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SYSTEMATIC REVIEW

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Childhood obesity in relation to risk of dental caries: a cumulative and dose-response systematic review and meta-analysis

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Abstract

Introduction Earlier studies reported inconsistent findings for the association of childhood obesity with the risk of dental caries. In this systematic review and meta-analysis, we aimed to summarize earlier studies on the association of overweight and obesity with risk of dental caries in children.

Methods Relevant studies published up to December 2023 were identified through searches in PubMed, MEDLINE, SCOPUS, EMBASE, and Google Scholar, using suitable keywords. All observational studies, including cross-sectional or cohort or case-control studies, about the association of each obesity index with risk of dental caries in children which reported odds ratio (OR), hazard ratio (HR), or relative risk (RR) and 95% CIs, were included. Studies involving adults, randomized clinical trials, studies on animals or pregnant women, and studies on other dental disorders were excluded. Risk of bias was assessed using standard methods for observational studies. A total of 22 studies including 40673 participants were included. Studies were pooled using the random-effect model, and results were synthesized with subgroup analyses and assessments of heterogeneity. Limitations included potential publication bias and heterogeneity among study designs. The quality of the included studies was assessed using the Newcastle–Ottawa scale (NOS).

Results Children at the highest category of BMI were 44% more likely to have early childhood caries (ECC) than those at the bottom (OR: 1.44; 95% CI: 1.16 to 1.78). Moreover, combined analysis also showed no significant association between waist circumference (WC) and risk of dental caries in children. However, significant linear and non-linear associations were found between BMI and risk of childhood dental caries. No publication bias was found for the relationship between BMI and the risk of ECC based on visual inspection of a funnel plot and Egger's test.

Conclusions This study showed a significant direct association between BMI and the risk of dental caries in children. Non-linear analysis showed higher risk of dental caries in children with higher BMI and also among underweight children. Further prospective studies are required to expand current knowledge in this issue.

Impact statement The findings of this study have significant implications for public health and dental care, suggesting association between BMI and the risk of dental caries in children. This comprehensive meta-analysis is among the

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first to summarize earlier publications on the association of obesity with risk of dental caries in children, highlighting the need for more accurate methods of obesity assessment and further research to understand this relationship better. These findings can help inform public health policies and interventions to reduce the prevalence of childhood obesity and dental caries.

Keywords Children, Dental caries, Obesity, Overweight

Introduction

Obesity is a chronic disease characterized by excess or abnormal accumulation of fat in the body that might disturb a person's health [1]. In 2016, it was reported that 1.9 billion adults 18 years old or above were overweight, of which over 600 million were obese [2]. The prevalence of obesity in children and adolescents is quickly increasing, such that more than 340 million children and adolescents aged between 5 to 19 are suffering from overweight or obese, worldwide [2].

Childhood obesity is linked with different chronic diseases, such as cardiovascular disease, certain types of cancers, type 2 diabetes, coronary heart disease, or hypertension in adulthood [3, 4]. Besides, it is positively linked to the development of various physical disabilities and diverse psychological problems [5]. Accordingly, obesity is considered as a critical threat to health-care systems and imposes a substantial burden on countries [6].

Dental caries (known as tooth decay or dental cavity) is accounted as the most prevalent non-communicable diseases worldwide, often causing pain and infection, resulting in tooth extraction and altered quality of life [7, 8]. It has been estimated that near 5-10% of the health care annual budget in the developed countries is spent for the treatment of dental caries [9]. In addition, dental caries can threaten children's development and growth, especially those on a poor diet [10]. The association between obesity and dental caries might be related to low-socioeconomic status, high-sugar diet, low use of health services, and limited health literacy. These shared risk factors leads to higher prevalence of both conditions [11]. Many studies have examined association between obesity and dental caries in different locations; however, their findings are controversial. Several studies reached no remarkable association [12], while others found a positive or an inverse association between obesity and dental caries [13–16]. Earlier systematic reviews and meta-analyses also reported controversial findings [11, 14, 17, 18]. In addition, A recent meta-analysis suggested that obesity increases the risk of caries in older children, while it was equivocal in younger children [19], which highlights needs for a comprehensive analysis in this area. Those meta-analyses have substantial limitations, including focusing only on cross-sectional studies [11, 20, 21], lack of examination for the association in children under six years [11, 17, 21], and the majority of them had an incomplete search strategy in a small number of databases [11, 17, 19–21]. Furthermore, they did not separately analyze continuous and categorical effect sizes to reach a firm conclusion. Lack of different subgroup analyses is another limitation of those studies.

Given the aforementioned reasons and to address the knowledge gaps, current systematic review and meta-analysis was done to examine association between obesity indices and risk of dental caries in children.

Methods

This research was carried out in line with the PRISMA (preferred reporting items for systematic reviews and meta-analyses) guidelines.

Search strategy

Relevant studies published up to December 2023 were searched through PubMed, MEDLINE, SCOPUS, EMBASE, and Google Scholar, using the following suitable MESH and non-MESH keywords: (("early childhood caries"[tiab] OR "Dental Care for Children"[tiab] OR "tooth decay"[tiab] OR "pediatric dentistry"[tiab] OR "dentistry"[tiab] OR "dental"[tiab] OR "teeth"[tiab] OR "tooth"[tiab] OR "caries"[tiab] OR "dental caries"[tiab] OR "Dental Decay"[tiab] OR "Teeth decay"[tiab]) AND ("child"[tiab] OR "kid"[tiab] OR "childhood"[tiab] OR "pediatric"[tiab] OR "paediatric"[tiab] OR "preschool children"[tiab]) AND ("weight"[tiab] OR "body mass index"[tiab] OR "BMI"[tiab] OR "waist circumference"[tiab] OR obesity[tiab] OR "overweight"[tiab] OR "Birth weight"[tiab])). No restrictions were done in terms of language or time of publication. Duplicate citations were removed. To avoid missing any publication, we also reviewed reference lists of all included studies and relevant review articles.

