The American Journal of Clinical Nutrition

Dairy foods and bone health: examination of the evidence[1,2]

Roland L Weinsier and Carlos L Krumdieck

ABSTRACT It is unclear whether dairy foods promote bone health in all populations and whether all dairy foods are equally beneficial. The objective of this review was to determine whether scientific evidence supports the recommendation that dairy foods be consumed daily for improved bone health in the general US population. Studies were reviewed that examined the relation of dairy foods to bone health in all age, sex, and race groups. Outcomes were classified according to the strength of the evidence by using a priori guidelines and were categorized as favorable, unfavorable, or not statistically significant. Of 57 outcomes of the effects of dairy foods on bone health, 53% were not significant, 42% were favorable, and 5% were unfavorable. Of 21 stronger-evidence studies, 57% were not significant, 29% were favorable, and 14% were unfavorable. The overall ratio of favorable to unfavorable effects in the stronger studies was 2.0 (4.0 in <30-y-olds, 1.0 in 30–50-y-olds, and 1.0 in >50-y-olds). Males and ethnic minorities were severely underrepresented. Dairy foods varied widely in their content of nutrients known to affect calcium excretion and skeletal mass. Foods such as milk and yogurt are likely to be beneficial; others, such as cottage cheese, may adversely affect bone health. Of the few stronger-evidence studies of dairy foods and bone health, most had outcomes that were not significant. However, white women <30 y old are most likely to benefit. There are too few studies in males and minority ethnic groups to determine whether dairy foods promote bone health in most of the US population. *Am J Clin Nutr* 2000;72:681–9.

KEY WORDS Dairy food, milk, dietary calcium, bone density, bone mass, bone mineral, bone fracture, review

INTRODUCTION

Mandated by the US Congress, the *Dietary Guidelines for Americans* uses an evidence-based approach to provide consumers information to assist them in making healthy dietary choices (1). Foods are grouped in a convenient way to inform the public about similarities of certain foods while allowing flexibility in dietary options. When foods are allocated to a particular group, comparability of nutrient composition is given primary consideration, along with how the foods are habitually used and how they were grouped in past guidelines (1). Dairy foods represent a distinct group, presumably because of their relatively high calcium content; calcium is considered to be important for bone health. Calcium in nondairy sources is less concentrated, making it difficult to meet the recommended dietary allowance for calcium without concomitant consumption of dairy foods or supplements (2).

Dairy foods have not been part of the diets of adults for most of human evolution. Only since domestication of dairy animals did select populations begin to use these products regularly after the age of weaning. In the first US dietary guidelines of 1916, dairy foods were identified within the meat group. Since the 1930s, they have been listed as a separate group, including milk, yogurt, cheese, ice cream, and ice milk (3). Of 28 dietary guidelines from other countries that we reviewed, 43% had a separate dairy group, whereas 57% divided dairy foods into other groups, indicating that they are nutritionally interchangeable with nondairy products.

As suggested previously, further study of the effects of dairy foods on health is needed (4). The purpose of this review was to determine whether there is a sound body of evidence indicating that dairy products confer bone health. Evidence regarding recommendations for total dietary calcium was not addressed because this was reviewed previously (2, 5). The following issues are specifically addressed herein:

1) Does research support the recommendation for daily intake of dairy foods by the general US population for improved bone health? Are there select age, sex, or ethnic groups that are more or less likely to benefit from regular use of dairy foods?

2) Are all dairy foods equivalent vehicles for dietary calcium, such that they should be listed as exchangeable within one group?

METHODS

A MEDLINE (National Library of Medicine, Bethesda, MD) search was conducted of scientific papers in the English language published since 1985 using the key words *dairy* or *milk* plus *osteoporosis*, *bone*, or *fracture*. Additional publications were identified from review articles and references provided in original papers. Studies were categorized as having a statistically nonsignificant effect, a favorable effect, or an unfavorable effect of dairy food or dairy calcium intake on bone health. Only outcomes for which $P < 0.05$ were included in the favorable or unfavorable categories. Studies were also categorized according to the age of the subjects when the dairy foods were consumed: <30 y (approximate age of peak bone mass) (6), 30–50 y, and

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[1] From the Department of Nutrition Sciences, University of Alabama at Birmingham.

