

Food Insecurity and Dental Caries Prevalence in Children and Adolescents

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1 **Food Insecurity and Dental Caries Prevalence in Children and Adolescents: A Systematic**
2 **Review and Meta-analysis**

3

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6

7

8 **Abstract**

9 **Aim:** This study aimed to investigate the relationship between food insecurity (FI) and dental
10 caries prevalence in children and adolescents.

11 **Design:** MEDLINE (via PubMed), EMBASE, SCOPUS, ISI web of knowledge, Cochrane, and
12 ProQuest Dissertations & Theses databases (up to April 19th, 2022) as well as reference lists
13 were searched. Eligible studies compared dental caries prevalence in food-secure and food-
14 insecure individuals younger than 19 years. Two independent reviewers performed study
15 selection, data extraction, and risk of bias assessment using a modified Newcastle-Ottawa Scale.
16 Meta-analysis was done, and the pooled odds ratio (OR) was calculated at 95% confidence
17 interval (95% CI).

18 **Results:** Among the 1350 retrieved records, 10 cross-sectional reports were selected for
19 systematic review. Six studies involving 8,631 participants were included in the meta-analysis.
20 More than half of the reports were published within the period 2019-2021. All studies except one
21 were judged as low risk of bias. Overall, the prevalence of dental caries was greater among the
22 food-insecure children and adolescents (OR: 2.01, 95% CI: 1.52-2.65, $P < .001$, I^2 : 73.5%).
23 Similarly, all three categories of FI showed significant association with caries experience

24 (marginal FI: OR: 1.88, 95%CI: 1.56-2.27, $P < .001$, I^2 : 0.0%; low: OR: 2.42, 95%CI: 1.42-4.14,
25 $P = .001$, I^2 : 74.4%; very low FI: OR: 2.37, 95%CI: 1.88-3.00, $P < .001$, I^2 : 0.0%).

26 **Conclusion:** The results showed a significant association between FI status and dental caries in
27 both childhood and adolescence; however, there was a lack of longitudinal studies for better
28 understanding of this association. Health policies leading to reduction of FI may also aim to
29 reduce dental caries.

30 **Keywords:** Adolescent; Child; Dental caries; Food security; Food supply; Meta-analysis

31 INTRODUCTION

32 Dental caries remains a major public health problem globally despite the overall decline in more
33 developed countries, imposing a considerable economic burden on health care services.¹⁻³ This
34 biofilm-mediated, diet-modulated and multifactorial disease significantly affects disadvantaged
35 social groups and is prevalent among school-aged children.^{1, 3} Dental caries, if it remains
36 untreated, causes pain and infection and therefore may affect physical and psychological
37 developments. Dental caries reportedly affect educational and personal achievements in
38 children.⁴

39 Dental caries is a preventable disease, resulting from the imbalance between pathological and
40 protective factors.⁵ A number of factors, including biological, environmental, and socio-
41 behavioral may contribute to development and progression of dental caries.² Diet and nutrition,
42 for example, affect the structure of the tooth before and after its eruption, making the teeth
43 susceptible/resistant to caries.^{6, 7} Socioeconomic circumstances also influence dental caries
44 through primary determinants of caries, that is cariogenic biofilm, dietary fermentable
45 carbohydrates, and susceptible teeth/hosts,^{7, 8} with those experiencing poverty in at least one
46 stage of their life from childhood through adolescence, and those coming from low-income and

47 low educational level families experiencing significantly greater prevalence/worse levels of
48 dental caries.^{8,9}

49 Food insecurity (FI) is a health and social issue affecting a wide range (7-97%) of households
50 with children in developed countries.¹⁰ The United States Department of Agriculture (USDA)
51 describes FI as “a household-level economic and social condition of limited or uncertain access
52 to adequate food” that may lead to hunger,¹¹ with low income and poverty being its main
53 determinants.¹⁰ This condition may lead to some serious health, developmental and social
54 consequences through changing children’s dietary intakes.¹⁰ Several cross-sectional studies have
55 also suggested the association between FI and childhood dental caries, albeit with some
56 inconsistencies.¹²⁻¹⁵ Moreover, with the ongoing battle with COVID-19, there has been an
57 increases in FI, affecting vulnerable households globally.¹⁶ It seems that this inevitably affects
58 oral health¹⁷ and therefore, investigating the impact of FI on dental caries is timely and worthy
59 of attention.

60 Despite some previous attempts to summarise the evidence on the impact of FI on dental caries¹⁸,
61 no systematic review or meta-analysis has critically examined such a relationship among
62 children and adolescents. Our research aims to answer whether the prevalence of dental caries
63 among children aged 19 and younger varies between food-secure and food insecure households.

64 In addition, we address the following questions:

65 a) Are dental caries and FI associated based on age group, tooth type, definition of caries, and
66 country?

67 b) Are other factors, including socioeconomic and dietary factors, associated with dental caries
68 in eligible studies?

69 The latter was qualitatively evaluated whenever the data was available.

70 **METHODS**

71 The reporting of this systematic review and meta-analysis is guided by the PRISMA 2020
72 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.¹⁹ The
73 protocol of the study was registered in the PROSPERO (International Prospective Register of
74 Systematic Reviews) database (CRD42021246379).

75 **Eligibility criteria**

76 The inclusion criteria for the present systematic review are defined according to the following
77 PECOS format: a) Population: participants of less than 19 years of age from the general
78 population, b) Exposure: (different categories of) household and/or child FI, c) Comparison: food
79 security (FS), d) Outcome: coronal dental caries evaluated by clinical examination, e) Study
80 design: observational (both longitudinal and cross-sectional designs).

81 FI/FS status must be directly assessed by a specific questionnaire in eligible studies. The
82 exclusion criteria were: a) recruitment of participants specifically from special healthcare need
83 populations, orthodontic patients, or individuals with dental anomaly, b) other study designs, and
84 c) full-text reports in languages other than English.

85 To be included in the meta-analysis, a study must report the number of food-secure and food-
86 insecure participants, as well as the prevalence of dental caries in each of these groups.

87 **Information sources and search strategy**

88 The following electronic bibliographic databases were independently searched up to April 19th,
89 2022 by two members of the research team (X and Y) without any language and publication date
90 limitations: MEDLINE (via PubMed), EMBASE, SCOPUS, ISI web of knowledge (all
91 databases), Cochrane Central Register of Controlled Trials (CENTRAL), Cochrane Database of
92 Systematic Reviews, and ProQuest Dissertations & Theses Database Global (Appendix 1). In

93 addition, handsearch search was performed on the cited reference lists of included reports and
94 relevant systematic reviews.

95 **Study selection, data extraction, and risk of bias assessment**

96 Initial study selection was independently performed by two other members of the research team
97 (Y and Z) using the EndNote software (EndNote™ 20 (Clarivate Analytics, Philadelphia,
98 Pennsylvania)). The final decision was arrived at after independent full-text evaluation, and
99 following consensus between the two authors. Any disagreements at this phase were resolved
100 through discussion with a third research team member (W).

101 Data extraction from the included reports and the risk of bias assessment of individual studies
102 were performed independently by the same two reviewers (Y and Z). Following consensus
103 between them, the third reviewer (W) checked and finalized the extracted data. Missing data
104 required for statistical synthesis were requested by emailing the correspondent authors.

105 The following data regarding the study characteristics were tabulated: first author and year of
106 publication, country under study, setting, study design, sample size and sampling method, dental
107 caries definition and scoring system, FI assessment tool and status, other factors affecting dental
108 caries (including socioeconomic and dietary factors), and relationship between FI/other factors
109 and dental caries.

110 The risk of bias assessment of included studies was conducted using a Newcastle-Ottawa Quality
111 Assessment Scale adapted for cross-sectional studies.²⁰ This 7-item scale is organized into three
112 domains: selection (representativeness of the sample, sample size, non-respondents, and
113 ascertainment of exposure), comparability, and outcome (assessment of outcome, and statistical
114 test).²⁰ The risk of bias of each study was rated based on the total score as low (7-10), moderate
115 (5-6), and high (0-4).