Inclusion criteria

All observational studies, including cross-sectional or cohort or case-control studies, that investigated the association of each obesity index with risk of dental caries in children. Eligible studies were required to report odds ratio (OR), hazard ratio (HR), or relative risk (RR) and 95% CIs, were included. In case of several publications with the same data set, we included only the most complete one. If data for specific subgroups were reported, results for the whole population were used. Studies on adults, randomized clinical trials, animal studies, those enrolled pregnant women, and studies assessed risk of other dental disorders in relation to obesity were not included in our systematic review and meta-analysis. We did not also include unpublished data and grey literatures, including dissertations, congress abstracts, and patents in the current meta-analysis.

Data extraction

Following data were extracted by two independent reviewers: first author's name, publication year, location, study sample size, number of subjects in each group, participants' age, participants' gender, study design, exposure, exposure assessment method, outcomes, outcome assessment methods, and any confounder adjusted for.

Statistical analysis

All statistical analyses were performed using STATA software version 14.0 (Stata Corp LP, College Station, TX). Statistical significance was set at $p < 0.05$. We focused on studies that reported odds ratios (ORs) for all-cause or early childhood caries across different BMI categories. A dose-response meta-analysis, following the method developed by Greenland and Longnecker [22] and further refined by Orsini et al. [23], was used to assess the trend from correlated log OR estimates across BMI categories. For each BMI category, the midpoint was considered the corresponding OR estimate. Open-ended categories were assumed to be of equal width to the adjacent categories.

A two-stage random-effects dose–response meta-analysis was employed to explore a potential non-linear relationship between BMI and early childhood caries risk. This involved modeling BMI with restricted cubic splines, with knots placed at the 10th, 50th, and 90th percentiles of the distribution, as described by Harrell et al. [24]. Using a generalized least-squares regression, we accounted for the correlation within each set of published ORs, combining the study-specific estimates with the restricted maximum likelihood method in a multivariate random-effects meta-analysis. The non-linearity probability was assessed by testing the null hypothesis that the coefficient of the second spline was zero.

For a linear dose-response relationship, we evaluated the impact of 1 kg/m2 increments in early caries on childhood using generalized least-squares trend estimation. We calculated pooled ORs and standard errors from all reported effect sizes and their 95% confidence intervals (CIs) using a random-effects model. Additionally, we applied a multivariate linear regression model to investigate the association between obesity indices and childhood dental caries risk, adjusting for potential confounders such as age, gender, socioeconomic status, and dietary habits.

Between-study heterogeneity was examined using the Cochrane Q test and I^2 statistics, with I^2 values over 50% indicating substantial heterogeneity. To identify sources of heterogeneity, we conducted subgroup analyses based on country population size (large vs. small), region (Asian vs. European vs. American countries), participants' age (≤7 years vs. >7 years), sample size (≤900 vs. >900), study design (cross-sectional, case-control, or cohort), and adjustments for age and gender. To assess publication bias, both the funnel plot and Egger's regression test were employed.

Quality assessment

The Newcastle Ottawa Scale (NOS), which is tailored for observational studies, was employed to evaluate the quality of the selected cohort, case-control and cross-sectional studies [25]. The NOS assigns up to ten points to each study: five for selection, two for comparability, and three for outcome assessment, with ten representing the highest quality. Any disagreements were resolved through discussion. In this study, publications scoring 5 or higher on the NOS were deemed high-quality (Supplementary Table 2).

PECO Framework

The study focused on the association between obesity indices (exposure), such as BMI and waist circumference, and the risk of dental caries (outcome) in children (population). Although the specific formulation of the PECO question was not explicitly stated, the study implicitly addressed these components to guide its research focus and parameters. Additionally, the comparator used was different levels of BMI (e.g., normal weight, overweight, obese). Detailed information on the PECO framework can be found in Supplementary Table 1.

Results

Systematic review

Flow-diagram of study selection has been shown in Fig. 1. Overall, 22 studies including 40673 participants were judged to be eligible for the current systematic review. Of these, 16 studies were included in the meta-analysis. Characteristics of these studies are summarized in Table 1. Included studies were published between 2007 and 2023; such that 8 studies were published before 2015 [12–15, 26–29] and 14 studies were published after that year [16, 30–42]. Included studies were done in Finland [30, 39], Brazil [26, 27, 37] , Sweden [32], Mexico [15], Germany[31, 35], Vietnam [16], China [29], UK [28, 34], India [13], Nepal [33], New Zealand [36], Belgium [38],

