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REVIEW ARTICLE

Breastfeeding and the risk of dental caries: a systematic review and meta-analysis

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ABSTRACT

Aim: To synthesise the current evidence for the associations between breastfeeding and dental caries, with respect to specific windows of early childhood caries risk.

Methods: Systematic review, meta-analyses and narrative synthesis following searches of PubMed, CINAHL and EMBASE databases.

Results: Sixty-three papers included. Children exposed to longer versus shorter duration of breastfeeding up to age 12 months (more versus less breastfeeding), had a reduced risk of caries (OR 0.50; 95%CI 0.25, 0.99, I^2 86.8%). Children breastfed >12 months had an increased risk of caries when compared with children breastfed <12 months (seven studies (OR 1.99; 1.35, 2.95, I^2 69.3%). Amongst children breastfed >12 months, those fed nocturnally or more frequently had a further increased caries risk (five studies, OR 7.14; 3.14, 16.23, I^2 77.1%). There was a lack of studies on children aged >12 months simultaneously assessing caries risk in breastfed, bottle-fed and children not bottle or breastfed, alongside specific breastfeeding practices, consuming sweet drinks and foods, and oral hygiene practices limiting our ability to tease out the risks attributable to each.

Conclusion: Breastfeeding in infancy may protect against dental caries. Further research needed to understand the increased risk of caries in children breastfed after 12 months.

INTRODUCTION

Dental caries (tooth decay) is a major public health problem affecting 60–90% of school-aged children (1), with increased prevalence in children from lower socio-economic groups (2). It is caused by multi-factorial and complex interactions between cariogenic bacteria in the mouth with dietary carbohydrates that produce acids and demineralise the teeth (2). The pain and infection caused by dental caries can be extremely distressing and can impact on quality of life and ability to function (3), lead to lost productivity and involve high health care costs (4) including general anaesthesia for treatment of severe cases. This accounts for one of the most common causes of child hospitalisation in industrialised countries (5) and is among the most common causes of avoidable child hospitalisations (6). Early loss of deciduous dentition can lead to ongoing dental problems in the permanent dentition.

The evidence concerning infant feeding as a risk factor for dental caries is inconsistent. Dental caries risk is related to the carbohydrate content of breast milk or formula along with factors which determine the length of contact between breast milk or formula and the erupted dentition (i.e. frequency of feeding, and feeding practices which result in pooling of breast milk or formula around the teeth surfaces, such as feeding babies to sleep). The central determinant of caries risk, however, is the age of colonisation and levels of cariogenic bacteria (e.g. *Streptococcus mutans*) (7) in an infant's mouth. Earlier and denser oral colonization by cariogenic bacteria are related to increased caries risk (8). Breast milk, in contrast to formula, contains breast-specific

Abbreviations
95%CI, 95% Confidence Intervals; NOS, Newcastle Ottawa Scale; OR, Odds ratio; RCT, Randomized controlled trials; RR, Relative risk; WHO, World Health Organization.

Key notes

- Children exposed to more versus less breastfeeding up to 12 months had reduced risk of dental caries.
- Increased risk of dental caries in children breastfed >12 months, especially if frequent or nocturnal, may be due to unmeasured confounders including dietary sugars and oral hygiene practices.
- Research should simultaneously investigate breastfeeding practices including frequency and nocturnal routines, along with dietary and oral hygiene practices to more accurately determine specific risks.

Lactobacilli and substances, including human casein and secretory IgA, which inhibit the growth and adhesion of cariogenic bacteria, particularly oral *Streptococci* (9,10). The risk of dental caries is also dependent on the presence of teeth and rises with increasing number of teeth. Risk also changes as the infant's diet starts to include foods and drinks other than breast milk or formula, depending on the carbohydrate content, acidity and consumption frequency of the introduced diet.

The important aspect of timing of tooth eruption for our systematic review is that the deciduous teeth most at risk of early childhood caries (eight upper and lower central and lateral incisors) start to erupt at 6 months and are fully erupted by 12 months. The next most vulnerable deciduous teeth (four upper and lower first molars) erupt between 13 and 19 months, the remainder are erupted by 33 months (11).

Current WHO breastfeeding guidelines recommend exclusive feeding for the first 6 months of life and complementary breastfeeding up to 2 years (12). Although the UNICEF calculated global prevalence of breastfeeding at 12 months from 62 countries is 74%, this figure hides the underlying heterogeneity between countries (13). As opposed to low income countries, the duration of total breastfeeding in high/middle income countries is shorter with only 21% of US mothers breastfeeding at 12 months (14) and similar rates in the UK (13), Canada (5) and Australia (15). National guidelines in high/middle income countries, where the risk of infant morbidity and mortality from gastrointestinal disease is relatively low, recommend breastfeeding for at least 12 months (16). Thus, investigating windows of exposure before and after 12 months of age is relevant to breastfeeding guidelines and practices as well as timing of tooth eruption.

The relationship between breastfeeding and dental caries has been systematically (17) and narratively reviewed (18–20) with conflicting results between studies. There is controversy about what constitutes the best form of infant feeding to prevent dental caries and promote optimal dental health (21). Consequently no definitive optimal weaning times or breastfeeding practices have been determined to specifically address the risk of dental caries.

AIM

To summarise the current evidence for the association between breastfeeding and dental caries with specific reference to exposure windows and breastfeeding practices.

METHODS

Search strategy

We identified human English language studies through systematically searching electronic databases: PubMed Central, CINAHL and EMBASE from inception to the present. Our exposure of interest was breastfeeding as compared to formula or other feeding. Our outcome of interest was the development of dental caries in deciduous or permanent teeth. An extensive list of search terms was used and is reported in Table 1.

Table 1 Search terms used for the three databases electronically searched

[PUBMED]
#1 "Breast Feeding"[Mesh]
#2 "Milk, Human"[Mesh]
#3 Breast[All Fields] AND Feed*[All Fields]
#4 Breast-fe*[All Fields]
#5 Infant fe* [All Fields]
#6 Infant nutrition* [All Fields]
#7 #1 OR #2 OR #3 OR #4 OR #5 OR 6
#8 Dental caries (MeSH)
#9 Tooth decay
#10 "Early childhood caries"
#11 "Nursing bottle caries"
#12 #8 OR #9 OR #10 OR #11
#13 animals [mh] NOT humans [mh]
#14 #7 AND #12
#15 #14 NOT #13
[EMBASE]
#1 'breast feeding'/exp
#2 'breast milk'/exp
#3 Breast AND Feed*
#4 Breast-fe*
#5 Infant fe*
#6 Infant nutrition*
#7 #1 OR #2 OR #3 OR #4 OR #5 OR 6
#8 'dental caries'/exp
#9 Tooth decay
#10 "Early childhood caries"
#11 "Nursing bottle caries"
#12 #8 OR #9 OR #10 OR #11
#13 [animals]/lim NOT [humans]/lim
#14 #7 AND #12
#15 #14 NOT #13
[CINAHL]
#1 "Breast Feeding"
#2 "Milk, Human"
#3 Breast AND Feed*
#4 Breast-fe*
#5 Infant fe*
#6 Infant nutrition*
#7 S1 OR S2 OR S3 OR S4 OR S5 OR S6
#8 dental caries
#9 tooth decay
#10 early childhood caries
#11 nursing bottle caries
#12 S8 OR S9 OR S10 OR S11
#13 S7 AND S12
**For #13 limit to 'Human'

We checked reference lists of all primary studies and review articles for additional references. The titles and abstracts were independently reviewed for initial inclusion by two researchers (RT and GB). Disagreement was resolved by discussion and if consensus could not be reached, a third author (CL) made the final decision.

