# Effects of Dairy Consumption on Body Composition and Bone Properties in Youth: A Systematic Review

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## Abstract

**Background:** According to previous reviews, there is no clear evidence on the effects of dairy consumption on body composition and bone properties in pediatric populations. There is a need for further assessment of existing findings and the methodologic quality of studies before summarizing the evidence.

**Objective:** The aim of the study was to assess the quality, methodologies, and substantive findings of randomized controlled trials (RCTs) that examined the effects of dairy consumption on body size, body composition, and bone properties in children and adolescents.

**Methods:** After searching PubMed and Google Scholar up to December 2016, 15 RCTs were retained and included in this systematic review for further analysis. The quality of the included studies was assessed via the Jadad scale; detailed methodologic and statistical characteristics were evaluated, and the main findings were summarized.

**Results:** The effects of dairy consumption were found to be significant for bone structure and nonsignificant for body size and composition. Eight of the 11 RCTs that assessed bone found significant effects ($P < 0.05$) for bone mineral content and bone mineral density (BMD), with an average 8% increase in BMD after 16 mo of dairy consumption. Conversely, significant effects ($P < 0.05$) were found only in 2 of the 14 RCTs that focused on body size (i.e., height and weight) and in only 1 of the 11 RCTs that focused on body composition (i.e., lean mass).

**Conclusions:** The systematic consumption of dairy products may benefit bone structure and development, but it does not appear to affect body composition or body size in children and adolescents. On the basis of the Jadad scale, the methodologic quality of the 15 RCTs was rated as good overall. However, there were methodologic disparities and limitations that may have led to nonsignificant results, particularly for body size and composition. Future RCTs designed to address these limitations are warranted. *Curr Dev Nutr* 2017;1:e001214.

## Introduction

Over the years there has been an increased interest in the effects of dairy on body composition and bone development in humans. The results of the 4 following reviews, however, were inconclusive for body composition, possibly due to methodologic limitations of the included studies related to, for example, study design, experimental power, or compliance. In the review by Barr (1), which assessed 30 randomized controlled trials (RCTs) with the use of dairy products or calcium supplementation as the dietary intervention, only 3 RCTs focused on children (girls) and found nonsignificant effects of dairy consumption on body composition. Their nonsignificant findings were attributed to inappropriate study designs, inadequate experimental power, and the possible increase in energy intake with increased dairy consumption. Huang and McCrory (2) reviewed 5 observational studies and 10 RCTs that examined the effects of dairy intake and calcium supplementation on body composition in children.

Three of the 5 observational studies reported significant effects of intakes of dairy, calcium, or both on body composition. However, none of the 10 RCTs (3 RCTs used dairy products and 7 RCTs used calcium supplementation) showed significant effects, mainly due to dietary report problems, lack of compliance monitoring, and the confounding effects of other dietary variables (e.g., energy intake). A later review by Lanou and Barnard (3) found similar non-significant effects of dairy consumption on body composition. This review assessed 49 RCTs, 18 of which were in children and adolescents, with only 5 of them using dairy foods as opposed to calcium supplements. Finally, a recent systematic review and meta-analysis of 36 observational studies and 4 RCTs showed modest effects of dairy intake on body composition (adiposity) in adolescents but not in children (4).

The existing evidence for the positive effects of dairy consumption on bone in children and adolescents is more conclusive, even though many of the relevant studies are methodologically disparate. Early RCTs showed significant positive effects of dairy products (e.g., milk) on bone-related variables [e.g., bone mineral density (BMD) and bone mineral content (BMC)] in pediatric populations (e.g., 5–7). Similarly, the longitudinal study by Fiorito et al. (8) found calcium intake (especially from dairy foods) to have beneficial effects on BMC in young girls. However, the review by Lanou et al. (9) proposed that the existing evidence does not support the nutritional guidelines that suggest increased calcium or dairy intake for enhancing bone mineralization in children and adolescents. Lanou et al. (9) assessed 58 studies (22 cross-sectional, 13 retrospective, 10 longitudinal, and 13 RCTs) that examined the effects of dairy product consumption or calcium supplementation on bone health in children and young adults. Twelve of 13 RCTs had a minimum of 1 y of treatment, and 9 RCTs examined the effects of calcium supplementation. Only 3 of these 12 RCTs examined the effects of dairy products either in combination with calcium supplements [in 1 RCT by Matkovic et al. (10)] or alone [in 2 RCTs by Cadogan et al. (5) and Chan et al. (6), respectively]. Furthermore, 27 of 37 studies, which used dairy or dietary calcium intake and managed to control for weight, pubertal status, and exercise in children and young adults, showed no relation between dietary calcium or dairy intake and bone. As a result, the authors suggested the revision of the pediatric recommendations on calcium and dairy intake due to the marginal effects on bone (9, 11). In contrast, a later meta-analysis found that the increased consumption of dietary calcium, via dairy products or supplements with and without vitamin D, significantly increased total body and lumbar spine BMC in children with low baseline calcium intake (12). From the 21 RCTs assessed in this meta-analysis, only 4 studies used dairy, mainly milk. As stated by Huncharek et al. (12), the heterogeneity of the participants' diet and calcium intake (low, near normal, or normal intakes) might have affected the findings of this meta-analysis. The same study design limitation may also apply to the findings and conclusions of the previous reviews by Lanou et al. (9, 11).

