4 y for every serving increase of milk + yogurt + cheese per week. Similarly, no significant associations between any type of dairy and percentage change in BMD over 4 y at FN or LS were observed among vitamin D supplement users or nonusers \((P = 0.07–0.79)\). These associations did not change significantly after further adjustment for calcium and protein from nondairy-food sources (data not shown).

Only 73% of participants had the follow-up BMD measurements for the longitudinal analyses. Those who were lost to follow-up were older (mean age: 77 y) and had lower BMI (26.0) than those with follow-up assessments (mean age: 74 y; and BMI: 26.9).

### Discussion

In this group of older men and women, dairy-food intakes were not significantly associated with BMD or percentage of change in BMD over 4 y. On stratification by vitamin D supplement use, among vitamin D supplement users, but not nonusers, higher intakes of milk, fluid dairy, and a combination of milk + yogurt + cheese were significantly associated with higher LS BMD, whereas a higher cream intake was significantly associated with lower FN BMD. A higher intake of milk + yogurt + cheese was significantly associated with lower trochanter bone loss over 4 y. Trochanter BMD was 0.23% greater for each additional serving of milk + yogurt + cheese per week.

The 2010 Dietary Guidelines for Americans recommend consuming 3 cups/d (1 cup = 237 mL) of fat-free or low-fat milk or milk products for adults. Despite these recommendations, >80% of the US population does not meet the dairy intake recommendation (6). The percentage of Americans who consumed the recommended dairy equivalents/d of fluid milk, cheese, and yogurt has been estimated as 53%, 45%, and 2%, respectively (6). Adequate dietary calcium and protein are essential to achieve optimal peak bone mass during skeletal growth and to prevent bone loss in the elderly (30). Dairy products are not only rich in calcium and protein, but they also provide other key nutrients essential for bone health, including vitamin D, potassium, phosphorus, and magnesium. Although several studies have shown the positive impact of milk intake on BMD, few have examined dairy products beyond milk even though it has been suggested that dairy foods are not equivalent vehicles of calcium because of their different nutritional profiles (31). Additionally, consumption of fermented dairy products, such as yogurt, may confer additional advantage for gut microbiota (30), and their effects on bone health remains to be elucidated. Yet, few large-scale epidemiologic studies have specifically examined yogurt or have found it difficult to disaggregate the effect of yogurt consumption from general dairy intake (32).
Aged $\geq 60$ y. A cross-sectional study of women (aged 44–74 y) found consistent positive associations between self-reported milk consumption before the age of 25 y and BMD at total hip, FN, trochanter, intertrochanter ($P < 0.05$ each), and Ward’s triangle ($P < 0.005$) (33). Results from the Rancho Bernardo Study of 581 white elderly women (mean age: 71 y) showed that regular milk consumption in youth was associated with higher BMD at cortical and trabecular sites (34). A recent study of older women from the Calcium Intake Fracture Outcome Study (35). Our previous cross-sectional study in the Framingham Offspring Cohort (mean age: 55–65 y), those randomly assigned to a fortified dairy group (1200 mg calcium/d and 7.5 mg cholecalciferol/d) had more favorable changes in pelvis, total spine, and total body BMD ($P = 0.001$–0.04) over 12 m than a calcium-supplemented group (600 mg calcium/d) or the control group (9). Hence, a concomitant increase of calcium and vitamin D may be more important for bone density than increasing calcium intake alone through supplementation. In a study of 200 postmenopausal Chinese women in Malaysia (aged 55–65 y), those randomly assigned to a high-calcium skimmed-milk group (1200 mg calcium) had a reduced rate of bone loss at the hip and LS BMD compared with the placebo group. This study further reported significant improvements in the serum 25-hydroxy vitamin D concentration in the milk group ($P < 0.01$) (37). Taken together, these studies suggest a protective role for dairy intake with hip and LS BMD. However, they were unable to clarify if these beneficial bone effects of dairy were dependent on adequate vitamin D intake.

The evidence for protective effects of milk and dairy intake on longitudinal change in total hip and vertebral BMD and total hip bone mineral content comes largely from RCTs of premenopausal women (15, 36). Most of the RCTs in older age groups comparable to the current study were conducted in non-US populations of Malaysia (37), Greece (9), and South Australia (38, 39) with differing intakes of calcium and vitamin D. All these studies examined fortified milk except 2, which examined fortified dairy (milk + yogurt) intake (9) and fortified cheese intake (40). Interestingly, in a study of 101 postmenopausal women (55–65 y), those randomly assigned to a fortified dairy group had more favorable changes in pelvis, total spine, and total body BMD ($P = 0.001$–0.04) over 12 m than a calcium-supplemented group (600 mg calcium/d) or the control group (9). Hence, a concomitant increase of calcium and vitamin D may be more important for bone density than increasing calcium intake alone through supplementation. In a study of 200 postmenopausal Chinese women in Malaysia (aged 55–65 y), those randomly assigned to a high-calcium skimmed-milk group (1200 mg calcium) had a reduced rate of bone loss at the hip and LS BMD. However, they were unable to clarify if these beneficial bone effects of dairy were dependent on adequate vitamin D intake.