Eligibility criteria

We included observational and experimental studies published in full text. We included children and adolescents from both general and high-risk populations (e.g. low socio-economic communities). Dental caries as reported by appropriately qualified practitioner/researchers, a parent or through health records databases were included. We excluded participants who were born prematurely (<36 weeks gestation) because these infants are often fed by other sources and can have complicated medical interventions.

Assessment of quality and risk of bias

Two researchers (RT and GB) independently conducted a quality assessment of each study using the Newcastle-Ottawa Scale (NOS) (22). Study quality was graded on a scoring system (see Tables 2–5 for key criteria). Differences in assessment and grading were resolved by discussion with a third researcher (CL).

The assessment of risk of bias was guided by the GRADE system for rating the quality of the evidence of observational studies (23).

Literature review identified key confounders that should be controlled for in breastfeeding and dental caries studies: socio-economic status, age, mother's educational level, number of teeth, and exposure to sugar in the diet (food or other liquid).

Data extraction

We extracted: study design; study country; age range of children; number of children; exposure and outcome definitions; how the outcome data were measured; effect estimates; confounders included in analysis; sub-group analysis; interactions; and findings.

Assessment for meta-analysis

Exposure and outcome definitions and effect estimates (odds ratios (OR), relative risks, prevalence ratios) with 95% Confidence Interval (95%CI) were abstracted where available for inclusion in a meta-analysis. Given the biological plausibility of the potential associations, we aimed to assess exposure to breastfeeding in two specific time windows: (i) Up to 12 months of age (upper and lower incisors present) and (ii) Beyond 12 months of age (other teeth erupting up to 33 months- increased risk of caries). As there were very few mothers who exclusively breastfed infants until 12 months or beyond, within these time windows we categorized studies into: (i) Never breastfed compared to any breastfeeding and (ii) More versus less breastfeeding. This category was created to include all

Table 2 Newcastle-Ottawa Quality Assessment score for Cohort studies nested in Randomized Controlled Trials

RCT	Representativeness	Selection of non- exposed cohort	Ascertainment of exposure	Outcome of interest not present at start	Comparability	Assessment of outcome	Adequate follow up time	Adequate follow up of cohorts	Score/10
Feldens et al. (30)	*	*	*	*		**	*	*	8
Feldens et al. (27)	*	*	*	*		**	*	*	8

Table 3 Newcastle-Ottawa Scale Quality Assessment score for Cohort Studies

Cohort studies	Representativeness	Selection of non-exposed cohort	Ascertainment of exposure	Outcome of interest not present at start	Comparability	Assessment of outcome	Adequate follow up time	Adequate follow up of cohorts	Score/10
Feldens et al. (25)	*	*	*	*	**	**	*	*	10
Chaffee et al. (26)	*	*	*	*	*	*	*	*	8
Hong et al. (31)	*	*		*	**	**	*		8
Kramer et al. (29)	*	*	*	*		**	*	*	8
Kramer et al. (28)	*	*	*	*		**	*	*	8
Ollila (38)	*	*		*		**	*	*	7
Silver (32)		*	*			*	*	*	5
Tada et al. (33)		*				*	*	*	5
Tanaka et al. (34)	*	*		*	**	**	*		8
Thitasomakul et al. (35)	*	*	*	*		**	*		7
van Palenstein Helderman et al. (36)		*	*			**	*	*	6
Yonezu et al. (37)		*				**	*	*	5

Table 4 Newcastle-Ottawa Scale Quality Assessment score for Case-Control Studies

Case control	Adequate case definition	Representativeness of cases	Selection of controls	Definition of controls	Comparability	Ascertainment of exposure	Method of ascertainment	Nonresponse rate	Score/10
Bahuguna et al. (39)	*			*	*		*	*	5
Matee et al. (40)	*		*	*			*		4
Roberts et al. (41)			*	*	**			*	5

studies, which compared groups with relatively more (longer duration of breastfeeding) and relatively less breast milk exposure (shorter duration). To choose between multiple reported ORs for a single study we preferentially selected: estimates for exclusive breastfeeding or, if not available, any breastfeeding; then the longest duration compared with the shortest. If there were multiple ages of outcome within the particular group then we chose the oldest age reported.

We performed meta-analysis if there were three or more studies in each time window and category of breastfeeding. Random effects meta-analyses were performed if the heterogeneity (I^2) was >25%. Heterogeneity was considered to be high, and results unreliable if I^2 values were >75%. We were unable to quantitatively assess for publication bias as no group contained more than 10 studies. Studies not meeting these criteria were qualitatively assessed.

Statistical analysis was performed using Stata IC 13 (StataCorp., LP Texas, USA).

RESULTS

Search results

Electronic literature search (2 October 2014) and manual search found 480 peer-reviewed scientific articles after duplicate papers were removed. Of these, 366 were excluded after abstract review for failing to meet the eligibility criteria. A large number of these papers were not related to breastfeeding or dental caries, were not in English or were not original research. Of the remaining 114 full text articles, 51 were excluded as: (i) they did not assess the relevant exposure (breastfeeding) and outcome (dental caries) or (ii) all feeding types were analysed together or (iii) data were duplicated in more than one paper or (iv) no analysis was reported or studies lacked control or comparator groups [Fig. 1 (24)]. In total 63 papers were included.

Characteristics of included studies

Although the 63 papers did not include randomised controlled trials (RCT) of breastfeeding, six cohort studies (25–30) were nested within RCTs of breastfeeding promotion interventions. There were eight additional cohort studies (31–38) and three case–control studies (39–41). The remaining 46 studies were cross-sectional in design (42–86). The studies were predominantly conducted in high and middle income countries with only eight studies from low income countries (87). All caries outcomes were assessed by dental professionals through oral examination. Key characteristics are summarised in the Appendix.

Quality assessment

Tables 2 3, 4, and 5 detail the NOS score assigned to each included study. The cohort and cross-sectional studies that were embedded in RCTs of a range of breastfeeding promotion interventions (25–30) scored highly as the study designs overcame many sources of bias and reporting limitations that were apparent in the other cohort, case–control and cross-sectional studies. Other cohort studies were weakened by the method used to ascertain infant feeding practices (self-report) which subjected them to recall bias, recruitment of children through oral health services (selection bias), lack of reporting of the absence of caries at the commencement of the study (ascertainment bias), loss to follow –up and accounting for these participants (attrition bias), and lack of controlling for confounders. Case–control study designs were inherently subject to recall bias when ascertaining infant feeding practices. Furthermore, cases and controls were not representative of the broader population as they were recruited in settings where children were likely to have caries. Selection bias was also a problem as the selection of controls was not clearly described. Cross-sectional studies were the weakest but most common study design. The studies which scored <4 were classified as unsatisfactory due to major limitations in study design and reporting. Studies that scored 4 were classified as satisfactory, however, all of these studies lacked consideration of key confounders. In the higher quality studies (≥5) there were limitations in how exposure was ascertained as many studies used self-report questionnaires (recall bias).