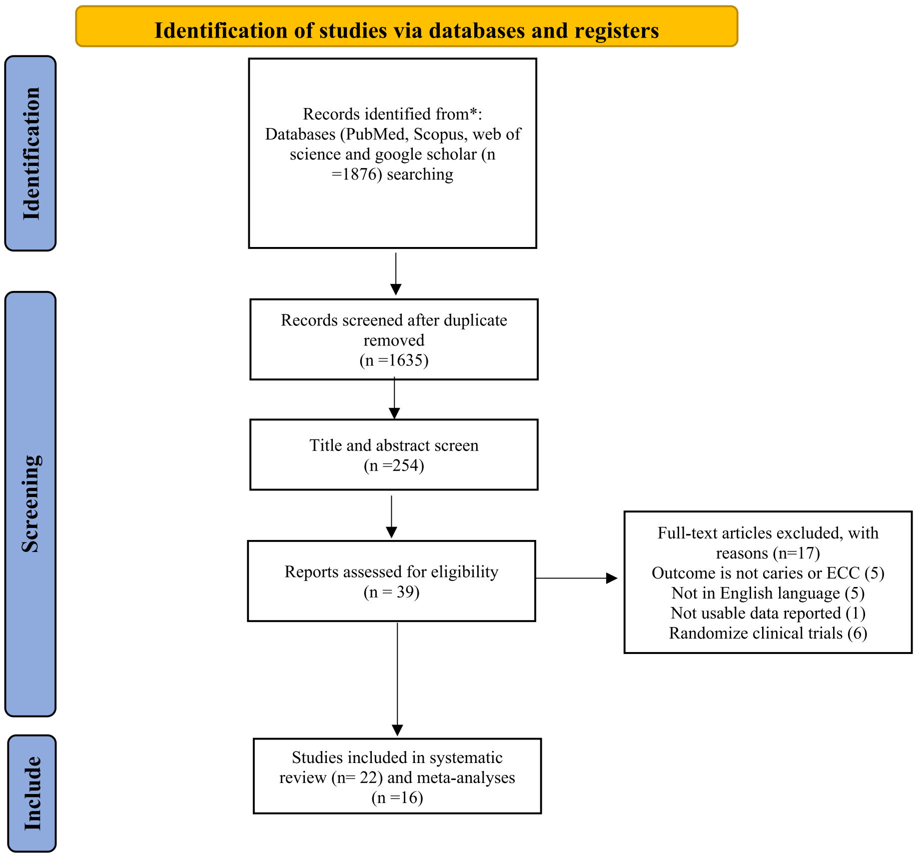

Fig. 1 Flow diagram of study selection

Saudi Arabia [40], Tiwan [42] and USA [12, 14, 41]. They had case–control [30, 35, 38, 43], cross-sectional [13, 14, 16, 26, 27, 29, 31, 33, 34, 36, 40, 42, 44], or prospective cohort design [12, 15, 28, 32, 35, 37, 39, 41]. The sample size of these studies varied between 71 and 27333 and could be classified into two subgroups of less than 900 [13, 14, 26, 27, 29–32, 34, 35, 37–39, 42] and more thanf 900 [12, 15, 16, 28, 33, 36, 40, 41]. Moreover, study sample size was not reported in one of included papers [28]. The mean age of children in the included studies varied from 4 to 18 years. Fourteen studies were done on children aged <7 years [12, 14, 15, 27–29, 31, 32, 34–37, 40, 41], while 8 studies enrolled children between 7 and 15 years [13, 16, 26, 30, 33, 38, 39, 42]. All included studies were done on both genders.

The measured exposures were BMI as a continuous [28, 29, 31, 34] or categorical [12–16, 26–28, 30, 32, 33, 36–42] variable and WC categories [29, 34]. Exposure assessment method was not reported in some studies [31], while the others directly measured participants' weight and height to calculate BMI [12–16, 26–30, 32–42]. The outcome of interest was dental caries in most studies [12–16, 26–42]. Some other studies also reported odds ratio for erosive tooth wear [30, 31]. Assessment of outcomes was done by an experienced dentist in most included studies [12–16, 26–42]. In some studies findings were adjusted for participants' gender [16, 26, 29, 30, 33, 36, 38–42]. In addition, some other studies adjusted their findings for the participants' age [28, 30, 33, 37, 38, 41, 42]. Furthermore, a considerable number of included studies did not report any adjustment [13, 27, 31, 32, 34].

Meta-analysis

Combining data from 16 studies, we found a significant direct association between BMI and risk of ECC; such that those at the highest category of BMI had 44% higher risk of dental caries than those at the bottom category (OR: 1.44; 95% CI: 1.16 to 1.78, I^2= 88.9 %) (Fig. 2). In our study, the subgroup analysis presented in Table 2 included articles that utilized consistent standards for defining both obesity and dental caries. When we did subgroup analysis by the predefined variables, the association significant relationship was found between BMI and risk of ECC among studies done in Asian countries (OR: 1.70; 95% CI: 1.25, 2.32), also among studies with cohort design (OR: 1.27; 95% CI: 1.07, 1.56) and