116 **Synthesis methods and reporting bias assessment**

117 Meta-analysis was conducted using Stata software, version 11.0 (Stata Corp, College Station,
118 TX, USA). FI was considered both as a dichotomized variable and a categorical variable for
119 statistical analysis. Heterogeneity among the included studies was determined based on I^2
120 statistics, with values >50 indicating substantial heterogeneity. The random-effect model was
121 employed to calculate pooled odds ratio (OR) and its corresponding 95% confidence interval
122 (95% CI) using sample size and caries prevalence in the included studies. Moreover, the
123 potential sources of heterogeneity (i.e., year of study, sample size, age of participants, tooth type,
124 caries assessment criteria, and country under study) were investigated using subgroup analyses
125 and meta-regression. Egger's regression test was applied to detect the publication bias. The level
126 of statistical significance was set at P value $< .05$.

127 **RESULTS**

128 **Study selection**

129 Overall, 1350 records were identified through electronic search. After duplicate removal and
130 screening of a total of 995 remaining records, 24 records were selected for full-text evaluation.
131 Excluding 14 reports mainly because they did not assess dental caries/health through clinical
132 examination (Appendix 2)²¹⁻³⁴, nine journal articles (eight studies)^{12, 14, 15, 35-40} and one thesis¹³
133 meeting the inclusion criteria were included in the present systematic review. Except four
134 journal articles (one duplicate report of the same study³⁹, one with the same data source³⁸, and
135 two with insufficient required data^{36, 40}), the other six reports were all considered for meta-
136 analysis. Two studies independently reported outcomes for each study sub-group; therefore, they
137 were separately incorporated in the systematic review and meta-analysis.^{13, 15} Of these, only the
138 data from one sub-group were dependent (two different outcomes from one single population).¹³

139 Handsearching of the bibliographic references of the included studies and relevant systematic
140 reviews^{18, 41} did not yield any additional studies fulfilling the eligibility criteria of our study
141 (Figure 1).

142 **Study characteristics**

143 Table 1 shows the characteristics of the included studies in the systematic review. The majority
144 of reports were published within the period 2019-2021 (publication year range: 2008-2021).^{12, 14,}
145 ^{15, 35, 38, 40} While only one study analyzed data collected in the last five years,¹² half of the reports
146 analyzed data from the past 10 years (data collection year range: 2001-2016).^{12, 15, 35, 38, 40} Five
147 reports were from the United States (US),^{12, 13, 35, 36, 38} three reports (two studies) were from
148 Brazil,^{14, 37, 39} one from Canada¹⁵ and one from South Korea.⁴⁰ Eight studies were cross-
149 sectional^{12-14, 35-40} and one study stated that the paper was nested in the Baby Teeth Talk Study,¹⁵
150 a community-based early childhood caries (ECC) randomized controlled trial.⁴² Nonetheless, the
151 analyses of this report on FI and child oral health were based on the second-year post-parturition
152 data, making it also cross-sectional.¹⁵ Five studies analyzed the data from the US and South
153 Korea National Health and Nutrition Examination Survey,^{13, 35, 36, 38, 40} while the rest (four
154 studies) were either sub-projects^{15, 37} or independent studies.^{12, 14, 39}

155 Sample size of the eligible studies varied from 82 to 4822 individuals. Three studies included
156 children not older than five years old,^{12, 15, 40} and five articles selected children and/or adolescents
157 aged five years and older.^{14, 35-37, 39} However, samples of two studies comprised individuals both
158 under and over five years of age.^{13, 38} Regarding the tooth type, four studies assessed caries
159 experience in both primary and permanent teeth,^{13, 36-38} three articles only in primary teeth^{12, 15, 40}
160 and two reports (one study) only in permanent teeth.^{14, 39} Bahanan et al. did not specify the tooth

161 type.³⁵ For the purpose of our meta-analysis, with regard to the age of the participants in the
162 latter study, it was assumed that the authors considered both primary and permanent teeth.
163 Assessment of FI in all studies except one¹⁵ was performed by administering the USDA
164 questionnaires or their versions validated for other populations. For dichotomization of FI
165 categories in these studies, three reports considered score 0 as FS and score ≥ 1 as FI.^{13, 14, 39} We
166 used this measure for the dichotomizing FI variable in the other three studies included in the
167 meta-analysis.^{12, 37, 38} The study by Kim et al. (not included in the meta-analysis), however,
168 selected a different cut-off point: score 0-2: FS and score ≥ 3 : FI.⁴⁰ On the other hand, Tsai and
169 Lawrence used an under-validation one-item tool modified from the WHO's Adverse Childhood
170 Experiences (ACE) International Questionnaire for assessing FI.¹⁵ Overall, three studies
171 considered child FI for their statistical analysis.^{13, 15, 38}
172 In terms of caries experience, cut-off points in all studies but one were presence (≥ 1) or absence
173 (= 0) of any caries affected teeth. Tsai and Lawrence selected a disparate cut-off and considered
174 severe-ECC as having dmft > 9 .¹⁵ Four studies only incorporated the data on untreated caries
175 experience (decayed teeth component in decayed, missing and filled teeth index) into their
176 statistical analysis.^{14, 35-37, 39} Regarding the definition of dental caries, three studies classified
177 non-cavitated lesions or white spots as caries besides cavitated lesions.^{12, 15, 35} One study
178 included only active caries in its assessments.³⁸

179 **Risk of bias in studies**

180 All studies were judged as low risk of bias, except one, which was judged as moderate risk of
181 bias, mainly because it achieved lower scores for three items (representativeness of the sample,
182 comparability of subjects, and statistical test) compared with most of the studies. None of the
183 studies was free from risk of bias (Appendix 3).

184 **Individual studies**

185 Tables 1 and 2 summarize the results of studies on the relationship between dental caries and FI,
186 and between dental caries and socioeconomic/dietary factors, respectively. Other factors having
187 an association with child/adolescent dental caries were as follows (only adjusted values are
188 presented):

189 *Child/adolescent-related variables:* health insurance coverage (for DMFT: $P = .038$)¹³, dental
190 visit in the last year ((for ECC: other visit: OR: 11.4, 95%CI: 3.86-33.71, and no visit: OR:
191 0.52, 95%CI: 0.29-0.95; for dft: $P < .001$; for DMFT: $P = .028$)¹³ (OR: 0.29, 95%CI: 0.23-0.37,
192 $P < .0001$)³⁵), number of school lunches eaten per week (for dft: $P = .045$),¹³ and caries
193 experience in the primary teeth ((for DMFT: $P = .014$)¹³ (for dt: $r = 0.710$)⁴⁰)

194 *Mother-related variables:* nutritional status (mothers' number of nutrients with an index of
195 nutritional quality less than 1 (NINQ): for dft: $r = 0.091$, $P < .05$ and for dt: $r = 0.088$, $P < .05$;
196 mothers' mean nutritional adequacy ratio (MAR): for dft: $r = -0.094$, $P < .05$),⁴⁰ psychosocial
197 well-being (perceived stress for on-reserve population: OR: 2.48, 95%CI: 1.40–4.37, $P = .002$;
198 sense of control for off-reserve population: OR: 0.17, 95%CI: 0.03–0.95, $P = .04$),¹⁵ and alcohol
199 consumption during pregnancy (for off-reserve population who stopped or currently drinking:
200 OR: 0.09, 95%CI: 0.01–0.90, $P = .04$)¹⁵

201 *Household/Family-related variables:* household overcrowding (for on-reserve population: OR:
202 1.89, 95%CI: 1.06–3.38, $P = .03$),¹⁵ household smoking exposure (for ECC: OR: 2.60, 95%CI:
203 1.50-4.50, $P < .001$)¹³

204 **Statistical synthesis**

205 Considering FI as a dichotomous variable, the meta-analysis of nine comparisons from six
206 studies (five with low risk of bias, involving a total of 8,631 participants) demonstrated greater

207 prevalence of dental caries in food insecure children and adolescents (OR: 2.01, 95%CI: 1.52-
208 2.65, $P < .001$).^{12-15, 35, 37} Heterogeneity among these studies was high (I^2 : 73.5%, $P < .001$)
209 (Figure 2).