As mentioned in previous relevant reviews (1, 13), there is a need for assessing the methodologic quality of the studies before summarizing the evidence. In fact, the use of only RCTs for assessing whether an experimental treatment is effective or not may be more appropriate (14). Therefore, the purpose of this review was to examine the potential impact of dairy consumption on body size and composition and on bone in children and adolescents with the exclusive use of RCTs. In addition, this review assesses the quality of the methodologies and summarizes the findings of the included RCTs.

## Methods

### Search and selection criteria—strategy
Two databases [PubMed (https://www.ncbi.nlm.nih.gov/pubmed) and Google Scholar (https://scholar.google.ca/)] were electronically searched for studies suitable for this review up to December 2016. The search terms included different combinations of relevant key words, namely dairy (consumption), body composition, bone, children, adolescents, and pediatric population. The inclusion criteria were as follows: articles written in English; RCTs; studies in pediatric populations (<18 y old), males or females, or both sexes; interventions that included dairy products; and studies with outcomes relevant to anthropometric measurements (e.g., height, weight, and BMI), body composition [e.g., lean body mass (LBM), fat mass (FM)], and bone measurements [e.g., BMD, BMC, and bone turnover markers (BTMs)].

First, the titles of all of the studies found in the databases were read and their relevance to the topic of the review was assessed. Then, the abstracts and the full texts of the relevant studies were read in order to check whether all of the inclusion criteria were met. Last, the references of the relevant studies as well as of previous systematic reviews and meta-analyses were checked to locate additional studies.

### Data extraction and management
Each study that met all of the inclusion criteria was subjected to the systematic extraction of a number of key design, methodologic, and statistical characteristics (**Tables 1** and **2**). The methodologic and statistical characteristics included the following: sample size estimation and power calculation (yes or no; if yes, the percentage of power), adjustment for confounding effects (yes or no; if yes, the variables or covariates), control group (yes or no), dropouts (number of participants, percentage), calculation of effect size and CIs (yes or no), diet and exercise assessment (method of assessment), and limitations and recommendations (stated or not; if stated, which limitations and recommendations) (Table 1). The design-specific characteristics were as follows: *1*) sample size (*n* after dropout) and participants' sex (male or female), age (mean and range in years), country, weight profile (e.g., normal weight, overweight, or obese), and health status (healthy or not healthy); *2*) study duration (weeks, months, or years); *3*) intervention [diet (dairy or calcium intake) and exercise (type, frequency, duration, and intensity)]; *4*) measurements and variables (assessment tool); and *5*) main findings (anthropometric measurements, body composition, and bone properties) (Table 2).

### Quality assessment: Jadad scale
The quality of the included studies was assessed via the Jadad et al. (26) scale. This scale has been used extensively in previous systematic reviews in various clinical areas, such as in obesity (27–29), due

**TABLE 1**  Methodologic and statistical characteristics of RCTs examining the effects of dairy on body size, body composition, and bone in a pediatric population[1]

| Study (ref) | Sample size estimation and power calculation | Control group | Dropouts, n (%) | Adjustment for confounding | Effect size/ CIs | Diet and PA assessment (method) | Limitations | Recommendations |
|---|---|---|---|---|---|---|---|---|
| Lappe et al., 2004 (15) | No | Yes | 4 (6.3) | Yes (baseline weight and energy and protein intakes) | No/no | Diet: 3-d food records (8 times) and daily checklist with calcium rich foods; PA: questionnaire | Pilot study, small sample size, self-report of dietary intake | Not stated |
| Weaver et al., 2011 (16) | Yes (80% power) | Yes | 4 (9.5) | Yes (sex) | No/no | Diet: 9-d food records (9 times), monitoring of dietary intake at each meal by camp counsellors; PA: accelerometer | Convenient and relatively small sample, short-term study | Intervention with higher calcium intake and energy-reducing diets |
| Chan et al., 1995 (6) | No | Yes | 2 (4.2) | No | No/no | Diet: 3-d food records (4 times) and FFQ; PA: questionnaire | Not stated | Not stated |
| Cadogan et al., 1997 (5) | No | Yes | 2 (2.4) | Yes (pubertal status) | No/yes | Diet: 7-d food records with weighted method (2 times) and 4-d food records (5 times); PA: questionnaire | Not stated | Not stated |
| Merrilees et al., 2000 (7) | No | Yes | 22 (21) | No | No/no | Diet: 3-d food records, calcium FFQ, dairy products compliance questionnaire (5 times); PA: questionnaire | Not stated | Not stated |
| Gibbons et al., 2004 (17) | Yes (80% power) | Yes | 31 (20) | No | No/no | Diet: calcium FFQ (5 times) and daily (milk product consumption) compliance checklist | Not stated | Not stated |
| Matkovic et al., 1990 (10) | Yes (80% power) | Yes | 3 (9.6) | No | No/no | Diet: 3-d food records (5 times) | Not stated | Larger samples, matching of participants for skeletal age, bone mass, and calcium intake |
| Lau et al., 2004 (18) | No | Yes | 20 (5.8) | Yes [sex, baseline dietary calcium and protein intakes, PA, puberty (Tanner stage)] | No/yes | Diet: 3-d food records (3 times) and daily record of milk product consumption; PA: questionnaire | Not stated | Not stated |
| Du et al., 2004 (19) | No | Yes | 59 (7.8) | Yes (body and bone size; e.g., height, weight, and puberty status) | No/yes | Diet: 7-d recall (1 time) and 3-d recall (4 times) and daily record of milk product consumption; PA: questionnaire | Not stated | Not stated |