Meta-analysis

We meta-analysed the small number of studies which included statistical effect measures.

Breastfeeding up to 12 months of age

One prospective cohort (34) and four cross-sectional studies (48,52,59,70) reported odds ratios for the association between children who were exposed to more versus less breastfeeding up to 12 months (OR 0.50; 0.25–0.99, I^2 86.8%) (Fig. 2). There were not enough studies to perform metaregression for formal investigation of this heterogeneity. There appeared to be differences, however, based on the comparison groups of the included studies. The two studies

Table 5 Newcastle-Ottawa Scale Quality Assessment score for Cross-sectional Studies

Cross-sectional	Representativeness	Selection of non-exposed cohort	Ascertainment of exposure	Comparability	Assessment of outcome	Score/7
Alaluusua et al. (42)		*	*		*	3
al-Dashti et al. (43)		*	*		**	4
Azevedo et al. (44)	*	*	*		**	5
Campus et al. (45)	*	*		**	*	5
Cariño et al. (46)		*			**	3
Dini (47)	*	*		*	*	4
Du et al. (48)		*		**	*	4
Dye et al. (49)	*	*		**	**	6
Folayan et al.(50)		*	*	*		3
Folayan et al. (87)		*	*		*	3
Forsman et al. (51)		*	*		*	3
Hallett et al. (52)	*	*		**	**	6
Hallonsten et al. (53)		*	*		*	3
Haq et al. (54)			*		*	2
Hardy (55)	*					1
Harrison et al. (56)		*	*		**	4
Holt et al. (57)		*	*		*	3
Hong et al. (58)	*	*		**	*	5
Iida et al. (59)	*	*	*	*	*	5
Johansson et al. (60)		*	*		*	3
Livny et al. (61)		*	*		*	3
Majorana et al. (62)	*	*			**	4
Masumo et al. (63)	*	*	*		**	5
Mattos-Graner et al. (64)		*	*		**	4
Nobile et al. (65)		*		*	*	3
Nunes et al. (66)		*		**	**	5
Perera et al. (67)		*	*		*	3
Prakash et al. (68)	*	*	*		*	4
Prakasha Shrutha et al. (69)	*	*				2
Qadri et al. (70)	*	*	*		*	4
Retnakumari (71)		*	*		*	3
Rosenblatt (72)		*	*		*	3
Sankeshwari et al. (73)	*	*			*	3
Santos (74)		*			*	2
Sayegh et al. (75)	*	*			**	4
Sayegh et al. (76)	*	*		*	**	5
Serwint et al. (77)		*	*		*	3
Slabsinskiene et al. (78)	*	*			*	3
Songo et al. (79)		*			*	2
Tanaka, (80)	*	*		**	*	5
Tiano et al. (81)		*	*		*	3
Tyagi, (82)					*	1
Vachirarojpisan et al. (83)	*	*	*	*	*	5
Vazquez-Nava et al. (84)	*	*		**	*	5
Wendt (85)	*	*	*		*	4
Yonezu et al. (86)		*				1

which compared ever breastfeeding in the first 12 months with never breastfeeding (48,70), both showed a marked protective effect of breastfeeding on dental caries compared with other feeding. Whereas the three studies which compared a longer duration of breastfeeding in the first 12 months to a comparison group which included children who had had some exposure to breastfeeding did not (34,52,59). A meta-analysis on this three study subgroup found an OR of 0.92; 0.69–1.23, I^2 0% (Fig. 3).

Breastfeeding after 12 months of age

Two cohort studies (33,34), one case control study (40) and four cross-sectional studies (52,65,75,78) reported odds ratios for the association between more or less breastfeeding after the age of 12 months and dental caries. The comparison groups for these studies included both those who had never been breastfed and those who had been breastfed for shorter durations. The pooled estimate was OR 1.99; 1.35–2.95, I^2 69.3% (Fig. 4).

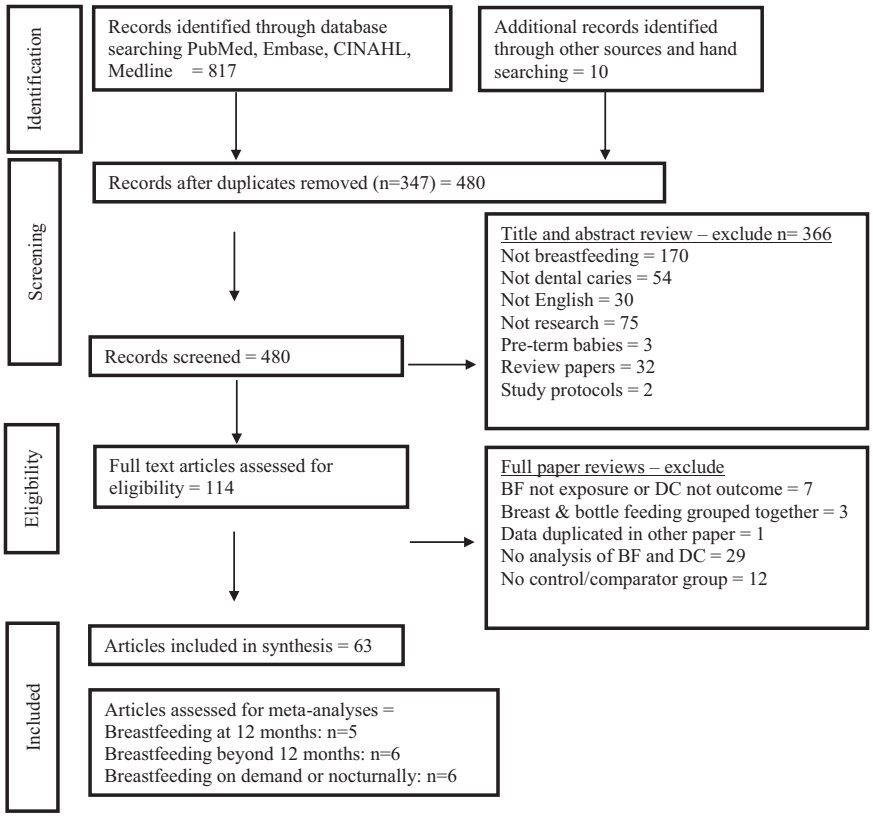

Figure 1 PRISMA Flow diagram of review.

Only two studies (26,80) reported prevalence ratios so these could not be meta-analysed.

Nocturnal breastfeeding in those breastfed longer than 12 months

One cohort (36), one case–control (40) and three cross-sectional studies (67,84,86) reported odds ratios for the association between more versus less nocturnal breastfeeding and the risk of dental caries amongst the subgroup of children breastfed longer than 12 months. The pooled estimate was OR 7.14; 3.14–16.23, I^2 77.1% (Fig. 5).