210 *Subgroup analysis based on country (Figure 2-A)*: Three studies (five data subsets)^{12, 13, 35} were
211 from the US. Pooled OR of experiencing dental caries in food insecure US children and
212 adolescents was 1.86 (95% CI=1.30-2.66, $P = .001$) as compared to those with FS. The
213 heterogeneity of this analysis was high (I^2 : 82.3%, $P < .001$). Two studies^{14, 37} from Brazil and
214 one study¹⁵ from Canada, each with two data subsets, were meta-analyzed. Pooled OR of dental
215 caries experience in food insecure Brazilian and Canadian populations compared with their food
216 secure counterparts was 2.27 (95% CI=0.87-5.92, $P = .095$, I^2 : 76.5%) and 3.09 (95% CI=1.75-
217 5.44, $P < .001$, I^2 : 0.0%), respectively.

218 *Subgroup analysis based on age of participants (Figure 2-B)*: Four comparisons from three
219 studies and five comparisons from four studies were used for subgroup analyses of populations
220 under^{12, 13, 15} and over five years old^{13, 14, 35, 37}, respectively. Both analyses demonstrated greater
221 odds of dental caries experience in food insecure individuals (pooled OR for population under
222 five years: 2.48 (95%CI: 1.82-3.37, $P < .001$, I^2 : 3.6%), and pooled OR for population over five
223 years: 1.75 (95%CI: 1.22-2.51, $P = .002$, I^2 : 83.1%)).

224 *Subgroup analysis based on caries assessment criteria (Figure 2-C)*: Two subgroup analyses
225 (each with one included study)^{13, 15} of different cut-offs of caries experience showed inconsistent
226 results (pooled OR for caries experience (DMFT/dft/dmfs) > 0 : 1.61, 95%CI: 0.89-2.92, $P =$
227 .118, I^2 : 88.8%, and pooled OR for caries experience (dmft) > 9 : 3.09, 95%CI: 1.75-5.44, $P <$
228 .001, I^2 : 0.0%). Four studies were included in subgroup analysis of untreated caries.^{12, 14, 35, 37}

229 This analysis demonstrated a greater prevalence of untreated caries in food insecure individuals
230 (pooled OR: 2.15, 95%CI: 1.50-3.09, $P < .001$, I^2 : 59.2%).

231 *Subgroup analysis based on tooth type (Figure 2-D)*: Three and two different studies were
232 included in subgroup analyses of the primary,^{12, 13, 15} and both primary and permanent dental
233 caries,^{35, 37} respectively. The results of the meta-analyses for both comparisons were consistent,
234 showing higher prevalence of dental caries among the food insecure children (pooled OR for
235 primary tooth caries: 2.38 (95%CI: 1.92-2.95, $P < .001$, I^2 : 0.0%), and pooled OR for primary
236 and permanent dental caries: 2.47 (95%CI: 1.30-4.72, $P = .006$, I^2 : 60.2%). Data from two
237 studies were meta-analyzed to evaluate caries experience in the permanent teeth.^{13, 14} This
238 analysis showed no differences in dental caries prevalence among food secure and food insecure
239 individuals (pooled OR: 1.14, 95% CI: 0.67-1.94, $P = .639$, I^2 : 76.4%).

240 Considering FI as a categorical variable, a total of four studies were included in this part.^{12, 13, 35,}
241 ³⁷ All studies except one were assessed as low risk of bias. All three categories of FI showed
242 significant association with caries experience in both children and adolescents (marginal FI: OR:
243 1.88, 95%CI: 1.56-2.27, $P < .001$, I^2 : 0.0%; low: OR: 2.42, 95%CI: 1.42-4.14, $P = .001$, I^2 :
244 74.4%; very low FI: OR: 2.37, 95%CI: 1.88-3.00, $P < .001$, I^2 : 0.0%) (Figure 3).

245 **Reporting biases**

246 The results of meta-regression of the association between dental caries and FI based on year of
247 study ($P = .17$), sample size ($P = .5$), country ($P = .75$), and age of participants ($P = .9$) were not
248 significant (Figure 4). The Egger's test showed no significant publication bias for all outcomes in
249 the meta-analysis ($P = .47$) (Figure 5).

250 **DISCUSSION**

251 This systematic review and meta-analysis found significant association between FI and both
252 childhood and adolescent dental caries. This relationship was more significant among preschool
253 children as compared to adolescents which is indicated by the greater OR for primary tooth
254 decay. These results were similar to those of a previous systematic review that found an
255 association between the cumulative history of oral health problems (including untreated dental
256 caries, restorations and use of prosthesis, and extractions) and FI; however, it is suggested that
257 examination of the role of FI in dental/oral health should be conducted through longitudinal,
258 rather than cross-sectional, studies involving clinical examinations and dietary analyses.¹⁸

259 The association between FI and dental caries, on the one hand, may be related to the dietary
260 behaviors of low socio-economic households, aiming to meet the energy needs of their children,
261 including adherence to diets high in readily fermentable carbohydrates.¹² In fact, when food
262 needs compete with non-food basic needs, these households are less likely to choose more
263 expensive healthy diets rich in fruits and vegetables. Instead, they opt for a cheaper unhealthy
264 and highly cariogenic diet, which is often high in fat and sugar, and likely to be highly processed.

265 ¹⁸ Hence, frequent sugar consumption; a known risk factor for tooth demineralization, may be
266 associated with the greater prevalence of dental caries and consequent extractions in food-
267 insecure individuals.^{18, 43} On the other hand, decayed teeth resulting from FI may interfere with
268 mastication and restrict the type and variety of foods an individual ingests, with decreased intake
269 of proteins, fiber, micronutrients (e.g., vitamins A, B and C, folic acid), minerals (e.g., calcium,
270 zinc, iron) and increased consumption of fats and carbohydrates, and thus, worsen the problem.¹⁸

271 Moreover, nutritional deficiencies can lead to more permanent tooth susceptibility to caries,
272 which is another determinant of tooth loss.⁴⁴

273 The relationship between FI and dental caries could also be attributed to the interaction between
274 FI and poverty. The FI could be an indication of a bigger issue of poverty in which the decision
275 making is influenced by the stress of limited resources. Accordingly, for poor households with
276 numerous competing demands, purchasing of dental hygiene products or attending regular
277 preventive dental visits may not be a priority.^{12, 45} Dietary habits and access to dental hygiene
278 supplies were not analyzed in the present study due to lack of sufficient information. Besides, it
279 has been suggested that in extreme economic conditions of the household, there are other factors
280 beyond cariogenic diets or suboptimal dental care contributing to dental problems, e.g.,
281 childhood toxic stress. Facing strong, frequent or prolonged adversity, including the accumulated
282 burdens of household financial hardship accompanying such deprivation, is viewed as a stressor
283 for children.^{15, 39}

284 Among other things, FI is related with low maternal educational level, which can, in turn,
285 contribute to lower oral health literacy.⁴⁶ Low-income neighbourhoods may also limit dietary
286 choices of their food insecure residents.^{36, 47} Higher dental caries in children belonging to the
287 black American and Mexican American ethnic groups has also been reported.^{35, 48} Household
288 socioeconomic status, income/wealth, and dietary intake were, in descending order, the most
289 significant predictors of dental caries in both children and adolescents.^{40, 49}

290 A variety of approaches was adopted in the reviewed studies for the purpose of caries
291 assessment. Recent studies were more inclined to report non-cavitated lesions, with higher
292 sensitivity.⁵⁰ Given the growing interest in minimally invasive dentistry, detecting pre-cavitated
293 lesions seems to be considered. Nonetheless, adopting such an approach might not be viable for
294 epidemiological surveys, especially in low-income settings where resources are scarce.⁵¹
295 Besides, most studies included in this meta-analysis reported data from children aged five years

296 and older; of those, all but one reported data on both primary and permanent tooth caries. This
297 allowed us consider the non-age-dependent approach, and further avoided the common caries-
298 free pattern seen in permanent teeth of individuals in their early mixed dentition.³⁷

299 Almost all cross-sectional studies included in the present systematic review were of low risk of
300 bias; however, four studies were not included in the meta-analysis due to either
301 insufficient/overlap data, or being the duplicate report of the same study.^{36, 38-40} Using the USDA
302 Household Food Security Scale Measure or its local versions for determining household and
303 child FI as a valid measure, large sample size, and controlling the confounders by advanced
304 statistical models ensured the low risk of bias of most of the reviewed studies.