[2] Address reprint requests to RL Weinsier, Department of Nutrition Sciences, University of Alabama at Birmingham, Birmingham, AL 35294. E-mail: weinsier@shrp.uab.edu.

Am J Clin Nutr 2000;72:681–9. Printed in USA. © 2000 American Society for Clinical Nutrition

TABLE 1
Number of outcomes showing favorable and unfavorable effects of dairy food intake on bone health, categorized according to strength of evidence and age of subjects when dairy food intake was assessed[1]

Category[1]	No effect	Favorable effect	Unfavorable effect	Favorable:unfavorable effect	Total
Strength of evidence					
A	6	5	1	5.0	12
B	6	1	2	0.5	9
C	11	11	0	—	22
D	7	7	0	—	14
Age					
<30 y					
Categories A and B	5	4	1	4.0	10
All categories	16	16	1	16.0	33
30–50 y					
Categories A and B	3	2	2	1.0	7
All categories	10	10	2	5.0	22
>50 y					
Categories A and B	10	2	2	1.0	14
All categories	20	10	2	5.0	32
Outcomes in evidence categories A and B[2]	12 [57]	6 [29]	3 [14]	2.0	21
Total outcomes[2]	30 [53]	24 [42]	3 [5]	8.0	57

[1] Strength of evidence was the greatest in category A, the least in category D. *See* text for details.

[2] Percentages in brackets.

>50 y (common age of menopause). Some studies examined the effect of dairy foods on more than one bone site. Other studies surveyed intake patterns at more than one age. Thus, some studies had more than one reported outcome.

To compare outcomes from different studies with different designs, 4 evidence-strength categories were developed a priori, considering the study design issues reviewed by Heaney (7). Studies using bone mass and fracture rates as endpoints were treated similarly because each has advantages and disadvantages (8, 9). The categories took into account the following criteria: nature of study, number of participants, duration of study, and adjustment for confounding variables. These categories were more narrowly defined, as described below, after completion of the study. Category A was considered the strongest evidence-based category and category D was considered the weakest evidence-based category.

1) Category A: a randomized, controlled trial or longitudinal cohort study with ≥3000 participants followed for an average of >5 y; significant associations were adjusted for ≥3 of the following confounding variables: age, sex, physical activity, body mass, years since menopause, and hormone replacement therapy (yes or no).
2) Category B: a longitudinal cohort study with <3000 participants followed for <5 y of follow-up, or significant associations adjusted for <3 of the above confounding variables; or a case-control study with >200 participants and significant associations adjusted for ≥3 of the confounding variables.
3) Category C: a case-control study with <200 participants or significant associations adjusted for <3 of the confounding variables or a cross-sectional study with >300 participants in which significant associations were adjusted for ≥2 of the confounding variables.
4) Category D: a cross-sectional study of <300 participants or significant associations adjusted for one or none of the confounding variables.

To answer the question "Are all dairy foods equivalent vehicles for dietary calcium?" the literature was examined to identify components of dairy foods that are known to affect calcium excretion and skeletal mass. Although important for bone health, vitamins D and K are found only in relatively small amounts in unfortified dairy foods and, hence, were not addressed in this review. By contrast, protein, sodium, potassium, and vitamin A were reviewed because of their relatively high, yet variable, concentrations in dairy foods and because of their known potential for modifying the effects of dairy foods on calcium excretion or skeletal mass. Additionally, the manufacturing process of dairy products was examined to determine how the altered compositions of these nutrients in commonly used dairy foods might affect health.

RESULTS

Forty-six studies specifically examined the relation between dairy food intake and bone health. Because 11 of the 46 studies had 2 distinct outcomes, there were 57 separate outcomes. Of the 57 outcomes, 7 (12%) were from randomized, controlled trials; 6 (11%) were from longitudinal cohort studies; 13 (23%) were from case-control studies; and 31 (54%) were from cross-sectional studies. Twenty-one outcomes (37%) fell into the stronger-evidence categories, namely A and B.