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TABLE 1  (Continued)

| Study (ref) | Sample size estimation and power calculation | Control group | Dropouts, n (%) | Adjustment for confounding | Effect size/ CIs | Diet and PA assessment (method) | Limitations | Recommendations |
|---|---|---|---|---|---|---|---|---|
| Volek et al., 2003 (20) | Yes | Yes | Not stated | No | No/no | Diet: 7-d food records (3 times) and daily record of milk product consumption | Not stated | Not stated |
| Kelishadi et al., 2009 (21) | Yes (95% power) | Yes | 25 (25) | No | No/no | Diet: 3-d food records (7 times); PA: questionnaire | Bias in recording food intake and answering PA questionnaire, estimation of energy expenditure with questionnaire, DXA for measuring body fat instead of using the gold standard method of underwater weighing | Not stated |
| Albala et al., 2008 (22) | Yes (80% power) | Yes | 5 (5.1) | Yes (age, sex) | No/no | Diet: FFQ (2 times) | Small sample size and short intervention period, reliance on self-report for dietary assessment | Larger samples |
| Renner et al., 1998 (23) | No | Yes | 61 (32.1) | No | No/no | Diet: FFQ and 24-h food recall (1 time); PA: questionnaire | Not stated | Not stated |
| St.-Onge et al., 2009 (24) | No | No | 16 (26.2) | Yes (sex, race, age) | No/no | Diet: 24-h food recall (7 times); PA: report of participation via recall method | Small sample size, short duration, participants possibly in different pubertal stages | Longer duration of intervention |
| Cheng et al., 2005 (25) | Yes (90% power) | Yes | 22 (11.3) | Yes (baseline puberty Tanner stage) | No/yes | Diet: 3-d food records; PA: questionnaire | Not stated | Future studies in calcium-deficient participants |

[1] PA, physical activity; RCT, randomized controlled trial; ref, reference.

**TABLE 2**  RCTs on the effects of dairy with or without exercise on body size, body composition and bone properties in a pediatric population[1]

| Study (ref) | n[2] | Sex/age,[3] y | Country | Weight | Study duration | Diet (dairy) | Exercise | Measurements and variables (assessment tool) | Main findings |
|---|---|---|---|---|---|---|---|---|---|
| Lappe et al., 2004 (15) | 59 | F/9.5 (9.1–9.9) | United States | Normal weight | 2 y | Calcium-rich foods (mainly dairy); average intake: 1656 mg Ca/d | No | Height, weight, BMI, LBM, and FM (DXA) | Nonsignificant effects ($P > 0.05$) |
| Weaver et al., 2011 (16) | 38 | F + M/ (12–15) | United States | Overweight or obese (≥85th percentile of BMI-for-age) | 3 wk | Dairy (2 servings chocolate milk/d); average intake: 1461 mg Ca/d (controlled diet) | No | Weight loss | Nonsignificant effects ($P > 0.05$) |
| Chan et al., 1995 (6) | 46 | F/11 (9–13) | United States | Not stated (possibly normal weight[4]) | 1 y | Dairy (milk, cheese, yogurt); average intake: 1437 mg Ca/d | No | Height, weight, LBM, and FM (DXA); BMC, BMD of different sites (e.g, lumbar spine) (DXA); serum calcium, magnesium, phosphate, 25(OH)D, 1,25-dihydroxyvitamin D, albumin, serum alkaline phosphatase, urinary hydroxyproline, calcium-creatinine ratio | Body size and composition: nonsignificant effects ($P > 0.05$); significant increase in lumbar spine BMD (22.8% ± 6.9%) and total body BMC (14.2% ± 7.0%) ($P < 0.001$); biochemical markers: nonsignificant effects ($P > 0.05$) |
| Cadogan et al., 1997 (5) | 80 | F/12.2 (11.8–12.5) | United Kingdom | Not stated (possibly normal weight[4]) | 18 mo | Dairy (whole or reduced-fat 568-mL milk, average consumption 486 mL/d); average intake: 1125 mg Ca/d | No | Height, weight, BMI, LBM, and FM (DXA); total body BMC and BMD (DXA); serum PTH, estradiol, IGF-I, osteocalcin, urine N-telopeptide of type I collagen, and deoxypiridinoline cross-link | Body size and composition: nonsignificant effects ($P > 0.05$); significant increase in BMC (27%; $P = 0.009$) and BMD (9.6%; $P = 0.0017$); significant increase in IGF-I ($P = 0.02$) |
| Merrilees et al., 2000 (7) | 73 | F/(15–16) | New Zealand | Not stated (possibly normal weight[4]) | 3 y (1 y of intervention and 2 y of follow-up) | Dairy (e.g, milk); average intake: 1160 mg Ca/d | No | Height, weight, LBM, and FM (DXA); bones: BMC and BMD (total body and different sites) (DXA); biochemical (bone) markers: urine hydroxyproline, creatinine, calcium, and sodium excretion; calcium-creatinine and hydroxyproline-creatinine ratios | Body size and composition: nonsignificant effects ($P > 0.05$); significant increase in BMD of trochanter (4.6%), lumbar spine (1.5%), and femoral neck (4.8%) after 1 y and in BMC of trochanter after 2 y ($P < 0.05$); significant increase in creatinine ($P < 0.05$) |