305 The main limitation of the present study was the small number of included studies. Adopting
306 different approaches for caries assessment and FI were among other limitations encountered. In
307 addition, there was overlap in the data sources analyzed in two studies. To avoid duplication, the
308 study by Bahanan et al. with larger sample size, shorter age span, and more accurate definition of
309 dental caries was selected for the meta-analysis.³⁵ Moreover, two dependent outcomes were
310 reported from one sub-group (6-to-11-year-old children) of the study by Braunstein et al., i.e.,
311 the prevalence of dental caries was separately reported for primary (dft) and permanent (DMFT)
312 teeth.¹³ Including both datasets in the meta-analysis can also be accounted as a limitation.

313 Although most of the included studies used national data to examine the association between FI
314 and dental caries, some reported from a small sample of dental clinics which may not be
315 regarded as representative of the target population. Another limitation was that the data came
316 from four countries, of which one failed to be included in the meta-analysis, however,
317 publication bias of the included studies was not significant.

318 Nevertheless, it appears that FI is an independent predictor of dental caries in both children and
319 adolescents after adjusting for socioeconomic status. Therefore, public health efforts and policies
320 should be targeted to reduce FI, especially in low-income households. For example, targeted cash
321 and food transfers toward increasing nutritious food access and decreasing empty calorie food
322 consumption may be considered. These measures may also affect both obesity and dental caries,
323 two non-communicable diseases, which is in line with the Common Risk Factor Approach.⁵² It
324 is suggested that future longitudinal studies may focus on behaviors that link FI to pediatric tooth
325 decay for better understanding of such a relationship. Furthermore, researchers are encouraged to
326 investigate the time point and duration of being food insecure that may affect the prevalence/rate
327 of dental caries as well as any interventions that may mitigate the adverse effects of FI on early
328 childhood.

329 **Why this paper is important to paediatric dentists?**

- 330 • For pediatric dentists working in low-income settings, the awareness of relationship
331 between dental caries and FI can help them adopt additional/appropriate measures for
332 dental caries prevention.
- 333 • The presented results highlight key areas for future studies and policymaking.

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Table 1. Characteristics of included studies in the systematic review of food insecurity and dental caries in children and adolescents.

NO.	First author, Publication (Study) year	Country/ Setting	Study design	Sample size/ Sampling method	FI assessment tool	FI categories/ status	Definition and scoring system of dental caries	Relationship between food (in)security and dental caries [†]	Risk of bias assessment [‡]
1	Bahanan et al., ³⁵ 2021 (2011-2014)	US/NHANES 2011-2012 and 2013-2014	A cross-sectional study using NHANES data	4822 children aged 5-17 years/ Nationally representative population-based sample	USDA 18-item scale Household Food Security Survey Measure	Overall (marginal, low, very low) FI: 41.9% Household full FS (score 0): 66.23%, marginal FS (1-2): 12.31%, low FS (3-7): 14.39%, very low FS (≥ 8): 7.07%	Untreated dental caries, including white spots on smooth surfaces (no carious teeth (83.73%) vs. ≥ 1 carious teeth) using the carious teeth index	Untreated dental caries in FI children was 1.38 times more than in fully FS ones (95%CI: 1.11-1.72, $P = .006$) after controlling for cofounders. Untreated caries was 1.48 and 1.59 times greater in children living in marginal (95%CI: 1.10-2.01, $P = .01$) and very low (95%CI: 1.12-2.26, $P = .01$) FS households, respectively, compared with those from fully FS households.	Low
2	Tsai & Lawrence, ¹⁵ 2021 (2014-2015)	Canada (Ontario and Manitoba)/ First Nations communities (on-/off-reserve population)	2nd-year post-parturition data nested in the Baby Teeth Talk Study (a community-based ECC	344 First Nations children aged 2 years/The participants were recruited through referrals and media. On-reserve population (n= 229)	Modification of the WHO's one-item ACE International Questionnaire (undergoing validation)	Four-point scale: Sometimes/Most of the time (67.4%), Rarely/Never (32.6%)	S-ECC: having a dmft score >9 (including non-cavitated lesions) S-ECC: 47.6%, non-S-ECC: 52.4%	FI was associated with S-ECC for on-reserve children after adjusting for maternal age, source of income and other variables (OR: 2.86, 95% CI: 1.53–5.34, $P = .001$)	Low

NO.	First author, Publication (Study) year	Country/ Setting	Study design	Sample size/ Sampling method	FI assessment tool	FI categories/ status	Definition and scoring system of dental caries	Relationship between food (in)security and dental caries [†]	Risk of bias assessment [‡]
			randomized controlled trial)	Off-reserve population (n=115)		Sometimes/Most of the time (58.4%), Rarely/Never (41.6%)	S-ECC: 7.0%, non-S-ECC: 93.0%	Not significant (OR: 2.25, 95%CI: 0.43–11.67, <i>P</i> = .47) [§]	
3	Hill, ³⁸ 2020 (2013-2014)	US/NHANES 2013-2014	Analysis of a piece of data from the cross-sectional survey (NHANES)	4406 children aged 1-19 years/ Nationally representative sample	NHANES interview questionnaire (including child and family FS status)	Child full FS: 86.1%, marginal FS: 5.6%, low FS: 7.0%, very low FS: 1.3%	Presence or absence of active carious lesions on a primary or permanent tooth (the prevalence of dental caries: ~15%)	Children categorized as having very low FS experienced 2.84 (95% CI: 1.13-7.12) times more dental caries than food secure children after adjusting for age, household FIP ratio and family SNAP category	Low
4	Kim et al., ⁴⁰ 2020 (2013-2015) [¶]	South Korea/ KNAHNES VI	The study used the data from KNHANES	610 preschool children aged 3-5 years/ Multistage, stratified, and clustered samples	18-item FS survey	FS (0-2): 91.3%, FI (≥3): 8.7%	dft and dt (untreated decayed teeth) following the WHO protocol-1997 (The threshold was D3 caries into the dentine), experience rate of dft/dt: yes (dft/dt ≥ 1), no (dft/dt = 0)	FI was significantly associated with dft (<i>B</i> = 0.809, <i>P</i> = .030) and dt (<i>B</i> = 1.018, <i>P</i> < .001) after adjusting for age and sex	Low