Of the 57 outcomes, 53% showed a nonsignificant effect, 42% showed a favorable effect, and 5% showed an unfavorable effect of dairy foods on bone health (**Table 1**). The ratio of favorable to unfavorable effects was 8.0 (ie, 24 studies showed a favorable outcome and 3 studies showed an unfavorable outcome). Of the 21 outcomes in categories A and B, 57% showed a nonsignificant effect, 29% showed a favorable effect, and 14% showed an unfavorable effect. The ratio of favorable to unfavorable effects was 2.0 (6/3). Individual study outcomes according to the findings of either favorable, unfavorable, or nonsignificant effects of dairy foods on bone health are shown in **Tables 2**, **3**, and **4**, respectively.

Outcomes by the age of subjects when dairy food intake was assessed (<30, 30–50, and >50 y) are summarized in Table 1. The favorable-unfavorable effects ratios for the 3 age groups, respectively, were 16.0, 5.0, and 5.0; within categories A and B, the ratios were 4.0, 1.0, and 1.0, respectively. Of the 57 outcomes,

TABLE 2
Studies showing a favorable effect of dairy food intake on bone health[1]

Study design and strength-of-evidence category[2]	Subjects[3]	Age when dairy intake was assessed			Duration	Outcome measure (site of effect)	Adjustment variables
		<30 y	30–50 y	>50 y			
RCT							
A (10)	22 white girls and 24 controls aged 11 y (United States)	X	—	—	1 y	Bone mass	Matched age, weight, height, sexual stage
A (11)	21 nonblack, lactating adolescents and 15 controls aged 17 y (United States)	X	—	—	14 wk	Bone mass	Matched age
A (12)	80 white girls aged 12 y (United Kingdom)	X	—	—	1.5 y	Bone mass	Age, BMI
A (13)	20 women and 17 controls aged 30–42 y (United States)	—	X	—	3 y	Bone mass	Matched age, weight
A (14)	42 postmenopausal women and 42 controls (Australia)	—	—	X	2 y	Bone mass	Matched age, PA
Case-control							
B (15)	2806 women with bone fractures and 3532 controls aged 78 y (international)	X	X	X	—	Fracture	Age, BMI, PA, YSM
C (16)[4]	65 osteoporotic men and women and 76 controls aged 57 y (Germany)	X	—	—	—	Bone mass	Age
C (17)	33 osteoporotic women and 33 controls aged 54–56 y (Austria)	—	—	X	—	Bone mass or fracture	Age (weight significantly less in osteoporotic group)
Cross-sectional							
C (18)	5398 women aged 40–80 y (United States)	—	X	X	—	Fracture	Age, PA
C (9)	843 women aged 35–75 y (China)	—	X	X	—	Bone mass	Age, weight
C (19)	965 men aged 27–83 y (Japan)	X	X	X	—	Bone mass	Age, weight
C (20)	11 619 women aged 47–56 y (Finland)	—	X	X	—	Fracture	Age, weight, YSM
C (21)	980 white women aged 50–98 y (United States)	X	X	—	—	Bone mass	Age, BMI, PA, YSM
C (22)	2025 women aged 48–59 y (Finland)	—	—	X	—	Bone mass	Age, weight, YSM, HRT
C (23)[4]	2120 Japanese men and women aged 66 y (United States)	—	—	X	—	Bone mass (at 1 of 5 sites in women; in 3 of 5 sites in men)	Age, weight, PA, HRT
C (24)[4]	994 women aged 45–49 y (Scotland)	X	—	—	—	Bone mass (at 1 of 4 sites)	Age, weight, PA, smoking
C (25)	624 white women aged 71 y (United States)	X	X	X	—	Bone mass	Age, BMI, PA, YSM, smoking
D (26)	161 girls aged 19–25 y (Japan)	X	—	—	—	Bone mass	BMI, PA
D (27)[4]	224 white women aged 18–31 y (United States)	X	—	—	—	Bone mass	Weight
D (28)[4]	82 white girls aged 15 y (Iceland)	X	—	—	—	Bone mass	Age
D (29)[4]	255 white women aged 49–66 y (United States)	X	—	—	—	Bone mass	Age, BMI
D (30)[4]	366 women aged 60–98 y (United States)	X	X	—	—	Bone mass	Age
D (31)[4]	284 women aged 44–74 y (United Kingdom)	X	—	—	—	Bone mass	Age, BMI, PA, YSM, smoking
D (32)[4]	421 Japanese and white women aged 25–34 y (United States)	X	X	—	—	Bone mass (at 1 of 4 sites)	Sports activity

