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SUPPLEMENT ARTICLE

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Total dairy consumption in relation to overweight and obesity in children and adolescents: A systematic review and meta-analysis

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Summary

A systematic review and meta-analysis of cross-sectional and prospective cohort studies was conducted to assess the associations between total dairy consumption and its different subtypes with the prevalence and incidence of overweight, obesity, and overweight/obesity in children and adolescents. A literature search was conducted in Medline through PUBMED and Cochrane Library databases until October 18, 2021. Articles reporting the risk estimates as odd ratios (OR), risk ratios (RR), or hazard ratios and their corresponding 95% confidence interval (CI) for the association between dairy product consumption and the risk of overweight and/or obesity were included. In the meta-analysis from cross-sectional studies, results showed an inverse association between total dairy consumption and obesity prevalence (OR (95% CI): 0.66 (0.48–0.91). No significant associations were found between milk or yogurt and obesity prevalence risk. Regarding prospective studies, total milk consumption was positively associated with overweight prevalence (OR (95% CI): 1.13 (1.01–1.26)) and incidence (RR (95%CI): 1.17 (1.01–1.35)) risk. Evidence from pooled analysis of cross-

Abbreviations: BMI, Body mass index; CDC, Centers for Disease Control and Prevention; CI, Confidence interval; FFQ, Food frequency questionnaire; HR, Hazard ratios; IOTF, International Obesity Task Force; MOOSE, Meta-analysis of Observational Studies in Epidemiology; OR, Odds ratio; RR, Risk ratio; WHO, World Health Organization.

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sectional studies suggested an inverse association between total dairy consumption and obesity. However, there is limited and no conclusive evidence to confirm an inverse relationship from pooled analysis of prospective studies in children and adolescents.

KEYWORDS
adolescent, child, dairy, obesity

1 | INTRODUCTION

Childhood obesity has emerged as one of the most serious worldwide problems. This is recognized by the World Health Organization (WHO) which has included childhood obesity as a priority in the 2013–2020 Global Plan of Action for the prevention and control of chronic noncommunicable diseases.[1] In fact, this institution has already defined a set of global targets for detaining the increase of obesity among children and adolescents by 2025. Recently, data from a systematic review and meta-analysis[2] indicated that despite a recent stabilization of the trend of increasing prevalence of excessive weight during childhood in most European countries, the prevalence continues to be high. According to the latest Childhood Obesity Surveillance Initiative (COSI) report, the prevalence of overweight and obesity for boys and girls aged 6 to 9 years was 29% and 27%, respectively, worldwide.[3] However, when considering Mediterranean countries, including Spain, more than 40% of children are estimated to have overweight and obesity.

Childhood overweight and obesity are the result of a complex interaction of biological, behavioral and environmental factors that have an impact on the long-term energy balance.[4] Therefore, identification of modifiable risk factors, including dietary components, is a crucial step in the prevention of childhood obesity and its comorbidities. For example, in the last few decades, sugar-sweetened beverage consumption has increased globally,[5] paralleling the rise in childhood obesity.[6] It has been suggested that the increase in sugar-sweetened beverage consumption has been associated with a decline in dairy consumption.[7–9] Displacement of dairy from the diet with sugar-sweetened beverages could result in insufficient daily intake of essential nutrients because, although the nutrient content varies by type of dairy product, dairy, in general, provides a dietary source of proteins, fat, calcium, phosphorus, vitamins, and other milk-derived bioactive compounds important for good health.

A few reviews[10–14] and meta-analyses[10,15,16] of epidemiological studies, exploring the potential relationship between the consumption of dairy products and risk of obesity in children and adolescents, have been published to date. Findings suggest an inverse or null relationship between dairy product consumption and the prevalence or incidence of overweight and obesity. However, these analyses present with some methodological issues, for instance, the combination of studies with different exposures (e.g., full fat milk and total milk) in the total dairy product analysis[16] or the inclusion of different outcomes (obesity and abdominal obesity) together in the main analysis.[15] Moreover, since the publication of the last meta-analysis in 2016, new epidemiological studies evaluating these associations have been published. Therefore, in order to update the evidence and clarify the aforementioned limitations, the aim of this work was to systematically review and meta-analyze the associations between total dairy consumption and its different subtypes with the prevalence and incidence of overweight, obesity, and overweight/obesity in children and adolescents.

2 | METHODS

2.1 | Search strategy and study selection

For the present systematic review and meta-analysis, we followed the methodological guidelines of the Cochrane Handbook for Systematic Reviews of interventions[17] and results were reported in accordance with the Meta-analysis of Observational Studies in Epidemiology (MOOSE) guidelines.[18] The protocol was registered at https://www.clinicaltrials.gov/ with the identifier NCT04297722.

We conducted a comprehensive electronic systematic search of two databases (Medline through PUBMED and the Cochrane Library) until October 18, 2021, combining relevant MeSH terms and key words. Table S1 depicts the detailed search strategy. Additionally, the reference lists of the retrieved articles were manually reviewed to ensure all relevant studies were identified.

First, duplicate studies from the identified articles through the search strategy were discarded. Next, two independent reviewers (LL and IPG or JFGG) performed an initial screening of the titles and abstracts of the retrieved papers against eligibility. To aid in performing this task, the online screening program, Abstrackr (http://abstrackr.cebm.brown.edu/) was used. Cross-sectional or prospective cohort studies, with at least 1 year of follow-up, were included if they were conducted in children or adolescents (aged between 2 and 21 years old). Included articles had to reported risk estimates as odd ratios (OR), relative risks (RR), or hazard ratios (HR) and their corresponding 95% confidence intervals (CI) for the association between dairy product consumption (including total dairy products, full-fat or low-fat total dairy, total milk, full-fat or low-fat milk, total yogurt, full-fat or low-fat yogurt, and cheese) and the risk of overweight and/or obesity. We did not consider published abstracts or proceedings for inclusion.

2.2 | Data extraction

To verify that the articles which passed the initial title and abstract screening process met the eligibility criteria, two independent researchers (LL and IPG or JFGG) reviewed the full text. Additionally, relevant information was extracted from articles that met inclusion criteria using a standardized proforma. Collected data included authors, article title, journal and year of publication, study name, participant characteristics, sample size, follow-up (only for cohort studies), type of exposure, dietary assessment method, type of outcome and assessment method, number of cases, statistical analyses, and multivariable-adjusted risk estimates (OR, RR or HR, and 95%CI) for the association of interest. A third researcher (NB-T or SKN) was consulted to provide consensus and solve any disagreements.