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**TABLE 2** (Continued)

| Study (ref) | Participants | | | | Intervention | | Measurements and variables (assessment tool) | Main findings |
|---|---|---|---|---|---|---|---|---|
| | $n^2$ | Sex/age,[3] y | Country | Weight | Study duration | Diet (dairy) | Exercise | | |

| Study (ref) | $n^2$ | Sex/age,[3] y | Country | Weight | Study duration | Diet (dairy) | Exercise | Measurements and variables (assessment tool) | Main findings |
|---|---|---|---|---|---|---|---|---|---|
| Gibbons et al., 2004 (17) | 123 | F + M/9.4 (8–10) | New Zealand | Not stated (possibly normal weight[4]) | 30 mo (18 mo of intervention and 12 mo of follow-up) | Dairy (80 g milk powder); average intake: ~2076 mg Ca/d (1200 mg from milk and 876 mg from diet) | No | Height, weight, LBM, and FM (DXA); BMC and BMD (total body and different sites: hip and spine) (DXA) | Nonsignificant effects ($P > 0.05$) |
| Matkovic et al., 1990 (10) | 28 | F/14 | United States | Not stated (possibly normal weight[4]) | 2 y | Dairy (900 mL 2%-fat milk/d); average intake: 1383.5 mg Ca/d | No | Height, weight, bone size, mass, BMD (SPA and DPA) | Nonsignificant effects ($P > 0.05$) |
| Lau et al., 2004 (18) | 324 | F + M/10 (9–10) | China | Not stated (possibly normal weight[4]) | 18 mo | Dairy (milk powder enriched with calcium: one group with 40 g, 650 mg Ca/d, and one group with 80 g, 1300 mg Ca/d | No | Height, weight, LBM, FM (DXA); BMD (g/cm$^2$; total body and different sites: hip and spine) (DXA) | Body size and composition: nonsignificant effects ($P > 0.05$); significant effects (higher in 80-g group: 7.4% ± 0.4% vs. 6.3% ± 0.4% in control group for hip BMD, 8.4% ± 0.5% vs. 7.0% ± 0.5% in control group for spine BMD; lower in 40-g group: 3.1% ± 0.3% vs. 2.4% ± 0.2% in control group for total BMD) ($P < 0.05$) |
| Du et al., 2004 (19) | 698 | F/10 (9.7–10.4) | China | Not stated (possibly normal weight[4]) | 2 y | Dairy (milk fortified with calcium with or without vit. D; average intake: 144 mL/d (650 mg Ca, 3.3 μg vit. D/d) | No | Height, sitting height, weight, BMI, BMC, BMD (DXA); plasma 25(OH)D, serum PTH, plasma and urine calcium, urine calcium-creatinine ratio | Significant increase in height (0.6%), sitting height (0.8%), weight (2.9%) ($P < 0.05$); significant increase in (size-adjusted) total body BMC (1.2%) and BMD (3.2%) (more effects with the fortified milk with calcium and vit. D) ($P < 0.05$); significant increase in plasma 25(OH)D and urinary calcium in group consuming milk fortified with calcium and vit. D ($P < 0.05$) |

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**TABLE 2** (Continued)

| Study (ref) | Participants | | | | Study duration | Intervention | | Measurements and variables (assessment tool) | Main findings |
|---|---|---|---|---|---|---|---|---|---|
| | $n^2$ | Sex/ age,[3] y | Country | Weight | | Diet (dairy) | Exercise | | |
| Volek et al., 2003 (20) | 28 | M/14.3 (13–17) | United States | Not stated (possibly normal weight[4]) | 12 wk | Dairy (3 servings, 708 mL 1%-fat milk/d); average intake: 1723 mg Ca/d | Resistance training (1 h × 3 times/ wk) | Height, weight, LBM, and FM (DXA);BMC and BMD (total body and different sites) (DXA) | Body size and composition: nonsignificant effects ($P > 0.05$); significant effect (2.49% increase) in total body BMD (0.028 vs. 0.014 g/cm² in treatment and control groups, respectively) ($P < 0.05$) |
| Kelishadi et al., 2009 (21) | 95 | F + M/ 5.6 (4.8– 6.2) | Iran | Obese (≥95th percentile of BMI-for-age) | 36 mo (6 mo of intervention and 30 mo of follow-up) | Dairy (milk, cheese, yogurt-rich diet); average intake: ~850 mg Ca/d | No | Height, weight, waist circumference, BMI, body fat (BIA); CRP | Nonsignificant effects ($P < 0.05$); however, small increase in BMI and waist circumference in dairy group at follow-up |
| Albala et al., 2008 (22) | 93 | F + M/ (8–10) | Chile | Overweight or obese (≥85th percentile of BMI-for-age), healthy | 16 wk | Dairy (3 servings, 600 mL 1.5%-fat milk/d); average intake: ~1650 mg Ca/d | No | Height, weight, BMI, LBM, and FM (DXA); bone mass (DXA) | Significant increase in height only in boys ($P < 0.05$); significant increase in LBM (3.72%; 0.92 ± 0.10 vs. 0.62 ± 0.11 kg) ($P = 0.04$); nonsignificant effects on bone mass ($P > 0.05$) |
| Renner et al., 1998 (23) | 129 | F + M/ (15–16) | Germany | Not stated | 1 y | Dairy (milk, cheese, yogurt, low-fat or not); average intake: 1400 mg Ca/d (1150 mg from dairy and 250 mg from other foods) | No | BMD (SPA); serum FSH, LH, PTH, calcium, osteocalcin, alkaline phosphatase, urine pyridine derivatives: pyridinoline and deoxypyridinoline | Significant increase (13.4%) in BMD in dairy group (0.053 vs. 0.036 g/cm²) ($P < 0.05$); higher decrease in concentrations of PTH, alkaline phosphatase, and osteocalcin in intervention group |
| St-Onge et al., 2009 (24) | 45 | F + M/ 9.4 (8– 10) | United States | Overweight or obese (≥85th percentile of BMI-for-age) | 16 wk | Dairy (0–1%-fat milk, high milk group with 944 mL/d and low milk group with 236 mL/d) | No | Height, weight, waist-hip circumference ratio, BMI, total adipose tissue, subcutaneous adipose tissue, visceral adipose tissue, intermuscular adipose tissue, and muscle mass (MRI); serum leptin | Nonsignificant effects ($P < 0.05$) |