[1] RCT, randomized, controlled trial; PA, physical activity; HRT, hormone replacement therapy; YSM, years since menopause or menopausal status.

[2] Strength of evidence was the greatest in category A, the least in category D. *See* text for details.

[3] Race indicated when known; age reported as mean or range.

[4] Study reported more than once in Tables 2–4 because certain findings indicated favorable effects and other findings indicated no favorable or even unfavorable effects.

55 (96%) included females and 15 (26%) included males. Of the 15 studies including males, 2 (13%) showed a significant effect of dairy foods in this sex group (both favorable), although neither study fell into category A or B. One study included a substantial proportion of ethnic minority groups—African Americans and Hispanic Americans (52). Risk of bone fracture was lower in these groups than in whites; however, dairy food intake did not explain differences in fracture risk between or within the ethnic groups.

Regarding the equivalency of dairy foods as vehicles for calcium, several nutrients that are found in relatively high, but variable, concentrations in dairy foods and that may affect calcium excretion or skeletal mass include protein, sodium, potassium, and vitamin A. The manufacture of fresh, aged, and processed cheeses results in products that differ markedly in their content of these nutrients compared with milk (**Table 5**). Calcium and potassium have been shown to favorably affect skeletal mass, whereas sodium, protein, potential renal acid load, and vitamin A have been reported to adversely affect skeletal mass. For example, production of acid-curd cheeses, such as cottage cheese, reduces the calcium and potassium content of milk by about one-half, increases the protein content by ≈4 times, and increases the sodium content by ≈8 times. Compared with milk, the ratio of calcium to protein in cottage cheese is 7-fold lower, and the calcium-sodium ratio is 16-fold lower.

Processed cheese products, such as American cheese, are produced by blending and emulsifying natural cheeses with sodium phosphate salts (56). Calcium sequestration occurs, wherein calcium is replaced with sodium from the emulsifying salt, increasing

TABLE 3
Studies showing an unfavorable effect of dairy food intake on bone health[1]

Study design and strength-of-evidence category[2]	Subjects[3]	Age when dairy intake was assessed			Duration	Outcome measure (site of effect)	Adjustment variables
		<30 y	30–50 y	>50 y			
					y		
Cohort							
A (33)[4]	77 761 women (98% white) aged 46 y (United States)	—	X	X	12	Fracture (at femur or forearm)	Age, BMI, YSM, HRT, smoking
Case-control							
B (34)[4]	209 men and women with fractures and 207 controls aged >65 y (Australia)	X	—	—	—	Fracture	Age, sex, weight, PA, smoking
B (35)	98 women with fractures and 98 controls aged 41–75 y (Sweden)	—	X	X	—	Fracture	Age, BMI

[1] PA, physical activity; HRT, hormone replacement therapy; YSM, years since menopause or menopausal status.
[2] Strength of evidence was the greatest in category A, the least in category D. *See* text for details.
[3] Race indicated when known; age reported as mean or range.
[4] Study reported more than once in Tables 2–4 because certain findings in the study indicated favorable effects and other findings indicated no favorable or even unfavorable effects.

the sodium and phosphorus content of the cheese. The potential renal acid load of processed cheese foods tends to be high and can be predicted from their nutrient compositions (57). Cheeses high in protein produce a potential renal acid load ≈25-fold that of milk: 23.6 and 1.0 mmol per 100 g, respectively (57, 58). Numerous studies (*see* below) have shown the effect of individual nutrients on calcium status and bone mass, but only 2 studies compared the effects of different dairy foods. In both studies, milk had a favorable effect whereas total dairy food and cheese intakes did not have a favorable effect on bone mass (17, 26).