Table 1 Summary of the included studies

N St	First Author (Year)	Country	Age range/ Mean age	Sex	Sample size	Study design	Follow-up (y)	Exposure	Exposure assessment method	Compared categories	Outcomes	Outcome assessment method	OR (95%CI)	Adjustment for diet related risk factor	Adjustments*
1	Tschammler et al. (2019) [31]	Germany	4–17	Both	223	Cross-sectional	NR	BMI	NR	Continues	Caries experience or severity, erosive tooth wear	NR	Erosive tooth wear: Children with primary teeth BMI: 1.025 [1.005-1.046] Children with permanent teeth: BMI: 1.041 [1.010-1.097]	NR	NR
2	Marrol et al. (2020)	Finland	11–18	Both	71 obese adolescents	Case–control	NR	BMI (obesity)	Measured weight and height	Obese vs. non-obese	Caries, Erosive tooth wear, Gingivitis, Plaque	Caries experience was screened using DMFT index	Caries: 0.83 (0.04, 1.63) Erosive tooth wear: 0.34 (0.45, 1.14) Gingivitis: 1.87 (0.52, 3.23) Plaque: 3.08 (1.51–4.65)	NR	1, 2
3	Paulo, et al. (2014)	Brazil	7-9	Both	203 schoolchildren	Cross-sectional	NR	BMI	Measured weight and height	Upper quintile Vs. Lower quintile	Caries	Caries experience was measured using the decayed, missing, and filled teeth (dmft/DMFT) index	0.63 (0.40, 1.13)	NR	2, 3
4	Nava, et al. (2010) [15]	Mexico	4-5 Years	Both	1,160 children	Cross-sectional based on a cohort	~4	At-risk overweight, Overweigh	Measured weight and height	Overweight vs. non-overweight At risk of overweight vs. No at risk	Caries	Diagnosis of dental caries was established according to the World Health Organization (WHO) guidelines by three calibrated dentists	At-risk overweight: 1.94 (1.30-2.89) Overweigh: 1.95 (1.42-2.64)	4	4,5,6,7
5	Boustedt. et al. (2020) [32]	Sweden	0-6.5	Both	208 children	Cohort	~6.5	LGA, SGA	Medical records	LGA and SGA Vs. AGA	Early childhood caries (ECC)	Dental examination was performed by experienced and calibrated examiners. Manifest caries was registered according to the WHO criteria	SGA: 2.3 (1.2, 4.5) LGA: 2.8 (1.2, 6.4)	NR	NR

Table 1 (continued)

N St	First Author (Year)	Country	Age range/ Mean age	Sex	Sample size	Study design	Follow-up (y)	Exposure	Exposure assessment method	Compared categories	Outcomes	Outcome assessment method	OR (95%CI)	Adjustment for diet related risk factor	Adjustments*
6	Pham, et al. (2019) [16]	Vietnam	10	Both	1,079 children	Cross-sectional	NR	Obesity	Measured weight and height	Obese Vs normal weight	Caries	The examination was performed by two dentists	Primary teeth: 2.77 (1.72–4.46) Permanent teeth: 1.74 (1.18–2.56)	8	2, 8 9,10
7	Honne, et al. (2012) [13]	India	13-15	Both	463 school children	Cross-sectional	NR	Overweight /obese	Measured weight and height	Overweight /obese vs. normal	Caries	Assessed according to the guidelines given by WHO	3.68 (1.79 - 7.56)	NR	NR
8	Costa, et al. (2013) [27]	Brazil	approximately 6 years of age	Both	363 families	Cross-sectional	NR	Overweight /obese	Measured weight and height	Overweight /obese vs. normal	Early childhood caries (ECC)	A trained dentist by a dental exam	1.32 (0.70–2.50)	NR	NR
9	Marshall et al. (2007) [14]	USA	4.5–6.9	Both	427 children	Cross-sectional	NR	Children 'at risk' of overweight	Measured weight and height	Risk of overweight vs. normal weight	Caries	By trained and calibrated dentist examiners	-3.02 (1.46, 6.25)	17	11, 12, 13, 14, 15, 17
10	Hong, et al. (2008) [12]	USA	2-6 Years	Both	1,507 children	Cross-sectional from cohort	NR	Overweight	Measured weight and height	Overweight vs. normal weight	Dental caries, ECC	Coronal caries was assessed by trained and calibrated dentists	Any decayed and/or filled tooth: 1.20 (0.67-1.03) Severe ECC: 1.08 (0.81-1.43)	16, 17	13, 16, 17
11	Karki, et al. (2019) [33]	Nepal	5 to 6, 12 and 15 years old	Both	1135 schoolchildren	Cross-sectiona	NR	High BMI	Measured weight and height	High vs. low BMI	Caries	Dental examiners	High: 1.30 (0.96-1.77) Low: 1.07 (0.89-1.30) Normal: 1 (1)	17, 18	1, 2 17, 18, 19
12	Kay et al. (2010) [28]	UK	5 years	Both	985	Cohort study	~5	BMI	Measured weight and height	Continues	Caries	Trained Examiner	0.94 (0.81- 1.09)	NR	1, 9, ,10, 11
13	Paisi, et al. (2018) [34]	UK	4-6 years	Both	347 children	Cross-sectional study	NR	BM, WC	Measured weight and height	Continues	Caries	Examiner	BMI: 1.02 (0.95-1.10) WC: 1.02 (0.95, 1.10)	NR	NR
14	Peng, et al. (2014) [29]	China	5-year-old	Both	324 children	Cross-sectional study	NR	BM, WC	Measured weight and height	Continues	Caries	Examiner	BMI: 1.26 (0.94-1.70) WC: 1.26 (0.94-1.68)	NR	2, 19, 20, 21
15	Schüler, et al. (2018) [35]	Germany	3-4 years	Both	128 infants	Prospective Case-Control	NR	LBW, VLBW, ELBW	Records	Continues	Caries	Dentist System	LBW: 1.5 (0.5 – 4.7) VLBW: 1.0 (0.1 – 9.4) ELBW: 3.1 (0.7 – 14.3)	NR	NR
16	Aung, et al. (2021) [36]	New Zealand	5 years	Both	27333 children	Cross-sectional study	NR	BMI	Record	Obese vs. normal/underweight	Early childhood caries (ECC)	Dental therapists	BMI: 1.88 (1.73, 2.03)	NR	2, 3

Table 1 (continued)