2.3 | Quality assessment of the included studies

Two different quality assessment tools were utilized to assess the quality of the included studies. For cross-sectional studies, we used The Study Quality Assessment Tool for Observational Cohort and Cross-sectional Studies from the National Heart, Lung, and Blood Institute.[19]

For prospective cohort studies the Newcastle–Ottawa Scale[20] was used. This is a rating scale ranging from 0 to 9 points that are given to the studies based on three domains, population selection, outcome assessment, and comparability. Studies with a total punctuation of at least 7 points were considered to be high quality (i.e., low risk of bias). Any disagreement between researchers (MM and LL or IPG and JFGG) was solved by consensus or consulting a third researcher (NB-T or SKN). When additional information from included articles was required for the analyses, the corresponding author was contacted by e-mail.[21–31] We received responses from seven authors,[22,24–26] where two provided additional information relevant for inclusion in the analyses.[25,31]

2.4 | Outcomes

Obesity, using body mass index (BMI) as a proxy where applicable, was the primary outcome. Secondary outcomes were overweight and overweight/obesity combined. There is no standard worldwide BMI cut-off point to define overweight and obesity in children. Hence, most of the studies followed the international criteria suggested by Cole et al. (2000)[32] and (2007),[33] which define overweight and obesity based on age- and sex-specific BMI cut-off points that correspond to the worldwide accepted cut-off points for defining overweight (BMI ≥ 25 kg/m^2) and obesity (BMI ≥ 30 kg/m^2) in adults. Other studies used BMI percentiles as a cut-off point to define overweight or obesity for the children and adolescents. For instance, the criteria proposed by the Centers for Disease Control and Prevention (CDC) growth charts for United States based on BMI-for-age cut-off point, which defined overweight as BMI between the 85th and 95th percentiles, and obesity as BMI greater than or equal to the 95th percentile. The China Obesity Task Force used the same criteria as CDC to define overweight and obesity.[34] One study also classified severe obesity in children as BMI ≥ 99th percentile.[35] Another possible definition is that proposed by WHO based on BMI-z scores for each specific age and sex.[36] Moreover, there are other specific national definitions for each country.[37–40] Therefore, definitions were not homogeneous across eligible studies since they used different standards.

2.5 | Statistical analyses

All analyses were conducted using STATA software, versions 14.2 and 15 (StataCorp LP). The natural log-transformed ORs, RRs, and HRs and 95% CI comparing highest versus lowest categories of dairy product consumption were pooled using the generic inverse-variance method with fixed-effects or random-effects models when there were five or fewer or at least five comparisons, respectively. Studies using continuous risk per dose were excluded from the analyses, but their findings were described within the text. Separate meta-analyses were conducted for cross-sectional and prospective cohort studies.

For all meta-analyses, the Cochran Q statistic was used to estimate interstudy heterogeneity and it was quantified by the I^2 statistic. We considered substantial heterogeneity as $I^2 \geq 50\%$ and $P_{heterogeneity} < 0.10$.

Subgroup analyses were not conduced as there were less than 10 studies per outcome available. Likewise, dose–response meta-regression analyses could not be conducted due to the few studies with applicable data available. Less than three studies reported sufficient data to perform dose–response meta-regression, and we were unable to obtain the missing information after several attempts to contact the corresponding author of these papers.

Sensitivity analyses were conducted when more than three study comparisons were available in the analyses by the removal of one study at a time from the meta-analyses and recalculating the summary risk estimates. We considered an influential study as one that changed the evidence of heterogeneity or the magnitude by more than 20%, the significance, and/or direction of the association.

Potential publication bias was not possible to be tested since less than 10 study comparisons were included in each analysis.[41]

3 | RESULTS

3.1 | Study characteristics

A total of 4367 articles were identified after a primary search of MEDLINE-PubMed and Cochrane databases as shown in Figure S1. Of these, 4290 articles were excluded according to title and abstract based on eligibility criteria. Therefore, 77 articles were collected as full texts and were further assessed for inclusion. A total of 24 articles

TABLE 1 Characteristics of studies included in the systematic review and meta-analysis

Study	Country	Study name	Population	Age[a] (years)	Dairy consumption assessment method	Type of dairy products	Comparisons	Outcome and assessment method	Follow-up[a]	Quality [b]
Cross-sectional studies										
Abreu et al. (2013)[1]	Portugal	Azorean Physical Activity and Health Study II	1209 (503 boys and 706 girls)	15–18	FFQ	Total dairy (milk, yoghurt, and cheese)	T3 versus T1	Overweight/obesity Cole et al. (2000)[2] and (2007)[3]	NA	FAIR
						Total milk (whole, semiskimmed, and skimmed)	T3 versus T1			
						Total yoghurt	T3 versus T1			
						Cheese	T3 versus T1			
Al-Hazzaa et al. (2012)[4]	Saudi Arabia	Arab Teens Lifestyle (ATLS)	2845 (boys and girls)	14–19	FFQ	Total milk	≥5 days/week versus <3 days/week	Overweight/obesity Cole et al. (2000)[2] and BMI > =25 kg/m^2 for participants aged 18–19 years	NA	FAIR
Amin et al. (2008)[5]	Saudi Arabia	-	1148 (only boys)	10–14	FFQ	Total dairy (milk, cheese and other dairy)	5–6 times/week versus ≤once/week	Overweight/obesity BMI ≥ 85th percentile	NA	POOR
Barba et al. (2005)[6]	Italy	The BRAVO Project and the Gabbiano Study	884 (456 boys and 428 girls)	3–11	FFQ	Whole milk	≤1/week versus ≥2/day	Overweight Cole et al. (2000)[2]	NA	POOR
Beck et al. (2017)[7]	USA	Birth cohort study of Latino children and mothers	145 (71 boys and 74 girls)	3	FFQ and 24-h dietary recalls	Total milk	Ounce per day	Severe obesity BMI ≥ 99th percentile[8]	NA	POOR
Beck el al. (2014)[9]	USA	Cohort of Mexican American children	319 (150 boys and 169 girls)	8–10	FFQ	Flavored milk	240-ml servings per week	Obesity CDC (2000)[10]	NA	POOR
						Whole milk	240-ml servings per week			
						2% milk	240-ml servings per week			
DeBoer et al. (2015)[11]	USA	Early childhood longitudinal survey birth cohort	8950 (4550 boys and 4400 girls)	4	Not specified	Total milk (whole, 2%, 1%, skim, and soy)	≥3 servings/day versus ≤2 servings/day	Overweight CDC (2000)[10] Obesity CDC 2000[10]	NA	POOR

