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REVIEW

Long-term association between dairy consumption and risk of childhood obesity: a systematic review and meta-analysis of prospective cohort studies

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BACKGROUND/OBJECTIVES: Data from small-scale, short-term, clinical trials suggest a beneficial effect of dairy consumption on the risk of childhood obesity; however, the long-term association is unclear. Therefore, we aim to examine the longitudinal association between dairy consumption and the risk of overweight/obesity in children and adolescents by conducting a systematic review and meta-analysis of prospective cohort studies.
SUBJECTS/METHODS: Eligible studies were identified by searching PubMed and EMBASE through March 2015. Additional studies were retrieved via Google Scholar or a hand review of the reference lists from relevant articles. Pooled associations of interest were estimated by using a random-effects model. The heterogeneity for each pooled analysis was evaluated by I^2 statistic as well as by Cochran's *Q* test. Publication bias was assessed by using both Egger's and Begg's tests.
RESULTS: Ten studies comprising 46 011 children and adolescents with an average 3-year follow-up were included. As compared with those who were in the lowest group of dairy consumption, children in the highest intake group were 38% less likely to have childhood overweight/obesity (pooled odds ratio (OR) = 0.62; 95% confidence interval (CI): 0.49, 0.80). With each 1 serving/day increment in dairy consumption, the percentage of body fat was reduced by 0.65% ($\beta = 0.65$; 95% CI: −1.35, 0.06; $P = 0.07$), and the risk of overweight/obesity was 13% lower (OR = 0.87; 95% CI: 0.74, 0.98).
CONCLUSIONS: Accumulated evidence from prospective cohort studies suggests that dairy consumption is inversely and longitudinally associated with the risk of childhood overweight/obesity. Further studies are warranted to examine the types of dairy products in relation to the risk of childhood overweight/obesity.

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INTRODUCTION

Obesity in childhood and adolescence has become a serious health disorder worldwide. According to the National Health and Nutrition Examination Survey (2011–2012), 17.3% children and adolescents were obese.[1] Concern has been raised because childhood obesity may be an antecedent of diseases later in life.[2–4] Identifying modifiable risk factors of obesity in childhood is therefore a crucial step in preventing lifelong morbidity because of obesity.[5]

Dairy products are considered as an important food group for children's and adolescent growth or development, and milk is the most consumed/favored dairy food among children.[6–10] However, a common perception is that consumption of dairy products, particularly those with high fat content, may lead to excessive weight gain. During the past decades, a number of studies have been published examining the associations between dairy consumption and risk of obesity or weight gain in children or adolescents; however, findings are inconsistent.

A meta-analysis quantitatively summarized results from 29 small-scale and short-term randomized clinical trials (RCTs) conducted in adults and found that dairy consumption might have modest benefits in facilitating weight loss in a short time period (i.e., <1 year), and the meta-analysis concluded that the long-term ($\geqslant 1$ year) association was uncertain.[11] Similar results were observed in another meta-analysis of 14 RCTs.[12] In addition, a recent systematic review evaluated studies among children and adolescents and reported a modest inverse association between dairy intake and adiposity in adolescence.[13] However, that review did not estimate the pooled relative risk (RR) of childhood overweight/obesity, change in body mass index (BMI) or percentage of body fat (PBF) in relation to dairy consumption. Therefore, we conducted this systematic review and meta-analysis of prospective cohort studies to examine the longitudinal association between dairy consumption and risk of overweight/obesity in children and adolescents.

MATERIALS AND METHODS

Data source and study selection

The meta-analysis was performed following the guidelines of the Meta-analysis Of Observational Studies in Epidemiology (MOOSE).[14]

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Until March, 2015, we searched PubMed, EMBASE and Google Scholar using the terms '*dairy products*', '*milk*', '*cheese*', '*yoghurt*', '*ice cream*', '*dairy desserts*' and '*obesity*', '*overweight*', '*body mass index*', '*body weight*', '*percentage of body fat*', '*waist circumference*', '*skinfold thickness*', '*subcutaneous fat*', '*adiposity*' or '*visceral fat*', and '*follow-up studies*', '*longitudinal studies*' or '*prospective studies*' as well as '*children*', '*childhood*', '*adolescence*' or '*adolescents*'. We also additionally reviewed the reference lists from the retrieved articles. Detailed searching strategy was summarized in the Supplementary Information.

Studies were included in the meta-analysis if they were published in English, prospective cohort studies and conducted in children or adolescents; the exposures of interest included any type of dairy products such as white milk (e.g., cow's milk, sheep's milk and goat's milk), flavored milk, cheese, yogurt and ice cream made with dairy and other dairy desserts (e.g., pudding); and the outcomes of interest included risk of overweight/obesity, changes in PBF or BMI gain; the associations were measured by hazards ratio (HR), RR, odds ratio (OR) or β-coefficient with the corresponding 95% confidence interval (CI), or these data could be derived and baseline BMI or other related anthropometry measure was adjusted. Studies were only included in the systematic review if the information on the aforementioned measurements for the associations of interest was not available or there were not enough studies on a specific outcome for the pooled analysis.

Data extraction and quality assessment

Two authors (LL and PX) independently extracted the relevant information from the identified studies using a predesigned data collection form. The collected data include the first author's last name, the cohort's name (if applicable), year of publication, country where the study was conducted, age at baseline, proportion of boys, follow-up time, total number of participants/number of cases, exposure's categories and assessment, outcome and its definition, covariates in the fully adjusted model and the measures (e.g., OR and 95% CI) for the associations of interest. Disagreements were resolved by group discussion.

Quality assessment was listed in Supplementary Table 1.