Narrative synthesis

The majority of studies (n = 46) were not included in the meta-analyses due to methodological differences in the measures of exposure and outcomes, or reporting of correlational analyses only.

Studies embedded in randomised controlled trials (RCTs)

It is not ethical to conduct randomized trials assigning participants to breastfeeding and non-breastfeeding groups in order to more definitively assess the association between breastfeeding and dental caries. However, a number of RCTs have been conducted that investigated the impact of breastfeeding promotion programmes (25–30). In a RCT of an intervention that provided monthly advice on healthy feeding practices over 12 months via home visits in Brazil (25,27,30) the intervention group demonstrated a lower incidence of caries at 12 months (OR = 0.52, 0.27–0.97, p = 0.03) and 4 years (RR = 0.78, 0.65–0.93, p = 0.004). Investigating breastfeeding frequency at 12 months, the study also found a doubled risk of caries when feeding frequency was 3–6 times/day (RR = 2.04, 1.22–3.39, p = 0.000) and ≥7 times/day (RR = 1.97, 95%CI 1.45–2.68, p = 0.000) compared to 0–2 times/day. Analyses were adjusted for maternal schooling level, daily meals, bottle use for fruit juice/soft drinks, consumption of high density sugar and number of teeth. Another birth cohort study nested in an intervention conducted through maternal health centres in Brazil (26) found that, in adjusted regression models, as breastfeeding continued beyond 6 months the prevalence ratio of caries in breastfed children increased (compared to breastfeeding <6 months) but was only significant when still breastfeeding at ≥24 months: 6–11 months (PR = 1.45, 95% CI 0.83–2.53); 12–23 months (PR = 1.39, 95%CI 0.73–2.64); ≥24 months (PR = 1.85, 95%CI 1.11–3.08). A birth cohort study nested in a breastfeeding promotion intervention in Belarus found no significant difference in caries incidence or prevalence in the intervention group when children were aged 6.5 years (28,29).

Breastfed versus formula fed

Studies that examined ever versus never breastfed children reported a range of findings. Six cross-sectional studies

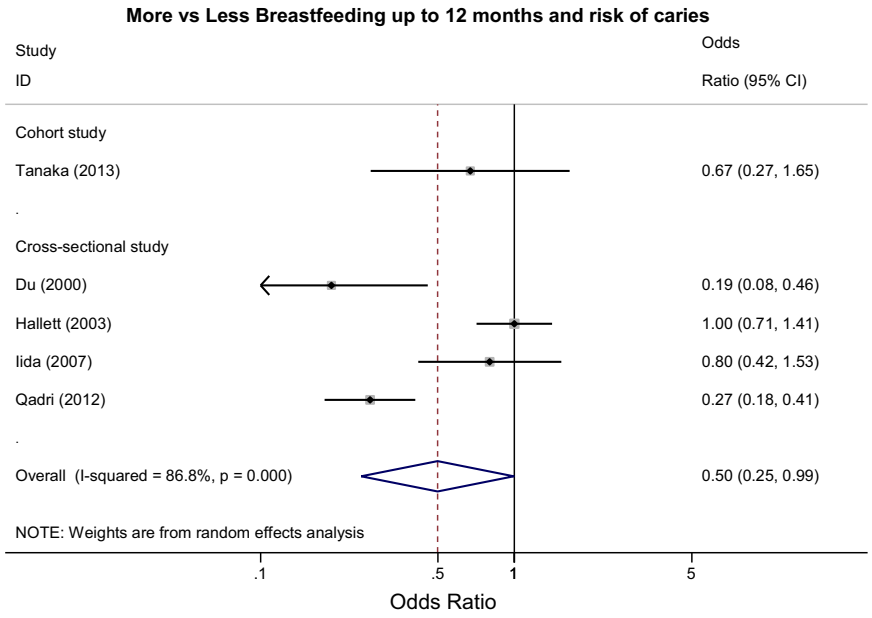

Figure 2 More versus Less breastfeeding (including never breastfed) up to 12 months of age and the risk of dental caries

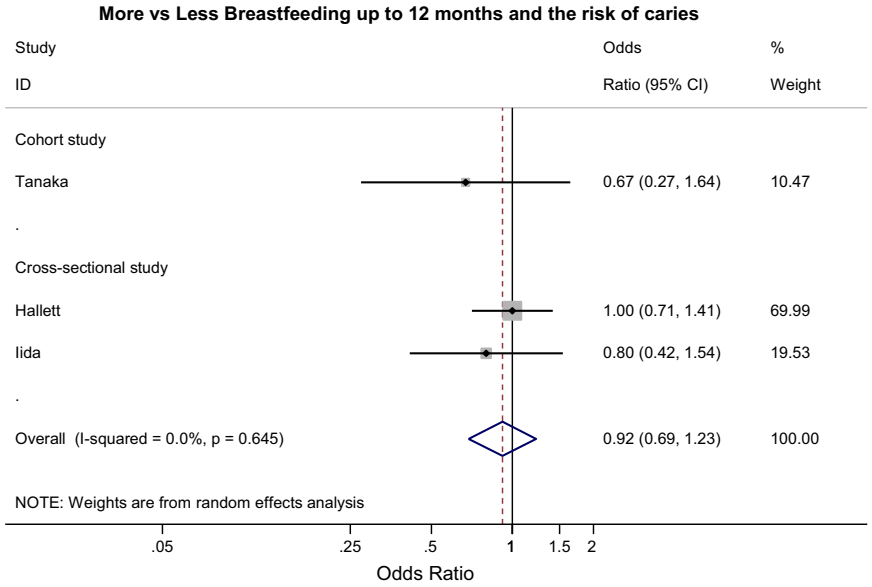

Figure 3 More versus Less Breastfeeding (excluding never breastfed) up to 12 months of age and the risk of dental caries.

reported no significant difference in the prevalence of caries between the two groups (49,61,72–74,83); one cohort and one cross-sectional study reported significantly lower caries in breastfed children (32,57); one cross-sectional study found a lower adjusted caries risk in breastfed versus bottle-fed children (OR = 0.61, 95%CI 0.39–0.97, p = 0.038) (70); one cohort study reported higher caries increment in breastfed children between 12 to 18 months but the association disappeared in the multivariate analysis (35); one cross-sectional study reported an increased risk of dental caries in ever breastfed children of borderline significance (p = 0.08) (77); and one cross-sectional study found a lower adjusted caries risk in breastfed versus bottle-fed children.