TABLE 1 (Continued)

Study	Country	Study name	Population	Age[a] (years)	Dairy consumption assessment method	Type of dairy products	Comparisons	Outcome and assessment method	Follow-up[a]	Quality [b]
Govindan et al. (201)3[12]	USA	Project healthy schools	848 (girls)	10–12	24-h dietary recalls	Total milk (any type)	≥2 servings/day	Obesity CDC 2000[10]	NA	POOR
Guo et al. (2020)[13]	China	The Chinese Environmental Exposure-Related Human Activity Patterns Survey-Children (CEERHAPS-C)	40,607 (19,618 boys and 20,989 girls)	6–17	Standard questionnaire administered in one-on-one interviews with the aid of standard measuring containers.	Total milk (plain whole, low-fat, and skim cow's milk but not other types of milk such as goat milk or soymilk)	>100 ml per month versus 0 ml per month	Overweight/obesity China NHaFPCotPsRo[15]	NA	POOR
Huus et al. (2009)[16]	Sweden	All babies in Southeast Sweden (ABIS)	7356	5	FFQ	Total milk	≥4 times/day versus 2 times/day	Overweight/obesity Cole et al. (2000)[2]	NA	POOR
						Cheese	≥4 times/day versus 1 to 3 times/week			
						Cheese	Daily versus 3 to 5 times/week			
Li et al. (2007)[10]	China	China National Nutrition and Health Survey	6828 (3988 boys and 2840 girls)	7–17	24-h dietary recall for three consecutive days	Total dairy	≥100 g/day versus <100 g/day	Overweight/obesity Group of China Obesity Task Force (2004)[17]	NA	FAIR
Marcos-Pasero et al. (2018)[18]	Spain	GENYAL study	201 (108 boys and 93 girls)	6–9	48-h dietary recall	Total dairy (milk, yogurt, cheese, commercial milkshakes, and other preparations containing milk such as flans or ice creams)	1 serving/day	Overweight/obesity Cole et al. (2000)[2]	NA	POOR
Matthews et al. (2011)[19]	USA	Child-Adolescent Blood Pressure Study	1764 (879 boys and 885 girls)	6–19	FFQ	Total dairy (whole milk, chocolate milk, cottage cheese, cheeses, yogurt, pudding, ice cream, frozen	Q4 versus Q1	Overweight Expert Committee Recommendations (2007)[20]	NA	POOR

(Continues)

TABLE 1 (Continued)

Study	Country	Study name	Population	Age[a] (years)	Dairy consumption assessment method	Type of dairy products	Comparisons	Outcome and assessment method	Follow-up[a]	Quality [b]
						yogurt, and milkshake)				
Nasreddine et al. (2014)[21]	Lebanon	National Survey of Household living conditions	868 (439 boys and 429 girls)	6–19	24-h dietary recalls	Total dairy (milk and dairies)	T3 versus T1	Overweight WHO (2007)[22] Obesity WHO (2007)[22]	NA	FAIR
Nilsen et al. (2017)[23]	Sweden	Swedish WHO COSI Study	2620 (1365 boys and 1255 girls)	7–9	FFQ	Full-fat milk (whole-fat milk, 3% fat)	≥4 days/week versus <4 days/week	Overweight Swedish national growth reference from Werner[24] Obesity Swedish national growth reference from Werner[24]	NA	POOR
						Low-fat milk (skimmed/semiskimmed milk, (0.1%–0.5% fat))	≥4 days/week versus <4 days/week			
O'Sullivan et al. (2015)[25]	Australia	Western Australia Pregnancy Cohort (Raine) Study	1418	13.0–14.9	FFQ	Total dairy (core dairy products + noncore dairy products → butter, cream and ice cream)	1 serving/day	Overweight/obesity Cole et al. (2000)[2] and (2007)[3]	NA	POOR
						Core dairy (milk—including milk-based beverages such as smoothies, milkshakes and flavored milk, yoghurt, cheese, and custard).	1 serving/day			
Olivares et al. (2004)[26]	Chile	-	1723 (927 boys and 774 girls)	8–13	FFQ	Total dairy (milk and yogurt)	g/day	Obesity CDC (2000)[10]	NA	POOR

TABLE 1 (Continued)

Study	Country	Study name	Population	Age[a] (years)	Dairy consumption assessment method	Type of dairy products	Comparisons	Outcome and assessment method	Follow-up[a]	Quality [b]
Orden et al. (2019)[27]	Argentina	-	1366 (653 boys and 713 girls)	6–12	FFQ	Total milk	Cups/day	Overweight/obesity Cole et al. (2000)[2] and (2007)[3]	NA	POOR
Pei Pei et al. (2019)[28]	China	Chinese Nutrition and Health Surveillance (CNHS)	27,720 (13,887 boys and 13,833 girls)	6–17	FFQ	Total dairy (Full-fat milk, skimmed and low-fat milks, milk powder, yogurt, and cheese)	≥300 g/day versus 0 g/day	Overweight Technical Standard For Physical Examination For Students (GB/T26343-2010)[29] Obesity Technical Standard For Physical Examination For Students (GB/T26343-2010)[29]	NA	POOR
						Total milk	≥300 g/day versus 0 g/day			
						Total yoghurt	≥300 g/day versus 0 g/day			
Perez-Rodríguez et al. (2012)[30]	México	-	191	8–10	24-h dietary recalls	Total dairy (whole and skim milk and yogurt)	≥3 servings versus < 3 servings	Obesity CDC (2000)[10]	NA	POOR
Zhang et al. (2020)[14]	China	Nutrition Improvement Program for Rural Compulsory Education Students (NIPRCES)	22,315 (11,273 boys and 11,042 girls)	8–16	NIPRCES Nutrition and Health Monitoring Student Questionnaire	Total milk (various milk products including cow milk, goat milk, yogurt, and milk powder)	<200 ml per week versus 200–600 ml per week versus 800–1200 ml per week versus ≥1400 ml per week	Overweight/obesity National Health Industry Standard Screening for School-age children and adolescent malnutrition (WS/T456-2014)[31]	NA	POOR
Prospective cohort studies										
Berkey et al. (2005)[32]	USA	The growing up today study	12.829 (5550 boys and 7279 girls)	9–14	FFQ	Total milk (white and chocolate milk)	>3 servings/day versus >1to ≤ 2 servings/day	Overweight CDC (2000)[10]	1 year	5/9