*(Continued)*

**TABLE 2** (Continued)

| Study (ref) | n[2] | Sex/age[3] y | Country | Weight | Study duration | Intervention — Diet (dairy) | Intervention — Exercise | Measurements and variables (assessment tool) | Main findings |
|---|---|---|---|---|---|---|---|---|---|
| Cheng et al., 2005 (25) | 173 | F/(10–12) | Finland | Not stated (possibly underweight, normal weight, and overweight or obese[4]) | 2 y | Dairy (mainly low-fat cheese); average intake: 1413 mg Ca/d | No | Height, weight, BMI, LBM, and FM (DXA); BMC, areal and volumetric BMD (total body and different sites; e.g., spine), cortical thickness of tibia, etc. (DXA, pQCT); serum PTH, vit. D, leptin, BTMs, urine calcium | Body size and composition: nonsignificant effects ($P > 0.05$); significant increase in areal BMD (total body: 10.4% ± 0.5%) and cortical thickness of tibia (37.1% ± 1.3%) ($P < 0.05$); biochemical markers: nonsignificant effects ($P > 0.05$) |

[1] BIA, bioelectrical impedance analysis; BMC, bone mineral content; BMD, bone mineral density; BTM, bone turnover marker; CRP, C-reactive protein; DPA, dual-photon absorptiometry; FM, fat mass; FSH, follicle-stimulating hormone; IGF-I, insulin-like growth factor I; LBM, lean body mass; LH, luteinizing hormone; pQCT, peripheral quantitative computed tomography; PTH, parathyroid hormone; RCT, randomized controlled trial; ref, reference; SPA, single-photon absorptiometry; vit. D, vitamin D; 25(OH)D, 25-hydroxyvitamin D.

[2] Sample number after dropout (except for Matkovic et al. (10) in which dropout is not stated].

[3] Age is indicated as means (ranges in parentheses). In 2 studies [Cadogan et al. (5) and Kelishadi et al. (21)], range was calculated as follows: minimum age = mean age − SD, maximum age = mean + SD.

[4] Based on BMI percentiles for participants' (mean or range) age (BMI was calculated from the provided height and weight mean values if it was not available).

to its efficiency in assessing the methodologic quality of RCTs (30). The scale includes 7 items leading to a 5-point scoring system that assesses the methodologic quality of RCTs according to criteria relevant to randomization, blinding, and dropouts. Specifically, 5 questions are positively scored by adding 1 point each for the "yes" answers or 0 for the "no" answers, whereas the other 2 questions are negatively scored by either subtracting 1 point for a positive answer or by giving 0 for a negative answer (scores of −1 and −2 indicate bad quality, scores of 0 and 1 indicate poor quality, scores of 2 and 3 indicate good quality, a score of 4 indicates very good quality, and a score of 5 indicates excellent quality).

### Included and excluded studies

A total of 15 studies met all of the inclusion criteria and were included in this systematic review (Tables 1 and 2). Studies that did not meet all of the inclusion criteria were excluded from further analysis, such as the study by Bonjour et al. (31), in which participants were given a variety of other calcium-enriched foods (e.g., cakes, biscuits) along with dairy. Another example of an excluded study was a study by Matkovic et al. (32), in which the study design for examining the effects of dairy consumption was not suitable (2 designs were used in this study: an observational design for the assessment of the effects of a high-calcium diet with dairy, whereas an RCT was used for the effects of calcium supplements).

### Results

#### Assessing the quality of the included studies (Jadad scale)

Most of the included studies were rated as good quality. Eight studies (6, 15–19, 22, 24) had a score of 2, and 5 studies (5, 7, 10, 21, 25) had a score of 3. Only 2 studies (20, 23) had a score of 1, which indicates poorer quality. However, it was previously shown in one systematic review (28) that the methodologic quality of studies can be underestimated by 1–2 points with the use of the Jadad scale. Specifically, items 3 and 4 of this scale refer to blinding, which is not always applicable to the type of research, which assesses nutritional and exercise interventions. Overall, the design quality of the 15 included RCTs was assessed as satisfactory for the purpose of this review.