N St	First Author (Year)	Country	Age range/ Mean age	Sex	Sample size	Study design	Follow-up (y)	Exposure	Exposure assessment method	Compared categories	Outcomes	Outcome assessment method	OR (95%CI)	Adjustment for diet related risk factor	Adjustments*
17	Feldens, et al. (2021) [37]	Brazil	3-6 years	Both	259 children	Cohort study	~6	BMI	NR	z-scores (≤ 1 SD vs > 1 SD)	Caries	Calibrated dental examinations	BMI: 1.05 (0.34, 3.23)	4, 8	1, 4, 8, 13, 14
18	Marro et al. (2021) [38]	Belgium	11-18 years	Both	162 adolescents	Case–control	~1	BMI	Record	Obese vs normal	Caries	Dental examinations	BMI: 0.83 (0.04, 1.63)	NR	1, 2, 3
19	Methuen, et al. (2021) [39]	Finland	6-8 years	Both	202 children	Cohort study	~8	BMI	Measured weight and height	Highest vs Lowest	Caries	Dental examinations	BMI: 1.25 (0.45, 3.46)	4	2, 3, 4
20	Mohamed, et al. (2022) [40]	Saudi Arabia	4.3±1.1 years	Both	1250 children	Cross-sectional study	NR	BMI	Measured weight and height	Overweight /obese vs. normal	Early childhood caries (ECC)	Dental examinations	BMI: 2.59 (1.88, 3.57)	4, 18	2, 3, 4, 11, 18, 21, 22
21	Piovesan, et al. (2022) [41]	USA	2-5 years	Both	2275 children	Cohort study	~8	BMI	Record	Obese vs. normal	Caries	Clinical examinations	BMI: 1.13 (0.73, 1.75)	16	1, 2, 3, 4, 16, 23
22	Yen, et al. (2021) [42]	Tiwan	6-12 years	Both	569 children	Cross-sectional study	NR	BMI	Measured weight and height	Obese vs. normal/underweight	Dental caries	Dental examinations	BMI: 0.81 (0.63, 1.05)	NR	1, 2, 20, 24

Adjustments: 1:age, 2: sex, 3: socio–economic status, 4: sugar consumption antecedents, 5: smoking in the home, 6: bottle-feeding, 7: oral hygiene practices, 8: daily intake of sugar-sweetened drinks 9: Gestation, 10: Breastfeeding, 11: Frequency of tooth brushing, 12: age at 61-month clinic, 13: Maternal education, 14:age housing, 15: age at exam, 16: energy intake, 17: relative sugar intake, 18: maternal prepreg Nancy BMI, 19: tooth brushing habit (less than once a day, at less once a day). 20: parents' education attainment (primary school graduate or below, secondary school, post-secondary or above), 21: household monthly income, 21: bottle feeding at night with sugared drinks, 22: oral hygiene practices, 23: race/ethnicity, 24: Number of primary teeth

BMI Body mass index, *ECC* early childhood caries, *LGA* large for gestational age, weight and/or length, *SGA* small for gestational age, weight and/or length, *AGA* appropriate for gestational age, *LBW* low birth weight, *VLBW* very low birth weight, *ELBW* extra low birth, *NR*: Not reported

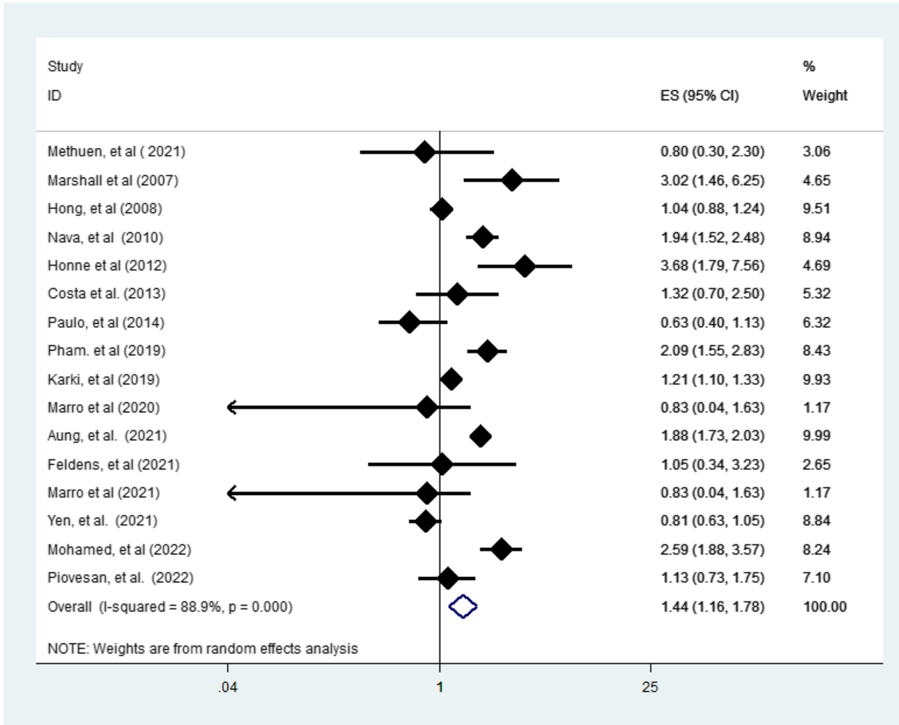

Fig. 2 Forest plot for the association between BMI (categorical) and risk of childhood dental caries. Diamonds represent pooled estimates from random-effects analysis. Horizontal lines represent 95% CIs

Table 2 Subgroup analysis for the association of BMI and risk of childhood dental caries