(Continues)

TABLE 1 (Continued)

Study	Country	Study name	Population	Age[a] (years)	Dairy consumption assessment method	Type of dairy products	Comparisons	Outcome and assessment method	Follow-up[a]	Quality [b]
Bigornia et al. (2014)[33]	United Kingdom	Avon Longitudinal Study of Parents and Children (ALSPAC)	2455 (1154 boys and 1301 girls)	10.6 ± 0.2	3 day dietary records	Total dairy (milk, flavored milk, cheese, yogurt, ice cream, and other dairy desserts)	Q4 versus Q1	Overweight Cole et al. (2000)[2]	3.2 ± 0.2	6/9
						Total full fat dairy (dairy products made with whole milk)	Q4 versus Q1			
						Total low-fat dairy (semiskimmed or skimmed milk and any reduced fat-cheese or yogurt product)	Q4 versus Q1			
DeBoer et al. (2015)[11]	USA	Early Childhood Longitudinal Survey Birth Cohort	7000 (boys and girls)	5	Not specified	Total milk (whole, 2%, 1%, skim and soy)	≥3 servings/day versus ≤2 servings/day	Overweight CDC (2000)[10] Obesity CDC (2000)[10]	1 year	4/9
Huh et al. (2010)[34]	USA	Project Viva	645	2–3	FFQ	Total dairy	≥5 servings/day versus >0 to ≤1 servings/day	Overweight Expert Committee Recommendations 2007[20]	1 year	5/9
						Whole milk	≥5 servings/day versus >0 to ≤1 servings/day			
						2% milk	≥5 servings/day versus >0 to ≤1 servings/day			
						1% milk	servings/day			
						Total milk	≥5 servings/day versus >0 to ≤1 servings/day			

TABLE 1 (Continued)

Study	Country	Study name	Population	Age[a] (years)	Dairy consumption assessment method	Type of dairy products	Comparisons	Outcome and assessment method	Follow-up[a]	Quality [b]
Huus et al. (2009)[16]	Sweden	All babies in Southeast Sweden (ABIS)	8763	2.5	FFQ	Total Milk	≥ 4 times/day versus 2 times/day	Overweight/obesity Cole et al. (2000)[2]	2.5 years	3/9
						Cheese	Daily versus 3 to 5 times/week			

Abbreviations: CDC, Centers for Disease Control and Prevention; FFQ, food frequency questionnaire; NA, no applicable; Q, quartile; T, tertile; WHO, World Health Organization.
[a]Mean, median, or range.
[b]Assessed by The Newcastle–Ottawa Scale for prospective cohort studies and Study Quality Assessment Tools from the National Heart, Lung and Blood Institute for cross-sectional studies.

were included in the qualitative synthesis,[9,21–31,42–51] and 15[9,22–24,26,28,30,31,39,40,42,43,47,48,51] (which reported risk estimates comparing extreme categories) were included in quantitative synthesis meta-analyses (Figure S1). Two of the studies (DeBoer et al.[9] and Huus et al.[26]) conducted both cross-sectional and prospective cohort analyses.

The characteristics of each study are presented in Table 1. This meta-analysis included a total of 101,330 subjects from different continents: 10 studies were performed in America, 6 in Europe, 7 in Asia, and 1 in Oceania. The duration of follow-up in the prospective cohort studies ranged from 1 to 3.2 years. Most of them assessed dairy exposure through FFQs or using a 24-h dietary recall and evaluated the outcome according to Cole et al. (2000)[32] criteria or CDC growth charts.[52] Some studies (i.e., Berkey et al.,[22] Abreu et al.,[42] Nasreddine et al.,[28] Guo et al.,[39] and Xu et al.[51]) stratified the analysis by age or sex. Consequently, we considered those results separately in the meta-analyses.

Six studies (i.e., Huh et al.,[25] Olivares et al.,[29] Beck et al., 2014[45] O'Sullivan et al.,[50] Beck et al., 2017[44] and Marcos-Pasero et al.[27]) reported the estimate risk on a continuous scale, instead of categories of dairy consumption (i.e., highest versus lowest) and were not meta-analyzed.

3.2 | Cross-sectional studies

Figure 1 shows the superplot of cross-sectional findings, summarizing the meta-analysis investigations for each of the different subgroups of dairy products (i.e., total dairy, total milk, total yogurt, and cheese) in relation to the prevalence of obesity, overweight, and overweight/obesity combined.

3.2.1 | Total dairy products consumption and risk of obesity, overweight, and overweight/obesity

Overall, total dairy consumption was associated with a 34% reduction in obesity prevalence risk (OR (95% CI): 0.66 (0.48–0.91); Figure S2). However, a nonsignificant association was observed between total dairy consumption and overweight risk (OR (95% CI): 1.04 (0.73–1.49); Figure S3). When overweight and obesity were analyzed as a merged category, a nonsignificant association was also found between total dairy product consumption and risk of overweight/obesity (OR (95% CI): 0.90 (0.76–1.08); Figure S4).

Regarding the results on a continuous scale, Olivares et al.[29] found a significant inverse association between total dairy consumption (g/day) and obesity risk (OR (95%CI): 0.998 (0.997–0.998) and a nonsignificant association between total dairy consumption and overweight risk (OR (95%CI): 1.02 (0.90–1.16)). Moreover, Marcos-Pasero et al.[27] also found a significant 52% reduction in overweight/obesity risk (OR (95%CI): 0.48 (0.29–0.75)) by total dairy consumption (one serving/day).