#### Methodologic and statistical characteristics

The methodologic and statistical characteristics of the included studies are summarized in Table 1. Power analyses to estimate sample size were performed in 7 studies. Specifically, 4 studies (10, 16, 17, 22) used a power of 80%, 2 studies (7, 25) used a power of 90%, and 1 study (21) used a power of 95%. A control group was implemented in all of the studies except for that of St.-Onge et al. (24). Fourteen of the 15 reviewed studies reported dropouts. The percentage of dropouts was, on average, 13.3%, and ranged between 2.4% (5) and 32.1% (23).

Adjustments for confounding factors [puberty, age, sex, body and bone size, baseline weight, energy, protein and calcium intakes, and physical activity (PA)] were made in 7 studies (5, 15, 16, 18, 22, 24, 25). Effect size was not estimated or presented in any of the 15 studies, and CIs were reported in 4 studies (5, 18,

19, 25). Dietary intake was assessed with food records (3-, 7-, or 9-d; 2–9 times during the study) in 10 studies (5–7, 10, 15, 16, 18, 20, 21, 25). In addition, 24-h, 3-and 7-d recalls were used in 3 studies (19, 23, 24), an FFQ for nutritional or calcium intake was used in 5 studies (6, 7, 17, 22, 23), and a daily record of dairy product consumption was used in 6 studies (7, 15, 17–20). Eight of the 15 included studies (6, 7, 15, 17–20, 23) used more than one nutritional assessment tool [e.g., FFQ and 24-h recalls in 1 study (23)]. PA was assessed in 11 of the 15 included studies (5–7, 15, 16, 18, 19, 21, 23–25) mainly via questionnaires [only one study used accelerometers (16)].

Methodologic limitations were stated in 5 studies (15, 16, 21, 22, 24). The main limitations were convenient and too-small sample sizes, short study duration, recall bias on food records and PA questionnaires, reliance on self-report for dietary assessment, and questionnaire-based estimation of energy assessment. Recommendations for future research were stated in 5 studies (10, 16, 22, 24, 25). The recommendations included larger sample sizes; matching of participants for skeletal age, bone mass, and calcium intake; use of participants with calcium deficiency; increasing calcium intake; and use of energy-reduced diets.

### Participant characteristics
The final samples sizes (*n*, after dropouts) ranged from 28 to 698 participants (mean *n* = 135). Ten studies used <100 participants and 5 studies used 123–698 participants. In total, 2032 children and adolescents participated in the 15 studies included in this review. The sample comprised females only in 7 studies (*n* = 1157), males only in one study (*n* = 28), and both sexes in 7 studies (*n* = 857). The age of the participants ranged from 4.8 to 17 y, with more than half of the studies (8 studies) including participants aged ≤10 y old. Participants were described as overweight or obese in 4 studies (16, 21, 22, 24) and of normal weight in one study (15). In the remaining 10 studies, no data were reported on participants' weight classification; however, on the basis of the reported anthropometric data, these participants, on average, can be considered to be of normal weight. With the exception of one study (23), the health status of the participants was not stated; participants were reported as healthy in the other 14 included studies. The studies were undertaken in several countries, including the United States (6 studies), New Zealand (2 studies), China (2 studies), and the United Kingdom, Iran, Germany, Chile, and Finland (1 study each) (Table 2).

### Duration and intervention (dairy and exercise and PA)
Study durations ranged from 3 wk to 3 y; specifically, from 3 to 16 wk in 4 studies, from 1 to 2 y in 8 studies, and >2.5 y in 3 studies. Twelve studies only used an intervention period (3 wk to 2 y), whereas the remaining 3 studies also included a follow-up period (from 1 to 2.5 y) (Table 2).

The dairy intervention involved the intake of milk in various quantities or servings in most of the studies. As shown in Table 1, 9 studies (5, 10, 16–20, 22, 24) used only milk as the dairy product in their interventions. The milk differed in terms of percentage of fat (from 0%-fat to full-fat milk) and in the daily amount required to be consumed (from 236 to 900 mL). However, in 2 of these studies (17, 18), the intervention involved milk powder

(enriched with calcium) of different amounts [80 g in one study (17) and either 40 or 80 g in another study (18)]. The rest of the studies (6, 7, 15, 21, 23, 25) used other dairy products (i.e., yogurt and cheese) along with milk in their intervention. With the exception of 2 studies (18, 25), all of other studies reported participants' dietary calcium intake being between 650 (19) and 2076 (17) mg/d and, on average, 1330 mg/d with the dairy intervention. The study by Volek et al. (20) was the only study in which 12 wk of milk consumption (3 servings/d, 708 mL 1%-fat milk, 1723 mg Ca/d) was combined with resistance training (1 h $\times$ 3 times/wk).

### Measurement variables
Four main variables were measured in the 15 studies reviewed (Table 1), including the following: *1*) body size (height, sitting height, weight, waist and hip circumference ratio, and BMI); *2*) body composition (mainly LBM and FM) assessed by DXA in 9 studies (5–7, 15, 17, 18, 20, 22, 25), MRI in 1 study (24), and bioelectrical impendence analysis in 1 study (21); *3*) bone properties, mainly BMC and BMD of the total body and of different body sites, assessed by DXA in 9 studies (5–7, 17–20, 22, 25); peripheral quantitative computed tomography along with DXA in 1 study (25); and single- or dual-photon absorptiometry in 2 studies (10, 23); and *4*) biochemical markers (hormones, BTMs).