DISCUSSION

Most studies of dairy food intake and bone health provided inconclusive results. In the studies showing significant outcomes, the ratio of favorable to unfavorable effects was 8.0. Of the studies providing strong evidence, the ratio was 2.0. The group accounting primarily for these favorable ratios was women <30 y old, suggesting that a beneficial effect is most likely during the period of maximum bone accretion (6). If dairy food intakes confer bone health, one might expect this to have been apparent from the 57 outcomes, which included randomized, controlled trials and longitudinal cohort studies involving 645 000 person-years. In fact, of the studies providing strong evidence, only 29% showed favorable effects and 14% showed unfavorable effects on bone status. These values suggest that there is little risk of harm to the skeletal system if recommendations to the general population to consume dairy foods are heeded. However, these values do not provide a solid body of evidence to support this recommendation.

Of the 7 randomized, controlled trials, 5 were classified as showing favorable effects, although the outcomes were not always clearcut. In 2 of the 5 trials (10, 11), dairy food supplementation resulted in significantly less bone loss; however, treatment and control groups had comparable bone mass before and after the interventions (59). In one of the trials, the dairy food–supplemented group had a 50% greater energy intake, which itself is associated with greater bone mass (11). If these 2 studies were reassigned to the "statistically nonsignificant effect" category, the ratio of favorable to unfavorable effects for the studies in categories A and B would decrease from 2.0 to 1.3, making the picture even less clear. Such a reclassification would be especially notable among the <30-y-old group, in whom the ratio would decrease from 4.0 to 2.0. The potential effect of different interpretations of studies that are few in number and that do not provide clear outcomes indicates the need for more carefully designed intervention trials.

There were inadequate data for males and ethnic minorities to draw conclusions about the effect of dairy food intakes on bone health in these populations. The paucity of data in minorities such as blacks, relative to nonblacks, may have been due to the greater bone density of blacks at all anatomic sites and ages and their lower risk of osteoporosis (60–65) and hip fractures (66). It is not known whether calcium requirements are the same for all racial groups (2), and the greater bone mass in blacks than in nonblacks has apparently not been shown to be nutritionally based (67). Regardless of the explanation, there is insufficient evidence on which to base a recommendation about dairy food intake relative to bone health in ethnic minorities; consideration should be given to the high prevalence of lactase nonpersistence, a trait often associated with lactose intolerance in these populations. The finding that most study outcomes showed no relation between dairy food intake and bone health may have been due to methodologic problems inherent in the studies, which are discussed below.

Dietary recall

Small associations between long-term nutrient intakes and bone health may be overwhelmed by large errors introduced from weak dietary assessment techniques (68). Despite their shortcomings, dietary recall methods are considered by some to be reasonably reliable (69–71) and to correlate with clinical outcomes (72). The temporal relation between dietary assessment and occurrence of bone fracture may be critical. For example, Michaelsson et al (35) found that greater dairy food intake after a fracture predicted decreased fracture risk, whereas prefracture dietary habits showed that greater intake predicted increased fracture risk.

Confounding factors

Several factors that have been related to bone health may confound the relation with dairy food intake: age at menarche (28) and menopause (15), body mass and height (28), physical activity (25, 73) and strength (28), cigarette smoking (15, 25), alcohol con-

TABLE 4
Studies showing statistically nonsignificant effects of dairy food intake on bone health[1]

