REVIEW

Effects of Milk and Milk-Product Consumption on Growth among Children and Adolescents Aged 6–18 Years: A Meta-Analysis of Randomized Controlled Trials

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ABSTRACT

Although studies have suggested that milk and milk-product consumption may influence growth during childhood and puberty, results are inconsistent. This meta-analysis was performed to evaluate the available evidence of randomized controlled trials (RCTs) assessing whether milk and milk-product consumption could affect growth and body composition among children and adolescents aged 6–18 y. PubMed, EMBASE, Web of Science, and The Cochrane Library databases were systematically searched for all RCTs published up to December 2017 that investigated milk and milk-product consumption (≥12 wk) on growth and body composition among participants (aged 6–18 y) without undernourishment or diseases. Study screening and data extraction by 2 reviewers followed established PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The Cochrane Collaboration's tool was used to assess the quality of the trials. Data were pooled using a random-effects model. Seventeen trials with 2844 children and adolescents were included. Milk and milk-product interventions resulted in a greater increase in body weight (0.48 kg; 95% CI: 0.19, 0.76 kg; $P = 0.001$), lean mass (0.21 kg; 95% CI: 0.01, 0.41 kg; $P = 0.04$), and attenuated gain in percentage body fat (−0.27%; 95% CI: −0.45%, −0.09%; $P = 0.003$) compared with control groups. However, there were no significant changes in fat mass, height, or waist circumference in the intervention groups compared with the control groups ($P \geq 0.05$). In subgroup analyses, the baseline weight and age, and the duration of intervention were associated with the efficacy of milk and milk-product intake on the change in lean mass, percentage body fat, and waist circumference, respectively (test for subgroup differences: $P < 0.05$). Children and adolescents aged 6–18 y consuming milk and milk products are more likely to achieve a lean body phenotype. This meta-analysis was registered in the International Prospective Register of Systematic Reviews (PROSPERO) as CRD42018086850. *Adv Nutr* 2019;10:250–261.

Keywords: milk, weight, lean mass, meta-analysis, body phenotype

Introduction

Childhood and puberty are critical phases for growth and development and milk and milk products are natural, rich sources of a wide range of essential nutrients (1–3). Milk and milk products may be important modifiable dietary factors in managing a healthy body weight and body composition due to their richness in protein, vitamins, and minerals (particularly calcium) (4, 5). Consuming adequate amounts of some nutrients—such as calcium, potassium, and vitamin D—may be more difficult without including dairy foods in the diet (6).

Studies investigating the association between milk and milk-product consumption and body growth, such as height, weight, and body composition, during childhood and puberty have reported inconsistent results (7–11). Evidence from a 1-y family-centered lifestyle intervention study investigating the impact of milk and milk-product consumption on prepubertal children with obesity reported that fat mass percentage was significantly decreased among children who consumed 4 servings milk and milk products/d compared with a control group (10). However, a longitudinal cohort study in children from ages 10 to 13 y reported less-favorable changes in body weight and body fat for normal

Supported by the Dairy Farmers of Canada and the Dairy Research Cluster Initiative (Agriculture and Agri-Food Canada, Dairy Farmers of Canada, and the Canadian Dairy Commission).

Author disclosures: KK, OFS, and HAW, no conflicts of interest.

Supplemental Table 1 and Supplemental Figures 1–8 are available from the "Supplementary data" link in the online posting of the article and from the same link in the online table of contents at https://academic.oup.com/advances/.

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or overweight children consuming flavored milk compared with nonconsumers over a 2-y period (11).

Recently, an updated meta-analysis of 37 randomized controlled trials (RCTs) suggested that a high-dairy intervention increased body weight and lean mass and decreased body fat and waist circumference among adults (12). In addition, a systematic review of prospective cohort studies found that dairy consumption was inversely and longitudinally associated with the risk of childhood overweight and obesity (13). However, to our knowledge, there is no meta-analysis summarizing results from RCTs for the effects of milk and milk-product consumption on quality of growth during childhood and puberty. Therefore, this meta-analysis was conducted to evaluate the available evidence of RCTs assessing whether milk and milk-product consumption could affect growth among children and adolescents aged 6–18 y, primarily weight, height, lean mass, and fat mass.

Methods

This meta-analysis was conducted according to the recommendations and standards set by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (14).

Study search

PubMed, EMBASE, Web of Science, and The Cochrane Library databases were systematically searched for all RCTs investigating the effects of milk and milk-product consumption on growth among children and adolescents aged 6–18 y published up to December 2017. Three comprehensive search themes were specified. The first theme identified relevant terms for milk by combining exploded versions of the Medical Subject Heading (MeSH) terms dairy products, dairy, milk, cheese, or yogurt and corresponding keywords in titles and abstracts. The second theme identified expanded the MeSH terms by combining body height, body weight, weight loss, weight change, weight reduction, body composition, body fat, body fat percentage, fat mass, fat body mass, percentage of fat body mass, lean mass, fat free mass, fat-free mass, lean body mass, or percentage of lean body mass and corresponding keywords in titles and abstracts. The third theme identified terms related to children and adolescents by combining child, childhood, adolescent, teens, teen, teenagers, teenager, youths, or youth and corresponding keywords in titles and abstracts. The 3 themes were then combined and further filtered by "human" and the publication type of RCT, with no language restrictions. The initial search identified 1917 potentially relevant articles through databases and 2 records from other sources (reference lists). After removing duplicates and screening the titles and abstracts, full texts of 77 articles were screened. **Figure 1** provides detailed search selection, and the complete search algorithm is detailed in **Supplemental Table 1**.

Study selection

Studies were included if they met the following criteria: *1*) they were RCTs with a parallel controlled design, *2*) participants age range was 6–18 y, *3*) milk or milk products were used as the main intervention but not as part of a multicomponent dietary supplement in either the intervention or control groups, *4*) participants consumed dairy products for ≥12 wk, and *5*) measurements of the outcome related to growth and body composition were reported. Studies were excluded if *1*) they were not randomized designs, *2*) participants were undernourished or diseased, or *3*) milk and milk products were supplied in the same quantity for both experimental and control groups. Studies that supplied milk and milk products to control groups were not excluded from this meta-analysis because milk and milk products are a recommended food group and their impact on growth is well elucidated, especially in childhood through adolescence. In addition, we included studies categorizing intervention groups with different doses of milk and milk products.

