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Ultra-processed food consumption and dental caries in children and adolescents: a systematic review and meta-analysis

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Abstract

This study summarised the association between ultra-processed food (UPF) consumption and dental caries in children and adolescents through a systematic review and meta-analysis. The search of PubMed, Cochrane, Web of Science and Scopus databases using the 'PECOS' strategy retrieved 1462 eligible articles. Only studies with humans aged ≤ 19 years; that assessed groups of any UPF or specific UPF items; that measured dental caries as the decayed, filled and missing surfaces or teeth indexes, based on the WHO criteria; cross-sectional, case–control, cohort and all types of interventions that examined the adjusted association between UPF consumption and dental caries were included. All studies received qualitative evaluation. Meta-analysis using random-effects models combined multivariable-adjusted OR for case–control and cross-sectional studies and risk ratio (RR) for longitudinal studies of the highest *v.* lowest category of UPF consumption. Forty-two studies were included in the qualitative synthesis and twenty-seven in the meta-analysis. The pooled RR was 1·71 (95 % CI 1·31, 2·24), and the pooled OR was 1·55 (95 % CI 1·37, 1·75). The highest OR was found among participants who had dental caries prevalence >70 % (OR = 3·67, 95 % CI 2·16, 6·23). Better evidence quality was found among cohort studies that evaluated children <6 years old. The findings suggest that higher UPF consumption is associated with greater dental caries in children and adolescents. Public health efforts to reduce UPF consumption are needed to improve the oral health of children and adolescents.

Keywords: Ultra-processed foods: Dental caries: Child: Adolescent

Growing evidence has shown that frequent consumption of ultra-processed food (UPF) is extremely harmful to health[1], contributing to increasing the risk of several diet-related chronic diseases[2–5]. The vast majority of UPF contain sugars in their composition. The causal relationship between sugars and dental caries is well established in the literature[6]. Regardless of oral hygiene and frequent contact with fluorides, a diet rich in sugars can cause caries in children and adults[7]. Although sucrose is the most studied sugar in this relation, researchers discuss other fermentable carbohydrates (e.g. processed starches) with high retention on the teeth and usually added in UPF can play an important role[8–11].

More than 2 billion people are affected by untreated dental caries in permanent teeth worldwide[12]. This is the most prevalent chronic disease in the world[13]. The negative impact of oral diseases on the quality of life of individuals and the high cost related to the treatment of their consequences have been highlighted in the literature[14,15]. In addition, a significant association between dental caries and obesity has been reported in a systematic review[16]. The most likely hypothesis is that there is a combination of common risk factors[17], among which UPF consumption may be the confounding factor not always included in research analysing dental caries and obesity[16].

Considering changes in population dietary patterns and given the high prevalence of dental caries among children and adolescents and its impact on quality of life, understanding the role of UPF is key to planning appropriate health interventions aiming to improve health. It is also crucial to provide consistent

Abbreviations: UPF, ultra-processed food.

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recommendations to the population, translating meaningful information into public health practice. Childhood and adolescence are critical periods for exposure to dietary behaviours that could lead to health problems in the future[18], therefore investigations in these periods of life should be a priority. To date, evidence on the relationship between UPF and dental caries in childhood and adolescence has not been critically summarised in an extensive systematic review and meta-analysis. To examine the association of UPF consumption with dental caries, we conducted a systematic review and meta-analysis of studies that evaluated this association in children and adolescents ≤ 19 years of age.

Methods

The study protocol was registered under PROSPERO (https://www.crd.york.ac.uk as CRD42020167269) and followed the PRISMA Statement checklist to report systematic reviews and meta-analyses[19].

Search strategy

Four electronic bibliographic databases (PubMed, Cochrane, Web of Science and Scopus) were screened. Only original papers published in English, Portuguese and Spanish were selected. No limits were applied to the publication date, and all studies needed to be conducted on humans. The last search was run on 18 October 2021.

The search used the 'PECOS' strategy including related terms with population (children and adolescents), exposure (e.g. UPF groups or specific UPF and related terms with higher consumption), comparison (e.g. higher consumption *v.* lower or no consumption of groups of UPF or only UPF), outcome (dental caries) and type of study (cross-sectional, case–control, cohort, all types of interventions). The search terms were adapted for use in the databases, in combination with MeSH or other similar terms. The complete search strategy for each database is described in online Supplementary Appendix 1.