Breastfeeding duration

Three of four cohort studies found that breastfeeding beyond 12 months was correlated or associated with increased caries

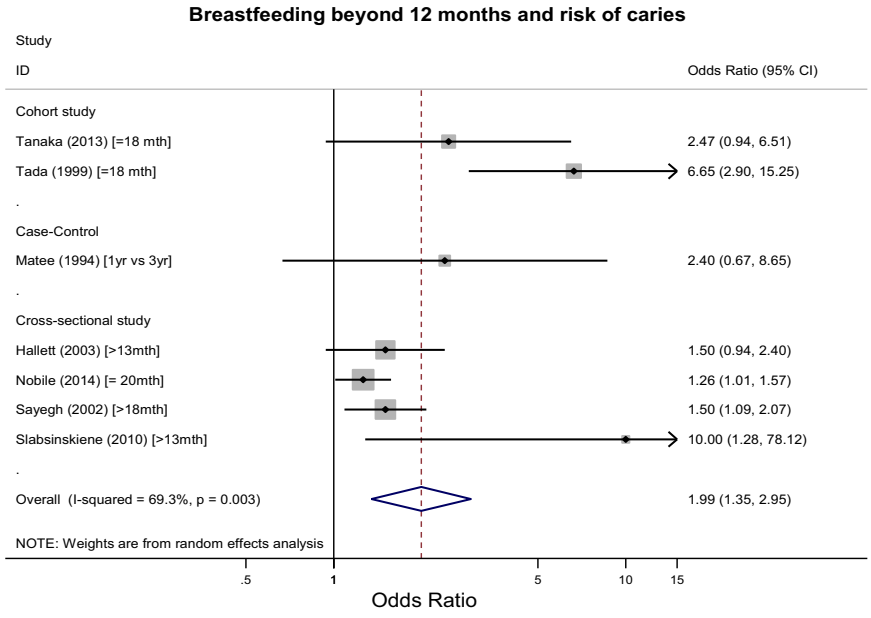

Figure 4 Breastfeeding beyond 12 months and the risk of dental caries.

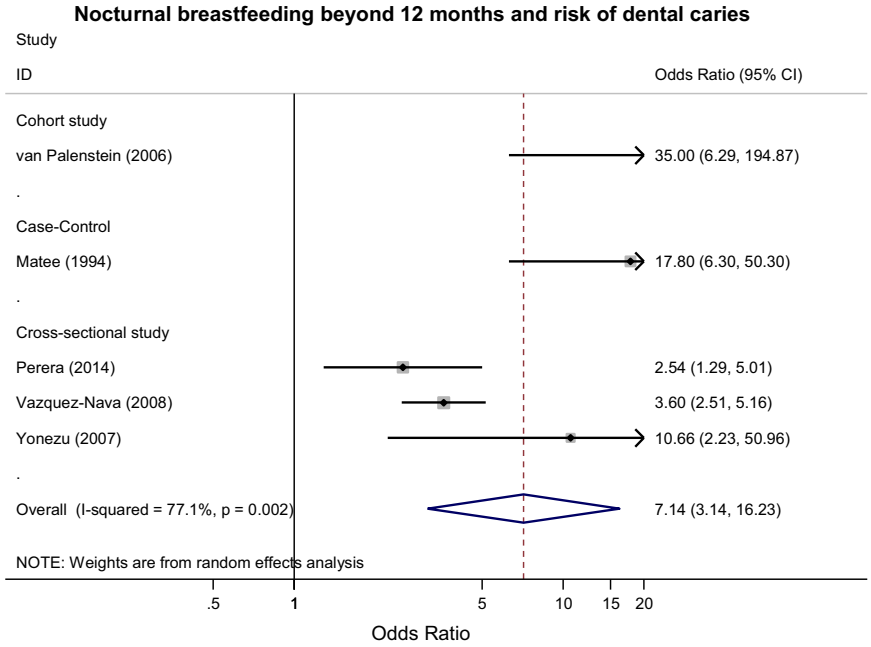

Figure 5 More versus Less nocturnal breastfeeding and the risk of dental caries in those breastfed longer than 12 months.

prevalence compared with shorter durations of breastfeeding. Chaffee et al. (26) found that the adjusted prevalence ratio of caries in children breastfed ≥24 months was 2.1 (95%CI 1.5–3.25) compared to children breastfed <6 months. Yonezu et al. (37) found significantly more caries in children breastfed >18 months than those weaned <18 months. Feldens et al. (25) found the risk of caries rose in children breastfed beyond 12 months. Ollila et al.'s (38) survival analysis found no difference between children breastfed >12 months and those not. Cross-sectional studies reported variable findings: increased caries prevalence in children breastfed longer than those breastfed for shorter times (44,45,53,54,63,65,71,75,78,81,85); and no difference in caries prevalence between duration groups (66,82).

The few studies that controlled for confounding factors found decreased caries risk with shorter breastfeeding duration (6–12 months) compared to longer duration (>13 months) (26,34,45,76,80) and increased risk of caries if breastfed <6 months (31,48).

Breastfeeding on demand and nocturnally

In addition to the meta-analysed studies, a number of cross-sectional studies reported significant correlations between infants/children breastfed during the night (44,67), on demand (68) or sleeping with a nipple in the mouth (60,71,76) and increased prevalence of dental caries. One cohort study found an increased adjusted risk of dental caries with increased daily breastfeeding frequency including nocturnal feeding (25).

DISCUSSION

Qualitative assessment of studies investigating breastfeeding up to 12 months of age suggested that children who were exposed to more breastfeeding (longer duration) compared to less or no breastfeeding were protected from dental caries. Meta-analysis of five studies also found reduced risk of dental caries in children breastfed more versus less up to 12 months, however, the heterogeneity between studies was too high to make the estimate reliable. In contrast, children who were breastfed beyond 12 months had an increased prevalence of dental caries. Amongst those who continued to be breastfed after 12 months, there was a further increased risk of caries in children who were breastfed nocturnally.

Three elements are essential for dental caries to occur: a tooth, cariogenic bacteria (e.g. *Streptococcus mutans*) and substrate for the bacteria (sugar) (2). The risk of developing dental caries changes as factors associated with each element change. The first tooth usually erupts in an infant's mouth between 6 and 12 months of age. As each tooth erupts the risk of developing dental caries increases, hence age and number of teeth increases risk. Cariogenic bacteria are transmitted to the child via close contact with the mother's saliva (88) but their levels and cariogenicity vary between individuals (2) depending on maternal bacterial levels, maternal caries prevalence, oral hygiene practices and exposure to dietary sugars (21). Breast milk is known to contain immunomodulatory factors along with a rich microbiome which is responsible for establishing normal intestinal flora (89). Initial protection from dental caries may be mediated through establishment of a healthy oral microbiome in infants through exposure to breastfeeding and contact with skin and breast milk microbiomes. Additionally, the child's oral microbiome changes over time with the emergence of new teeth. The essential substrates for cariogenic bacteria are simple carbohydrates (sugars) which can be in a range of forms (e.g. lactose, sucrose, glucose). The longer these sugars are in contact with teeth, the higher the risk of dental caries. The amount of carbohydrate (cariogenicity) contained in the different milks and formulas may also help to explain the different results we found before and after 12 months of age. The cariogenicity of human breast milk has not been extensively examined under *in vivo* conditions, however animal studies suggest that at high frequency exposures, human breast milk has greater cariogenicity compared to bovine milk but less than infant formula (90,91). Relative cariogenicity of breast milk will also depend on the comparison group. Below 12 months it is usual to feed infants either breast milk or formula which have around the same carbohydrate content. After 12 months, however, children in high income countries are often weaned onto cow's milk which has half the carbohydrate content of human milk. However, each element is subject to modification by risk factors such as socio-economic status, maternal educational level, maternal oral health, maternal smoking status, position in birth order, sugars in diet, oral hygiene and exposure to fluoride (2).