Relevant studies were identified in duplicate by 2 independent reviewers (KK and OFS) by first screening the titles and abstracts followed by the full text against inclusion and exclusion criteria. Any disagreement was resolved by consensus with the senior reviewer (HAW) experienced in the field of nutrition interventions and child health. When multiple articles for a single study were present, we used the latest publication and supplemented it, if necessary, with data from the most complete publication.

Data extraction and quality assessment

From each study, information was extracted including the following: first author, publication year, geographic location, study design (duration, randomization procedures, blinding), participant information (sample size, sex distribution, age, inclusion and exclusion criteria), details with regard to intervention and control regimens (category of milk and milk products, mean intakes per day, and proportion of nutrients), source of milk supplement, method of outcome ascertainment, outcome results (change in body height, weight, fat mass, lean mass, and waist circumference), and corresponding 95% CIs, SEs, or exact *P* values. When multiple time points were reported, only the end of the intervention was used.

Because differences in study populations and design might cause variations in results, the Cochrane Collaboration's tool was used to assess the quality of the trials, which contained 7 risk-of-bias items: random-sequence generation (selection bias), allocation concealment (selection bias), blinding of participants and personnel (performance bias), blinding of outcome assessment (detection bias), incomplete outcome data (attrition bias), selective reporting (reporting bias), and other bias (15). If all features were adequate, the study was allocated a low risk of bias. If ≥1 features were unclear, the risk of bias was unclear. If ≥1 features were inadequate or negative, the study was allocated a high risk of bias (16).

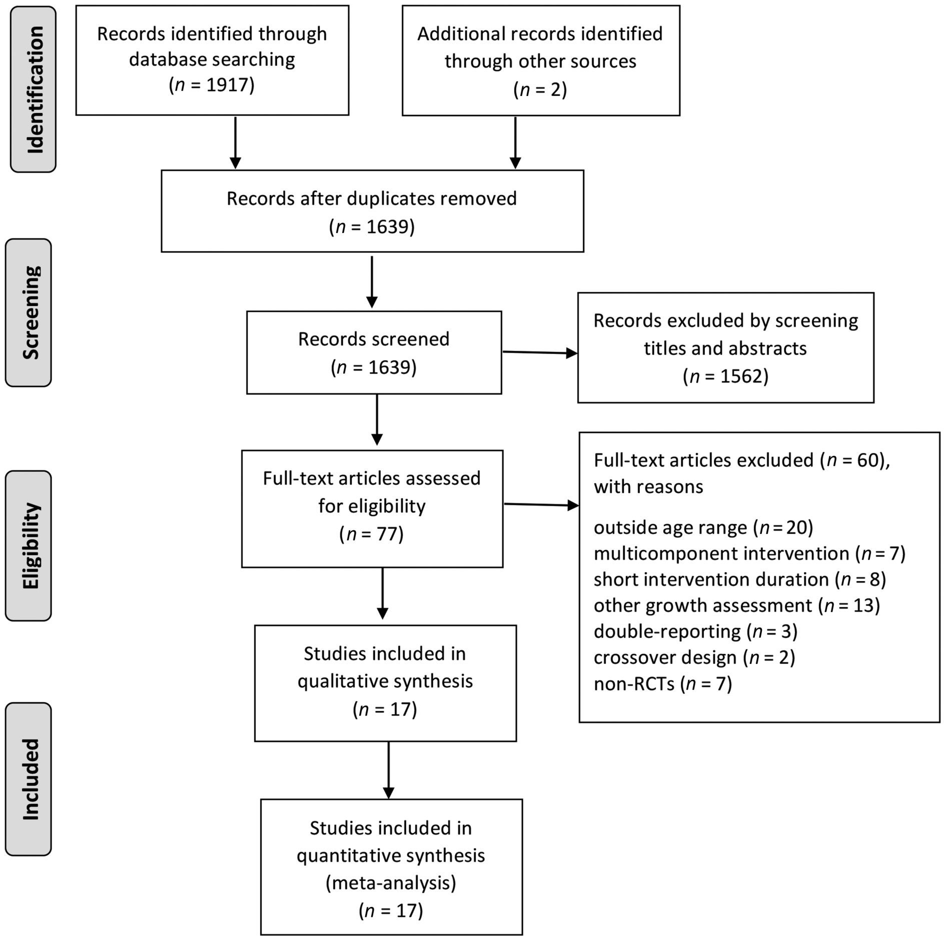


FIGURE 1 PRISMA flow diagram of the study selection process. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; RCT, randomized controlled trial.

Statistical analysis and exploration of heterogeneity

Data pooling was performed with the use of classical meta-analytic methodology using Review Manager 5.3 (Cochrane Informatics and Knowledge Management Department). Significance was set at $P < 0.05$, and 95% CIs were calculated for each investigation and for each outcome variable. Data were extracted from the text, tables, and figures of the original published articles. To include data from as many trials as possible, missing SD data for one trial (17) were imputed from SD data from all other trials using the same measure (18). When estimating the analysis indexes, the weighted mean difference was used as the effect size of the continuous variable.

Before calculating the standardized mean effect for all trials, statistical heterogeneity was evaluated by using the I^2 statistic and P values, which assessed the appropriateness of pooling the individual study results (19). The I^2 value provided an estimate of the amount of variance across studies because of heterogeneity rather than chance (20). I^2 values of 25%, 50%, and 75% corresponded to low, moderate, and high levels of heterogeneity, respectively (21). If $P \geq 0.05$, the heterogeneity was not substantial. Thus, a fixed-effects model was used to calculate forest plots with weighted mean difference and 95% CIs. If $P < 0.05$, however, the heterogeneity was considered substantial. Then, combined results were tested with a random-effects model of DerSimonian-Laird methods and inverse variance weighting.