NO.	First author, Publication (Study) year	Country/ Setting	Study design	Sample size/ Sampling method	FI assessment tool	FI categories/ status	Definition and scoring system of dental caries	Relationship between food (in)security and dental caries [†]	Risk of bias assessment [‡]
5	Angelopoulou et al., ¹² 2019 (2016)	US/A university-based community clinic	A cross-sectional study	82 preschool children aged 12-71 months (median: 48 months)/Invitation to participate	Six-item validated USDA FI questionnaire (English and Spanish versions) assessing family FI	High FS (Score 0): 58.5%, marginal FS (1): 11.0%, low FS (2-4): 24.4%, very low FS (5,6): 6.1%	dmft index (ECC) based on the ICDAS criteria (including early stage lesions at the pre-cavitation stage)/Prevalence of untreated dental caries was 56%.	A positive correlation existed between dental caries (dmft) and FI ($P = .002$, $R^2 = 0.115$), especially concerning the number of decayed teeth (dt, d1t) after adjusting for confounders.	Moderate
6	Ferreira et al., ¹⁴ 2019 (2010) Santin et al., ³⁹ 2016 (2010)	Brazil (Araucária in the state of Paraná)/ Urban public and private schools	A cross-sectional/ population-based study	538 schoolchildren aged 12 years (318 girls and 220 boys)/ Two-stage randomized cluster sampling (schools and children) using a simple lottery system, with additional stratification by regional administration district and type of school	15-item validated FIS-B (using a specific version for households with children and/or adolescents)	Household FS (score: 0): 61%, mild FI (1-5): 28%, moderate FI (6-10): 6%, severe FI (11-15): 5%	Untreated dental caries based on DMFT index: present (D component ≥ 1): 45% (95% CI: 41-50), absent (D component = 0)	FI was not associated with untreated dental caries after adjusting for per capita household income (PR: 1.14, 95% CI: 0.92-1.41).	Low

NO.	First author, Publication (Study) year	Country/ Setting	Study design	Sample size/ Sampling method	FI assessment tool	FI categories/ status	Definition and scoring system of dental caries	Relationship between food (in)security and dental caries [†]	Risk of bias assessment [‡]
7	Chi et al., ³⁶ 2014 (2007-2008) [†]	US/NHANES 2007-2008	A cross-sectional analysis of US NHANES data	2206 children aged 5-17 years/ Nationally representative data	18-item USDA validated Household Food Security Survey	Full FS (0): 62%, marginal FS (1-2): 13%, low FS (3-7): 17%, very low FS (≥ 8): 8%	Untreated dental caries (stains, white spots, pitted enamel, and erosion were not included): yes (~20.1%)/no	Food secure children had similar prevalence of dental caries compared to those with marginal (PR: 1.07, 95% CI: 0.66-1.75, $P = .77$), low (PR: 1.42, 95% CI: 0.85-2.38, $P = .17$) or very low (PR: 1.12, 95% CI: 0.60-1.12, $P = .77$) FS after adjusting for SES.	Low
8	Frazao et al., ³⁷ 2014 (2009-2010)	Brazil (The western Brazilian Amazon)/ Urban schools	A cross-sectional survey nested in a population-based cohort study	203 schoolchildren aged 7-9 years (108 girls and 95 boys)/ Census	15-item validated scale of USDA (Brazilian-Portuguese language version) for households with children and adolescents	Score 0 (food-secure household): 45.9%, Score 1-4: 32.4%, Score ≥ 5 : 21.6%	Untreated decayed deciduous and permanent teeth (dt+DT): 3.63 \pm 3.26 (mean \pm SD)/ dmft/DMFT index based on the WHO criteria (1997) for oral health surveys: 20.7% of children were caries-free.	High scores of FI (>4) were associated with dental caries after adjusting for sex and SES (wealth index) (RR= 1.48 (95% CI: 1.05-2.08, $P = .024$))	Low

NO.	First author, Publication (Study) year	Country/ Setting	Study design	Sample size/ Sampling method	FI assessment tool	FI categories/ status	Definition and scoring system of dental caries	Relationship between food (in)security and dental caries [†]	Risk of bias assessment [‡]
9	Braunstein et al., ¹³ 2008 (2001-2002)	US/NHANES 2001-2002	Cross-sectional data from NHANES	801 children aged 2-5 years/ A complex sampling design: over-sampling of low-income households, children, elderly, African Americans, and Mexican Americans	18-item U.S. Food Security Scale (including Child Food Security)	High FS (76.6%), marginal FS (7.4%), low FS (14.4%), and very low FS (1.6%)	ECC: one or more primary teeth with decayed cavitated lesions, missing due to caries, or filled tooth surfaces (yes: 25.6%, no: 74.4%)	ECC in food insecure children (38.2%) was 1.8 (95% CI: 1.09 - 2.97) times more than in food secure children (23.0%), (<i>P</i> = .022) after adjusting for confounders.	Low
				1097 children aged 6-11 years	Household and child FS	High FS (75.8%), marginal FS (8.6%), low FS (13.6%), and very low FS (2.0%)	Caries experience was measured by dft (yes: 51.0%, no: 49.0%)	Child FS was not associated with dft after adjusting for confounders (<i>P</i> = .174).	Low
							DMFT: (yes: 79.4%, no: 20.6%)	Child FS was not associated with DMFT after adjusting for confounders (<i>P</i> = .603).	

ACE: adverse childhood experiences; CI: confidence interval; d(m)(f)t: number of decayed (missing) (filled) primary teeth due to caries; D(M)(F)T: number of decayed (missing) (filled) permanent teeth due to caries; (S-)ECC: (severe) early childhood caries; FI: food insecurity/insecure; FIP: federal income to poverty; FIS-B: Brazilian Food Insecurity Scale; FS: food security/secure; ICDAS: International Caries Detection and Assessment System; (K)NHANES: (Korea) National Health and Nutrition Examination Survey; NM: not mentioned; OR: odds ratio; PR: prevalence ratio; RR: relative risk; SES: socioeconomic status; SNAP: Supplemental

Nutrition Assistance Program; USDA: US Department of Agriculture; WHO: World Health Organization; WIC: Women, Infants, and Children.

† Adjusted values are presented unless identified.

‡ Risk of bias of papers was assessed using adapted Newcastle - Ottawa Quality Assessment Scale for cross-sectional studies: 7-10: low risk of bias, 5-6: moderate risk of bias, 0-4: high risk of bias.¹⁹

§ Unadjusted values

¶ These two studies were not included in the meta-analysis due to insufficient required data reported.

Table 2. Relationship between dental caries and other socioeconomic and dietary factors in the studies included in the systematic review.

#NO.	First author, Year of publication	Country	Sample size	Dental caries definition	Other SES and dietary factors affecting dental caries					
					Household SES/income/wealth	Race/Ethnicity	Age	Gender	Maternal education	Dietary factors/sugar intake
1	Bahanan et al., ³⁵ 2021	US	4822 children aged 5-17 years	Untreated caries, including white spots on smooth surfaces	OR for children with annual family income <\$20,000 compared with those with ≥ \$20,000 = 1.48 (95% CI: 1.08-2.03, <i>P</i> = .02)	OR for black children compared to their white counterparts = 2.39 (95% CI: 2.09-1.77, <i>P</i> = .01)	OR for 8-11-year-old children compared with 5-7-year-olds= 1.33 (95% CI = 1.06-1.69, <i>P</i> = .02)	NS	-	NS [†] diet quality measured by the Healthy Eating Index-2015 was not significantly associated with untreated caries (<i>P</i> = .07).
2	Tsai & Lawrence, ¹⁵ 2021	Canada	344 First Nations children aged 2 years	S-ECC: having a dmft score >9 (including non-cavitated lesions)	Primary source of income: On-reserve population: NS Off-reserve population: NS	-	Age of mother: On-reserve population: NS Off-reserve population: NS	-	-	-

3	Hill, ³⁸ 2020	US	4406 children aged 1-19 years	Presence or absence of active carious lesions on a primary or permanent tooth	OR [†] for family income to poverty ratio >1.3 compared with ≤1.3 = 1.50 (95% CI = 1.16, 1.95)	NS	OR= 2.60 (95% CI: 1.67-4.05) for children aged 6-11, 2.9 (95% CI: 1.85-4.67) for children aged 12-15, 4.2 (95% CI: 2.42-7.22) for children aged 16-19 compared to children aged 1-5	NS [†]	-	-
4	Kim et al., ⁴⁰ 2020	South Korea	610 preschool children aged 3-5 years	dft and dt (untreated decayed teeth) following the WHO protocol-1997 (The threshold was D3 caries into the dentine)	Household income dt: NS dft: NS	-	dt: NS dft: B= 0.567, <i>P</i> < .001	dt: NS dft: NS	dt: NS dft: NS	Children's NINQ and MAR dt: NS dft: NS