Breastfeeding duration, frequency of breastfeeding and nocturnal breastfeeding during sleep are most often analysed as separate breastfeeding behaviours, however they are inter-related. Nocturnal breastfeeding is often used to comfort an infant or child who may then fall asleep with the nipple in their mouth. In this position, the tongue fills the mouth and holds the breast milk against the surfaces of the teeth, thereby prolonging the exposure of the substrate to the cariogenic bacteria that are attached to the teeth surfaces and hence increasing the risk of dental caries. It is possible that children breastfed beyond 12 months are also engaging in nocturnal breastfeeding but the modification of dental caries risk by infant feeding practices has not been examined in depth in any of the studies included in this review. In addition, children >12 months are no longer being exclusively breast or bottle fed and the diet is expanding to include other fluids and solids. It has been reported that children who are breastfed for longer durations also have more frequent cariogenic food intakes (25,53,58). Oral hygiene practices to remove bacterial plaque are important as more teeth erupt to reduce the risk of dental caries. Only a few studies included in this review controlled for key confounding factors and this may have resulted in an overestimation of the role of prolonged, frequent and nocturnal breastfeeding in the development of dental caries. Until the dietary and oral hygiene details of these children are controlled for we cannot be certain whether prolonged, frequent or nocturnal breastfeeding can be principally associated with early childhood caries.

This is the first systematic review of breastfeeding and dental caries that includes critical exposure windows, limited meta-analyses and a range of study types. We provide quantitative evidence that is suggestive of the potentially protective effects of breastfeeding from dental caries up to 12 months, but higher risk of dental caries in children breastfed beyond 12 months, frequently, and/or nocturnally. However, there is high heterogeneity between the studies included in the meta-analyses (possibly due to differing comparison groups) and lack of controlling for key confounders (e.g. other foods/drinks in the diet, oral

hygiene, maternal oral health status) which limits the reliability of the results.

CONCLUSION

Breastfeeding up to 12 months of age is not associated with an increased risk of dental caries and in fact may offer some protection compared with formula. However, children breastfed beyond 12 months, a time during which all deciduous teeth erupt, had an increased risk of dental caries. This may be due to other factors which are linked with prolonged breastfeeding including nocturnal feeding during sleep, cariogenic foods/drinks in the diet, or inadequate oral hygiene practices. Further research with careful control of pertinent confounding factors is needed to elucidate this issue and better inform infant feeding guidelines. As per recommendations from previous reviews (17,19), the introduction of food sources to infants should be low in simple carbohydrates (sugars) and oral hygiene practices should start with the eruption of the first tooth so that bacterial plaque is removed from tooth surfaces to reduce the risk of dental caries.

CONFLICT OF INTEREST STATEMENT

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APPENDIX Study characteristics and summary of NOS QA

References [NOS QA score]	Type of study/brief description	Study population/Country	Sample size (gender % given if reported)	Exposure definition	Outcome definition and age	Exposure estimate (95% CI)	Other variables included in the models as confounders	Interactions
Randomised controlled trial (RCT)								
Feldens et al. (30) [8* Good]	RCT of an intervention that provided monthly advice on healthy feeding practices (exclusive breastfeeding up to 6 months. >6 months encouraged to continue breastfeeding and introduce foods) up to 12 months via home visits	Mothers who gave birth in public health system; Sao Leopoldi, Brazil; October 2001 – June 2002	N = 500 Intervention n = 200 Control n = 300	Intervention group received advice at home	Age 12 months Early Childhood Caries (ECC) –decayed surfaces ≥1 in any primary tooth (decay)	Intervention group risk of caries: OR = 0.52 (0.27–0.97) p = 0.03 cf control group	Number of teeth	
Feldens et al. (27) [8* Good]	As for Feldens et al. (2007)	Mothers who gave birth in public health system; Sao Leopoldi, Brazil; October 2001 – June 2002	N = 340 Boys = 195 (57.4%) Intervention n = 141 Control n = 199	Intervention group received advice at home	Age 4 years 1. ECC –dmfs ≥1 in any primary tooth (decay) 2. Severe-ECC (S-ECC) – dmfs ≥5 or one or more cavitated, missing, filled smooth surface of anterior teeth. 3. Affected teeth (decayed or cavitated) – dmft	Ref group = control with RR = 1.0 ECC: Interv RR = 0.78 (0.65–0.93) p = 0.004 NNT = 7 (4–20) S-ECC: Interv RR = 0.68 (0.5–0.92) p = 0.01 NNT = 8 (5–30) Affected teeth: Mean Interv = 3.25 (4.25) cf Control = 4.15 (4.57) p = 0.023	None reported	
Cohort								
Chaffee et al. (26) [8* Good]	Birth cohort study nested in a cluster RCT of an intervention in maternal health centres, 2008–2011	Birth to 38 months years; Porto Alegre, Brazil; Low income families	715 pregnant women	Breastfeeding duration: <6 months 6–11 months 12–23 months 24 months+	Dental status evaluated at 38 months Severe-ECC – 1 or more affected maxillary teeth or 4 or more decayed, missing due to caries or filled tooth surfaces (dmfs ≥4)	*Fully adjusted regression models* Breastfeeding at stages and S-ECC: *Prevalence ratio* <6 = 1 6–11 = 1.45 (0.83–2.53) 12–23 = 1.39 (0.73–2.64) ≥24 = 1.85 (1.11–3.08)	Maternal age; Education; Parity; Pre-pregnancy BMI; Smoking status; Social class; Child age; gender; Time varying bottle use; Feeding habits; Length-for-age z scores	High frequency day time breastfeeding Long duration, high frequency
Feldens et al., (25) [10* Very good]	Birth cohort study (nested in an RCT of an intervention in a birth cohort)	Cohort of children aged 4 years; Sao Leopoldo, Brazil	340 children (baseline = 500); Boys = 195 (57.4%)	Breastfeeding: Frequency	Age 4 years Severe ECC ≥1 cavitated, missing or filled smooth surfaces in primary maxillary anterior teeth, or dmfs values ≥5	Adjusted model: RR of S-ECC associated with daily breastfeeding frequency at 12 months: 0–2 RR = 1.0 3–6 RR = 2.04 (1.22–3.39) ≥7 RR = 1.97 (1.45–2.68) p = 0.000	Maternal schooling; Daily meals and snacks; Bottle use for fruit juice/soft drinks at 12 months; High density sugar at 12 months; Teeth at 12 months	
Hong et al. (31) [8* Good]	Longitudinal birth cohort study	Iowa, USA	N = 509 Questionnaires: 3–6 months from birth Dental exams: 5 years and 9 years	Breastfeeding duration <6 months ≥6 months	Age 5 years and 9 years Dental caries in: (a) All primary teeth (b) 2nd deciduous molars (e)	Tooth level: Caries in (e) at 5 years Mean dfs BF <6 months = 0.55 BF ≥6 months = 0.33 p = 0.02 Person level: caries in (e) at 5 years Breastfeeding <6 months OR = 15.58 [no 95% CI reported] (p = 0.005)	Gender, hypoplasia, parental education level, family income level, gestational weeks, birth weight, age at time of dental exam, average daily fluoride intake (mg), home tap water fluoride level(ppm), average daily soda pop intake, daily tooth-brushing frequency	