Statistical analysis

The average follow-up year was calculated as the sum of person-years divided by the total number of participants. The measures of the associations were either transformed to natural logarithms (e.g., ORs (95% CIs)) or directly used (e.g., β (95% CIs)) for computing standard errors. If a study did not provide information on linear association, we estimated it using Greenland and Longnecker's method.[15] If the highest category of dairy product intake was open ended, its upper limit was estimated by assuming its range the same width as the previous one. For example, $2.0\text{–}<3.0$ and $\geqslant 3.0$ serving/day are the two highest categories, then $\geqslant 3.0$ was estimated as $3.0\text{–}<4.0$ serving/day.

We pooled the associations of dairy consumption with risk of overweight/obesity, PBF and BMI gain, respectively, using a random-effects model. We evaluated the heterogeneity for each pooled analysis by Cochran's Q test and I^2 statistic. Low, moderate and high degrees of heterogeneity were corresponding to I^2 values of 25, 50 and 75%. Publication bias was assessed using both Egger's and Begg's tests. If publication bias was suggested, we used the Duval and Tweedie nonparametric 'trim and fill' method to give an adjusted estimate of the pooled association.[16]

Sensitivity analyses were conducted to evaluate the effect of removing any single study from the meta-analysis and the robustness of the results by replacing random-effects models with fixed-effects models.

A two-sided P-value $\leqslant 0.05$ was considered statistically significant. All analyses were performed using STATA 13.0 (STATA Corporation LP, College Station, TX, USA).

RESULTS

Literature searching

Figure 1 shows the flow of literature searching. Of the 128 related articles retrieved from PubMed, 32 were excluded after screening the study titles for one of the following reasons: (1) not published in English or not human studies; (2) not an original research; or (3) not a prospective cohort study. Also, 78 studies were excluded after reviewing abstracts because of (1) an ecological study; (2) not a prospective cohort study; (3) not conducted in children/adolescents; (4) the exposure did not include dairy products or (5) no results on the outcomes of interest or the information could not be derived from the available data. Twelve studies were further excluded after a full-text review because of the following reasons: (1) not a prospective cohort study; (2) the exposure was the percentage of calorie from dairy intake; or (3) no results on outcomes of interest or the information could not be derived from reported data. In addition, four studies were identified from

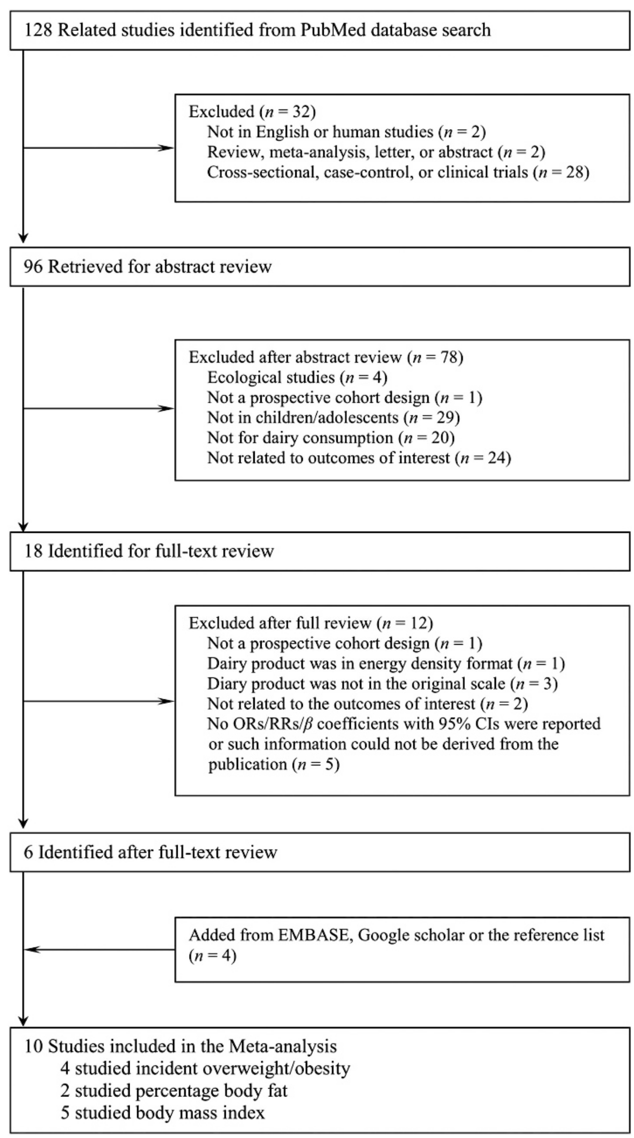

Figure 1. Flowchart of study screening and selection.

Table 1. Characteristics of 10 cohort studies included in the meta-analysis of the long-term association between dairy consumption and risk of childhood obesity