Variables	Subgroups	Number of effect sizes	OR*	95% CI	I^2 (%)
Study location	Asian-countries	6	1.70	1.25, 2.32	94.6
	European-countries	3	0.81	0.36, 1.81	0.0
	America-countries	7	1.28	0.91, 1.81	79.6
Country population	Big country	9	1.56	1.09, 2.21	85.2
	Small country	7	1.31	0.95, 1.81	92.4
Participants' age	Aged <7 years	9	1.59	1.22, 2.07	85.3
	Aged between 7 and 15 years	7	1.25	0.87, 1.81	84.1
Adjustment for sex	Yes	10	1.30	0.99, 1.71	91.2
	No	6	1.74	1.13, 2.68	83.1
Adjustment for age	Yes	6	1.04	0.84, 1.30	41.9
	No	10	1.68	1.29, 2.18	87.2
Study design	Cross-sectional	9	1.58	1.20, 2.08	92.6
	Case control	4	1.31	0.77, 2.22	82.4
	Cohort	3	1.27	1.07, 1.56	0.0
Study sample size	Less than 900	8	1.25	0.77, 2.02	75.1
	More than 900	8	1.59	1.25, 2.02	92.1

* Obtained from Fixed-effect model

cross-sectional design (OR: 1.58; 95% CI: 1.20, 2.08) and among studies done in participants' age less than 7 years (OR: 1.59; 95% CI: 1.22, 2.07) (Table 2). Pooling data for the risk of dental caries in studies that entered BMI as a continuous variable in their analyses showed no significant association between increasing BMI and risk of dental caries in children (OR: 1.01; 95% CI: 0.99 to 1.03, I^2= 3.5%.) (Fig. 3). Due to the limited number of included studies, we were unable to do subgroup analyses.

Furthermore, we found two studies about the association of waist circumference with risk of dental caries Combined analysis of these two studies showed no significant association between WC and risk of dental caries in children (OR: 1.8 95% CI: 0.90 to 1.30, I^2= 47.7%) (Fig. 4).

In addition, our non-linear dose response analysis showed a significant non-linear association between body mass index and risk of dental caries (Fig. 5). Moreover, a significant linear association was found between each unit increment in BMI and risk of dental caries in children (Fig. 6).

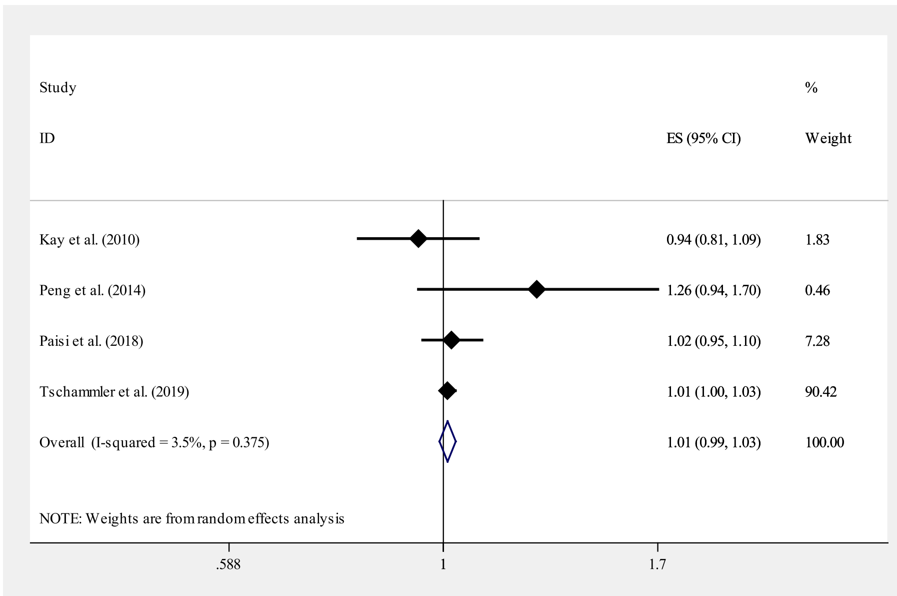

Fig. 3 Forest plot for the association between BMI (continuous) and risk of childhood dental caries. Diamonds represent pooled estimates from random-effects analysis. Horizontal lines represent 95% CIs

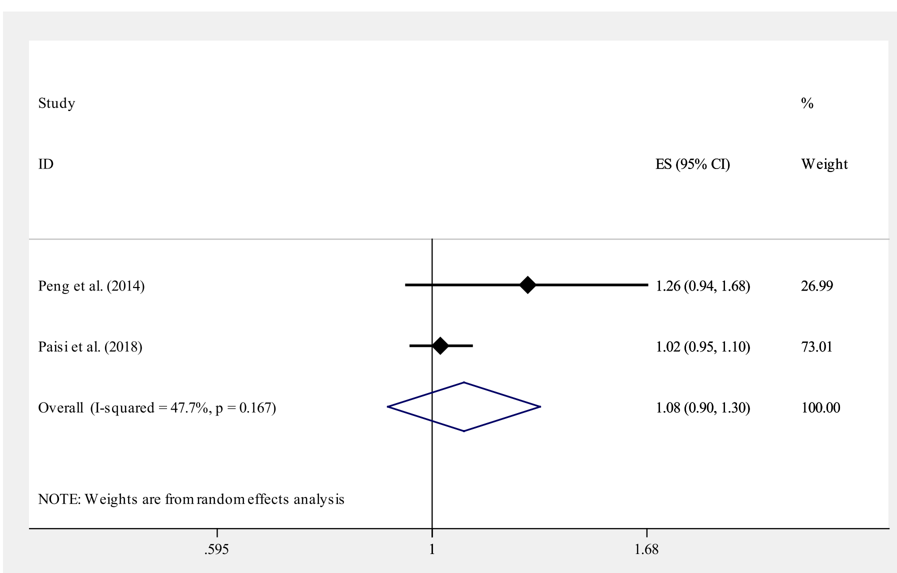

Fig. 4 Forest plot for the association of waist circumference with risk of childhood dental caries. Diamonds represent pooled estimates from random-effects analysis. Horizontal lines represent 95% CIs