Eligibility criteria

Only studies that met the following eligible criteria were included: (a) with humans aged ≤ 19 years; (b) assessed as exposure the consumption of any UPF groups (e.g. snacks, fast foods, junk foods and convenience foods) or specific UPF (e.g. sugar-sweetened beverages, sugary cereals, chocolate, sausages, hamburgers and instant noodles), having the concept of UPF as defined by the NOVA Food Classification System[20]: '*industrial formulations made entirely or mostly from substances extracted from foods (oils, fats, sugar, starch, and proteins), derived from food constituents (hydrogenated fats and modified starch), or synthesized in laboratories from food substrates or other organic sources (flavor enhancers, colors, and several food additives used to make the product hyper-palatable)*'; (c) studies that defined dental caries as the main outcome assessed through the decayed, filled and missing surfaces or teeth index (dmfs/dmft or DMFS/DMFT indexes) based on the WHO criteria[21]; (d) cross-sectional, case–control, cohort and all types of interventions that examined the association between UPF consumption and dental caries; and (e) with adjusted analyses for confounders in the association between UPF and dental caries (e.g. socio-economic, demographics, dental health services use and oral hygiene). Essential confounders were the main three factors related to caries aetiology and food consumption: socio-economic status/family variables (e.g. income and education) and individual variables (e.g. brushing teeth and dental visit).

Review articles, protocols/guidelines, letters, editorials comments, qualitative studies, case reports, studies with sample size < 30 and that have been carried out in participants with special health conditions were excluded.

Studies selection and data extraction

The search results were imported into bibliographic citation management software (EndNote X8, Clarivate Analytics) to exclude duplicates and assist with study selection. Two independent reviewers (NRJS and MSF) selected the studies by reading the tittles and abstracts. After this stage, the same two reviewers read the articles in full and selected them by consensus, discussing them according to eligibility criteria. In all stages, disagreements were solved by a third reviewer (AMC).

For this study, a data extraction sheet was adapted based on the Cochrane Consumers and Communication Review Group data extraction template. Two reviewer authors (NRJS and MSF) extracted the following data from included studies: (a) country of publication, (b) year of publication, (c) study design, (d) sample size, (e) age group studied, (f) type and measurements of UPF analysed, (g) outcome measurements, (h) covariates, (i) adjusted confounders and (j) main results/effect measurements. A third reviewer (AMC) double checked all the extracted data.

Risk of bias assessment

The individual study risk of bias assessment was conducted by two reviewers (NRJS and MSF) using the Joanna Briggs Institute Critical Appraisal Checklist for Cohort (11-items) and Analytical Cross-sectional (8-items) studies[22]. Both checklists should be answered by the reviewers with 'yes', 'no', 'unclear' or 'not applicable'. An adaptation was made for one non-randomised trial using the checklist for cohort studies, and for one case–control using the checklist for cross-sectional studies. Disagreements were resolved by consensus or by a third investigator (AMC). Furthermore, for each study the total number of 'yes' was considered in the checklist elements, and the study was classified as 'low' risk of bias when the study reached 70 % or more 'yes', 'moderate' if the proportion of answering 'yes' was between 50 and 69 % and 'high' risk of bias if the proportion of answering 'yes' was up to 49 %.

Data analysis

All included studies were assessed in the qualitative synthesis. Studies with missing data, including those where frequencies could not be extracted or those in which