Subgroups were categorized according to sex (males compared with females), age (6–12 y compared with 13–18 y), baseline body weight (normal weight compared with overweight or obesity) and intervention duration (<12 compared with ≥12 mo). The subgroup analysis was assessed using chi-square statistic, with $P < 0.05$ taken to indicate significance. Sensitivity analyses were conducted to evaluate the effect of removing any single study from the meta-analysis. The risk of publication bias was assessed by rendering funnel plots. This meta-analysis has been registered in the International Prospective Register of Systematic Reviews (PROSPERO; registration ID: CRD42018086850).

Results

Study characteristics

The search strategy and selection of studies for this meta-analysis are shown in Figure 1. In total, 2844 children and adolescents aged between 6 and 18 y from 17 RCTs (22–38) were included. Doses of milk and milk products in the included studies ranged from 190 to 1000 mL/d, and the intervention duration varied from 3 to 24 mo. Six trials investigated participants with overweight and obese (23, 28, 32, 34, 36, 37). The types of intervention included fluid milk (22–26, 28–38), cheese (26–28, 33, 34, 37), yogurt (26–28, 32–34, 37), whey (23), or casein (23). With regard to the source of intervention, most of them were provided free to the participants by the study. The characteristics of the selected trials are presented in **Table 1**.

Change in growth

Body weight.

In the analysis for change in body weight, 15 studies (22–27, 29–36, 38) (n = 3324 participants) were included. There was a significant difference in body-weight change between the intervention and control groups (0.48 kg; 95% CI, 0.19, 0.76 kg; P = 0.001; **Figure 2**A) However, significant heterogeneity was observed for change in body weight (I^2 = 98%; $P < 0.001$). Thus, subgroup analysis was performed by categorizing subgroups by sex (males compared with females), age (6–12 y compared with 13–18 y), baseline body weight (normal weight compared with overweight or obesity) and intervention duration (<12 compared with ≥12 mo). In all subgroup analyses, the impact of milk and milk products on change in body weight was not significantly different between the categories for any subgroup (test for subgroup differences: $P \geq 0.05$; **Supplemental Figure 1**).

Height.

In the analysis for the change in height, 13 studies (22, 24–27, 29, 30, 32, 33, 35–38) in 3007 participants were included. There was no significant difference in height change between the intervention and control groups (0.09 cm; 95% CI: −0.16, 0.35 cm; P = 0.47; Figure 2B). However, significant heterogeneity was observed for height (I^2 = 100%; $P < 0.001$). In all subgroup analysis, the effect of milk and milk products showed no significant difference on change in body height between the categories for any subgroup (test for subgroup differences: $P \geq 0.05$; **Supplemental Figure 2**).

Waist circumference.

Six studies (23, 28, 31, 32, 34, 36) (n = 916 participants) evaluated the effect of milk and milk-product consumption on change in waist circumference, and the analysis suggested there was no significant difference in waist circumference change between the intervention and control groups (0.08 cm; 95% CI: −0.70, 0.86 cm; P = 0.84; Figure 2C). Moreover, heterogeneity was significant (I^2 = 99%; $P < 0.001$). In subgroup analysis, the effectiveness of milk and milk-product consumption in reducing gain in waist circumference was more pronounced among participants with a short-term intervention (<12 mo; 0.90 cm; 95% CI: 0.36, 1.44 cm; P = 0.001) than in those with a long-term intervention (≥12 mo; −1.62 cm; 95% CI: −3.00, −0.23 cm; P = 0.02) (test for subgroup differences: I^2 = 90.9%; $P < 0.001$; **Supplemental Figure 3**). However, there were no significant differences between sex, age, baseline body weight, and waist circumference change, respectively (test for subgroup differences: $P \geq 0.05$; Supplemental Figure 3).

Change in body composition

Lean mass.

Ten studies (22, 25–28, 30–33, 38) (n = 1020 participants) evaluated the effect of milk and milk-product consumption on change in lean mass. A significant increase that favored milk and milk-product consumption on lean mass was shown (0.21 kg; 95% CI: 0.01, 0.41 kg; P = 0.04; **Figure 3**A). With regard to the significant heterogeneity (I^2 = 97%; $P < 0.001$), subgroup analysis was performed. The effectiveness of milk and milk-product consumption in increasing lean mass was more pronounced (test for subgroup differences: I^2 = 79.5%; P = 0.03) in participants with a baseline weight within the normal range (0.26 kg; 95% CI: 0.06, 0.46 kg; P = 0.01) than in those who were overweight or obese (0.02 kg; 95% CI: −0.05, 0.09 kg; P = 0.61). There were no significant differences on change in lean mass between the categories for sex, age, and intervention duration, respectively (test for subgroup differences: $P \geq 0.05$; **Supplemental Figure 4**).

Fat mass.

For fat mass (kilograms), 10 studies (22, 25, 27, 28, 30, 31, 33, 34, 37, 38) (n = 1010 participants) were included in the analysis and the heterogeneity was high (I^2 = 100%; $P < 0.001$). There was no significant difference in fat mass between the intervention and control groups (−0.15 kg; 95% CI: −0.52, 0.22 kg; P = 0.42; Figure 3B). Furthermore, in all subgroup analyses, the impact of milk and milk products on change in fat mass was not significantly different between the categories for any subgroup (test for subgroup differences: $P \geq 0.05$; **Supplemental Figure 5**).

Percentage body fat.

There were 8 studies (22, 25, 26, 28, 31, 32, 34, 38) in 829 participants that mentioned the change in percentage body fat, and the heterogeneity between them was significant (I^2 = 90%; $P < 0.001$). Participants in the intervention group gained less percentage body fat than did those in control groups (−0.27%; 95% CI: −0.45%, −0.09%; P = 0.003; Figure 3C). In subgroup analysis, the effectiveness of milk and milk-product consumption in reducing gain in percentage body fat was more pronounced among children (6–12 y; −0.44%; 95% CI: −0.56%, −0.32%; $P < 0.001$) compared with adolescents (13–18 y; −0.14%; 95% CI: −0.40%, 0.13%; P = 0.31) (test for subgroup differences: I^2 = 75.3%; P = 0.04). There were no significant differences on change in percentage body fat between the categories for sex, baseline body weight,

TABLE 1 Characteristics of the trials included in the meta-analysis[1]