Study design and strength-of-evidence category[2]	Subjects[3]	Age when dairy intake was assessed <30 y	30–50 y	>50 y	Duration	Outcome measure (site of effect)	Adjustment variables
					y		
RCT							
A (36)	13 white women and 9 controls aged 45–70 y (United States)	—	X	X	2	Calcium balance, bone mass	Matched menopause
A (37)	197 boys and girls and 174 controls aged 7–9 y (United Kingdom)	X	—	—	2	Bone mass, assessed 14 y later	Matched age
Cohort							
A (38)	4573 men and women aged 59 y (Japan)	—	—	X	13	Fracture	Age, sex, BMI, alcohol, age at menarche
A (39)	4342 white men and women aged 50–74 y (United States)	—	—	X	15	Fracture	Age, BMI, PA, HRT, alcohol, smoking
A (33)[4]	77 761 women (98% white) aged 34–59 y (United States)	X	—	X	12	Fracture (at forearm or femur)	Age, BMI, YSM, HRT, smoking
A (40)	13 987 white men and women with a median age of 73 y (United States)	—	—	X	7	Fracture	Age, BMI, PA, smoking
B (41)	9704 nonblack women aged >65 y (United States)	X	X	X	2	Fracture	Age, weight, PA, YSM, HRT
Case-control							
B (34)[4]	209 men and women with fractures and 207 controls aged >65 y (Australia)	—	—	X	—	Fracture	Age, sex, weight, PA, smoking
B (42)	241 women with fractures and 719 controls aged 64 y (Italy)	—	—	X	—	Fracture	Age, BMI, HRT, smoking
B (43)	266 white women with fractures and 397 controls aged 45–75 y (United States)	—	—	X	—	Fracture	Age, weight, YSM, smoking
B (44)	570 men and women with high fracture risk and 391 men and women with low risk aged 40–80 y (Sweden)	X	X	X	—	Fracture	Age, sex, PA, HRT
B (45)	161 white women and 168 controls aged 50–103 y (United States)	X	—	—	—	Fracture	Age, BMI
C (16)[4]	65 osteoporotic men and women and 76 controls aged 57 y (Germany)	—	X	X	—	Bone mass	Age
C (46)	101 retired female dancers and 101 nondancers aged 21–78 y (Australia)	X	—	—	—	Bone mass	Age, sex, weight, YSM (case-control comparison not based on bone mass or fracture risk)
C (47)	46 white women aged 50–83 y (Australia)	—	—	X	—	Bone mass	Age
Cross-section							
C (48)	1359 boys and girls aged 7–11 y (Netherlands)	X	—	—	—	Bone mass	Age, weight
C (49)	9704 nonblack women aged 71 y (United States)	X	X	X	—	Bone mass	Age, weight, PA, YSM, smoking
C (50)	404 men and women aged 15–83 y (China)	X	X	X	—	Bone mass	Age, BMI, PA, YSM, smoking
C (24)[4]	994 women aged 47 y (Scotland)	X	—	—	—	Bone mass (at 3 of 4 sites)	Age, weight, PA, smoking
C (30)[4]	366 women aged 60–98 y (United States)	—	—	X	—	Bone mass	Age, BMI, energy intake
C (51)	348 women aged 82 y (Netherlands)	—	—	X	—	Bone mass	Age, mobility, weight, YSM
C (52)	953 white, black, and Hispanic women aged 50–100 y (United States)	—	—	X	—	Fracture	Age, race, BMI, PA, smoking
C (23)[4]	2120 men and women aged 64–68 y (Japan)	—	—	X	—	Bone mass (at 4 of 5 sites in women; at 2 of 5 sites in men)	Age, weight, PA, HRT
D (31)[4]	284 women aged 44–74 y (United Kingdom)	—	X	X	—	Bone mass	Age, BMI, YSM, PA, smoking
D (27)[4]	224 white women aged 18–31 y (United States)	X	—	—	—	Bone mass	Weight
D (53)	50 white women (United States)	X	X	X	—	Bone mass	Age, weight, HRT, smoking
D (28)[4]	80 white girls aged 13 y (Iceland)	X	—	—	—	Bone mass	Age, weight
D (54)	46 men aged 23 y (Argentina)	X	—	—	—	Bone mass	Age, BMI
D (32)[4]	421 Japanese and white women aged 25–34 y (Hawaii)	X	X	—	—	Bone mass (at 3 of 4 sites)	Sports activity
D (29)[4]	255 white women aged 57 y (United States)	X	X	—	—	Bone mass	Age, BMI

[1] RCT, randomized, controlled trial; PA, physical activity; HRT, hormone replacement therapy; YSM, years since menopause or menopausal status.