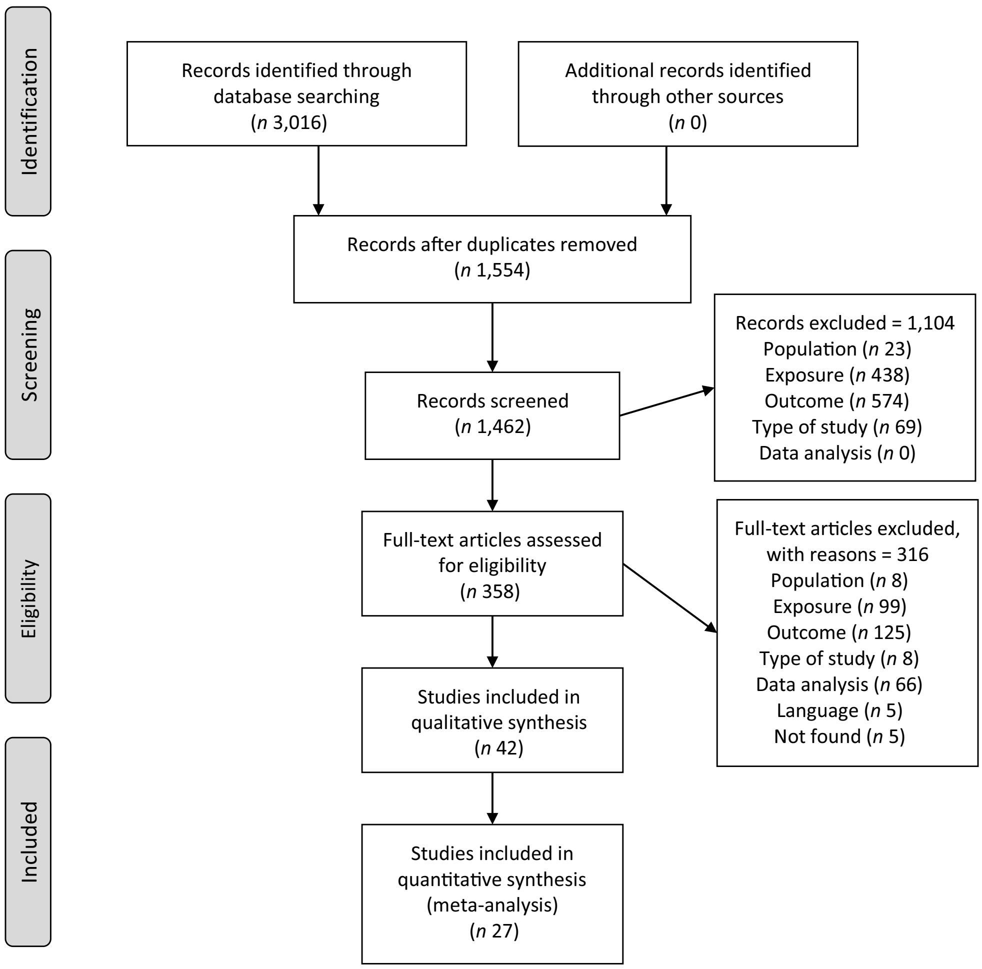

Fig. 1. Preferred reporting items for systematic reviews and meta-analysis flow diagram for search strategy[19].

outcomes were not comparable, were excluded from the meta-analysis. Meta-analysis was performed using Review Manager (RevMan; version 5.4 for Windows) if two or more studies were available. The pooled effects were reported as risk ratio for longitudinal studies and as OR for case–control and cross-sectional studies and presented with 95 % CI. A random-effects model (DerSimonian and Laird method) was applied to combine multivariable-adjusted OR or risk ratio of the highest *v.* the lowest category of any UPF consumption, regardless of the criteria used to measure and classify UPF in the studies. The meta-analysis outcome was defined as increase in dmfs/dmft or DMFS/DMFT indexes in longitudinal studies, and dmfs/dmft or DMFS/DMFT indexes ≥ 1 in case–control and cross-sectional studies. The statistical heterogeneity between studies was estimated using the χ^2 Cochran's Q-test with the I^2 statistic, which provides an estimate of the amount of variance between studies due to heterogeneity rather than sampling error[23]. A subgroup and sensitivity analysis was performed to explore the source of the heterogeneity when I^2 exceeded 50 %[24], based on the characteristics of the extracted studies. If ten or more studies were available, the presence of publication bias was explored using funnel plots[25].

Results

Study selection and characteristics

The searches resulted in 3016 potential articles (PubMed (*n* 1053); Cochrane (*n* 163); Web of Science (*n* 450); Scopus (*n* 1350)), of which 1554 were duplicates. Of 1462 eligible articles, 358 were selected for full-text reading (Fig. 1). The main reason for excluding studies was the outcome, not measured as dmft/dmfs or DMFT/DMFS indexes or based on WHO criteria. Finally, forty-two studies[26–67] were included in the qualitative synthesis (eight cohort, one non-randomised controlled, one case–control and thirty-two cross-sectional studies) and twenty-seven in the meta-analysis (seven cohort, one non-randomised controlled, one case–control and eighteen cross-sectional studies). Among the fifteen studies[27,32,33,36,38,42,43,47,50,51,55,56,58,64,66] excluded from the meta-analysis, all had a cross-sectional design, with one exception[47].