Study, year, country (ref)	Age,[2] y	No. of participants (no. in intervention)[3]	Percentage of girls; population characteristics	Intervention	Control	Duration, mo	Source of milk supplement	Main outcomes	Design
Albala et al., 2008, Chile (22)	8–10	93 (47)	47.3; prepubertal	3 servings milk/d (~200 g/serving provided 80 kcal, 8 g protein, 3 g fat, 11 g carbohydrate, and 320 mg Ca)	Usual diet	4	Delivered to home weekly	Weight, height, body composition (DXA), FFQ	R, P
Arnberg et al., 2012, Denmark (23)	12–15	193 (48/48/47)	62; age- and sex-adjusted BMI (kg/m^2) >25	1 L skim milk/d, 1 L whey/d, or 1 L casein/d	1 L water/d	3	Provided at the start of and halfway through the intervention	Weight, waist circumference, fasting plasma insulin, HOMA, and plasma C-peptide	R, B, P
Baker et al., 1980, UK (24)	7–8	520 (281)	48.7; families with ≥4 children	One-third of a pint (190 mL) milk/d	Usual diet	21	Provided free at school	Weight, height	R, B, P
Cadogan et al., 1997, UK (25)	12.2 ± 0.3[4]	82 (44)	100; white	568 mL (1 pint) whole or reduced-fat milk/d	Usual diet	18	Delivered to home every morning	Height, weight, pubertal staging, bone mass, body composition (DXA), biochemical values	R, P
Chan et al., 1995, USA (26)	9–13	48 (22)	100; Tanner stage II	Allowance of 1200 mg Ca/d of dairy products (milk, cheese, and yogurt)	Usual diet	12	Delivered weekly	Bone mineral content and density, body composition (DXA), serum or urinary biochemical values	R, P
Cheng et al., 2005, Finland (27)	10–12	77 (39)	100; Tanner stage I–II, dietary calcium intakes <900 mg/d	Dairy products (low-fat cheese and lactose-reduced yogurt; 1000 mg Ca/d)	Habitual diet (calcium intakes >900 mg/d)	24	Donated by VALIOOy, Helsinki, Finland	Height, weight, pubertal staging, bone mass, body composition (DXA), biochemical values	R, DB, PC
Cohen et al., 2016, Canada (28)	6–8.5	73 (23/24)	57; obese, prepubertal	2 or 4 servings milk and alternatives/d, preferably with lower %MF (i.e., 1%MF milk, 15%–18%MF cheese, 1%–2%MF yogurt)	Usual diet	12	Self-support	Anthropometry, BAZ, waist circumference, body composition (DXA), biochemical values	R, P

(*Continued*)

TABLE 1 (*Continued*)

Study, year, country (ref)	Age,[2] y	No. of participants (no. in intervention)[3]	Percentage of girls; population characteristics	Intervention	Control	Duration, mo	Source of milk supplement	Main outcomes	Design
Du et al., 2004, China (29)	10–12	346 (111/113)	100	330 mL UHT milk/d (560 mg Ca); 330 mL UHT milk/d (560 mg Ca and 5 or 8 mg cholecalciferol)	Habitual diet	24	The UHT milk was specially formulated by Murray Goulburn Co-operative Co. Ltd. (Brunswick, Australia)	Height, weight, bone mass, body composition (DXA), biochemical values	R, P
Gibbons et al., 2004, New Zealand (30)	8–10	154 (74)	51.3; prepubertal	High-calcium milk provided 600 mg Ca per 40-g serving or 1200 mg/d	A control drink reconstituted with water	18	Delivered to school fortnightly or to home monthly	Height, weight, bone mineral density, bone mineral content, body composition (DXA)	R, B, P
Lambourne et al., 2013, USA (31)	13.6	74 (36)	66; RT (3 d/wk)	24 oz fat-free chocolate milk or low-fat white milk/d on RT days: 16 fl oz fat-free chocolate milk (16 g protein, 280 kcal) immediately after completion of RT, and 8 fl oz low-fat white milk (8 g protein, 100 kcal) at lunch; non-RT days: 16 fl oz low-fat white milk before their first class and 8 fl oz fat-free chocolate milk at lunch	Bottled water	6	Provided at school	Height, weight, body composition (DXA), waist circumference, muscle strength, daily physical activity, energy/macronutrient intake	R, B, P
Lappe et al., 2017, USA (32)	13–14	274 (136)	100; overweight, intakes of ≤600 mg/d	Low-fat milk (skim, 1%, or 2%) or yogurt servings providing ≥1200 mg Ca/d	Usual diet	12	Participants refunded for yogurt and milk purchased after receipt submission	Anthropometry, bone mineral density, bone mineral content, body composition (DXA), biochemical values	R, P

(*Continued*)

TABLE 1 (*Continued*)