Subgroup	No.	N	OR [95% CI]	Pooled OR [95% CI]	Heterogeneity I²%	Heterogeneity $P_{heterogeneity}$	P - value
Obesity							
Total dairy	5	28,740	0.66 [0.48, 0.91]		27.6	0.24	0.01
Total milk	6	78,128	0.90 [0.78, 1.05]		33.1	0.19	0.17
Total yogurt	2	27,714	0.94 [0.50, 1.78]		-	-	-
Overweight							
Total dairy	5	30,313	1.04 [0.73, 1.49]		75.6	<0.01	0.83
Total milk	5	77,276	1.05 [0.93, 1.20]		22.0	0.27	0.43
Total yogurt	2	27,714	1.10 [0.72, 1.68]		0	0.63	0.65
Overweight/Obesity							
Total dairy	4	9,183	0.90 [0.76, 1.08]		97.5	<0.01	0.25
Total milk	6	35,091	0.94 [0.80, 1.10]		66.5	0.01	0.43
Whole-fat milk	1	2,154	0.60 [0.39, 0.78]		-	-	-
Low-fat milk	1	2,154	1.90 [1.40, 2.48]		-	-	-
Total yogurt	2	1,209	1.12 [0.85, 1.48]		47.2	0.17	0.42
Cheese	3	8,565	0.86 [0.63, 1.16]		14.4	0.31	0.31

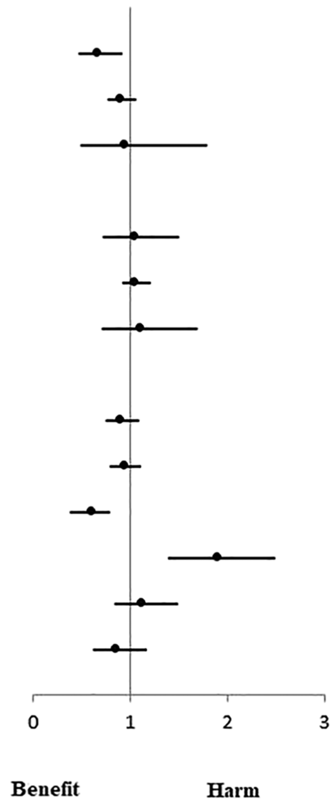

FIGURE 1 Superplot of cross-sectional studies

3.2.2 | Milk consumption and risk of obesity, overweight, and overweight/obesity

We reported a nonsignificant association between total milk consumption and prevalence of obesity risk (OR (95% CI): 0.90 (0.78–1.05); Figure S5), overweight/obesity risk (OR (95% CI): 0.94 (0.01–1.10); Figure S6), and overweight risk (OR (95% CI): 1.05 (0.93–1.20); Figure S7). We could not perform meta-analyses in the cross-sectional studies by subtypes of milk, since only one study for each type[17,43] of milk was identified (Figure 1). A significant 40% reduction in overweight/obesity risk (OR (95%CI): 0.60 (0.39–0.88)) by whole-fat milk consumption was reported in Nielsen et al.[49] as well as a significant direct association between low-fat milk consumption and overweight/obesity risk (OR (95%CI): 1.9 (1.40, 2.48)). Moreover, Barba et al.[21] found that whole-fat milk was significantly associated with overweight risk (OR (95%CI): 2.18 (1.30–3.66) for poor versus high categories of consumption). However, in this case, the highest consumption category was taken as the reference; thus, it was not possible to pool these results with those from Nielsen et al.

Regarding the cross-sectional results reported on a continuous scale, a significant 11% reduction in obesity risk (OR (95%CI): 0.89 (0.81–0.97)) by total milk consumption (oz/day) was reported in Beck et al. (2017).[44] Moreover, Beck et al. (2014)[45] reported a significant inverse association between flavored (OR (95%CI): 0.88 (0.80–0.96)) and whole-fat (OR (95%CI): 0.92 (0.84–1.01) milk consumption (per 240-ml serving/week) and obesity risk and a nonsignificant association between low-fat milk consumption and obesity risk (1.02 (0.98–1.07)).

3.2.3 | Total yogurt consumption and risk of obesity, overweight, and overweight/obesity

A nonsignificant cross-sectional association was found between total yogurt consumption and prevalence of obesity risk (OR (95% CI): 0.94 (0.50–1.78); Figure S8), overweight risk (OR (95% CI): 1.10 (0.72–1.68); Figure S9), and overweight/obesity risk (OR (95% CI): 1.12 (0.85–1.48); Figure S10).

3.2.4 | Cheese consumption and risk of overweight/obesity

Results for the cross-sectional association between cheese consumption and obesity and/or overweight risk were only available when they were combined (overweight/obesity). No association was found between cheese consumption and prevalence of overweight/obesity risk (OR (95% CI): 0.86 (0.63–1.16); Figure S11).

3.3 | Prospective cohort studies

Figure 2 shows the superplot of the prospective summary risk estimates of the relation between total dairy product and each different dairy subtype and incidence of obesity, overweight, and overweight/obesity. Due to the reduced number of prospective cohort studies within each specific subgroup (i.e., obesity, overweight, and overweight/obesity) and dairy category (i.e., total dairy, total milk, total yogurt, and cheese), we only performed a meta-analysis of prospective cohort studies with results for the association between total milk consumption and risk of overweight.

3.3.1 | Total, full-fat, and low-fat dairy consumption and risk of obesity, overweight, and overweight/obesity

We could not perform a prospective meta-analysis for total, full-fat, and low-fat dairy products and obesity, overweight, and overweight/obesity due to the limited number of available studies. The association between total dairy consumption and obesity risk was not reported in any of the included studies. However, a significant 44% reduced risk of overweight by total dairy consumption was reported only by Bigornia et al.[46] (RR (95% CI): 0.56 (0.32, 0.97)). Full-fat dairy consumption was associated with a 43% reduced risk of overweight (RR (95% CI): 0.57 (0.34–0.94)), while the association with low-fat dairy consumption was nonsignificant (RR (95% CI): 0.74 (0.43–1.28); Figure 2). On a continuous scale, Huh et al.[25] reported a nonsignificant association between total dairy consumption (serving/day) and overweight risk (RR (95% CI): 1.01 (0.83–1.23)).