Table 1 presents the main characteristics of forty-two selected studies, in general and according to the type of study and the data analysis (included or not in the meta-analysis). Overall, most studies were conducted in low-middle income countries[26–28,32–37,41–46,49,51,52,54–57,59,60,62–64,66,67] and published from 2010 to present[26–29,32,33,35–37,39–42,44–52,54–59,62–64], as in all

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Table 1. Description of selected studies (*n* 42) (Numbers)

	Studies included in the qualitative synthesis and meta-analysis			
	Longitudinal (*n* 8)	Cross-sectional and case–control (*n* 19)	Studies included in the qualitative synthesis only (*n* 15)	Overall (*n* 42)
Characteristics	*n*	*n*	*n*	*n*
Country				
Low-middle income	5	13	11	29
High income	3	6	4	13
Year of publication				
Before 2010	3	5	3	11
2010 to present	5	14	12	31
Sample size				
<500	2	6	7	15
501–1500	6	8	7	21
>1500	–	5	1	6
Age group of participants				
< 6 years	5	6	6	17
6–19 years	3	13	9	25
School based				
Yes	1	15	12	28
No	7	4	3	14
Caries prevalence	%	%	%	%
< 40	–	4	1	5
40–70	7	11	13	26
> 70	1	4	1	6
Type of ultra-processed foods	*n*	*n*	*n*	*n*
Sugar-sweetened beverages (soft drinks and juices)	4	15	11	30
Chocolate milk/flavoured milk	–	4	3	7
Sweets/candies/chocolate/ice cream	5	9	9	23
Snacks/chips	3	10	3	16
Cookies/cakes/biscuits/crackers/pastries/cereals	2	4	5	11
Other†	1	3	1	5
Positive association				
Yes	7	16	11	34
No	1	3	4	8
Main confounders‡				
Yes	4	7	3	14
No	4	12	12	28
Risk of bias assessment				
Moderate or high	4	12	11	27
Low	4	7	4	15

† E.g., processed meats, instant noodles, fast foods.
‡ The main three factors: socio-economic status/family variables (e.g. income and education) and individual variables (e.g. brushing teeth and dental visit).

categories of data analysis. Half of the studies had a sample population ranging from 501 to 1500 participants[26–28,30,31,34,41–43,45,49,53,54,56–59,61,62,64,66], and in all categories of data analysis, this sample size was the most frequent observed. Most longitudinal studies included in the meta-analysis investigated children aged < 6 years[28,30,40,53,57,59,60], while children 6–19 years of age were more commonly investigated in case–control and cross-sectional studies[26,29,31,34,35,37,39,41,44–46,48,49,52,61–63,65,67] included in the meta-analysis and those included only in qualitative synthesis[27,33,36,38,42,47,50,56,66]. A total of twenty-eight studies were carried out with participants in schools[26–29,31–34,36–38,41–46,49,51,55,56,58,61–65,67], and only one was longitudinal[28]. A prevalence of dental caries > 70 % was found in six studies in general[26,46,51,52,57,67], four of them were cross-sectional studies included in the meta-analysis[26,46,52,67]. Sugar-sweetened beverages (soft drinks and juices) were the UPF most frequently assessed, overall[26–29,33,35,39–45,47–52,54–58,61–63,65–67] and in all categories of data analysis. Other non-sweet UPF, such as instant noodles and fast foods, were investigated only in five studies[26,30,35,61,64], three of them were cross-sectional included in the meta-analysis[26,35,61].

A detailed description of the forty-two selected studies can be found in online Supplementary Appendix 2.

Risk of bias in the studies

The risk of bias assessment identified that twenty-seven studies[27–31,34,36,38–43,45–48,50–53,56,61,62,64–66] had moderate to high risk (Table 1).

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Author (Year)	*Joanne Briggs Institute (JBI)*											*Risk of Bias*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	
Arheiam et al. (2019)	-	+	-	-	-	+	+	+	+	?	+	Moderate
Campain et al. (2003)	+	+	-	-	-	+	?	+	-	?	+	High
Ghazal et al. (2015)	+	+	-	-	-	+	+	+	+	NA	+	Moderate
Jamieson et al. (2013)	+	+	-	-	-	+	?	+	-	-	+	High
Matilla et al. (2001)	+	+	-	-	-	+	+	+	+	NA	-	Moderate
Mei et al. (2021)	+	+	-	+	+	+	+	+	+	+	-	Low
Nirusittirat et al. (2016)	+	+	-	+	+	+	+	+	-	-	+	Low
Peltzer et al. (2014)	+	+	-	+	+	+	?	+	+	NA	+	Low
Peres et al. (2005)	+	+	-	+	+	+	+	+	+	+	+	Low

JBI - Critical appraisal checklist for analytical cohort studies

(1) Were the two groups similar and recruited from the same population?
(2) Were the exposures measured similarly to assign people to both exposed and unexposed groups?
(3) Was the exposure measured in a valid and reliable way?
(4) Were confounding factors identified?
(5) Were strategies to deal with confounding factors stated?
(6) Were the groups/participants free of the outcome at the start of the study (or at the moment of exposure)?
(7) Were the outcomes measured in a valid and reliable way?
(8) Was the follow up time reported and sufficient to be long enough for outcomes to occur?
(9) Was follow up complete, and if not, were the reasons to loss to follow up described and explored?
(10) Were strategies to address incomplete follow up utilized?
(11) Was appropriate statistical analysis used?