5	Ferreira et al., ¹⁴ 2019 Santin et al., ³⁹ 2016	Brazil	538 school children aged 12 years	Untreated dental caries: D component of DMFT index ≥ 1	PR for per capita household income (BMMW divided by the number of residents in the home) \leq US\$ 71 compared with $>$ US\$ 284 = 1.59 (95% CI: 1.06-2.37)	-	-	NS [†]	PR [†] for children whose mothers had up to 8 years of schooling compared with those with >8 years = 1.26 ($P = .021$, 95% CI 1.04-1.52)	PR [†] for 4-6 and >7 daily sugary food intake compared with 0-3 daily sugary food consumption was 1.36 ($P = .025$, 95% CI 1.04-1.79) and 1.60 ($P < .001$, 95% CI 1.24-2.05), respectively.
6	Chi et al., ³⁶ 2014	US	2206 children aged 5 to 17 years	Untreated dental caries (stains, white spots, pitted enamel, and erosion were not included)	PR for household SES (household income to poverty ratio) = 0.79 (95% CI: 0.64- 0.97, $P = .03$)	-	-	-	-	-
7	Frazaio et al., ³⁷ 2014	Brazil	203 school children aged 7-9 years	Untreated decayed deciduous and permanent teeth (dt+DT)	RR for upper tercile of household wealth index compared with lower tercile= 0.66 (95% CI: 0.46-0.95, $P = .024$) (P for trend = 0.037)	-	NS [†]	RR for boys compared with girls= 1.31 (95% CI: 1.02–1.67, $P = .032$)	RR for mother schooling >7 years compared with <4 years= 0.74 (95% CI: 0.56-0.99, $P = .045$)	-

8	Braunstein et al., ¹³ 2008 (2001-2002)	US	801 children aged 2-5 years	ECC: one or more primary teeth with decayed cavitated lesions, missing due to caries, or filled tooth surfaces	OR for Poverty Income Ratio <1.30 compared to $\geq 1.85 = 2.61$ (95% CI: 1.36-5.02), $P = .007$	OR for Mexican Americans compared to non-Hispanic whites = 2.12 (95% CI: 1.23-3.66), $P = .033$	$P < .001$	NS [†]	-	OR for the highest quartile of the Revised Child Diet Quality using a single 24-hour recall compared to the lowest and second lowest = 0.31 (95% CI: 0.18-0.56) and 0.43 (0.29-0.64), respectively, $P < .001$
			1097 children aged 6-11 years	dft	dft: NS	dft: NS	dft: $P = .027$	dft: $P = .002$	-	Soda consumption ($P = .002$) and total number of meals and snacks per day ($P < .001$) were associated with dft.
				DMFT	DMFT: $P = .036$	DMFT: NS	DMFT: $P < .001$	DMFT: NS	-	Quartiles of the Revised Child Diet Quality Index were associated with DMFT ($P = .045$).

B(M)MW: Brazilian (monthly) minimum wage; CI: confidence interval; d(m)(f)t: number of decayed (missing) (filled) primary teeth due to caries; D(M)(F)T: number of decayed (missing) (filled) permanent teeth due to caries; (S-)ECC: (severe) early childhood caries; MAR: mean nutritional adequacy ratio; NINQ: number of nutrients with an index of nutritional quality less than 1; NS: not significant; OR: odds ratio; PR: prevalence ratio; RC-DQI: Revised Child Diet Quality Index; RR: relative risk; SES: socioeconomic status; WHO: World Health Organization.

†: Unadjusted (based on crude analysis)

Figure Legends

Figure 1. PRISMA 2020 flow diagram of the study selection.

Figure 2. Pooled odds ratio of caries experience in food-secure and food-insecure children and adolescents based on (A) country, (B) age of participants, (C) caries assessment criteria, and (D) tooth type. Both: primary and permanent teeth; CI: confidence interval; d(m)(f)t/s: number of decayed, (missing), and (filled) primary teeth/tooth surfaces due to caries; D(MF)T: number of decayed (missing and filled) permanent teeth due to caries; FI: food insecurity; FS: food security; N: no; NM: not mentioned; OR: odds ratio, WSLs: white spot lesions; Y: yes.

Figure 3. Pooled odds ratio of caries experience in food-secure children and adolescents compared to those with (A) marginal, (B) low, and (C) very low food insecurity. Both: primary and permanent teeth; CI: confidence interval; d(mf)t/s: number of decayed (missing and filled) primary teeth/tooth surfaces due to caries; DT: number of decayed permanent teeth; FI: food insecurity; FS: food security; N: no; OR: odds ratio, WSLs: white spot lesions; Y: yes.

Figure 4. Meta-regression of the association between dental caries and food insecurity in children and adolescents based on (A) year of study, (B) sample size, (C) country under study, and (D) age of participants.

Figure 5. Egger's test results on publication bias.

Appendices

Appendix 1

Details of search strategy for electronic databases.

#	Database	Search strategy
1	MEDLINE (via PubMed)	("Dental Caries"[Mesh] OR (Dental Decay) OR (Cariious Dentin*) OR (Dental White Spot*) OR (White Spot*)) AND ("Food Supply"[Mesh] OR (Food Supplies) OR (Food Insecurity) OR (Food Insecurities) OR (Food Security))
2	EMBASE	((Dental Caries) OR (Dental Decay) OR (Cariious Dentin*) OR (Dental White Spot*) OR (White Spot*)) AND ((Food Supply) OR (Food Supplies) OR (Food Insecurity) OR (Food Insecurities) OR (Food Security))
3	Cochrane Central Register of Controlled Trials (CENTRAL), Cochrane Database of Systematic Reviews	("Dental Caries" OR (Dental Decay) OR (Cariious Dentin*) OR (Dental White Spot*) OR (White Spot*)) AND ("Food Supply" OR (Food Supplies) OR (Food Insecurity) OR (Food Insecurities) OR (Food Security))
4	Web of Science (all databases)	
5	SCOPUS	
6	ProQuest Dissertations & Theses Database Global	

Appendix 2

Excluded records identified from electronic search and reasons for exclusion from the systematic review.

No.	Author, Publication year	Main reason for exclusion
1	Miller and Morrissey, ³³ 2021	Dental caries was not assessed among health outcomes
2	Patel, ³⁴ 2021	Food insecurity was not assessed by a specific questionnaire (Food desert was identified by patients' ZIP code of residence)
3	Bencze et al., ²³ 2021	Food insecurity was not assessed as a risk factor of early childhood caries
4	Jackson and Testa, ²⁶ 2021	Child teeth condition was evaluated through a question asking from caregivers
5	Sachdev et al., ²⁹ 2021	Participants were adult women aged 18-50 years
6	Bahanan, ²² 2019	The full text of this thesis document could not be retrieved. However, its published report was available. ³⁵
7	Calache et al., ²⁴ 2019	Food insecurity was not assessed among the potential risk factors for dental caries
8	Ziegler et al., ³¹ 2019	The full text could not be retrieved
9	Bae and Obounou, ²¹ 2018	Presence of dental caries was identified through asking a question in the health interview
10	Weigel et al., ³⁰ 2016	Dental disease was assessed by a structured questionnaire
11	Ismail et al., ²⁵ 2008	Food insecurity was not assessed among the caries risk indicators

12	Jamieson and Koopu, ³² 2008	A computer-based home interview was used to collect data on dental health
13	Jamieson and Koopu, ²⁸ 2007	A computer-based home interview was used to collect data on dental health
14	Jamieson and Koopu, ²⁷ 2006	A computer-based home interview was used to collect data on dental health

Appendix 3

Risk of bias of included studies in the systematic review, assessed by Newcastle-Ottawa quality assessment scale adapted for cross-sectional studies.