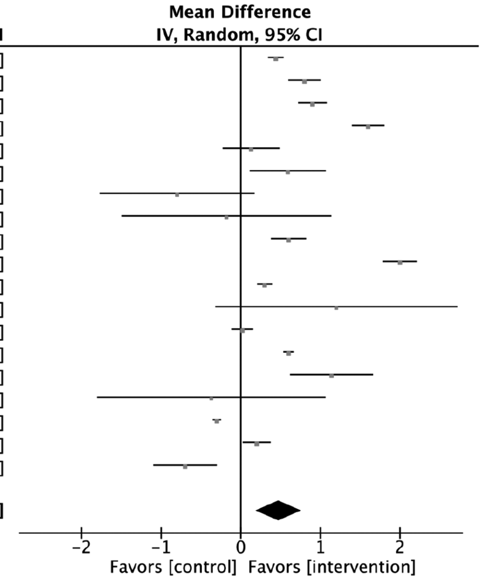
Study, year, country (ref)	Age,[2] y	No. of participants (no. in intervention)[3]	Percentage of girls; population characteristics	Intervention	Control	Duration, mo	Source of milk supplement	Main outcomes	Design
Merrilees et al., 2000, New Zealand (33)	15–16	91 (45)	100; postpubertal	Dairy food products (milk, flavored milk, dairy dessert, cheese, or yogurt; low-fat options were available; >1000 mg Ca/d)	Usual diet	24	Delivered fortnightly	Height, weight, bone mineral density, bone mineral content, body composition (DXA), biochemical values	R, P
Mobarhan et al., 2009, Iran (34)	12–18	96 (28/33)	Not mentioned; Overweight or obese	A calorie-restricted diet providing 500 kcal/d with 3 or 4 servings of dairy products/d	A calorie-restricted diet providing 500 kcal/d	3	Not mentioned	Height, weight, waist circumference, body composition (BIA), biochemical values	R, P
Rahmani et al., 2011, Iran (35)	6–9	469 (235)	51	250 mL 2.5% milk/d	Usual diet	3	Provided at school	Weight, height, midarm circumference	R, P
St-Onge et al., 2009, USA (36)	8–10	45 (21)	80; overweight	3 × 236 mL of skim milk and 1 × 236 mL of 1% low-fat chocolate milk/d	Usual diet with 3 × 200 mL of sugar-sweetened beverage and 236 mL of milk/d	4	Provided weekly	Height, weight, % body fat, waist and hip circumferences, MRI	R, P
Vogel et al., 2017, USA (37)	8–15.9	181 (overweight 47; healthy weight 55)	64; early pubertal, low amounts of dairy (<800 mg Ca/d)	3 servings (equivalent to ∼900 mg Ca)/d of milk, yogurt, or cheese	Habitual diet	18	Provided biweekly	Height, weight, waist circumference, pubertal staging, bone mass, body composition (DXA), biochemical values	R, P
Volek et al., 2003, USA (38)	13–17	28 (14)	0; RT (3 d/wk)	3 servings (708 mL or 24 fl oz) 1% fluid milk/d	Habitual diet with unfortified juice	3	Provided weekly	Anthropometric measures, body composition (DXA), bone density, dietary intakes, performance measures	R, P

[1] B, blind; BAZ, BMI-for-age *z*-score; BIA, bioimpedance analysis; DB, double-blind; fl, fluid; HOMA, homeostatic model assessment; oz, ounces; P, parallel; PC, placebo-controlled; R, randomized; ref, reference; RT, resistance training; UHT, ultra-high temperature; %MF, percentage of milk fat.
[2] The mean age range is provided for studies that presented mean age separately for each group (control and intervention).
[3] The multiple intervention numbers represent the number of participants in different intervention groups.
[4] Mean ± SD.

A

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Albala et al. (22)	1.57	0.24	47	1.13	0.24	46	6.2%	0.44 [0.34, 0.54]
Arnberg et al. 1 (23)	2.4	0.6	48	1.6	0.4	50	6.0%	0.80 [0.60, 1.00]
Arnberg et al. 2 (23)	2.5	0.5	48	1.6	0.4	50	6.1%	0.90 [0.72, 1.08]
Arnberg et al. 3 (23)	3.2	0.6	47	1.6	0.4	50	6.0%	1.60 [1.40, 1.80]
Baker et al. (24)	5.25	2.26	281	5.12	1.9	239	5.7%	0.13 [−0.23, 0.49]
Cadogan et al. (25)	7.89	1.1	44	7.3	1.1	38	5.3%	0.59 [0.11, 1.07]
Chan et al. (26)	6.4	1.3	22	7.2	2.1	26	3.6%	−0.80 [−1.77, 0.17]
Cheng et al. (27)	11.32	3.13	39	11.5	2.76	38	2.7%	−0.18 [−1.50, 1.14]
Du et al. 1 (29)	2	1.2	209	1.4	1.2	247	6.0%	0.60 [0.38, 0.82]
Du et al. 2 (29)	3.4	1.2	242	1.4	1.2	247	6.0%	2.00 [1.79, 2.21]
Gibbons et al. (30)	6.9	0.3	74	6.6	0.3	80	6.2%	0.30 [0.21, 0.39]
Lambourne et al. (31)	3.4	3.7	36	2.2	2.9	38	2.3%	1.20 [−0.32, 2.72]
Lappe et al. (32)	0.31	0.54	136	0.29	0.6	138	6.2%	0.02 [−0.12, 0.16]
Merrilees et al. (33)	4.6	0.2	45	4	0.1	46	6.2%	0.60 [0.53, 0.67]
Mobarhan et al. 1 (34)	−3.4	1.52	33	−4.54	0.16	35	5.2%	1.14 [0.62, 1.66]
Mobarhan et al. 2 (34)	−4.91	3.87	28	−4.54	0.16	35	2.4%	−0.37 [−1.80, 1.06]
Rahmani et al. (35)	0.3	0.1	235	0.6	0.4	234	6.2%	−0.30 [−0.35, −0.25]
St-Onge et al. (36)	1.3	0.3	21	1.1	0.3	24	6.1%	0.20 [0.02, 0.38]
Volek et al. (38)	1.1	0.7	14	1.8	0.3	14	5.6%	−0.70 [−1.10, −0.30]
Total (95% CI)			**1649**			**1675**	**100.0%**	**0.48 [0.19, 0.76]**

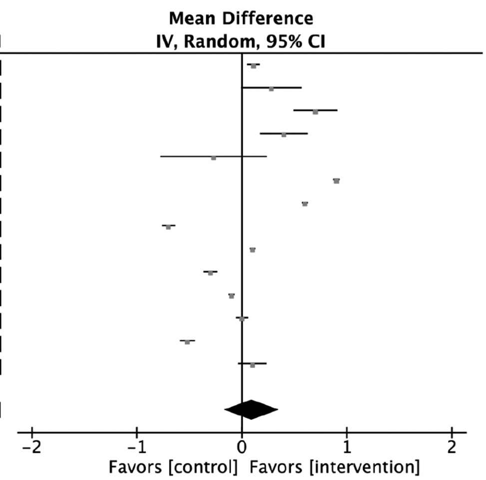
Heterogeneity: $Tau^2 = 0.34$; $Chi^2 = 1112.61$, df = 18 ($P < 0.00001$); $I^2 = 98\%$
Test for overall effect: Z = 3.28 (P = 0.001)