Fig. 2. Risk bias assessment of eight cohort studies and one non-randomised trial included in the qualitative synthesis. +, Yes; -, No; ?, Unclear; NA, Not applicable.

Fig. 2 shows the risk bias assessment for longitudinal studies. From a total of eight cohort studies, four[54,57,59,60] were classified as having low risk of bias, all including preschool children. The single non-randomised trial[28] received a moderate or high risk of bias classification. No longitudinal study had measured UPF in a valid and reliable way (e.g. measured using validated FFQ) and five[28,30,40,47,53] did not evaluate the main confounders between the association of UPF and dental caries.

Fig. 3 presents the risk bias assessment for cross-sectional and case–control studies. In relation to the thirty-two cross-sectional studies[26,27,29,31–38,41–46,48–52,55,56,58,61–67], only nine[26,32,33,35,37,44,49,55,58,63,67] were classified as having low risk of bias. The main methodological problems were the evaluation of the UPF without valid and reliable measures[26,29,31,34,36,37,41,44,46,56,58,62,64–67], and without considering the main confounders or established appropriate strategies to deal with them[27,29,31,33,36,38,41–43,45,48,50–52,55,56,61–63,65,66].

Ultra-processed food consumption and dental caries

Fifteen studies[27,32,33,36,38,42,43,47,50,51,55,56,58,64,66] did not report final effect measures, had incomplete information on frequencies or did not have comparable outcomes and were excluded from the meta-analysis.

Fig. 4 shows a pooled risk ratio of UPF consumption and dental caries of 1·71 (95 % CI 1·31, 2·24; I^2 = 69 %; P = 0·002; total sample size = 5068) in seven cohort studies and one non-randomised trial. No subgroup differences were detected for longitudinal studies (online Supplementary Appendix 3). Lower heterogeneity (< 50 %) was found among studies conducted in low-middle income countries[28,54,57,59,60] and with a low risk of bias assessment[54,57,59,60] (online Supplementary Appendix 3). The sensitivity analysis did not change most of the results. When Campain *et al.*[30] and Mattila *et al.*[53] are removed, heterogeneity drops to < 50 % among studies with sample size of 500–1500 participants (online Supplementary Appendix 3).

Fig. 5 shows that the pooled OR of UPF consumption and dental caries was 1·55 (95 % CI 1·37, 1·75; I^2 = 91 %; P < 0·001; total sample size = 35 427) in one case–control[39] and eighteen cross-sectional studies[26,27,29,31–38,41–46,48–52,55,56,58,61–67]. According to subgroup analysis, higher effects of UPF in dental caries were found in children and adolescents 6–19 years of age[26,29,31,34,39,44,45,49,52,61,62,65,67], sample size with < 500[29,35,39,46,48,52] and 500–1500 participants[26,31,34,41,45,49,61,62], moderate or high risk of bias assessment[29,31,34,39,41,44,46,48,61,62,65] and in those where prevalence of dental caries was > 70 %[26,46,52,67] (online Supplementary Appendix 3). Lower heterogeneity (< 50 %) was found among