#	Author, Year of publication	Selection				Comparability	Outcome		Total score*
		Representativeness of the sample	Sample size	Non-respondents	Ascertainment of exposure	Controlling confounding factors/ Comparability of subjects	Assessment of outcome	Statistical test	
1	Bahanan et al., ³⁵ 2021	*	*		**	**	**	*	9
2	Tsai & Lawrence, ¹⁵ 2021	*	*	*	*	**	**	*	9
3	Hill, ³⁸ 2020	*	*		**	**	**	*	9

#	Author, Year of publication	Selection				Comparability	Outcome		Total score*
		Representativeness of the sample	Sample size	Non-respondents	Ascertainment of exposure	Controlling confounding factors/ Comparability of subjects	Assessment of outcome	Statistical test	
4	Kim et al., ⁴⁰ 2020	*			**	**	**		7
5	Angelopoulou et al., ¹² 2019		*		**	*	**		6
6	Ferreira et al., ¹⁴ 2019 Santin et al., ³⁹ 2016	*	*		**	**	**	*	9
7	Chi et al., ³⁶ 2014	*	*		**	**	**	*	9

#	Author, Year of publication	Selection				Comparability	Outcome		Total score*
		Representativeness of the sample	Sample size	Non-respondents	Ascertainment of exposure	Controlling confounding factors/ Comparability of subjects	Assessment of outcome	Statistical test	
8	Frazaio et al., ³⁷ 2014	*			**	**	**	*	8
9	Braunstein et al., ¹³ 2008- Chapter 2	*	*		**	**	**	*	9
10	Braunstein et al., ¹³ 2008- Chapter 3	*	*		**	**	**		8

* 7-10: low risk of bias, 5-6: moderate risk of bias, 0-4: high risk of bias

Figure 1

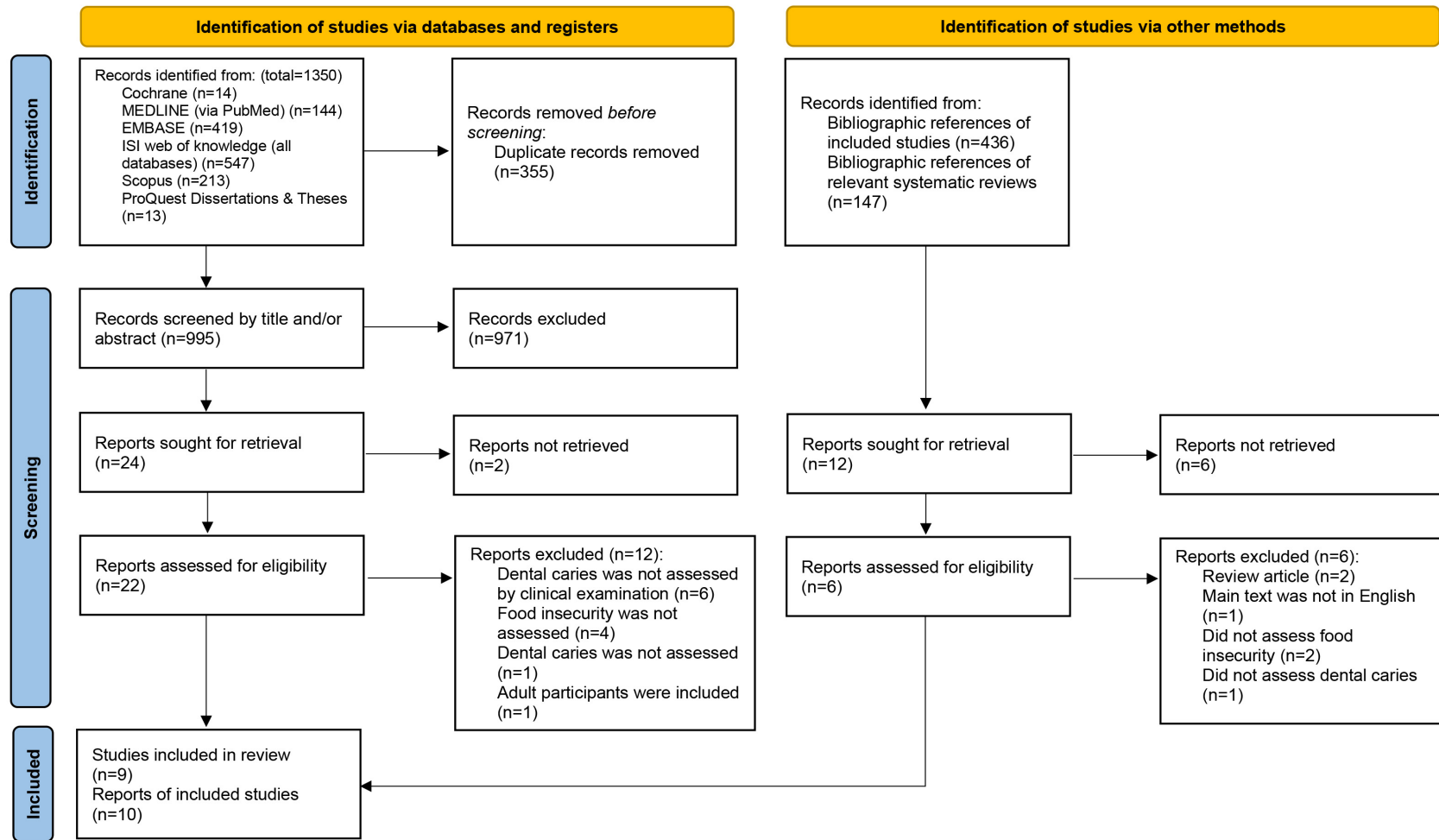


Figure 2

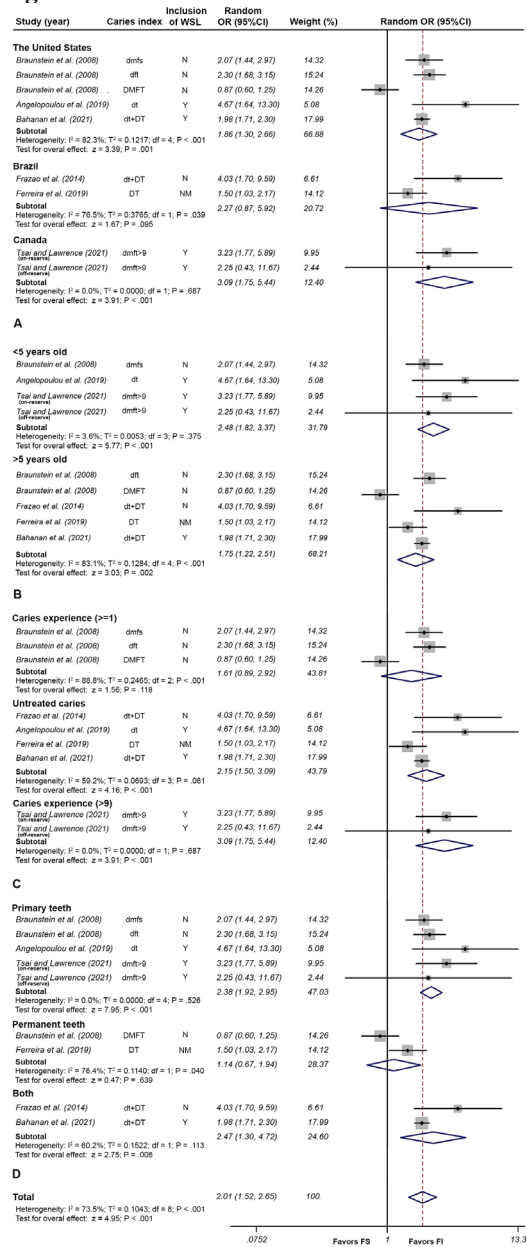
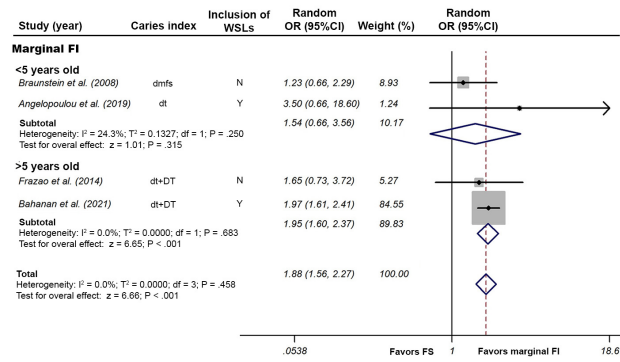
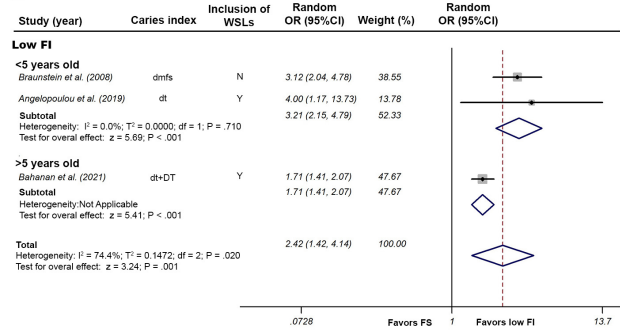