### Main findings
From the 14 studies (5–7, 10, 15–25) that assessed body size, only 2 found significant effects ($P < 0.05$). Specifically, Du et al. (19) found a significant increase ($P < 0.05$) in height, sitting height, and weight in Chinese 10-y-old girls after 2 y of a dairy intervention. In contrast, Albala et al. (22) examined the effects of a 16-wk dairy intervention in 8- to 10-y-old overweight or obese boys and girls in Chile and found a significant increase in height for boys only. The same study by Albala et al. (22) was the only one from the 11 studies that also assessed body composition (5–7, 15, 17, 18, 20–22, 24, 25) that found a significant increase in LBM in both boys and girls (Table 2). In fact, this study was the only study out of the 3 studies (16, 21, 24) that examined the effects of dairy on body size and composition in overweight or obese boys and girls that found significant effects (Table 2).

From the 11 studies (5–7, 10, 17–20, 22, 23, 25) that assessed bone mainly in normal-weight boys and girls, 8 (5–7, 18–20, 23, 25) reported significant positive effects on BMD and BMC for total body or specific body sites (e.g., lumbar spine). Five of these studies (5, 19, 20, 23, 25) showed a significant increase in total body BMD ranging from 2.5% (after a 12-wk intervention with dairy and three 1-h resistance exercise sessions/wk) (20) to 13.4% (after a 1-y intervention) (23). Furthermore, the other 2 of these 5 studies with an 18-mo intervention (5) and a 2-y intervention (25) found changes of 9.6% and 10.4% in total body BMD, respectively, whereas 1 study with a 2-y intervention (19) found a 3.2% increase in BMD after adjusting for size.

Biochemical markers, including hormones [e.g., parathyroid hormone (PTH), 25-hydroxyvitamin D]; BTMs, including markers of bone formation (e.g., osteocalcin and bone-specific alkaline phosphatase) and bone resorption markers (e.g., urinary calcium to creatinine ratio); and in a few cases, inflammatory markers (C-reactive protein, leptin) were assessed in 8 studies (5–7, 19,

21, 23–25) (Table 1). Specifically, BTMs were assessed in 6 studies (5–7, 19, 23, 25), which showed nonsignificant results in 4 studies (5, 6, 23, 25) and some significant changes in only 2 studies (7, 19). Nonsignificant effects were also reported for the other biochemical markers, with the exception of a significant increase in insulin-like growth factor I (IGF-I) in the dairy group, which was found in 1 study (5).

## Discussion

This review examined the outcomes of dairy consumption interventions in children and adolescents. Overall, the findings suggest positive effects of dairy consumption on bone properties, with 8 of the 11 studies showing significant increases in BMC and BMD (total body and different sites). Specifically, the combined results of 5 of these studies showed an average increase of ~8% in BMD after an average 16 mo of dairy consumption (milk, yogurt, or cheese), with calcium intakes of ~1000 mg/d. These 5 studies assessed BMD in boys and girls aged 10–17 y old, who were mainly of normal weight and health status and from different countries (e.g., the United States, the United Kingdom, and China). Some of these studies were included in previous reviews by Lanou et al. (9) and Huncharek et al. (12).

The positive effects of dairy consumption on bone-related variables (BMD and BMC) can be attributed to significant increases in dietary calcium intake, with the latter being significantly higher in the dairy group than in the control group in most of the included studies. For example, in the study by Chan et al. (6), the control group had a daily calcium intake of 728 mg compared with 1461 mg in the dairy group. However, significant treatment effects were also reported by Cheng et al. (25), although there was a nonsignificant difference in dietary calcium intake between the dairy (cheese) group and the calcium-supplement (calcium carbonate tablets) group. Thus, the positive effects of dairy product consumption on bone might be better explained by the improved absorption of calcium from dairy due to the presence of lactose, casein phosphopeptides, or vitamin D in dairy products (33).

There are various nutritional components found in dairy products that can affect bone structure and physiology. For example, calcium and protein can affect bone mineralization (through the formation of hydroxyapatite crystals) and collagen formation, respectively (34). According to a review by Tang et al. (35), experimental and observational studies have shown beneficial effects of high protein intake on bone health and an increased risk of fracture with inadequate protein intake. In addition, the high calcium and vitamin D intakes achieved via dairy products can lead to decreased circulating PTH, decreased bone turnover, and increased bone mass (34). Specifically, PTH increases when blood calcium concentrations are low (i.e., due to low dietary calcium). This causes calcium to be released from the bones, leading to bone resorption and eventually a reduction in BMD. The latter has been negatively correlated with the concentrations of serum PTH in adolescent males and females in the RCT by Renner et al. (23), who examined the effects of calcium intake through milk and milk products on BMD.

It is noteworthy that 4 of the studies (5, 6, 19, 25) that reported significant effects of dairy consumption on BMC and BMD did not also show significant effects on BTMs. One reason for this may relate to the relatively long duration (>1 y) of these RCTs. BTMs can respond to treatment more quickly than BMD, so these can be better used in clinical trials that measure acute and shorter-term effects (<6 mo) of different treatment modalities such as diet and exercise (36–38). Another possible reason may be the relative difficulty in evaluating the magnitudes of changes in BTMs, because they are affected by a variety of factors such as puberty, growth, hormones, nutrition, exercise, circadian rhythm, and sensitivity and specificity of assays (39).