3.3.2 | Total milk consumption and risk of obesity, overweight, and overweight/obesity

We could only perform a prospective meta-analysis for the association between total milk consumption and overweight incidence, since only one study was identified for the other outcomes. The results of the meta-analysis revealed a significant 17% increased risk of overweight by total milk consumption (RR (95% CI): 1.17 (1.01–1.35); Figure S12). However, a nonsignificant association between total milk consumption and risk of obesity (RR (95%CI): 1.05 (0.86, 1.27)) and overweight/obesity (RR (95%CI): 0.91 (0.73–1.13)) was found in DeBoer et al.[9] and Huus et al.,[26] respectively. Although we could not perform a meta-analysis because only one study comparison was available, a nonsignificant association between full-fat (RR (95% CI): 1.49 (0.25–9.03)), and 2% skim milk (RR (95% CI): 1.16 (0.12–11.48)) and overweight risk was reported by Huh et al.[25] when comparing extreme categories of consumption. Similar results were observed

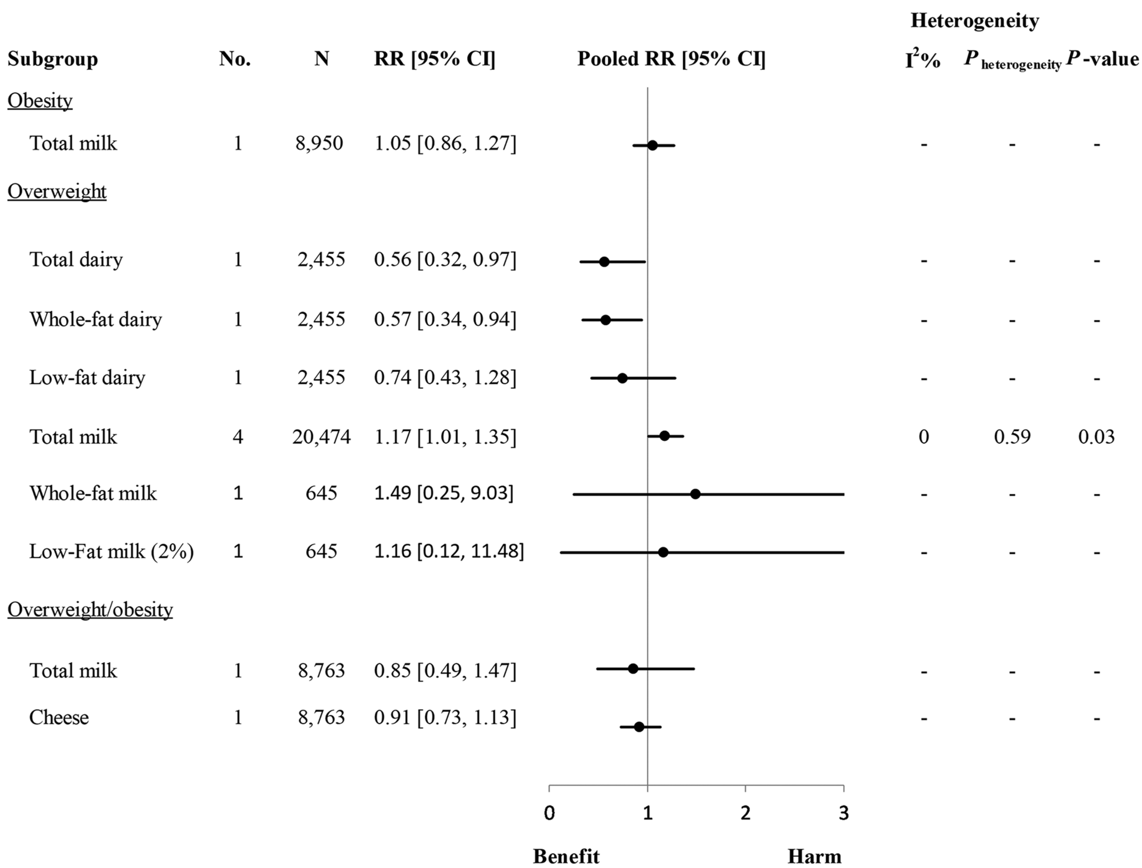

FIGURE 2 Superplot of prospective cohort studies

when analyzed in continuous scale (RR (95% CI): 1.04 (0.74–1.44)) for whole-fat milk, (RR (95% CI): 0.91 (0.62–1.34) for 2% milk, and (RR (95% CI): 0.95 (0.58–1.55)) for 1% skim milk).

3.4 | Meta-analysis heterogeneity and publication bias

In the cross-sectional studies, no evidence of substantial interstudy heterogeneity was found for any dairy category (i.e., total dairy, total milk and total yogurt) and obesity risk (Figure 1). However, substantial and significant levels of interstudy heterogeneity was reported in the meta-analyses for total dairy consumption and overweight risk (I^2 = 75.6%) and overweight/obesity risk (I^2 = 97.5%. Finally, 66.5% of interstudy heterogeneity was also observed for total milk consumption and overweight/obesity risk (Figure 1). In prospective cohort studies, due to the lack of studies, we could only analyze the heterogeneity in the meta-analysis of overweight risk by total milk consumption, where no evidence of interstudy heterogeneity was observed (Figure 2). Finally, due to the reduced number of studies (i.e., <10 in each meta-analysis), neither publication bias nor sources of heterogeneity, as assessed by subgroups, could be analyzed.

3.5 | Sensitivity analysis

Sensitivity analysis with one study removed at a time (leave-one out approach) was performed for analyses of more than two studies, in order to assess whether the results could have been substantially affected by a single study. In the cross-sectional studies, the removal of the Xu et al.[51] results for girls turned the association between total dairy consumption and obesity risk from significant to nonsignificant. Moreover, in case of the removal of Xu et al.[51] results for boys, the pooled risk estimates for total dairy and obesity risk were reduced by more than 10% (from an OR of 0.66 to 0.53; Table S2). The removal Li et al.[47] or Amin et al.[43] in total dairy consumption and overweight/obesity turned the OR significant. Furthermore, the removal of the Guo et al.[39] findings for boys in the assessment of total milk consumption and overweight risk resulted in the RR becoming statistically significant. Finally, the exclusion of Matthews et al.[48] in total dairy and overweight risk and the exclusion of Al-Hazza et al.[31] in total milk and overweight/obesity risk, drastically reduced the heterogeneity from 75.6% to 23.3% and 66.5% to 0%, respectively.