Author (Year)	*Joanne Briggs Institute (JBI)*								*Risk of Bias*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	
Alhabdan et al. (2018)	+	?	-	+	+	+	+	+	Low
Almasi et al. (2016)	+	+	+	+	-	-	?	+	Moderate
Arora et al. (2017)	+	?	-	+	-	-	+	+	Moderate
Campus et al. (2008)	-	+	-	+	-	-	+	+	Moderate
Chen et al. (2017)	?	+	+	+	+	+	+	+	Low
David et al. (2005)	?	+	-	+	-	-	+	+	Moderate
Gao et al. (2014)	?	+	-	+	-	-	+	?	High
Gao et al. (2018)	+	?	-	+	+	+	+	+	Low
Garcia-Closas et al. (1997)	+	?	+	+	-	-	+	+	Moderate
Garcia-Pola et al. (2021)	+	+	-	+	-	-	?	+	Moderate
Han et al. (2014)	?	+	-	+	-	-	?	+	High
Hasheminejad et al. (2002)	+	?	+	+	-	-	+	+	Moderate
Hashim et al. (2009)	+	+	+	+	-	-	?	+	Moderate
Hu et al. (2018)	+	?	-	+	+	+	+	+	Low
Huew et al. (2012)	+	?	+	+	-	-	+	+	Moderate
Jain et al. (2018)	+	?	-	+	+	+	+	?	Moderate
Kierce et al. (2016)	+	?	+	+	-	-	?	+	Moderate
Kumar et al. (2016)	-	?	+	+	+	+	+	+	Low
Laniado et al. (2020)	+	+	+	+	-	-	+	+	Moderate
Lin et al. (2016)	?	+	+	+	-	-	+	+	Moderate
Markovic et al. (2014)	?	?	+	+	-	-	?	+	High
Morikava et al. (2018)	+	+	+	+	-	-	+	+	Low
Myint et al. (2019)	+	?	-	+	-	-	+	+	Moderate
Olczak-Kowalczyk et al. (2021)	+	+	-	+	+	+	?	+	Low
Serra Majem et al. (1993)	?	?	+	+	-	-	?	+	High
Silveira et al. (2018)	+	+	+	+	-	-	+	+	Low
Simangwa et al. (2019)	+	+	-	+	-	-	+	+	Moderate
Souza et al. (2021)	+	+	+	+	+	+	+	+	Low
Su et al. (2018)	+	+	+	+	-	-	+	+	Low
Tsang et al. (2019)	?	?	-	+	+	?	?	?	High
Vanobbergen et al. (2001)	+	?	-	+	-	-	+	+	Moderate
Varenne et al. (2006)	?	+	-	+	-	-	?	?	High
Villalobos-Rodelo et al. (2007)	+	+	-	+	+	+	+	+	Low

JBI - Critical appraisal checklist for analytical cross -sectional studies
(1) Were the criteria for inclusion in the sample clearly defined?
(2) Were the study subjects and the setting described in detail?
(3) Was the exposure measured in a valid and reliable way?
(4) Were objective, standard criteria used for measurement of the condition?
(5) Were confounding factors identified?
(6) Were strategies to deal with confounding factors stated?
(7) Were the outcomes measured in a valid and reliable way?
(8) Was appropriate statistical analysis used?

Fig. 3. Risk bias assessment of thirty-two cross-sectional studies and one case–control included in the qualitative synthesis. +, Yes; -, No; ?, Unclear; NA, Not applicable.

studies where dental caries prevalence was > 70 % (online Supplementary Appendix 3). In the sensitivity analysis, the heterogeneity among studies published before 2010 drops to 12 % when Campus *et al.*[31] is removed, and to 41 % when Kierce *et al.*[48] is removed among studies published with sample size of < 500.

The publication bias evaluation of cross-sectional and case–control studies shows that studies with low precision that have negative or non-significant results are missing from the funnel plot, as they may not have been published (online Supplementary Appendix 3).

Discussion

Overall, in longitudinal studies, higher consumption of UPF was associated with a 71 % higher risk of having dental caries. Among case–control and cross-sectional studies, higher UPF consumption produced 55 % higher odds of presenting dental caries in childhood and adolescence. Among children and adolescents with dental caries prevalence > 70 %, the odds increased to 267 %. However, the overall quality of evidence is weak, as almost 70 % of the included studies had moderate or high risk of bias. Several studies did not use valid and reliable UPF consumption measures or consider relevant confounding factors between the association of UPF with dental caries. Better evidence quality was found among cohort studies assessing preschool children.

Our findings are, in general, consistent with a previous review showing that higher frequency consumption of processed sugar and starch-containing foods was associated with greater experience with dental caries in five prospective studies of children and adolescents[10]. However, our review included a much larger number of studies, an extensive meta-analysis with additional subgroup analyses. To date, the present systematic review and meta-analysis was the first to critically summarise the evidence for the association between UPF and oral health.

The NOVA is a system that classifies food products according to the degree of food processing and has been applied to classify quality of diet and risk to non-communicable disease[20]. From the five food processing classifications available, the NOVA system has been considered the most specific, coherent, clear, comprehensive and workable[68]. The way the four NOVA groups are defined makes it easy to understand the characteristics of UPF and to evaluate the health issues associated with their consumption[69]. In this systematic review, we used the definition of UPF as described in the NOVA Food Classification to select the studies assessing types of UPF, rather than including studies that used NOVA in the measurements. We found that very few[30,35,38,43] of the included studies have based their dietary assessment on food processing and only one[35] considered the NOVA system for food classification. Furthermore, the vast majority of studies evaluated UPF in terms of frequency of consumption, using a single question. They included few items or groups of UPF, usually sugary products, long-established known as cariogenic. The evidence for the effect of UPF viewed as 'non-sweet' on dental caries remains unclear. No summary evidence of consumption in grams or in total energy content provided by UPF exists. There is a lack of evidence provided by randomised controlled trials. The coherence, consistency and biological plausibility of all associations between UPF consumption and dental caries in our review support the need to design and implement innovative randomised controlled trials that focus on preventing dental caries through behavioural changes in diet, especially focusing on reducing UPF consumption.