In relation to body size and composition, there are few possible mechanisms through which the consumption of dairy products may have positive effects. First, a calcium and vitamin D interaction can affect adipocyte lipogenesis and lipolysis, as well as fat oxidation (40–42). Second, calcium can help decrease fat absorption and increase fat excretion (43). Third, calcium can help regulate appetite and food-fat intake (44). A fourth mechanism may be related to the beneficial effects of various nutritional components found in dairy products such as BCAAs (45) and medium-chain TGs (46).

Despite the aforementioned mechanisms, dairy consumption did not show significant effects on body size and composition in most of the included RCTs. Specifically, only 2 (19, 22) of the 14 studies showed significant effects on height and weight, and only 1 (22) of the 11 studies that examined body composition found a significant increase in LBM. Specifically, Albala et al. (22), who examined the effects of replacing the habitual consumption of sugar-sweetened beverages with milk for 16 wk in Chilean overweight or obese boys and girls, could not show significant effects in body fat despite the significant increase in LBM. According to the authors, either the short duration of the intervention or the replacement of one energy-containing beverage for another that affected the energy reduction in participants' diets was the reason for not showing significant effects on body fat.

Certain design and methodologic limitations of the included studies (Table 2) can explain, in part, why most of the effects, especially on body size and composition, were not significant. Some of these limitations have been previously mentioned (1–3). For example, most of the RCTs did not estimate sample size nor did they consider the experimental power required for detecting a significant effect. Thus, their sample size was relatively small, which possibly explains the nonsignificant findings.

As previously mentioned by Huang and McCrory (2), the lack of compliance monitoring in the RCTs may be another important reason for not finding significant effects. Most of the included studies did not report their participants' compliance with the dairy intervention. On the other hand, compliance was relatively high (>80%) in the few studies in which compliance was reported (e.g., 99% and 100% in studies 8 and 9, respectively). The assessment of dietary intake by using self-report methods, such as food records or recall, is another methodologic weakness, which was highlighted as a potential reason for not finding significant effects on FM in 3 studies (15, 21, 22).

The potential confounding effects of decisive factors such as energy intake, PA, and puberty were not addressed in most of

the relevant studies and, as mentioned in previous reviews, may have affected the findings (2, 4, 13). For example, except for the study by Lappe et al. (15), energy intake was not statistically controlled for in all of the other RCTs, and this might have obscured the effects of dairy on body composition. In addition, healthy eating or energy restriction was not necessarily recommended and not followed by participants in any of these RCTs that assessed the effects of dairy consumption on body composition. As a result, this may be the main reason for not finding significant effects of increased dairy consumption on body composition. In keeping with this trend, Weaver et al. (16) suggested that areas of future research should include energy-reducing diets along with an increased dairy intake to adequately assess these effects. Other confounding factors, such as sex, puberty, and PA level, were controlled for in 7 studies (5, 15, 18, 19, 22, 24, 25), but not in all of the RCTs, which adds to the limited acceptability of the composite results.

Even though most of the included studies scored quite well on the Jadad scale, future RCTs should address these methodologic limitations in order to clarify both the statistical and the substantive significance of the findings. On the other hand, there is potential to improve the intervention models. For example, it has been previously suggested (16) that dietary interventions of higher calcium intake combined with energy restriction should be used in future RCTs, especially in overweight or obese participants. Thus, dairy consumption should be combined with healthy eating advice as well as exercise in order to achieve a modest energy deficit or a stimulus for body composition change in a pediatric population. Indeed, exercise should be included in any intervention that assesses the effects of dairy consumption on bone, as, for example, in one of the included studies by Volek et al. (20). As mentioned above, this study with a 12-wk dairy intervention (3 servings milk/d) combined with resistance exercise (3 times/wk) found significant effects on total body BMD, even in a relatively short period of time.

The present systematic review has 2 distinct advantages compared with previous relevant reviews: the exclusive use of RCTs and the use of a standardized tool (Jadad scale) for the assessment of the methodologic quality of the included studies. The Jadad scale has shown the best validity and reliability among other relevant scales that assess RCTs in health research (47). In addition, most of the methodologic and statistical criteria used in this review were in accordance with the criteria proposed in AMSTAR, a reliable and valid tool for assessing the quality of systematic reviews (48, 49). On the basis of the 11 questions of this tool, the current systematic review had a score of 6, which is satisfactory considering that 30 randomly selected systematic reviews had scores between 3 and 10 (49). However, the present systematic review also has limitations. Our search was limited to 2 databases and included only studies published in English. Therefore, future systematic reviews on this topic may extend their search to more databases and potentially to other languages.

The significance of this review relates to the importance of providing solid evidence on the role of dairy consumption on body size, body composition, and bone properties in children and adolescents. In conclusion, it appears that dairy consumption has overall positive effects on bone structure and development in children and adolescents, but there is not enough evidence to support the beneficial role of dairy consumption on body size and composition in this population. Further research (mainly RCTs) that overcomes the above limitations is needed to provide clear evidence on this critical issue.

## Acknowledgments

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