Appendix (Continued)

References [NOS QA score]	Type of study/brief description	Study population/Country	Sample size (gender % given if reported)	Exposure definition	Outcome definition and age	Exposure estimate (95% CI)	Other variables included in the models as confounders	Interactions
Kramer et al. (29) [8* Good]	Prospective cohort study nested in RCT of BF promotion intervention (PROBIT)	Children aged 6.5 years Belarus	Total n = 13,883 Experimental n = 7108 Control n = 6781	Experimental vs control groups	Age 6.5 years Dental caries DMFT/dmft	The experimental intervention had no significant effect on the DMFT/dmft numbers or proportions (both all teeth and incisors only)	None reported	
Kramer et al. (28) [8* Good]	Prospective cohort study nested in RCT of BF promotion intervention (PROBIT)	Children aged 6.5 years Belarus	Exclusive BF at 3 months: EBF3 n = 2862 Exclusive BF at 6 months EBF6 n = 621		Children aged 6.5 years Dental caries dmft	No significant difference in dmft in EBF3 and EBF6 groups	None reported	
Ollila and Larmas (38) [7* Good]	Cohort study Time points: Baseline = mean age 2.5 years (0.7–4.3 years) Follow up 7 years later = mean age 9.6 years (3.1-12.7 years) Survival analysis	11 day care centres Oulu, Finland	N = 183 (baseline) N = 175 (follow up)	Breastfeeding <12 months ≥ 12 months	Baseline 2.5 years Follow up 9.6 years Restoration due to caries in a primary 2nd molar and first permanent molar on upper right and lower left (teeth id numbers: 55 and 75; 16 and 36)	Prolonged breastfeeding (≥ 12 months) had no effect on caries onset in terms of survival estimates in either the deciduous molars or permanent molars.	None reported	
Silver, (32) [5* Satisf]	Longitudinal cohort study Baseline 3 years (1973) Follow up 8–10 years (1979) Kendall's Tau instead of X^2	Town north of London	3 years olds n = 161 Boys = 84 (52%) 8–10 years olds n = 161 Boys = 85 (53%)	Questionnaire at age 3: Breast fed Bottle fed (unsweetened/sweetened)	3 years & 8–10 years Dental caries dmft	Babies that were breast fed only had significantly lower dmft cf children bottle fed, especially those with sweetened bottle content. $p < 0.01$	None reported	
Tada et al. (33) [5* Satisf]	Cohort Examination at 18 months and 3 years of age – increment change was analysed.	Infants Chiba city, Japan	N = 392 Boys = 215 (54.8%)	Breast feeding (yes/no)	18 months & 3 years Dental caries dmft All Upper anterior Molar	Breast feeding at 18 months of age significantly associated with caries increment increase in caries in upper anterior teeth OR = 6.65 (2.89–15.2, p = <0.05)	None reported	
Tanaka et al. (34) [8* Good]	Prospective cohort study 5 surveys at baseline, 2–9 months, 16–24 months, 29–39 months, 41–49 months. Dental exam at 41–50 months	Pregnant women and their infants Neyagawa City, Japan	N = 315	Breast feeding duration: <6 months; 6–11 months; 12–17 months; ≥18 months	Aged 41–50 months Dental caries dft (missing teeth excluded) Moderate ECC = 1–4 teeth with caries not involving maxillary anterior teeth Severe ECC = ≥1 caries in maxillary anterior teeth or ≥5 caries in all teeth	Adjusted OR Risk of breastfeeding duration and ECC: <6 months OR = 1 6–11 months OR = 0.67 (0.27–1.62) 12–17 months OR = 1.09 (0.45–2.71) ≥18 months OR = 2.47 (0.95–6.59) Quadratic trend $p < 0.05$ Statistical significance was lost when comparing risk for M-ECC with caries free and S-ECC and caries free – but the trend was towards positive associations with increased BF duration	Adjusted for: Maternal age at baseline; Maternal smoking during pregnancy; Family income; Parental education level; Child's gender; Birth weight; Age at first tooth eruption; Tooth brushing frequency at 4th and 5th surveys; Use of fluoride; Regular dental check-ups; Household smoking at 5th survey; Age at oral examination	

Appendix (Continued)

References [NOS QA score]	Type of study/brief description	Study population/Country	Sample size (gender % given if reported)	Exposure definition	Outcome definition and age	Exposure estimate (95% CI)	Other variables included in the models as confounders	Interactions
Thitasomakul et al. (35) [7* Good]	Longitudinal observational community based study – birth cohort. Followed up at 9, 12 and 18 months	All women in district who gave birth November 2000 to October 2001 Thepa district Thailand	N = 495 Boys = 254 (51.3%)	Type of milk feeding: Breast feeding Bottle feeding Mixed breast- and bottle feeding	Age 9–12 months & 12–18 months Dental caries *Crude caries increment* = from 9–12 months and 12–18 months *Incidence density* = tooth surface developing caries; *Incidence density ratio* = ratio of incidence density of those exposed to those not exposed to the particular independent variable concerned.	Bivariate analysis: crude caries increment between 9–12 months and 12–18 months was significantly higher among children who were breast fed cf bottle fed or mixed feeding. Negative binomial analysis – no association between increased incident density and breastfeeding reported.	None reported	
van Palenstein Helderman et al. (36) [6* Satisf]	Retrospective cohort	Children aged 25–30 months – recruited through immunization records at health centres Daik-U, Burma	N = 163 breastfed children (children excluded who consumed 'jaggery; and those who were bottle fed and breastfed from 5 months)	Breastfeeding: Total number Of feeds (low/high) Total exposure time to breastfeeding (low/high) Median value sets low/high Prolonged breastfeeding beyond 12 months age	Children aged 25–30 months Dental caries ECC – presence of caries in ≥1 tooth	Significant associations: >2 nocturnal breast feedings and ECC OR = 35 ($p < 0.0001$) >15 min feeding per night OR = 100 ($p < 0.0002$)	None reported	
Yonezu et al. (37) [5* Satisf]	Prospective cohort Control sample = 205 children weaned off breast or bottle feeding <18 months	Infants attending preventive dental care programs at public health centres Japan	N = 922 at 18 months N = 742 at 24 months N = 910 at 36 months N = 592 followed longitudinally	Prolonged breastfeeding or bottle feeding at 18 months	Aged 18 months, 24 months and 36 months Dental caries dft	Mean dft of children being breastfed at 18 months (0.36) was significantly higher than the control group (0.06) $p < 0.05$ Mean dft of children being breastfed at 24 months (0.51) was significantly higher than the control group (0.11) $p < 0.05$	None reported	
Case control								
Bahuguna et al. (39) [5* Satisf]	Case control Cases had caries Control were caries free	Outpatient department of paedodontics and preventive dental clinic Lucknow, India	Case n = 400 Control n = 400	Breast feeding duration ≤6 months > 6 months Bottle feeding (no detail reported)	Children aged 1–18 years Dental caries DMFT/deft	Significantly higher proportion of case subjects were breastfed for longer than 6 months compared to control ($p < 0.001$) Significantly higher proportion of cases had been bottle fed ($p = 0.017$)	None reported	
Matee et al. (40) [4* Unsatisf]	Case control Cases = rampant caries Controls = no caries	Children aged 1–4 years attending maternal and child health centres in 9 out of 25 regions in Tanzania	Case n = 116 Control n = 243	Breastfeeding duration Night feeding (duration of nipple in the mouth: 0 h, ½ h, 1 h, >1 h) Bottle feeding and content in bottle	Case mean age = 1.6 years Control mean age = 2.1 years Dental caries Rampant caries (≥2 caries lesions in maxillary incisors)	Duration of breastfeeding (1 year vs 3 years) OR = 2.4 (0.7–9.1) $p = 0.18$ Night breast feeding habits OR = 17.8 (6.3–50.3) $p < 0.0001$ Linear hypoplasia OR = 15.6 (8.0–30.5) $p = <0.0001$	None reported	
Roberts et al., (41) [5* Satisf]	Case control Cases = caries Controls = caries free	1–4 year old children South Africa	Case n = 109 Control n = 109	Breast feeding frequency Breast feeding duration Bottle feeding	Aged 1–4 years Dental caries dmft dmfs	No significant association between frequency and duration of breast feeding and dental caries prevalence	None reported	