In prospective cohort studies, the removal of Berkey et al. (boys)[22] and Berkey et al. (girls)[22] changed the risk estimates from significant to nonsignificant in total milk and overweight incidence risk. Furthermore, the exclusion of DeBoer et al.[9] increased the RR from 17% to 35% (Table S2).

4 | DISCUSSION

We conducted a systematic review and meta-analysis of cross-sectional and prospective cohort studies in an attempt to draw the most reliable conclusions relating the association of total dairy intake and its different subtypes with the prevalence and incidence of overweight, obesity and overweight/obesity as a merged category. In the meta-analysis of cross-sectional studies, comparing extreme categories of consumption, an inverse association between total dairy consumption and obesity prevalence was shown. However, no significant associations were found between milk or yogurt and obesity prevalence. Regarding secondary outcomes, no associations between total dairy or other dairy subtypes were observed.

Due to the low number of prospective cohort studies analyzing the association between the consumption of different types of dairy products and the risk of obesity, overweight, and overweight/obesity, we only performed a meta-analysis for the association between total milk consumption and risk of overweight. Findings showed the frequency of total milk consumption to be significantly associated with an increased risk of overweight. Although we were not able to conduct a meta-analysis for the associations between total, whole-fat, and low-fat dairy products and the pre-established adiposity categories, whole-fat dairy consumption was associated with a decreased risk of overweight incidence in one prospective study,[25] while that association was nonsignificant with respect to low-fat dairy consumption.

Results from previous reviews[12,15] and meta-analysis[15] of cross-sectional studies are in line with our findings, indicating an inverse association between total dairy product consumption and obesity risk. However, it is important to highlight that pooled meta-analysis of cross-sectional studies is not sufficient to infer causality and that ruling out potential reverse causality is impossible. Importantly, to the best of our knowledge, this is the first meta-analysis analyzing the association between different types of dairy products and prevalence/incidence of obesity and overweight in children and adolescents. It is important to discriminate between dairy subtypes since their nutritional profiles differ, and therefore, they could also be differently associated with obesity, as evidenced in our results. Previously, only one meta-analysis of prospective cohort studies[16] evaluated the relationship between total dairy consumption and the risk of overweight/obesity incidence, showing an inverse association when comparing the highest versus the lowest category of intake, and a 13% risk reduction for the increase in 1 serving/day. It is worth noting that this meta-analysis of prospective cohort studies has methodological limitations that deserve to be mentioned. First, the authors included the same study in the analysis more than once because they reported the risk for different exposures (i.e., whole-fat dairy, reduced-fat dairy, and total dairy products). This leads to a unit of error analysis since participants were counted three times. To overcome this issue, care should have been taken when performing the statistical analysis, especially when conducting a pairwise meta-analysis. Second, the authors also mixed studies analyzing total dairy with other studies only assessing milk as exposure. Therefore, the inverse association observed in that meta-analysis could not be attributed to total dairy consumption. Bearing in mind the aforementioned shortcomings, the results of that meta-analysis should be interpreted with caution. The current meta-analysis tried to deal with all of these methodological issues to provide more reliable results for the analysis of the association between dairy product consumption and obesity risk. Importantly, another previous meta-analysis[13] as well as systematic[10,13] or narrative[53] and critical[12] reviews showed a protective association or no association between dairy intake and some indicators of adiposity, rather than obesity as a main outcome, in children or adolescents.

It is important to mention that we could only perform a meta-analysis of prospective cohort studies assessing total milk in relation to overweight incidence. This highlights the need for additional prospective cohort studies investigating the association between total dairy products and specific subtypes, taking also into account the fat content and the risk of obesity incidence in children and adolescents. Our results demonstrated a positive association between total milk consumption and overweight incidence risk. However, it is noteworthy that in the meta-analysis of prospective cohort studies available, data came from only three[9,22,25] of the five prospective studies identified. Therefore, these results should be interpreted with caution. Furthermore, DeBoer et al.,[9] the study which contributed the most to the weighted average in our meta-analysis of cross-sectional studies of total milk consumption and prevalence of overweight, with 47%, did not take into account energy intake as a potential confounder. This warrants consideration, given that in the study conducted by Berkey et al.,[22] the authors highlighted that their results might be mediated by total energy intake and not necessarily by milk consumption per se due to the associations being attenuated when the results were adjusted for energy intake. In contrast, the study conducted by Huh et al.[25] and in the other prospective studies,[26,46] which did not meet inclusion criteria and thus were not included in the meta-analysis, the authors took into account total energy intake as a confounder and neutral associations were found. For example, a nonsignificant association between total milk consumption and risk of overweight/obesity was found in Huus et al.[26] On the other hand, data from intervention studies reviewed recently by Douglas et al.[12] showed a neutral effect of dairy product and milk consumption on body weight and body composition in children and adolescents. It should be noted that three trials[54–56] that assessed milk consumption as an intervention showed an increase in body weight in parallel to an increase in lean mass[55,56] or overall growth.[53,54,57]

Recently, a narrative review[53] reported no association or negative association between milk consumption and overweight or obesity in children aged 12–60 months which supports our results. However, it is important to highlight that some studies conducted in well-nourished populations suggest that high protein intake early in life can increase the risk of developing overweight and obesity later in life.[57] Even so, given the controversial and limited data available from our results and the aforementioned effect seen in intervention trials, no definitive conclusions could be drawn in relation to milk consumption and overweight in children and adolescents.

Even though we could not conduct a meta-analysis for the associations between total, whole-fat, and low-fat dairy products and the incidence of obesity, overweight, and overweight/obesity due to the limited number of available studies, a significant inverse association between whole-fat dairy consumption and risk of overweight incidence was observed in one study, while the association with low-fat dairy consumption was nonsignificant.[46] Along these lines, a systematic review reported that whole-fat dairy products were not associated with increased measures of weight gain or adiposity.[11] The authors argued that whole-fat dairy may result in higher satiety due to the satiating effect of fat and protein which may contribute to a relative reduction in overall food consumption, thus possibly preventing the weight gain.