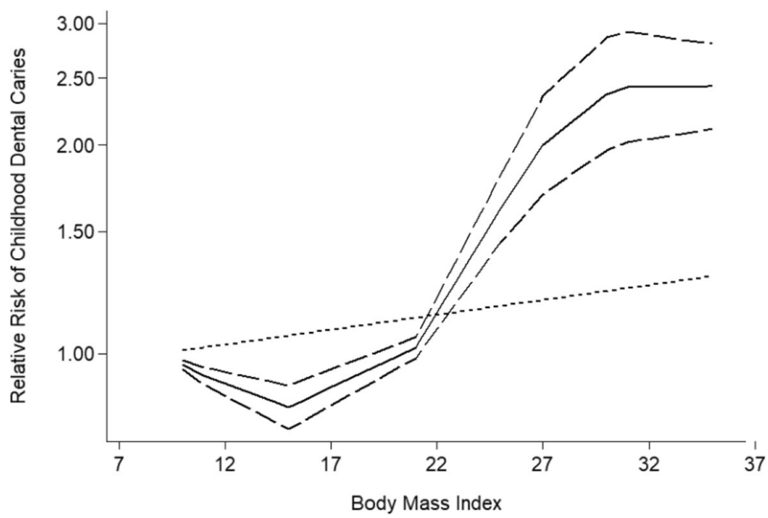

Fig. 5 The non-linear association meta-analysis between BMI and risk of childhood dental caries. BMI was modeled with restricted cubic splines in a multivariate random-effects dose-response model. The vertical axis is on a log scale. Horizontal lines represent 95% CIs

Publication bias was assessed through visual inspection of a funnel plot and Egger's test (significant at $p< 0.05$; Fig. 7). No evidence of publication bias was found for the relationship between BMI and the risk of early childhood caries ($p = 0.170$ with Egger's test).

Discussion

We found a significant direct association between BMI and risk of dental caries in children. In addition, a significant non-linear and linear associations were found between BMI and risk of ECC. To the best of our knowledge, this is among the first studies summarizing earlier

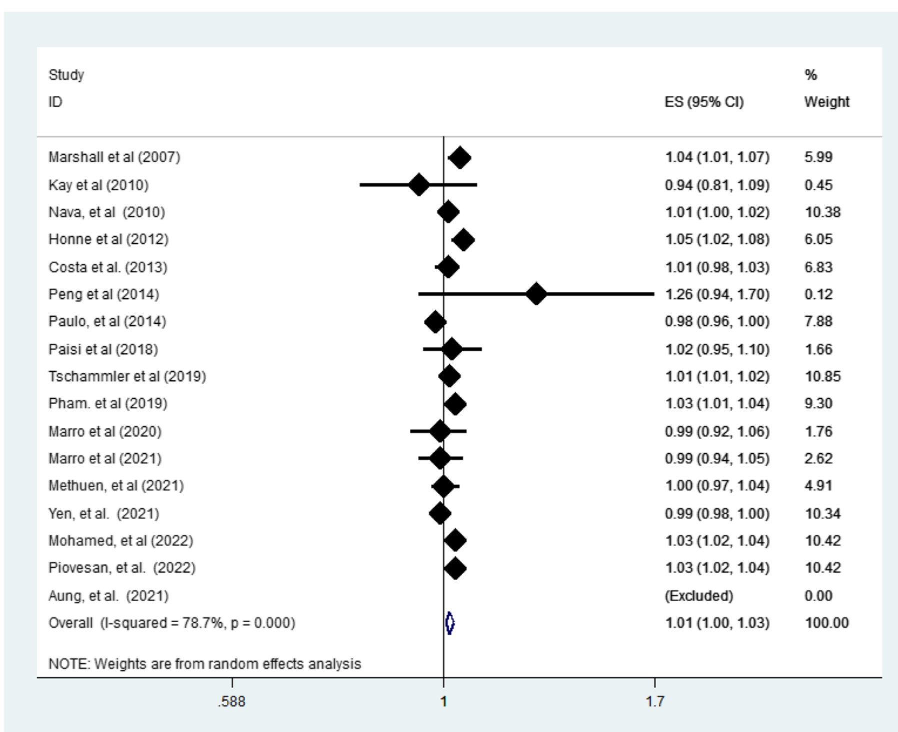

Fig. 6 Forest plot for the linear association between each unit increment in BMI and risk of childhood dental caries

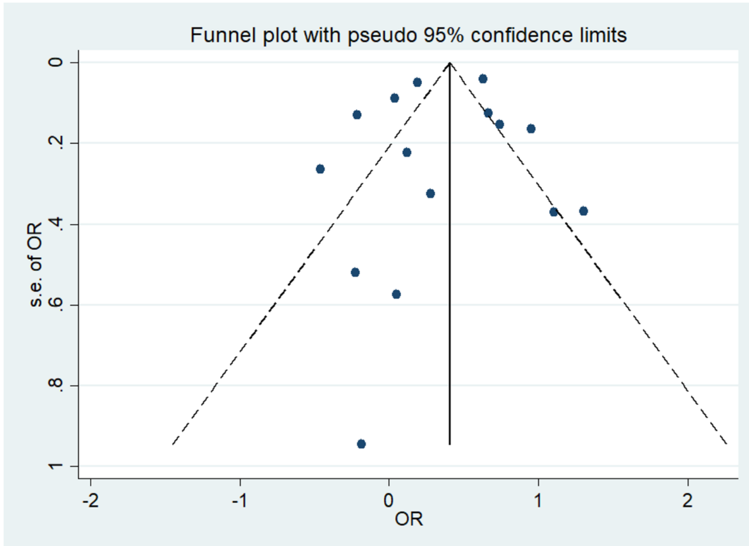

Fig. 7 Funnel plot for the association between BMI and the risk of ECC

publications about the association of obesity with risk of dental caries in children.