Source	*Age (years)*	*% of boys*	*Follow-up (year)*	*No. of individuals/ events*	*Exposure categories*	*Exposure assessment*	*Outcome and its assessment*	*Adjusted variables*	*Main results*
Carruth, 2001, USA	2–5	54.7	~2.5	53/NA	Dairy product (serving/day)	Three-day dietary records	Body fat as gram or percentage Body composition was assessed at 70 ± 2 months, using DXA (Model QDR Hologic2000)	Gender, BMI, intakes of protein, dietary fat and monounsaturated fat	Total body fat (g, $\beta \pm$ s.e.): -907.06 ± 284.60 PBF (%, $\beta \pm$ s.e.): -3.54 ± 1.04
Berkey_boy, the Growing Up Today Study, 2005, USA	9–14	100	4	5550/NA	Milk (serving/day): 0 ~; 0.5 ~; 1.0 ~; 2.0 ~; > 3.0	Self-administered semiquantitative FFQ	BMI	Race/ethnicity, age, same-year height growth, prior BMI *Z*-score, Tanner stage, menstrual history (girls) and same-year physical activity and inactivity (television/videos/computer games)	BMI gain (kg/m^2, $\beta \pm$ s.e.): 0.0; 0.052 ± 0.049; 0.005 ± 0.051; 0.022 ± 0.047; 0.081 ± 0.048 Linear (serving/day): 0.019 ± 0.009 ($P = 0.03$)
Berkey_girl, the Growing Up Today Study, 2005, USA	9–14	0	4	279/NA	Milk (serving/day): 0 ~; 0.5 ~; 1.0 ~; 2.0 ~; > 3.0	Self-administered semiquantitative FFQ	BMI	Race/ethnicity, age, same-year height growth, prior BMI *Z*-score, Tanner stage, menstrual history (girls) and same-year physical activity and inactivity (television/videos/computer games)	BMI gain (kg/m^2, $\beta \pm$ s.e.): 0.0; 0.058 ± 0.031; 0.072 ± 0.036; 0.056 ± 0.029; 0.093 ± 0.034 Linear (serving/day): 0.015 ± 0.007 ($P = 0.04$)
Moore, the Framingham Children's Study, 2006, USA	5	60.9	8	92/NA	Tertiles of dairy intake (median, serving/day): Boys: 1.38, 2.03 and 2.84 Girls: 1.09, 1.59 and 2.01	Three-day diet records	BMI	Age, activity, mother's education, baseline anthropometry, energy intake and percentage of energy from saturated fat	BMI gain (kg/m^2, mean ± s.e.): 0.83 ± 0.09; 0.52 ± 0.09; 0.59 ± 0.09
Huus, the ABIS study, 2009, Sweden	2.5	48.2	2.5	14 244/NA	Intakes of cream/crème fraiche, ice cream and cheese (time/week): < 1; 1–2; 3–5; daily Milk consumption: 0, 1–3/week; 4–6/week; 1/day; 2/day; 3/day and ⩾ 4/day	FFQ	Percentage of overweight and obesity children at 5 years Overweight was defined as BMI (kg/m^2): ⩾ 17.42 (male); ⩾ 17.15 (female) Obese was defined as BMI (kg/m^2): ⩾ 19.30 (male); ⩾ 19.17 (female)	Vegetables, potatoes, fried potatoes/French fries, eggs, sausage, chips, pastries, chocolate, candy(non-chocolate), porridge, lemonade, fruit, mother's education, father's education, mother's BMI, father's BMI and heredity for diabetes Cheese, ice cream, milk and cream/crème fraiche consumptions were mutually adjusted	Frequency in consumption of cheese at 2.5 years of age was positively associated with overweight or obesity at 5 years of age Ice cream, milk or cream/crème fraiche consumption at 2.5 years of age was not associated with overweight or obesity at 5 years of age
Vanselow, the Project EAT study, 2009, USA	14.9	45.0	5	2294/NA	White milk: (serving/week) 0; 0.5–6; ⩾ 7 Chocolate milk: (serving/week) 0; 0.5 ~ 6; ⩾ 7	Youth and adolescent FFQ	BMI	All baseline beverages, baseline BMI, age, cohort, sex, race/ethnicity, SES, baseline and time 2 strenuous physical activity, and time 2 weekday television watching and coffee and tea consumption	White milk: (kg/m^2, adjusted mean ± s.e.) 2.33 ± 0.25; 1.64 ± 0.12; 1.94 ± 0.11 Chocolate milk: (kg/m^2, adjusted mean ± s.e.) 1.89 ± 0.10; 1.77 ± 0.12; 2.43 ± 0.44
Huh, the longitudinal prebirth cohort study of mother–offspring pairs, 2010, USA	2	NA	1	656/NA for change in BMI score 645/NA for incidence of overweight	Milk (continuous, serving/day): whole milk; reduced-fat milk; 1%/nonfat milk.	Semiquantitative child FFQ	BMI *Z*-score; overweight was defined as BMI ⩾ its age- and gender-specific 85th percentile	Age, gender, race/ethnicity, energy intake, nondairy beverage intake (including juice), television-viewing; maternal education and BMI, paternal BMI and baseline BMI *Z*-score	BMI *Z*-score (β (95% CI)) −0.05 (-0.13, 0.02); −0.08 (−0.17, 0.02); 0.00 (−0.14, 0.14) Overweight (OR (95% CI)): 1.04 (0.74, 1.44); 0.91 (0.62, 1.34); 0.95 (0.58, 1.55)

Table 1. (Continued)