B

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Albala et al. (22)	2.27	0.15	47	2.16	0.15	46	7.4%	0.11 [0.05, 0.17]
Baker et al. (24)	9.46	1.68	281	9.18	1.67	239	6.8%	0.28 [−0.01, 0.57]
Cadogan et al. (25)	9.1	0.51	44	8.4	0.45	38	7.0%	0.70 [0.49, 0.91]
Chan et al. (26)	7.8	0.4	22	7.4	0.4	26	7.0%	0.40 [0.17, 0.63]
Cheng et al. (27)	13.1	1.22	39	13.37	1.05	38	5.7%	−0.27 [−0.78, 0.24]
Du et al. 1 (29)	9.5	0.2	209	8.6	0.1	247	7.4%	0.90 [0.87, 0.93]
Du et al. 2 (29)	9.2	0.2	242	8.6	0.1	247	7.4%	0.60 [0.57, 0.63]
Gibbons et al. (30)	9.2	0.2	74	9.9	0.2	80	7.4%	−0.70 [−0.76, −0.64]
Lappe et al. (32)	1	0.12	136	0.9	0.1	138	7.4%	0.10 [0.07, 0.13]
Merrilees et al. (33)	1.3	0.2	45	1.6	0.1	46	7.3%	−0.30 [−0.37, −0.23]
Rahmani et al. (35)	1.4	0.2	235	1.5	0.1	234	7.4%	−0.10 [−0.13, −0.07]
St-Onge et al. (36)	1.9	0.1	21	1.9	0.1	24	7.4%	0.00 [−0.06, 0.06]
Vogel et al. 1 (37)	4.43	0.23	102	4.95	0.25	79	7.3%	−0.52 [−0.59, −0.45]
Volek et al. (38)	0.8	0.15	14	0.7	0.21	14	7.2%	0.10 [−0.04, 0.24]
Total (95% CI)			**1511**			**1496**	**100.0%**	**0.09 [−0.16, 0.35]**

Heterogeneity: $Tau^2 = 0.23$; $Chi^2 = 4824.88$, df = 13 ($P < 0.00001$); $I^2 = 100\%$
Test for overall effect: Z = 0.72 (P = 0.47)



C

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Arnberg et al. 1 (23)	2.2	4.2	48	0.7	3.7	50	8.0%	1.50 [−0.07, 3.07]
Arnberg et al. 2 (23)	2.1	4.3	48	0.7	3.7	50	7.9%	1.40 [−0.19, 2.99]
Arnberg et al. 3 (23)	1.5	3.1	47	0.7	3.7	50	8.7%	0.80 [−0.56, 2.16]
Cohen et al. 1 (28)	0.02	1.23	24	5.11	0.22	26	11.3%	−5.09 [−5.59, −4.59]
Cohen et al. 2 (28)	4.51	0.12	23	5.11	0.22	26	11.9%	−0.60 [−0.70, −0.50]
Lambourne et al. (31)	1.2	3.1	36	0.6	4.2	38	7.7%	0.60 [−1.08, 2.28]
Lappe et al. (32)	0.8	0.2	136	0.1	0.1	138	11.9%	0.70 [0.66, 0.74]
Mobarhan et al. 1 (34)	−2.55	0.39	33	−3.64	2.03	35	10.9%	1.09 [0.40, 1.78]
Mobarhan et al. 2 (34)	−2.1	1.89	28	−3.64	2.03	35	10.0%	1.54 [0.57, 2.51]
St-Onge et al. (36)	−0.3	0.6	21	−0.5	0.6	24	11.6%	0.20 [−0.15, 0.55]
Total (95% CI)			**444**			**472**	**100.0%**	**0.08 [−0.70, 0.86]**

Heterogeneity: $Tau^2 = 1.33$; $Chi^2 = 1089.92$, df = 9 ($P < 0.00001$); $I^2 = 99\%$
Test for overall effect: Z = 0.20 (P = 0.84)

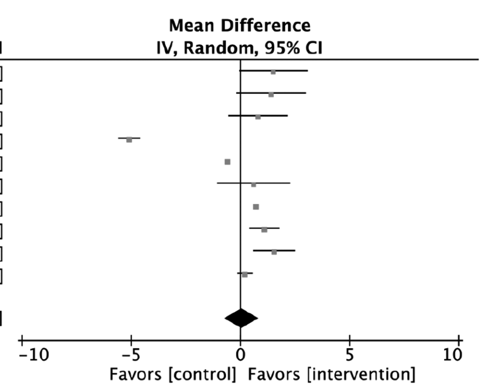
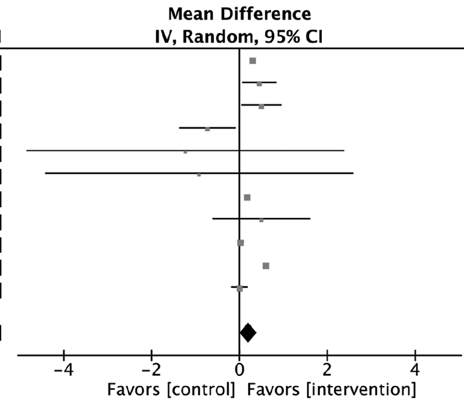


FIGURE 2 Forest plot of change in body weight (kilograms) (A), height (centimeters) (B), and waist circumference (centimeters) (C) between intervention and control groups: random-effects model. IV, inverse variance.

A

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Albala et al. (22)	0.92	0.1	47	0.62	0.11	46	15.0%	0.30 [0.26, 0.34]
Cadogan et al. (25)	5.5	0.99	44	5.05	0.81	38	9.5%	0.45 [0.06, 0.84]
Chan et al. (26)	4.3	0.6	22	3.8	1	26	8.3%	0.50 [0.04, 0.96]
Cheng et al. (27)	7.64	1.41	39	8.37	1.46	38	5.8%	−0.73 [−1.37, −0.09]
Cohen et al. 1 (28)	0.1	6.69	24	1.33	6.32	26	0.3%	−1.23 [−4.84, 2.38]
Cohen et al. 2 (28)	0.41	6.19	23	1.33	6.32	26	0.3%	−0.92 [−4.43, 2.59]
Gibbons et al. (30)	3.98	0.19	74	3.81	0.18	80	14.9%	0.17 [0.11, 0.23]
Lambourne et al. (31)	2.2	1.9	36	1.7	2.9	38	2.6%	0.50 [−0.61, 1.61]
Lappe et al. (32)	0.05	0.35	136	0.03	0.26	138	14.8%	0.02 [−0.05, 0.09]
Merrilees et al. (33)	0.72	0.09	45	0.12	0.06	46	15.0%	0.60 [0.57, 0.63]
Volek et al. (38)	2.4	0.3	14	2.4	0.2	14	13.3%	0.00 [−0.19, 0.19]
Total (95% CI)			**504**			**516**	**100.0%**	**0.21 [0.01, 0.41]**