Sugar-sweetened beverages; chocolate milk and flavoured milk; confectionery items, such as sweets, candies, chocolate; ice cream; sugary or salty snacks; cookies, cakes and pastries; breakfast cereals; industrialised pies, pasta and pizza dishes; nuggets and sticks; industrialised sausages, burgers, hot dogs and other meat products; instant soups and noodles are just

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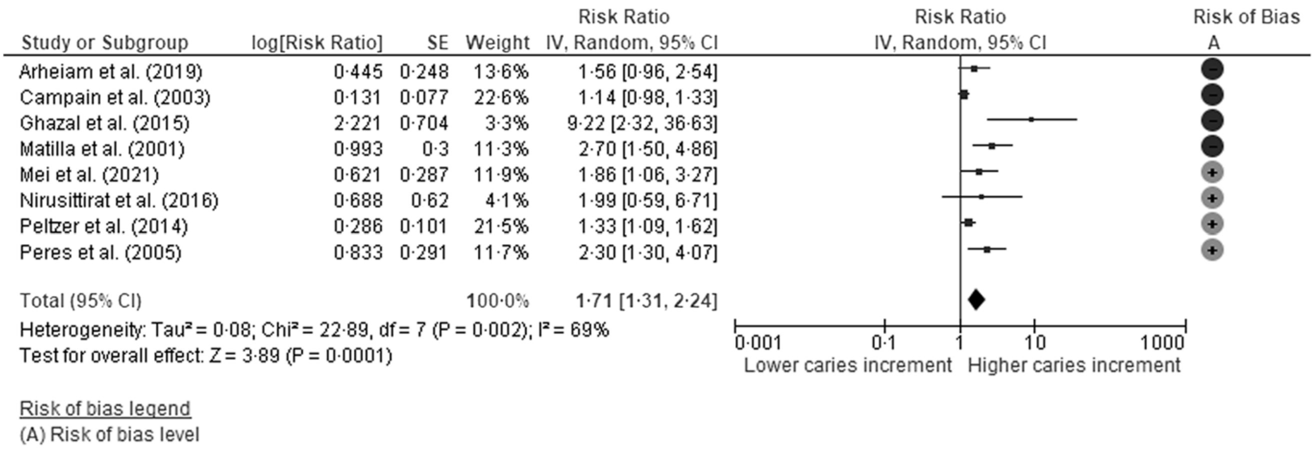

Fig. 4. Pooled effect of UPF consumption and dental caries among children and adolescents in seven cohort studies and one non-randomised trial (total sample size = 5068). UPF, ultra-processed food.