Source	Age (years)	% of boys	Follow-up (year)	No. of individuals/ events	Exposure categories	Exposure assessment	Outcome and its assessment	Adjusted variables	Main results
Noel, the ALSPAC study, 2011, UK	10	45.3	3	2270/NA	Total milk (serving/day) Full-fat milk (serving/day) Reduced-fat milk (serving/day)	Three-day dietary records	PBF change A lunar Prodigy DXA scanner was used to measure body composition	Age, gender, baseline BMI, height, height squared, pubertal status, maternal BMI and educational attainment, total fat intake, and ready-to-eat cereal, sugar-sweetened-beverage and 100% fruit juice intake	Intake of dairy products (β (95% CI)): total milk: −0.49 (−1.06,0.09); full-fat milk: −0.50 (−1.17, 0.17); reduced-fat milk: −0.08 (−0.66, 0.50).
Lin, Hong Kong's 'Children of 1997 birth cohort' 2012, China	11	48.6	2	5968/NA	Non-milk dairy products: none (reference); 1–3/week; 4–6/week; daily Milk: none (reference); 1–3/week; 4–6/week; daily	FFQ	BMI Z-score (1 unit of change in BMI score is about 2.9 kg/m^2 change in BMI)	Gender, BMI *Z*-score at baseline, birth order, maternal age, mother's birthplace, highest parental education, interaction of mother's birthplace and education, physical activity, vegetable, fruit and soft drink consumption	Non-milk dairy products (β (95% CI)): 0; 0.01 (−0.04, 0.06); 0.02 (−0.05,0.10); 0.001 (−0.07, 0.07) Milk (β (95% CI)): 0; 0.003 (−0.04, 0.05); −0.01 (−0.08,0.06); −0.01 (−0.07, 0.05).
Scharf, ECLS-B, 2013, USA	2	~50.0	2	5150/NA	Milk type: 2%/whole milk (reference) 1%/skim milk	FFQ	Overweight: 85th–95th percentile of BMI; Obese: ⩾95th percentile of BMI	Gender, race/ethnicity, SES, intakes of juice and SSB, mother's BMI, daily glass of milk and baseline BMI	Overweight/obese (OR (95% CI)): 1.57 (1.03, 2.42)
Bigornia, the ALSPAC study, 2014, UK	10	47.0	3	2455/NA	Quartiles of total, full-fat, and reduced- fat dairy intake	Three-day dietary records	BMI Overweight: The international obesity taskforce age- and gender-specific weight categories	Age, gender, height, adiposity at 10 years, total dairy at 13 years, maternal education and overweight status, physical activity at 13 years, pubertal stage at 13 years, pubertal state at 13 years, dieting at 13 years, baseline dietary intakes of fruit juice, fruit and vegetable, total fat, total protein, sugar-sweetened beverages, fiber and cereal, dietary reporting errors at 13 years and baseline total energy intake	BMI gain: Full-fat diary intake (mean (95% CI)): Q1: 2.7 (2.5, 3.0); Q2: 2.6 (2.4, 2.9); Q3: 2.6 (2.3, 2.8); Q4: 2.5 (2.2, 2.7). *P* for trend = 0.009 Overweight: Total diary intake (OR (95% CI)): Q1: 1.00; Q2: 0.85 (0.53, 1.34); Q3: 0.91 (0.56, 1.49); Q4: 0.56 (0.32, 0.97). *P* for trend = 0.07 Full-fat diary intake (OR (95% CI)): Q1: 1.00; Q2: 0.71 (0.46, 1.10); Q3: 0.78 (0.50, 1.22); Q4: 0.57 (0.34, 0.94). *P* for trend = 0.06 Reduced-fat diary intake (OR (95% CI)): Q1: 1.00; Q2: 0.83 (0.53, 1.30); Q3: 0.67 (0.41, 1.09); Q4: 0.74 (0.43, 1.28) *P* for trend = 0.19

Abbreviations: ABIS, All Babies In Southeast Sweden; ALSPAC, the Avon Longitudinal Study of Parents and Children; BMI, body mass index; CI, confidence interval; DXA, dual-energy X-ray absorptiometry; EAT, Eating Among Teens; ECLS-B, the Early Childhood Longitudinal Study, Birth Cohort; FFQ, food frequency questionnaire; NA, not applicable; OR, odds ratio; PBF, percentage body fat; SES, social economic status; SSB, sugar-sweetened beverages; UK, the United Kingdom; USA, the United States of America.

Table 2. Characteristics of 9 cohort studies included in the systematic review of long-term association between dairy consumption and risk of childhood obesity but not in the meta-analysis

Source	*Age (years)*	*% of boys*	*Follow-up (year)*	*No. of individuals/ events*	*Exposure categories*	*Exposure assessment*	*Outcome and its assessment*	*Adjusted variables*	*Main results*
Philiips, the MIT Growth and Development Study, 2003, USA	8–12	0	10	196/NA	Dairy food consumption: log daily servings of dairy food, percentage of daily calories from dairy food, square root dairy calcium, log percentage of calories from full-fat dairy and quartile of percentage of calories from low-fat dairy	Semiquantitative self-administered FFQ	BMI Z-score and PBF BMI *Z*-score was calculated using the revised CDC growth reference standards PBF was estimated using prediction equations developed in this cohort, using measures of total body water by isotopic dilution of $H_2^{18}O$ as the criterion method	Daily servings of fruits and vegetables, quartile of percentage calories from soda, protein intake (in gram or percentage of calories), daily kilocalories, and parental overweight	There was no relation between changes in BMI *Z*-scores or PBF and daily servings of dairy foods (either full-fat or low-fat), percentage of daily calories from dairy foods or their calcium content
Newby, the WIC study, 2004, USA	2–5	50.2	0.5–1	1345/NA	Milk (oz/day)	Semi-FFQ	BMI and weight	Age, gender, energy, ethnicity, residence, level of poverty, maternal education and birth weight	Weight gain (kg, $\beta \pm$ s.e.): 0.00 ± 0.01 BMI gain (kg/m^2, $\beta \pm$ s.e.): -0.00 ± 0.00
Phillips, the MIT study, 2004, USA	8–12	0	10	196/NA	Quartiles of percentage of calorie from ice cream: < 1.0; $1.0 \sim 2.9$; $3.0 \sim 3.9$; $\geqslant 4.5$	Semiquantitative self-administered FFQ	BMI *Z*-score and PBF BMI *Z*-score was calculated using the revised CDC growth reference standards PBF was estimated using prediction equations developed in this cohort, using measures of total body water by isotopic dilution of $H_2^{18}O$ as the criterion method	Age at menarche, parental overweight and servings of fruits and vegetables	BMI *Z*-score (β (*P*-value)): Q1: 0; Q2: 0.00054 (0.98); Q3: 0.0124 (0.14); Q4: −0.0092 (0.82) PBF (β (*P*-value)): Q1: 0; Q2: −0.0087 (0.37); Q3: 0.40 (0.46); Q4: 0.19(0.82)
Faith, the WIC study, 2006, USA	1–5	53.2	4	971/NA	Milk (serving/day) 2% or whole milk (serving/day)	Self-administered FFQ	BMI *Z*-score (change in age- and gender-standardized BMI per month)	Child's weight for height *Z*-score at baseline, gender, race/ethnicity, intakes of potatoes, carrots, vegetables, juice, fruit and parental behaviors including having tried offering more fruits, vegetables, limit how much food child eats and children should finish dinner before desert	BMI *Z*-score gain ($\beta \pm$ s.e.): milk: -0.002 ± 0.002. 2% or whole milk: 0.005 ± 0.007
Tam, The Nepean study, 2006, Australia	7–8	50.2	5	281/NA	Milk (ml/day)	Three-day food records	BMI	Stratified by BMI change: acceptable BMI vs BMI gainers vs BMI losers vs OW/OB at years 7 and 13	No association was found between milk consumption and BMI change ($P = 0.995$)
Johnson, the ALSPAC study, 2007, UK	5 7	NA NA	4 2	521/NA 682/NA	Milk (serving/day)	Three-day dietary records	Fat mass change Fat mass was estimated at age (mean ± s.d.) of 9.8 ± 0.15 years from DXA using the Lunar Prodigy DXA fan beam scanner	Gender, height at 9 years, child's BMI at baseline, television watching, maternal education, paternal class, maternal BMI, paternal BMI, misreporting of energy intake (energy intake per estimated energy requirement), dietary energy density, percentage of energy intake from fat and fiber density	Milk consumption at 5 or 7 years was inversely associated with fat mass change (kg/serving of milk, β (95% CI)) at 9 years: 5 years: −0.51 (−0.86, −0.16); 7 years: −0.35 (−0.57, −0.14)
Kral, 2008, USA	3–6	NA	3	49/NA	Calories consumed from milk at age 3–5.	Three-day weighed food records	WC change	Change in WC from ages 3 to 5 years and total energy intake at age 3 years	Change in WC from ages 5 to 6 years (cm, $\beta \pm$ s.e.): -0.01 ± 0.004
Fiorito, 2009, USA	5	0	10	166/NA	Milk (serving/day)	Three-day dietary records	PBF Triceps and subscapular skinfold thickness, measurements were collected when participants were 5, 7 9 and 11 years of age, and DXA scans were administered at 9, 11, 13 and 15 years of age	No adjustment	Milk intake at age 5 years was not associated with adiposity from age 7 to 15 years Standardized regression coefficients for milk intake at age 5 years in predicting PBF at age 7, 9, 11, 13 and 15 years were −0.02, −0.06, 0.01, 0.04 and −0.08, respectively