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Dairy products are rich in calcium as well as other nutrients, and thus, there is a benefit to increasing dairy intakes up to a level of 2–3 servings/d, as suggested by our previous work (11) and that of others as highlighted in 2 reviews (41, 42). In addition, vitamin D regulates calcium absorption and skeletal homeostasis. The active form 1,25-dihydroxyvitamin D facilitates the intestinal absorption of calcium by mediating active calcium transport across the intestinal mucosal brush border to the basolateral side of the cell (43). This suggests that a person needs both adequate calcium and vitamin D to ensure optimal

<table>
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<tr>
<th>Dairy food, servings/wk</th>
<th>Vitamin D supplement nonusers ($n = 629$)</th>
<th>Vitamin D supplement users ($n = 233$)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>$\beta \pm SE$</td>
<td>$P$</td>
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<tr>
<td>FN BMD</td>
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<tr>
<td>Milk</td>
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<td>Fluid dairy</td>
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<td>0.44</td>
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<td>Milk + yogurt + cheese</td>
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<td>0.35</td>
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<tr>
<td>Trochanter BMD</td>
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<tr>
<td>Milk</td>
<td>$-0.0011 \pm 0.0009$</td>
<td>0.95</td>
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<td>Yogurt</td>
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<td>0.95</td>
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<tr>
<td>Milk + yogurt + cheese</td>
<td>$-0.0004 \pm 0.0008$</td>
<td>0.63</td>
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<tr>
<td>LS BMD</td>
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<tr>
<td>Milk + yogurt + cheese</td>
<td>$-0.0012 \pm 0.0013$</td>
<td>0.39</td>
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1 Median total vitamin D intake is 184 IU/d for supplement nonusers and 591 IU/d for supplement users. BMD, bone mineral density; FN, femoral neck; LS, lumbar spine.

2 Dairy-food intakes were energy-adjusted residuals added to a constant, where the constant equals the nutrient intake for the mean energy intake of the study population. Parsimonious models were adjusted for age, weight, height, sex (men, women who never used estrogen or used it formerly, and women currently using estrogen), total energy intake, calcium supplement use, and smoking. Serving size for each dairy food: milk, skim or low-fat or whole (8-ounce glass or 237 mL), ice milk (1/2 cup or 118 mL), cottage or ricotta cheese (1/2 cup or 118 g), other cheese (1 slice, 1-ounce serving, or 30 g), cream (1 tablespoon or 15 g), sour cream (1 tablespoon or 15 g), ice cream (1/2 cup or 118 g), cream cheese (1 ounce or 30 g), and yogurt (1 cup or 237 g).

Dairy-food intake, vitamin D, and bone loss
net absorption of calcium for meeting various body needs from commonly available food sources (44). The main findings from the current study showed that specific dairy foods appeared to be protective against trochanteric bone loss but only among those with higher vitamin D intakes through supplements. These findings suggest that individuals who use vitamin D supplements may reap bone-protective benefits with higher dairy intakes. Of concern is the finding that dairy foods did not appear to protect against bone loss among those who did not use vitamin D supplements. In the United States, fortified foods provide most of the vitamin D in the diet (45) with 100 IU added per cup in most milk (45, 46). In addition to vitamin D fortification, many yogurts in the United States add skim milk powder, which increases the protein, calcium, and phosphorus content. Therefore, the lack of association between dairy foods and bone loss among non–supplement users suggests that the amounts of vitamin D in dairy foods, which are often fortified with vitamin D, may not be sufficient to provide bone benefits. However, it is important to note that those who did not use vitamin D supplements also tended to have lower intakes of total (from diet and supplements) vitamin D and calcium. Further, in this group, relatively fewer individuals were using calcium supplements (8.1% compared with 43.3% among vitamin D supplement users).

The current study is unique in that we used data from a population-based cohort of older individuals followed up for ≤4 y. Not only did we examine intake of milk and other dairy foods, but we further examined if vitamin D supplement use modified the association of dairy intake with bone loss. However, this study has several limitations. We used an FFQ, which is semiquantitative, and dietary data were available only at the baseline examination. Therefore, we were unable to adjust for possible changes in diet over follow-up. However, we examined not just total dairy intake but also specific dairy-food groups with both BMD and bone loss over 4 y. Dairy foods, such as milk, yogurt, and cream, have dissimilar nutritional profiles that may play a role in the way they affect bone health. Because of a lack of availability of serum vitamin D concentration in this cohort, we were only able to stratify these analyses by vitamin D supplement use alone, which does not account for the vitamin D formed in the skin by sun exposure. Residual confounding may occur despite our attempts to control for several potential confounders. Lastly, the results of this study are generalizable primarily to non-Hispanic, white men and women.

In conclusion, our results suggest that, in a population of older men and women, higher intakes of a combination of milk + yogurt + cheese are associated with lower trochanter bone loss over 4 y among vitamin D supplement users. Future studies should consider nutrient profiles of specific dairy groups while researching their associations with bone health in other populations and with other clinical outcomes, such as fractures. Additional studies are needed to confirm these findings by using serum vitamin D concentrations.

Acknowledgments
SS and MTH designed the study; DPK and MTH provided access to the data; SS conducted the data analysis, revised the manuscript content, and had responsibility for the integrity of the data analysis; SS, DPK, KLT, and MTH conducted data interpretation; and SS and KMM drafted the manuscript. All authors read and approved the final manuscript.
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