[2] Strength of evidence was the greatest in category A, the least in category D. *See* text for details.

[3] Race indicated when known; age reported as mean or range unless otherwise noted.

[4] Study reported more than once in Tables 2–4 because certain findings in the study indicated favorable effects and other findings indicated no favorable or even unfavorable effects.

TABLE 5
Nutrient content per 100 g of various dairy foods[1]

Dairy food	Calcium	Potassium	Protein	Sodium	Calcium:protein	Calcium:sodium
	mg	*mg*	*g*	*mg*		
Milk, skim	123	166	3	51	41	2.4
Yogurt, nonfat	199	255	6	77	33	2.6
Cheddar cheese	729	100	25	629	29	1.2
American cheese	443	164	21	1450	21	0.3
Cottage cheese	61	81	12	406	5	0.15

[1] From reference 55.

sumption (25), and energy intake (74). Greater dairy food consumption has been associated with intake of more fruit and fewer carbonated beverages (75), which themselves are associated with lower calcium excretion (76) and healthier bones (18, 77). Dairy food consumers also have a greater knowledge of nutrition (78), exercise more (15, 25, 73), smoke less (15, 25), and drink less alcohol (25). Thus, dairy food consumption may be a surrogate marker for lifestyle characteristics that contribute to bone health—characteristics that have not always been controlled for in past studies.

Small effect size

Dairy food intake generally accounts for a small proportion of the variance in bone mass. In 912 women, Yano et al (23) found that age, body size, hormone replacement therapy status, and thiazide use collectively explained 22–36% of bone mass variation; dairy calcium intake explained <0.3% (23). In 2025 women, Honkanen et al (22) found that age, body weight, years to menopause, and hormone replacement therapy explained 25% of bone mass variation; dairy calcium intake explained <0.7% (22). In 11000 women, Honkanen et al (20) found that high dairy calcium intake was associated with a reduction in the risk of bone fracture of <1% ($P = 0.03$). These results raise the possibility that dairy food intake has a small effect on bone health. Alternatively, the results may simply reflect the fact that dairy food intake is difficult to assess accurately, that the range of dairy food intake in the study populations is relatively narrow, or that current dairy food intake may not reflect the lifetime diet.

Differences among dairy foods

In studies that examined different dairy foods, milk appeared to be more beneficial for bone health than were other dairy foods (17, 26). It is difficult to draw conclusions from so few studies, but there is substantial evidence to suggest that all dairy foods are not equivalent vehicles of calcium, perhaps because of their different protein, sodium, potassium, and vitamin A contents. Dietary protein contributes to bone loss, in part because of the generation of fixed acids, mainly sulfuric and phosphoric acids. As a reservoir of labile base as calcium salts, the skeleton may provide neutralization at the expense of structure. Dairy food intake is closely linked to protein intake ($r = 0.91$) (79). Protein intake is related to calcium excretion (80, 81), bone resorption (36, 82, 83), and bone fracture risk (84). To offset protein's calciuric effect, greater calcium allowances have been recommended (85) at a calcium-protein ratio (in mg:g) of = 20:1 (86). The recommended 2–3 dairy servings taken as milk would provide ≈20 g protein. An equivalent amount of calcium from cottage cheese would provide 150 g protein. To protect against calcium loss from this 130 g extra protein from cottage cheese would require an additional calcium source providing 2600 mg/d (20 mg × 130 g).

Dietary sodium intake increases calcium excretion because of sodium-calcium exchange in the proximal renal tubule. An additional sodium intake of 1 g (43 mmol) has been associated with a calcium loss of 20–40 mg (0.5–1.0 mmol) (87–90). If uncorrected, the extra sodium would result in a skeletal loss of ≈1%/y (85). The manufacture of cheese increases its sodium content, particularly processed cheese products and acid-curd cheeses like cottage cheese (56). The calcium-sodium ratio of dairy foods varies widely, from 2.4 for milk to 0.15 for cottage cheese (Table 5). The recommended 2–3 dairy servings taken as milk (612 g, 2.5 cups) would provide ≈315 mg Na. A comparable intake of calcium from American cheese would increase the sodium intake to ≈2500 mg, and taken as cottage cheese would increase the sodium intake to ≈5000 mg.