Table 2. (Continued)

Source	Age (years)	% of boys	Follow-up (year)	No. of individuals/ events	Exposure categories	Exposure assessment	Outcome and its assessment	Adjusted variables	Main results
Noel, the ALSPAC study, 2013, UK	10	45.3	3	2270/NA	Flavored milk (consumers vs non-consumers)	Three-day dietary records	PBF and weight Total FM, lean body mass and bone mass were determined using a Lunar Prodigy DXA scanner at 11 and 13 years of age	Gender, pubertal status, maternal BMI and educational attainment, changes in age, height, height squared, physical activity and dietary intakes and dietary intakes (total fat, ready-to-eat cereal, 100% fruit juice, sugar-sweetened beverages, plain milk and fruit and vegetables)	Overweight/obese children who consumed flavored milk had less favorable changes in PBF compared with non-consumers (adjusted means (%): − 0.16 (95% CI: − 3.84, − 3.52) vs − 3.43 (95% CI: − 6.45, −0.42), $P=0.02$) Similar associations with body weight were observed (adjusted means (kg): 14.5 (11.1, 18.0) vs 11.6 (8.8, 14.4), $P=0.02$) No associations were found in the normal weight children

Abbreviations: ALSPAC, the Avon Longitudinal Study of Parents and Children; BMI, body mass index; CDC, Centers for Disease Control and Prevention; CI, confidence interval; DXA, dual-energy X-ray absorptiometry; FFQ, food frequency questionnaire; FM, fat mass; MIT, the Massachusetts Institute of Technology; NA, not applicable; OB, obesity; OW, overweight; PBF, percentage body fat; WC, waist circumference; WIC, Special Supplemental Nutrition Program for Women, Infants and Children.

EMBASE, Google Scholar or the reference lists. Ten studies (11 independent cohorts), comprising 46 011 children or adolescents with an average of 3-year follow-up, were included in this meta-analysis.

Description of studies

Table 1 presents the characteristics of the included studies. The primary studies were published from 2001 to 2014. Six studies were conducted in the United States,[5,17–21] two in the United Kingdom,[22,23] one in Hongkong, China[10] and one in Sweden.[24] The number of participants in each study ranged from 53 to 14 244, with the duration of follow-up ranging from 1 to 8 years. Age at baseline ranged from 2 to 14.9 years of age (mean = 7.4 years). Dairy consumption was measured by food frequency questionnaires (FFQs)[5,10,17,20,21,24] or 3-day diet records.[18,19,22,23] Of the 10 included studies, three reported results on total dairy products, seven on milk and one on ice cream, cream/crème fraiche or cheese. Overweight and obesity were defined by age- and gender-specified BMI percentiles or the International Obesity Taskforce age- and gender-specified BMI cutoffs for children.[23,24] A wide range of potential confounders including age, gender, race and energy intake were adjusted for in the primary studies.

The characteristics of nine cohort studies included in the systematic review were separately summarized (Table 2) because their results could not be pooled in the meta-analysis. These nine studies were published from 2003 to 2013. The number of participants ranged from 49 to 2270, and age at baseline ranged from 1 to 12 years of age (mean = 6.9 years). The duration of follow-up ranged from 0.5 to 10 years. Six studies were conducted in the United States,[25–30] two in the United Kingdom[31,32] and one in Australia.[33] Dairy consumption was measured by FFQs[25–28] or 3-day diet records.[29–33] Among the nine studies, six studies focused on milk,[26,28–31,33] one on total dairy products,[25] one on ice cream[27] and one on flavored milk.[32] Outcomes included weight, BMI, BMI *Z*-score, waist circumference, PBF and fat mass (FM).