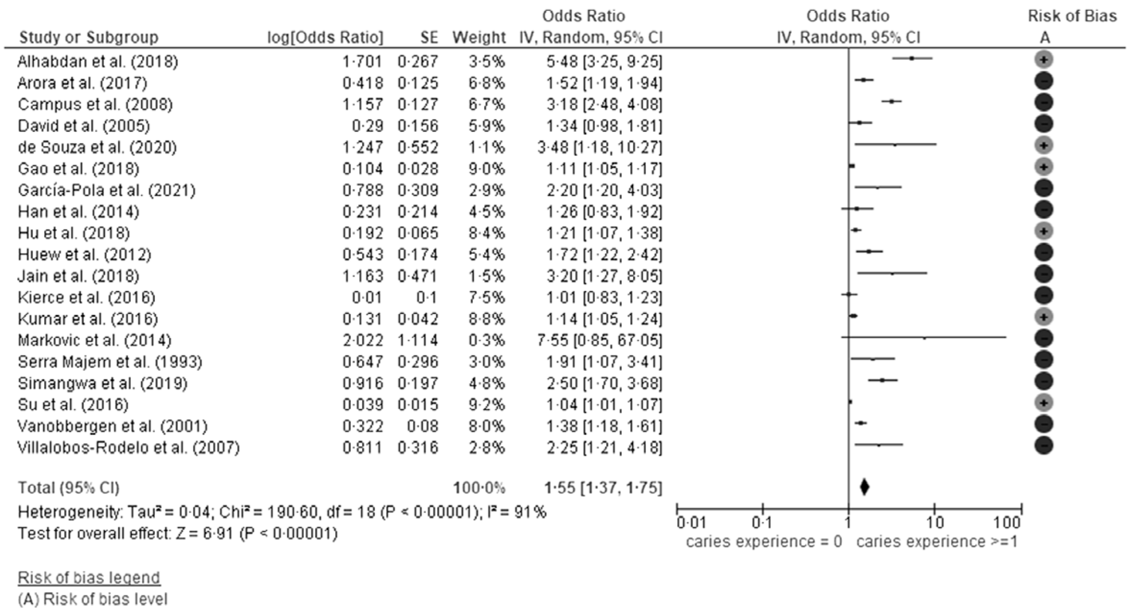

Fig. 5. Pooled effect of ultra-processed food consumption and dental caries among children and adolescents in eighteen cross-sectional studies and one case–control (total sample size = 35 425).

some examples of many other UPF products[70]. In summary, the industrialisation process of UPF fractionates whole foods into a variety of sugars (fructose, high-fructose maize syrup, fruit juice concentrates, invert sugar, maltodextrin, dextrose, lactose), oils and fats, proteins, starches and fibre, which are frequently hydrolysed or hydrogenated[69]. Artificial colours and flavours or stabilisers are also usually added to make the final product palatable or hyper-palatable[69]. In the end, very little or no whole food is present in UPF.

Fermentable carbohydrates present in UPF, such as sugars and starches, can be converted to lactic acid by *Mutans streptococci* and *Lactobacilli* species that drop the pH of saliva to below 5·5 and may result in demineralisation, leading to loss of tooth structure (dental caries)[71]. Both form and frequency affect the length of time that teeth are exposed to sugar[8]. Sticky UPF, such as cookies, breakfast cereals, industrialised pies and pizzas, given their retentive properties and intra-oral bioavailability, may stay in the mouth longer, increasing the chances of getting caries. Sugar-sweetened beverages break down in the mouth into simple sugars[72], when swished in the mouth, these liquids allow sugars to reach a larger surface area of teeth, increasing the probability of caries development. Consumption of sugar-sweetened beverages in small sips over extended periods of time has a greater cariogenic effect than drinking them at the same time[71], suggesting that the high frequency of consumption is more harmful. Ultra-processed meat products, such as sausages and hamburgers, are perceived as 'non-sweet'; however, they may contain large amounts of fermentable carbohydrates. For example, a portion of hamburger may have 15–30 g/100 g of carbohydrates, near a portion of a yogurt or an ice cream[73].

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There was a large heterogeneity overall and small in few subgroups. Taking into account the methodological differences between the studies, such as geographical location, sample sizes, diet assessment method and factors adjusted in the statistical models, some heterogeneity was expected. Sensitivity analysis suggests that most heterogeneity appeared to be driven by the very large effect measure, sample size < 500 and no adjustment for the main essential confounders (e.g. socio-economic and demographics, exposure to fluorides, health services and hygiene behaviours). A significant subgroup difference in studies comparing children and adolescents according to their prevalence of dental caries demonstrated that in high-risk populations, the effects of UPF are more harmful.

The low study quality of most included studies; the unexplained high heterogeneity, suggesting that unknown confounders may not entirely have explained the associations observed; the impossibility to investigate the effects of different types of UPF; and publication bias evaluation for cross-section and case–control studies should be mentioned as our main limitations. The funnel plot and the results of small-study effect test should be interpreted with caution, as many studies with results that were not statistically significant were not reported, limiting our assessment of publication bias. Strengths of our study include the wide search terms used; the large number of studies evaluated in the qualitative and quantitative synthesis of various low-middle and high-income countries, with different diet patterns and confounding factors; the large number of participants (more than 40 000), which increased the statistical power to detect the associations found; and the robustness of the findings in all subgroup analyses.

In conclusion, the findings suggest that a higher consumption of UPF is associated with a greater experience of dental caries in childhood and adolescence. Future and better methodological studies should consider the level of food processing and use valid and reliable diet measures. There is an urgent need to understand the role of the different subtypes of UPF, in order to define the dose–response relationship between their associations with oral health outcomes. Our findings reinforce the need for public health efforts, interventions and policies to reduce the consumption of UPF to improve the oral health of children and adolescents. Nutritionists, dentists and other health professionals working with children and adolescents should be educated about the potential negative effects of high UPF consumption on oral health.

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The authors declare no conflict of interest.

Supplementary material

For supplementary materials referred to in this article, please visit https://doi.org/10.1017/S0007114522002409

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