Dairy products have a complex food matrix characterized by a great variety of nutrients, including calcium, specific fatty acids, and probiotics. Moreover, the nutritional profile could differ depending on the subtype of dairy product, as well as the processing method applied. Some potential biological mechanisms underlying the potential beneficial relationship between dairy consumption and obesity have been suggested, bearing in mind its nutritional properties. For example, dairy products are rich in protein, where protein has been shown to have higher satiating effects in the short term compared to carbohydrate or fat.[58] Moreover, dairy bioactive peptides and calcium content have been suggested to play an important role in preventing weight gain by regulating insulinemia.[59] It has been reported that insulin concentrations are lower in individuals consuming diets high in dairy products compared to those consuming diets low in dairy products,[59] where it has been suggested that it is the calcium from dairy products that may have beneficial effects on glucose metabolism.[60] Furthermore, it has been demonstrated that calcium could decrease fat reabsorption and/or increase fecal fat excretion because of its capability to combine with fatty acids and bile acids in the intestine.[61] Intake of calcium from dairy products might also affect the lipid profile by decreasing the intracellular calcium levels, which results in the stimulation of lipolysis and the inhibition of fatty acid synthesis.[62–64] Animal studies have also shown that dietary calcium might interfere with gut microbiota, partly explaining the potential beneficial effects of calcium on body weight.[65] For example, high-calcium diets appear to positively affect gut microbiota composition towards increasing community diversity and specific bacterial abundance such as the growth of lactobacilli.[60] Other constituents from dairy products different than calcium, such as peptides in whey protein, medium-chain fatty acids, and conjugated linoleic acid, have also shown to reduce lipogenesis and to stimulate fat oxidation in the adipocyte, thereby resulting in a reduction in fat accumulation.[66,67]

The present systematic review and meta-analysis has some limitations which require acknowledgment. The number of studies identified and included in each type of analysis based on dairy subtypes and the three different outcomes was small. As a consequence, future studies are likely to change the pooled risk estimates. Moreover, we could not perform subgroup analyses to investigate potential sources of heterogeneity nor could publication bias be assessed, since there were less than 10 study comparisons. This is important since a high degree of interstudy heterogeneity was observed for the analyses of total dairy consumption and overweight and for total dairy, total milk, and overweight/obesity. It is noteworthy that the exclusion of Matthews et al.[48] in the cross-sectional study meta-analysis of total dairy and overweight and the exclusion of Al-Azzaa et al.[31] in the total milk and overweight/obesity cross-sectional study meta-analysis explained the observed heterogeneity. Additionally, the limited number of eligible studies prevented intercountry comparisons from being performed to assess whether the associations would change between different countries. Another important limitation is related to the outcome definition. Contrary to the adult population, there is not a universal definition of overweight or obesity in children and adolescents. Therefore, the included studies in the present systematic review and meta-analysis used different criteria to define these outcomes. These divergent criteria could affect the accuracy of our risk estimates. Unfortunately, due to the limited number of studies, we were not able to conduct subgroup analyses to explore the influence of those definitions on our results. Although we aimed and attempted to conduct dose–response meta-regression analyses, these analyses could not be conducted with confidence due to the limited available information, despite best attempts to contact authors where applicable. This is an important limitation because dose–response meta-regression analyses allow for the exploration of possible differential associations according to varying levels of exposure and provides an enhanced picture of the associations to inform clinical decisions.

The present systematic review and meta-analysis also has some strengths to be highlighted. To the best of our knowledge, this is the first meta-analysis differentiating the association between dairy products with obesity, overweight, and overweight/obesity. Moreover, we performed analyses based on different dairy subtypes (e.g., total dairy, total milk, yogurt, and cheese), which each have slightly different nutritional profiles and therefore could be differently associated with the obesity risk. Importantly, we included new information from two studies,[25,31] after contacting their respective corresponding authors. This allowed us to increase the number of studies in our analyses and provide extra information to update the results. Finally, we tried to solve the methodological issues of previous meta-analyses. We did not include in the analysis of total dairy products those studies that considered only one type of dairy product (e.g., only yogurt) as an exposure; we did not combine studies that reported the risk estimates in a continuous scale with those reporting the risk estimates comparing categories of consumption together in the same analysis.

In conclusion, evidence from pooled analyses of cross-sectional studies suggested an inverse association between total dairy consumption and obesity. However, there is limited and no conclusive evidence to confirm an inverse relationship from pooled analysis of prospective studies in children and adolescents. Our confidence in the effect estimates is low because of the few studies included in the meta-analyses, and future studies are likely to change the findings. Last but not least, it deserves to be mentioned that in the absence of evidence, this study does not support limiting the amount of total dairy or milk consumption in children and adolescents in terms of overweight or obesity risk. Nevertheless, our results should be interpreted with caution and further studies with a higher degree of evidence are needed to better understand the role of total dairy and its subtypes in relation to body weight in children and adolescents.

AUTHOR CONTRIBUTIONS

The following statements should be used: N. B and N.B-T has contributed equally. Conceptualization: N. B, N.B-T and J. S-S.; methodology: N. B, N.B-T, J.S-S., and S.K.N.; acquisition of data: L. L, I.P.G., J.F.G.G., and S.K.N; formal analysis, N.B-T. and S.K.N.; drafting the manuscript: N. B, N.B-T, J.S-S., and S.K.N.; review and editing, N. B, N.B-T, J.S-S, S.K.N., I.P.G., and J.F.G.G. All authors have read and agreed to the published version of the manuscript.

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CONFLICT OF INTEREST

Dr. Nancy Babio declares that she received grant support through his institution from Danone S.A. but not for preparing this study. In addition, she was one of the members of the Scientific Advisory Board of the EU program for the promotion of milk and milk products within the framework of appropriate dietary practices (2017–2019). Dr. Nerea Becerra-Tomás declares that she received grant support through her institution from Danone S.A. Dr. Stephanie K. Nishi is a volunteer member of the not-for-profit organization Plant-Based Canada. Professor Jordi Salas-Salvadó declares that he is a member of the Danone Institute Spain and that he received payments from Danone S.A. for the purposes of scientific and technical consulting but not for preparing this study. He has received personal consulting fees from Eroski and Mundipharma and has received grant support through his institution from the Nut and Dried Fruit Foundation and Eroski. The other authors declare that they have no conflicts of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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