Childhood obesity is a growing problem around the world [45]. Obesity is associated with many acute health problems and difficulties during childhood [46]. In addition, childhood obesity might also leads to adult obesity and its associated comorbidities [47]. The prevalence of dental caries is increasing among children all over the world [48], affecting their normal growth and health [49]. Findings from a prospective cohort study in Sweden showed that obese children at age 6 year had higher prevalence of dental caries compared to those with normal weight [50]. In another cohort study conducted in UK, higher BMI was associated with slightly higher chance of dental caries, but this association was not as statistically significant [28]. Moreover, several systematic reviews have been done on this topic, but their findings are controversial [11, 18, 21].

In the current study, we found a significant association between BMI and risk of childhood dental caries. In line with our findings Hayden et al. found a significant relationship between childhood obesity and dental caries [51]. In a recent meta-analysis of observational studies, children with high BMI scores were more likely to experience dental caries comparing to children with normal weight [29]. However, another meta-analysis published in this field showed no significant differences in risk of both primary and permanent dental caries between children in different BMI categories [20]. It should be noted that findings of that study might be misleading because of including only cross-sectional and low-to-middle quality studies, different criteria for BMI classification, different indices and definitions of dental caries. They also included only studies from developing countries, which might affect their findings.

Our meta-analysis also showed a linear and non-linear association between BMI and risk of childhood dental caries. Our non-linear association showed higher risk of dental caries in children with higher BMI and also among underweight children. Looking the plot, it seems that changes in risk of dental caries is more pronounced in children with BMIs lower or higher than 15. With regards to those at BMI higher than 30, we had only one study and more investigations are needed. Furthermore, we found only two studies about the association of WC and risk of childhood dental caries[34, 52]. Although the association was not significant, limited number of included studies make it difficult to discuss.

There are common risk factors linking overweight or obesity to dental carries. For example, children consumed high calorie diets rich in sugar sweetened beverages (SSB) and high calorie dense snacks are vulnerable to overweight and obesity [53]. High-calorie diet can also be associated with dental carries due to high content of fermentable sugars [18, 54, 55]. In addition, socioeconomic factors might also play a role in the association of obesity with risk of childhood dental caries [20, 51]. Reduced physical activity by increases in body weight increases snacks consumption and also time spent for watching TV [18]. Furthermore, obesity is an inflammatory state characterized by increasing cytokine production, which can in turn, leads to dental caries (57). In fact, previous studies have shown that increased inflammation in the body will result to destructive attacks to dental enamel, such that earlier studies suggested significant links between production of tumor necrosis factor (TNF-a), interleukin-6 (IL-6), and interleukin-8 (IL-8) in saliva and risk of dental caries (58).

To the best if our knowledge, current study is a comprehensive updated meta-analysis on the association of obesity with risk of childhood dental caries; moreover, it is the first dose-response analysis in this area. Along with these strengths, the study also has some limitations. High-between study heterogeneity is a common concern in these meta-analyses. We tried to find probable sources of between-study heterogeneity by doing subgroup analyses. Assessment of obesity by different methods, applying different indices and definitions for diagnosis of dental caries and inconsistent adjustment for potential confounders were the major concerns. In addition, lack of studies in which obesity was assessed by updated and accurate methods, rather than BMI, is another limitation of the current meta-analysis. There are diet-related factors such as energy intake, macronutrients, and micronutrients that that most of the studies included in our study did not adjust for these factors.

In conclusion, in this systematic review and meta-analysis we found a significant direct association between BMI with risk of childhood dental caries. In addition, significant non-linear and linear associations were found between BMI and risk of ECC. Notably, the reviewed articles were of high quality, which strengthens the reliability of these findings. However, it is important to consider the potential risk of bias present in some studies. To further clarify these associations, additional longitudinal studies employing diverse obesity assessment tools are necessary.

Supplementary Information

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Supplementary Material 1
Supplementary Material 2
Supplementary Material 3

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Authors' contributions
Mohammad Reza Bakhoda (M.B), Mohammad mehdi Haghighat-Lari (M.M.H) and Alireza Milajedi (A.M) designed the study. Fatemeh Abbasi (F.A), Mohammad Reza Bakhoda (M.B) and Mohammad mehdi Haghighat-Lari (M.M.H) collected data. Fatemeh Abbasi (F.A) and Alireza Milajedi (A.M) analyzed data. Zeinab Khademi (Z.K) and Alireza Milajedi (A.M) wrote the manuscript. All authors read and approved the final manuscript. In addition, Mohammad mehdi Haghighat-Lari (M.M.H), Gholamreza Khosravi (G.K) and Alireza Milajedi (A.M) revised the manuscript.

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Availability of data and materials
The datasets used and analysed during the current study available from the corresponding author on reasonable request

Declarations

Ethics approval and consent to participate
This section is not applicable because this study is a systematic review and Meta-analysis.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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