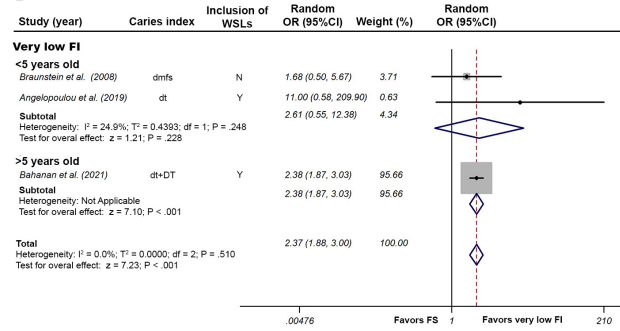
Figure 3



A



B



C

Figure 4

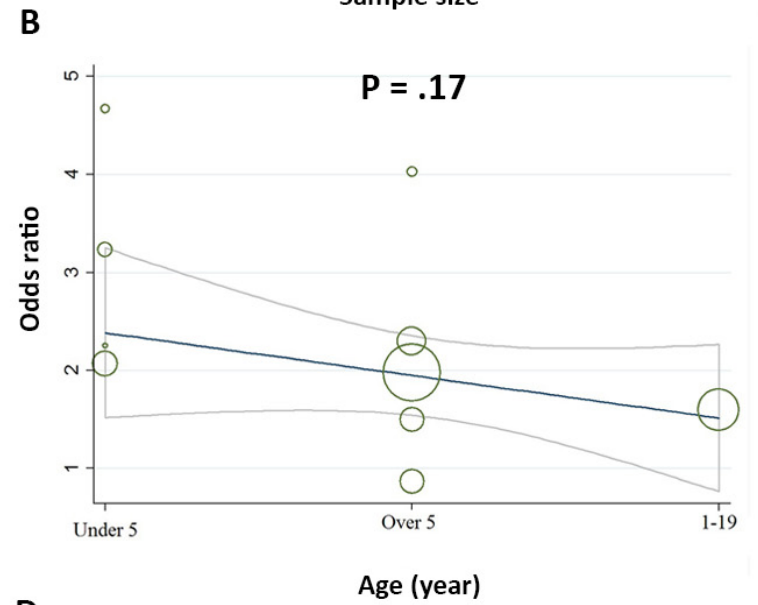
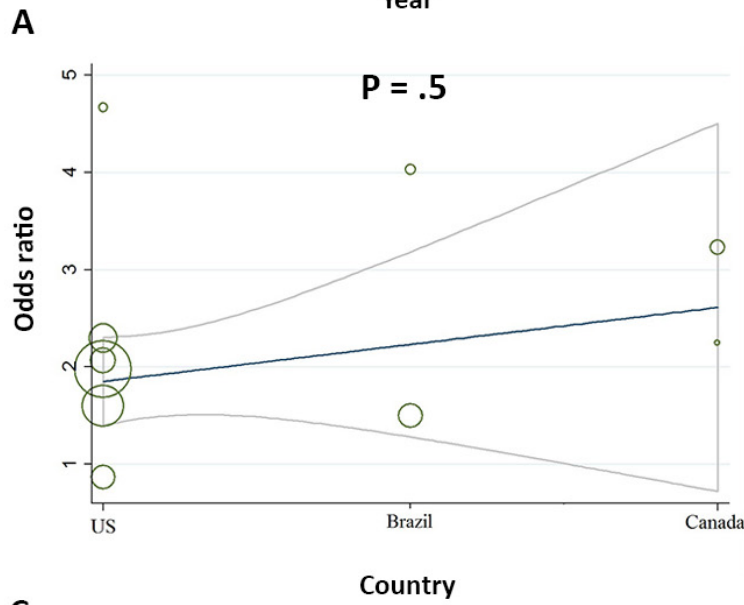
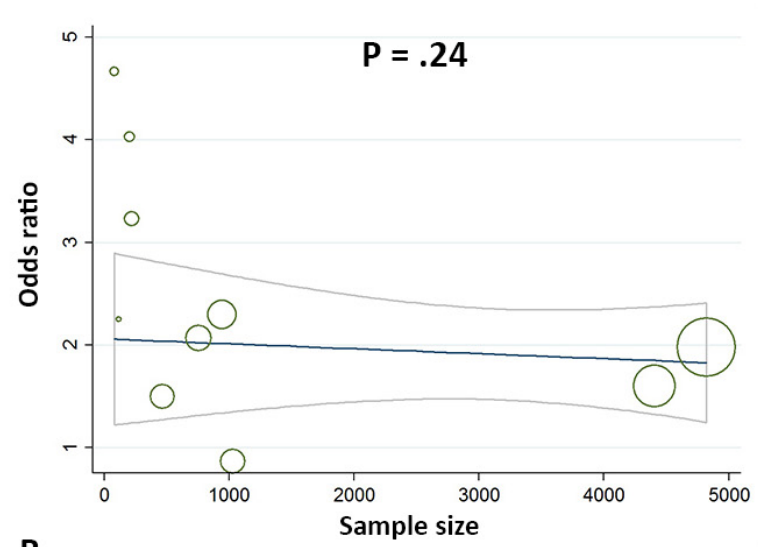
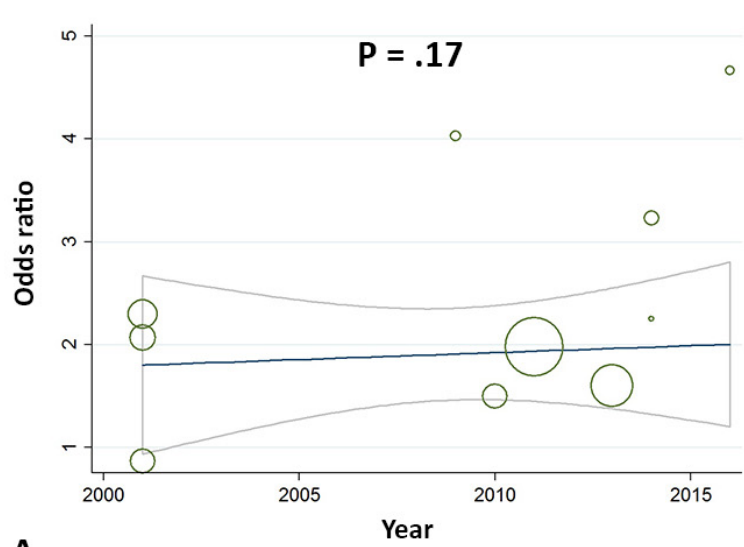


Figure 5