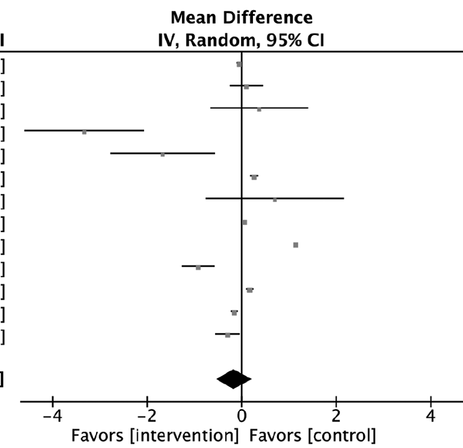
Heterogeneity: $Tau^2 = 0.07$; $Chi^2 = 369.71$, df = 10 ($P < 0.00001$); $I^2 = 97\%$
Test for overall effect: Z = 2.10 (P = 0.04)



B

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Albala et al. (22)	0.84	0.15	47	0.89	0.15	46	9.3%	−0.05 [−0.11, 0.01]
Cadogan et al. (25)	1.84	0.75	44	1.74	0.86	38	8.6%	0.10 [−0.25, 0.45]
Cheng et al. (27)	3.42	2.31	39	3.05	2.33	38	5.3%	0.37 [−0.67, 1.41]
Cohen et al. 1 (28)	−0.06	2.55	24	3.27	1.96	26	4.4%	−3.33 [−4.60, −2.06]
Cohen et al. 2 (28)	1.6	1.98	23	3.27	1.96	26	5.0%	−1.67 [−2.78, −0.56]
Gibbons et al. (30)	2.59	0.25	74	2.33	0.29	80	9.2%	0.26 [0.17, 0.35]
Lambourne et al. (31)	1.1	2.8	36	0.4	3.6	38	3.7%	0.70 [−0.77, 2.17]
Merrilees et al. (33)	2.62	0.05	45	2.56	0.09	46	9.3%	0.06 [0.03, 0.09]
Mobarhan et al. 1 (34)	−2.26	0.1	33	−3.4	0.02	35	9.3%	1.14 [1.11, 1.17]
Mobarhan et al. 2 (34)	−4.32	0.94	28	−3.4	0.02	35	8.6%	−0.92 [−1.27, −0.57]
Vogel et al. 2 (37)	1.68	0.2	47	1.51	0.17	32	9.2%	0.17 [0.09, 0.25]
Vogel et al. 3 (37)	1.35	0.15	55	1.51	0.21	47	9.3%	−0.16 [−0.23, −0.09]
Volek et al. (38)	−1.1	0.4	14	−0.8	0.3	14	8.9%	−0.30 [−0.56, −0.04]
Total (95% CI)			**509**			**501**	**100.0%**	**−0.15 [−0.52, 0.22]**

Heterogeneity: $Tau^2 = 0.38$; $Chi^2 = 2846.32$, df = 12 ($P < 0.00001$); $I^2 = 100\%$
Test for overall effect: Z = 0.80 (P = 0.42)



C

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Albala et al. (22)	0.36	0.24	47	0.78	0.25	46	12.1%	−0.42 [−0.52, −0.32]
Cadogan et al. (25)	−0.42	0.29	44	0.12	0.31	38	11.8%	−0.54 [−0.67, −0.41]
Chan et al. (26)	1.6	0.6	22	1.2	0.4	26	9.4%	0.40 [0.11, 0.69]
Cohen et al. 1 (28)	−0.67	0.59	24	−0.1	0.35	26	9.7%	−0.57 [−0.84, −0.30]
Cohen et al. 2 (28)	−0.33	0.39	23	−0.1	0.35	26	10.7%	−0.23 [−0.44, −0.02]
Lambourne et al. (31)	−0.2	3.3	36	0	3.5	38	1.2%	−0.20 [−1.75, 1.35]
Lappe et al. (32)	0.27	0.6	136	0.25	0.7	138	11.5%	0.02 [−0.13, 0.17]
Mobarhan et al. 1 (34)	−1.78	0.18	33	−1.5	0.29	35	12.0%	−0.28 [−0.39, −0.17]
Mobarhan et al. 2 (34)	−1.51	0.3	28	−1.5	0.29	35	11.6%	−0.01 [−0.16, 0.14]
Volek et al. (38)	−2.2	0.3	14	−1.4	0.4	14	9.9%	−0.80 [−1.06, −0.54]
Total (95% CI)			**407**			**422**	**100.0%**	**−0.27 [−0.45, −0.09]**

Heterogeneity: $Tau^2 = 0.07$; $Chi^2 = 90.15$, df = 9 ($P < 0.00001$); $I^2 = 90\%$
Test for overall effect: Z = 3.00 (P = 0.003)

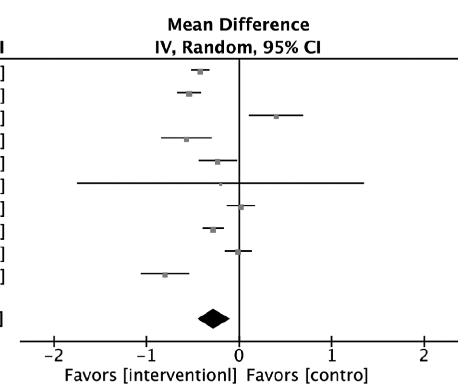


FIGURE 3 Forest plot of change in lean mass (kilograms) (A), fat mass (kilograms) (B), and percentage body fat (C) between intervention and control groups: random-effects model. IV, inverse variance.

and intervention duration, respectively (test for subgroup differences: $P \geq 0.05$; **Supplemental Figure 6**).