Dairy consumption and risk of overweight/obesity

The pooled association between dairy consumption and risk of overweight/obesity was estimated based on four prospective cohort studies[5,20,23,24] including 22 505 participants (Figure 2). As compared with those who were in the lowest intake group of dairy products, children in the highest intake group were 38% less likely to have overweight/obesity (pooled OR = 0.62; 95% CI: 0.49–0.80). There was no evidence on heterogeneity ($I^2 = 0.0\%$, $P = 0.88$) and publication bias (Egger's test, $P = 0.95$ and Begg's test, $P = 0.74$). To determine the possible dose–response relationship, we standardized dairy consumption to number of servings/day. The risk of childhood overweight/obesity was 13% lower with 1 serving/day increment in dairy intake (pooled OR = 0.87 (0.76, 0.98)). A moderate heterogeneity was observed across studies ($I^2 = 40.6\%$, $P = 0.09$), and no evidence on publication bias (Egger's test: $P = 0.26$ and Begg's test: $P = 1.00$).

Dairy consumption and percentage of body fat

Two prospective cohort studies[18,22] including 2323 children presented data on the association of dairy consumption with PBF that was measured by using the dual-energy X-ray absorptiometry (DXA) method (Figure 3). One study illustrated results on reduced-fat milk, full-fat milk and total milk separately. The pooled results indicated a marginally significant inverse association between dairy consumption and PBF ($\beta = -0.65$ (−1.35, 0.06); $P = 0.07$) with a high heterogeneity ($I^2 = 71.5\%$, $P = 0.02$). Also, publication bias was suggested by Egger's test ($P = 0.04$) but not Begg's test ($P = 0.31$). The adjusted pooled

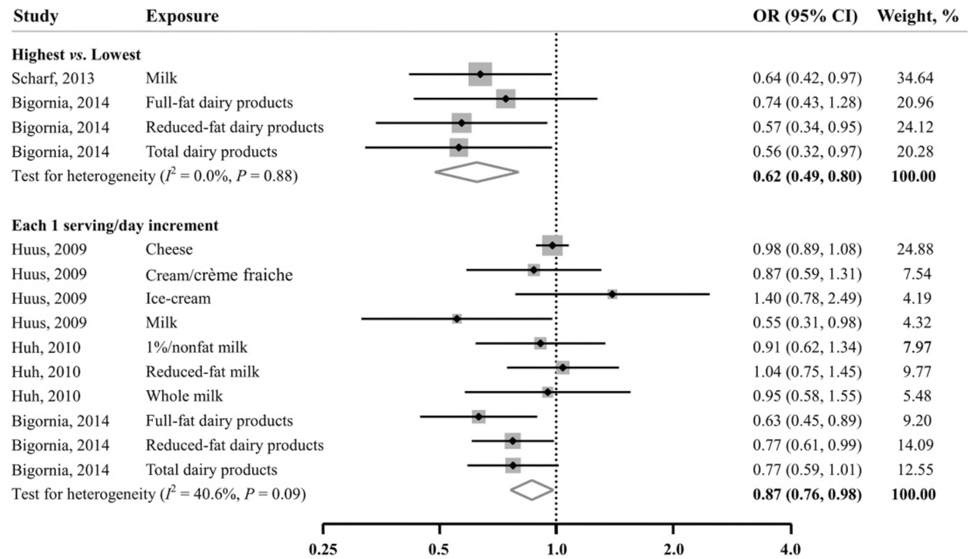

Figure 2. Multivariable-adjusted ORs and 95% CIs of childhood overweight/obesity in relation to dairy consumption. The pooled estimates were obtained by using a random-effects model. The dots indicate the adjusted ORs by comparing the highest with the lowest level of dairy intake or each 1 serving/day increment in dairy consumption. The size of the shaded square is proportional to the weight of each study. The horizontal lines represent 95% CIs. The diamond indicates the pooled OR.

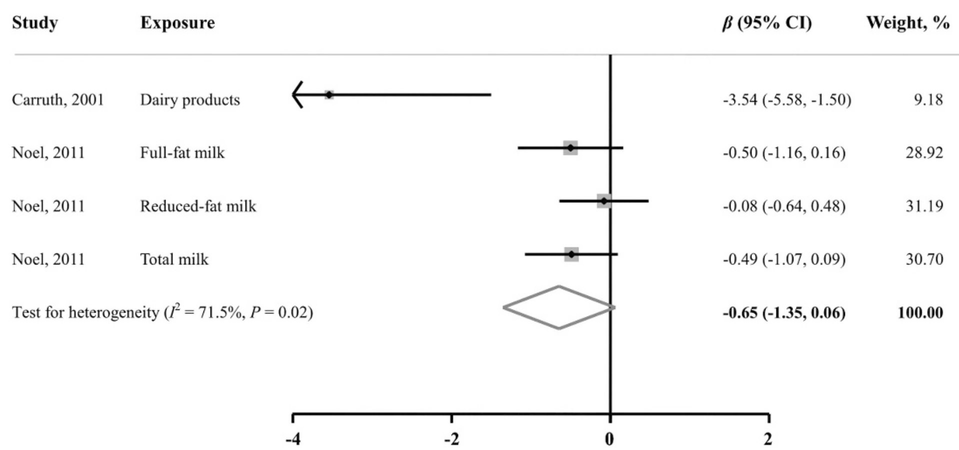

Figure 3. Multivariable-adjusted β-coefficients and 95% CIs of percentage body fat in relation to dairy consumption. The pooled estimate was obtained by using a random-effects model. The dots indicate the adjusted β-coefficient with 1 serving/day increment in dairy consumption. The size of the shaded square is proportional to the weight of each study. The horizontal lines represent 95% CIs. The diamond indicates the pooled β-coefficient. PBF indicates percentage body fat.

association using the Duval and Tweedie method became statistically significant ($\beta = -1.04$ (-1.91, -0.18); $P = 0.02$).