Potassium appears to play an important role in protecting against calcium loss from the renal acid load of protein. The mammary gland raises the potassium-sodium ratio of milk against high serum gradients, presumably to facilitate infant skeletal growth. Potassium added to a high-protein diet reduces urinary calcium (91, 92). The calcium-sparing effect occurs whether the potassium salt is citrate (92) or bicarbonate (93, 94) and appears to be cation dependent because sodium salts had less effect (92, 93). Potassium administration has been found to decrease urinary hydroxyproline and increase serum osteocalcin, suggesting reduced bone resorption and increased bone formation (94). In cross-sectional and longitudinal analyses, Tucker et al (77) showed that alkaline-producing dietary components such as potassium contribute to the maintenance of bone density. New et al (24) found that fruit (which has a high potassium content) predicted greater bone density at all 4 bone sites measured. Milk intake was positively associated at 3 sites. In a multivariate analysis, potassium was the only dietary factor related to bone density at all 4 sites. When potassium intake was considered, calcium intake was no longer significantly related to bone mass at any site. On the basis of emerging data, the differences in potassium content among dairy foods may be important (Table 5).

Vitamin A is important in bone remodeling, and hypervitaminosis A can result in bone resorption and fractures (95). A study among Swedes showed a dose-dependent relation between vitamin A intake and hip fracture risk (96). For each 0.5-mg increase in dietary retinol (not carotene), risk increased by 34%. The authors speculated that the benefits of a typically high calcium intake in Sweden may be offset by retinol intake, derived in part from milk fortification. Milk in the United States is fortified to a higher level [735 g (3 cups) provides ≈0.5 mg retinol]. Although the retinol content of dairy foods varies by >100-fold, there are inadequate data to determine the effect of such variations on bone health.

On the basis of the known effects of individual nutrients on calcium status, one could speculate that intake of foods such as yogurt and milk would be advantageous, hard cheeses and processed cheese products would be less advantageous, and cottage cheese would be disadvantageous. Studies are needed to verify this impression and to determine whether the dairy options in the *Dietary Guidelines* are nutritionally equivalent and exchangeable for optimal bone health (1).

Conclusions

There have been few carefully designed studies of the effects of dairy food intakes on bone health. The results of most of the available studies were nonsignificant. Persons most likely to benefit are white women aged <30 y. Even among studies showing a favorable effect, the clinical relevance is unclear because the variation in bone mass explained by dairy food intake is extremely small. This may have been due to methodologic problems, a small effect size, or both. There have been too few studies in males and ethnic minorities to determine the effect of dairy food intakes in these populations. Select dairy foods are nutritionally beneficial, and dairy food consumers have healthy behaviors, which favor greater bone mass. However, without more well-controlled studies, the body of scientific evidence appears inadequate to support a recommendation for daily intake of dairy foods to promote bone health in the general US population.

There are marked differences in the nutrient composition of dairy foods and their expected effects on skeletal mass. The high calcium content of processed cheese products may be offset by the high sodium, polyphosphate, and protein contents of these products, which can be expected to increase calcium losses. Acid-curd cheeses such as cottage cheese are relatively low in calcium and potassium and high in protein and sodium, giving them a nutrient profile unlikely to benefit skeletal mass. Thus, all dairy foods are not equivalent vehicles for dietary calcium and may not be exchangeable options for optimal bone health.

It is difficult to meet current recommendations for calcium intake without the consumption of dairy foods or supplements (2, 5); therefore, there has been a concerted effort recently by some investigators to recommend increased dairy food consumption, even among lactose-intolerant persons (97), and the consumption of calcium-rich nondairy products (85). Nordin et al (98) suggested that age-related bone loss may be more attributable to excessive calcium loss than to inadequate calcium intake. Accordingly, greater attention needs to be given to eliminating the causes of calcium loss, which in turn should lower calcium requirements (99).

We express our appreciation to Jill Foster, who assisted in the review of the literature and in the discussion of the issues.

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