Sensitivity analysis and quality assessment

To test the robustness of the results, we removed one study each time in the pooled analysis and found that no single study substantially influenced the pooled association of interest. Risk of bias for each domain in each included study is presented in **Supplemental Figure 7**. On the basis of the funnel plots (**Supplemental Figure 8**), it could be concluded that studies that evaluated changes in growth rarely had publication bias with the symmetric figures, except for change in waist circumference.

Discussion

Findings from this meta-analysis of 17 RCTs suggest that milk and milk-product interventions resulted in higher lean mass and body weight and attenuated gain in percentage body fat compared with control groups among children and adolescents aged 6–18. This result is consistent with the conclusion of a meta-analysis by Geng et al. (12) that a high-dairy intervention increased body weight and lean mass among adults. Furthermore, another meta-analysis by Abargouei et al. (39), including 883 adults aged 18–85 y, showed that increased dairy consumption without energy restriction might not lead to a significant change in weight or body composition, whereas the inclusion of dairy products in energy-restricted weight-loss diets significantly resulted in a greater reduction in weight, fat mass, and waist circumference and gain in lean mass compared with that in the usual weight-loss diets. Chen et al. (40) also found that dairy products may have modest benefits in facilitating weight loss when energy is restricted, but this effect seems to be short and not sustainable. In addition, the results of this meta-analysis showed that milk and milk-product consumption did not lead to change in fat mass, height, and waist circumference in the intervention groups compared with the control groups.

In this meta-analysis, high statistical heterogeneity was detected in the primary outcome, and several solutions were applied to minimize this. Sensitivity analyses were adopted, and the subgroup analyses investigated the effect of sex (males compared with females), age (6–12 y compared with 13–18 y), baseline body weight (normal weight compared with overweight or obesity), and intervention duration ($<$12 compared with $\geq$12 mo). Most of the subgroups were effective at reducing the heterogeneity. This analysis showed that the baseline weight and age and the duration of intervention were associated with the effectiveness of milk and milk-product intake on the change in lean mass, percentage body fat, and waist circumference, respectively. In addition, the asymmetry funnel plot suggested that possible publication bias existed between studies that evaluated change in waist circumference, which may be attributed to the limited number of trials included in the comparison.

The types of milk and milk-product interventions contained fluid milk, cheese, yogurt, whey, and casein in this meta-analysis. The potential mechanisms underlying the impact of milk and milk-product consumption on the regulation of body weight and body composition have not been elucidated. Milk and milk products are rich in protein and calcium. These 2 nutrients have been linked to growth status in childhood and puberty (41). Our meta-analysis of RCTs showed that milk and milk-product intake increased body weight and lean mass among children and adolescents. A potential mechanism is that the consumption of dairy protein may reduce appetite (42). Trials (22, 28) observed a significant reduction in energy intake among the milk intervention group compared with the control group. Moreover, studies suggest that a high intake of dietary protein generally associates with body-composition regulation by diet-induced thermogenesis, increasing satiety and decreasing hunger and preserving or increasing lean mass (43–46). For example, leucine, which is concentrated in milk and milk products, has been found to have a beneficial effect on protein synthesis and maintenance of lean mass (47); and the stimulation of protein synthesis might cause a repartitioning of energy from fat mass into lean mass (48). In addition, it has also been suggested that calcium may have an important role in weight and body-composition regulation in several different ways, such as decreasing de novo lipogenesis, increasing lipolysis by suppressing the formation of 1,25-dihydroxyvitamin D and secretion of parathyroid hormone or calciotropic hormones (49), interfering with FA absorption (50) by forming insoluble soaps (51, 52), or controlling intracellular calcium (49). More trials are necessary to further illustrate potential mechanisms of milk products on body growth.

This meta-analysis focused on evaluating the correlations between milk and milk-product intake and body growth among children and adolescents aged 6–18 y, in which the corresponding subgroups, on the basis of participants' age, sex, baseline body weight, and the duration of the intervention, were also assessed. However, there were some potential limitations. First, 11 of the total included RCTs (22–24, 26–28, 31, 32, 34, 36, 37) of milk and milk-product supplementation had height, weight, or body composition as a key outcome, with the remaining studies having bone health as the key outcome with change in height, weight, or body compositions as the secondary outcomes. Thus, it could be argued that these studies were not designed to evaluate body growth for height, weight, or body-composition changes. However, weight and height changes are easy to measure and are reproducible, which are necessary for the interpretation of studies evaluating bone outcomes. The technique of measuring bone outcomes in those studies was DXA, which is also accurate for evaluating body composition, such as lean mass, fat mass, and percentage body fat, and reference data exist from the NHANES (53). Therefore, the fact that it was not the primary measure should not influence these results. Second, the heterogeneity between all of the included studies meant that only the random-effects model could be used, which affected the efficiency of the study. Third, double blinding was almost not possible in this type of intervention trial (54), which could affect the quality assessment. Fourth, differences in effects of milk and milk-product type (e.g., amount of fat, fermented compared with nonfermented, liquid compared with solid/semisolid) were not evaluated. Another potential limitation may be other confounding factors influencing the relation between milk and growth, which were not accounted for, such as physical activity and other dietary factors.

In summary, our pooled analysis indicates that children and adolescents aged 6–18 y who consume milk and milk products are more likely to achieve a lean body phenotype. This is presumably caused by improving body composition, particularly increasing lean mass and consequently decreasing gain in percentage body fat. Because milk and milk products are considered constituting a package of healthy nutrients for child and adolescent development, in addition to the evidence generated from this meta-analysis, children and adolescents should be encouraged to add milk and milk products to their diet in sufficient amounts to reach healthy intakes. Future studies are needed to further investigate types of milk products (e.g., milk with different fat percentages or fermented milk) in relation to growth in children and adolescents.

Acknowledgments

The authors' responsibilities were as follows—KK: conceptualized and designed the study; collected and statistically analyzed the data; and drafted, edited, and critically reviewed and revised the manuscript; OFS: conceptualized and designed the study, collected the data; and edited, critically reviewed, and revised the manuscript; HAW: conceptualized and designed the study and edited, critically reviewed, revised, and supervised the manuscript; and all authors: read and approved the final manuscript.

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