Dairy consumption and BMI gains

There was no significant combined association between dairy consumption and BMI gain after weighing results from five prospective cohort studies[10,17,19,21,23] including 16 359 children and adolescents (Figure 4). The pooled β-coefficient was 0.01 (-0.08, 0.09) comparing the highest with the lowest intake group. Heterogeneity among studies existed ($I^2 = 57.1\%$, $P = 0.02$). There was no evidence for publication bias (Egger's test, $P = 0.29$ and Begg's test, $P = 0.39$). With each 1 serving/day increment in dairy consumption, BMI gained 0.02 (0.01, 0.03) kg/m^2 during the follow-up. No evidence on heterogeneity ($I^2 = 0.0\%$, $P = 0.87$) and publication bias (Egger's test, $P = 0.39$ and Begg's test, $P = 1.00$).

Sensitivity analysis

To test the robustness of our results, we removed one study each time in the pooled analysis and found that no single study substantially influenced the pooled association of interest (Supplementary Table 2). In addition, we replaced random-effects model with fixed-effects model in all analyses, and our findings were essentially unchanged (data not shown).

Systematic review

Results reported in some studies were not able to be combined into the meta-analysis (Table 2). Findings from some of those studies were consistent with our main results in meta-analysis. For example, an inverse association between milk consumption and changes in FM was observed in 1203 children with up to 4 years of follow-up ($\beta = -0.51$ (-0.86, -0.16)).[31] Similarly, an inverse association was found between milk consumption and changes in

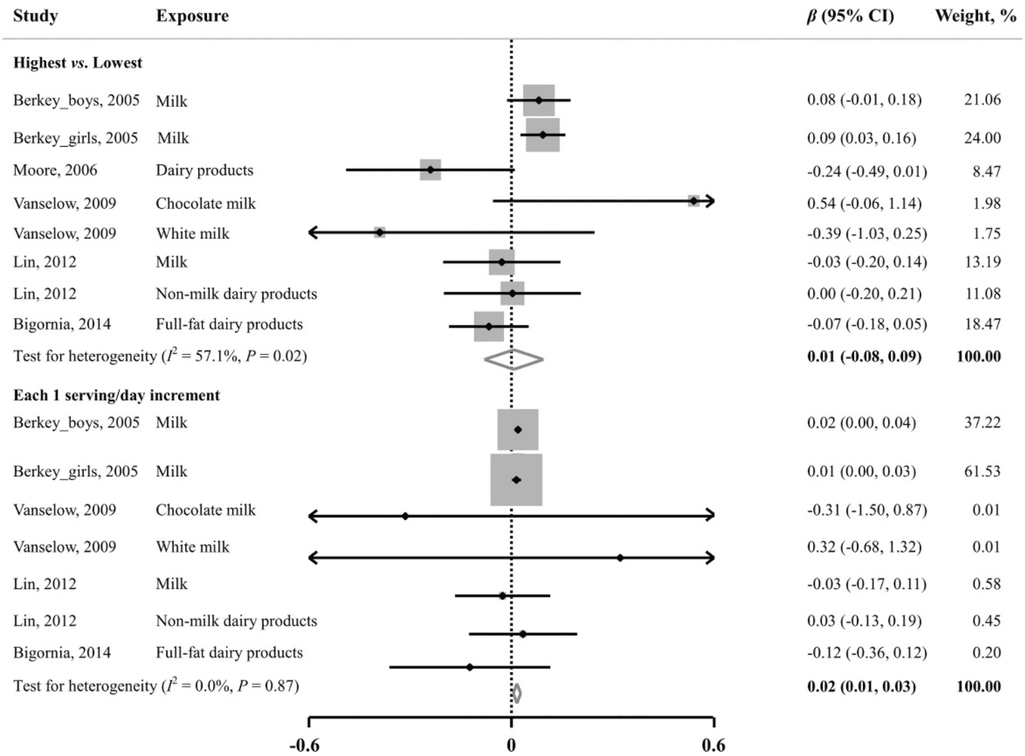

Figure 4. Multivariable-adjusted β-coefficients and 95% CIs of BMI gain in relation to dairy consumption. The pooled estimates were obtained by using a random-effects model. The dots indicate the adjusted ORs by comparing the highest with the lowest level of dairy consumption or each 1 serving/day increment in dairy consumption. The size of the shaded square is proportional to the weight of each study. The horizontal lines represent 95% CIs. The diamond indicates the pooled β-coefficient.

children's waist circumference over a 3-year follow-up ($\beta \pm$ s.e. $= -0.01 \pm 0.004$).[29] However, findings from the other studies were not in concordance with our results in meta-analysis. For instance, no significant associations were reported between dairy consumption and PBF,[25,27,30,32] BMI *Z*-score[25,27,28] and BMI change,[26,33] as well as weight gain.[26] Of these four studies that measured PBF, the DXA method was used in two of them,[25,27] and the indirect estimation method by measuring total body water by isotopic dilution of $H_2^{18}O$ was used in the other two studies.[30,32]

DISCUSSION

Findings from this meta-analysis suggest that childhood dairy consumption is inversely associated with the risk of overweight/obesity a few years later in life. This potential benefit may be largely explained by PBF decline and relative lean body mass (LBM) increment generated by dairy intake in children and adolescents.

Strengths and weaknesses

Several strengths need to be highlighted. First, our meta-analysis included 10 prospective cohort studies comprising 46 011 children and adolescents with an average of 3-year follow-up (up to 8 years), which enable us to detect potential longitudinal association of dairy consumption with childhood overweight/obesity. Second, the main results are generally consistent regardless of using categorical or continuous variable of dairy intake in the pooled analyses. Third, all primary studies reported results with adjustment for multiple potential confounders, for example, age, gender, BMI, race and baseline adiposity measures, which reduced the possibility that our findings are substantially biased by those variables.

A few limitations also need to be considered. First, this meta-analysis is based on observational studies, so that any inherent limitations in the primary studies may affect our results. For example, the possibility of residual confounding or bias due to measurement errors in both exposure and outcome cannot be ruled out. Second, because of the limited studies included the numbers of studies for some pooling are small. For instance, data are only available in two studies for assessing the association between dairy consumption and PBF. Nevertheless, findings from this meta-analysis provide useful information for future studies. Third, in the primary studies, incident cases of overweight/obesity could not be determined. However, this is a common methodological issue in the studies of childhood obesity.[34] Fourth, the methods used to assess dairy consumption varied across individual studies (e.g., FFQ and 3-day diet history), which may partially explain the heterogeneity or even confound the pooled results. Nevertheless, our main findings were not appreciably modified by the dietary measurement instruments. Fifth, no sufficient information enables us to study types of dairy products. It may be of great public health or clinical significance if examining the possible difference among types of dairy products, for example, skim milk, whole milk. Further studies are badly needed.

Comparison with existing literature

Numerous studies have examined dairy consumption in relation to the risk of obesity, weight gain or body fat. Two meta-analyses[11,2] of clinical trials in adults found that dairy products, especially included in energy-restriction diet, were beneficial to weight loss and body fat decline in a relatively short time period, that is, <1 year. On the basis of the available data from clinical trials, it was uncertain whether this beneficial effect would persist after a year. In addition, one systematic review[13] evaluated the studies on dairy consumption and adiposity in children and adolescents, suggesting a neutral relation between dairy consumption and adiposity in early and mid-childhood and a modest inverse association between dairy intake and adiposity in adolescents. However, that study pooled results from cross-sectional, prospective cohort and intervention studies together and defined the outcome adiposity by combining BMI, BMI percentile, BMI change, BMI *Z*-score, skinfold thickness, PBF, FM, waist circumference and waist-to-hip ratio all together.

Our meta-analysis adds important additional information to the literature. Because of ethical and practical considerations most RCTs on dairy consumption are short-term interventions. Data from longitudinal studies will help us understand the long-term association, which is particularly important for weight maintenance. Also, our meta-analysis summarized studies in childhood and adolescence. The prevalence of childhood overweight/obesity has increased globally.[35–37] Understanding modifiable risk factors of childhood overweight/obesity will be crucial for preventing chronic diseases later in life. In addition, our meta-analysis included data on both risk of childhood overweight/obesity and anthropometric measures, which strengthened our findings. Differing from adults, children and adolescence are in the growth and development of life span. Their BMI and PBF may change largely depending on LBM growth. In this meta-analysis, we observed that dairy consumption was inversely related to PBF and positively associated with BMI gain, which may reflect the fact that dairy products may expedite building LBM in children and adolescence,[38,39] and consequently decrease PBF and increase BMI.

Potential mechanisms

Dairy products are rich in calcium and protein. These two nutrients have been linked to weight status.[4] Studies suggest that calcium may have an important role in weight and body composition regulation by decreasing *de novo* lipogenesis, increasing lipolysis by suppressing the formation of 1, 25-dihydroxyvitamin D and secretion of parathyroid hormone or calciotropic hormones,[41] or interfering with fat absorption in the intestine by forming insoluble soaps, which causes a decrement in energy intake.[42]

Dairy protein has been generally associated with body composition regulation by diet-induced thermogenesis, increasing satiety and decreasing hunger, and preserving or increasing LBM.[43,44] For example, leucine concentrated in dairy products has been found to have a beneficial effect on protein synthesis and maintenance of LBM; and the stimulation of protein synthesis might cause a repartitioning of energy from FM into LBM.[45]

In addition, some minerals from dairy products are beneficial for children's and adolescent bone development: (1) calcium and phosphorus can be combined into salts called hydroxyapatite that form the inorganic matrix of bone; (2) vitamin D can regulate serum calcium and phosphate homeostasis;[46] and (3) potassium is involved in the regulation of bone turnover.[47] It was reported in a 2-year RCT among 10–12-year-old girls that cheese resulted in a higher percentage change in cortical thickness of the tibia and in higher whole-body bone mineral density.[48] Thus, findings from our meta-analysis are biologically plausible, because dairy consumption may increase LBM including bone mass in children and adolescence and decrease PBF resulting in a reduced risk of overweight/obesity and elevated BMI.

CONCLUSION

In conclusion, our pooled analyses indicate that children and adolescents with high-level consumption of dairy products are less likely to be overweight/obese later in life, presumably by improving the body composition, for example, increasing LBM and consequently decreasing PBF. As dairy product is considered a package of healthy nutrients for children and adolescent development plus the evidence generated from this meta-analysis, children and adolescent should be encouraged to add dairy products to their diet. Future studies are needed to investigate types of dairy products (e.g., dairy with different energy density) in relation to the risk of overweight/obesity in children and adolescents. Information derived from these studies should help individuals select healthy diet and reduce the risk of overweight/obesity.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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AUTHOR CONTRIBUTIONS

KH and WC designed the research; LL and PX performed literature search, study selection and data extraction; PX conducted statistical analyses; LL and PX prepared the tables and figures; LL drafted the manuscript; PX, KH, YW and WC contributed to the revision of the manuscript; and all authors completely consented with all the data in the study and approved the final version.

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