Appendix (Continued)

References [NOS QA score]	Type of study/brief description	Study population/Country	Sample size (gender % given if reported)	Exposure definition	Outcome definition and age	Exposure estimate (95% CI)	Other variables included in the models as confounders	Interactions
Cross-sectional								
Alaluusua et al. (42) [3* Unsatisf]	Cross-sectional	Children aged 5 who participated in a longitudinal nutrition and health study that promoted breast feeding up to 12 months; Finland	N = 144 Boys = 59 (41%)	Duration of exclusive breastfeeding: <2 months <2–6 months >6–9 months >9–12 months >12 months	Aged 5 years Dental caries dmfs	Distribution of dmfs among children with longer or shorter duration of breastfeeding was equal	None reported	
al-Dashti et al., (43) [4* Satisf]	Cross-sectional	Children aged 18–48 months born and continuously resident in Kuwait. Recruited through hospital and health centre	N = 227 Boys = 101 (44.5%)	Infant feeding practices Breast fed Bottle fed Breast and bottle fed	Aged 18–48 months Dental caries – no detail provided re how this is assessed	Children breast fed at birth significantly more likely to be caries-free than those breast and bottle fed or bottle fed only	None reported	
Azevedo et al. (44) [5* Good]	Cross-sectional	Preschool children; age 36–71 months; Brazil public health centres	N = 369 Boys = 188 (51%)	Infant feeding practices including patterns and duration of bottle feeding and breastfeeding	Age 36–71 months S-ECC – ≥1 dmfs in primary maxillary anterior teeth	Breastfeeding during night time = 265 (72%) – statistically associated with SECC (p = 0.02); Breastfeeding after 12 months of age = 70% of SECC children and 50% of non-SECC children – significant association b/w breastfeeding children >12 months and presence of SECC (p = 0.004)	None included as confounders	None
Campus et al. (45) [5* Good]	National cross-sectional survey; March 2004–April 2005	4 years old children, Italy	N = 5538 (aged 47.2 months +/− 3.5 months) Boys = 2518 (45.5%)	Duration of breastfeeding (≤13 months or >13 months)	Age 4 years Dental caries dmfs	Children BF for >13 months had significantly higher dmfs than those BF ≤13 months (p < 0.05) Association between prolonged BF and dental caries only seen in bivariate analysis and no conclusion about harmful consequences can be drawn from multivariate modelling	Gender; Parent nationality; Parent education; Pre-term births; Age of tooth eruption; Toothbrushing habits; Disease or medication during pregnancy	
Cariño et al. (46) [3* Unsatisf]	Cross sectional survey; October – November 1999	Children aged 2–6 years; Northern Philipines – 3 areas in 2 regions	n = 452 Aged 3–6 years Stratified 3–4 and 5–6 years	*Feeding* Breastfed only Mixed breastfed and bottle fed Bottle fed only No answer *Weaning age* ≤2 years old >2 years Still breast or bottle feeding No answer	Aged 2–6 years Dental caries ECC dmft	Bivariate analysis No significant difference in associations between breastfeeding, bottle feeding and weaning age and ECC	Child's primary caregiver; Feeding practices; Toothbrushing; Snacking frequency; Type of snacks eaten; Last dental visit; Reason for last visit	
Dini et al. (47) [4* Satisf]	Cross-sectional survey; 1998	Children enrolled in municipal nurseries; 3–4 years; Araraquara, Sao Paolo, Brazil	N = 245 Boys = 137 (56%)	Breast feeding and/or bottle feeding Duration of breastfeeding: Never ≤24 months >24 months	Aged 3–4 years Dental caries dmfs or dmft	*Statistically significant:* Caries in molars and incisors and children who were never breast fed or those who were breast fed beyond 24 months age OR = 3.1 (1.1–8.4) p = 0.03	None reported	

Appendix (Continued)

References [NOS QA score]	Type of study/brief description	Study population/Country	Sample size (gender % given if reported)	Exposure definition	Outcome definition and age	Exposure estimate (95% CI)	Other variables included in the models as confounders	Interactions
Du et al. (48) [4* Satisf]	Cross sectional survey	Children in kindergartens; urban Hanchuan, China	N = 426 Boys = 250 (59%)	Infant feeding – breast and /or bottle Duration of breast feeding	Aged 24–47 months; Mean age = 40 months Dental caries (dmfs or dmft) Rampant caries = 2 or more teeth with caries affecting palatal and /or labial surfaces of primary incisors	Bottle fed only children had statistically significant higher prevalence of incisor caries ($p < 0.05$) and rampant caries ($p < 0.01$) cf with partially or fully breast fed children. Children who had been wholly bottle fed had higher risk of caries cf children partially or wholly breastfed: rampant caries OR = 5.27 (2.16–12.89) p = 0.003 incisor caries OR = 2.38 (1.03–4.76) p = 0.042	Stepwise logistic regression: Gender (male/female); Age (24–35 months /36–47 months); Education (low/high); Income (low/high); Feeding (bottle/breast)	
Dye et al. (49) [6* Very good]	Cross sectional National Health and Nutrition Examination Survey III – 1988–1994	Children aged 2–5 years; USA	N = 4236 Boys = 2081 (49.1%)	History of breast feeding – yes or no	Aged 2–5 years Dental caries – decayed or filled primary dental surfaces (dfs)	In models adjusted for poverty, education and race/ethnicity the findings indicate that there is no relationship between caries and a history of ever breastfeeding	Poverty Education of parent Race/ethnicity	Poverty and educational attainment
Folayan et al. (50) [3* Unsatisf]	Cross-sectional	Children aged 6–71 months; 3 randomly selected LGAs in Lagos State, Nigeria	N = 396 Boys = 217 (54.8%)	-Exclusive breastfeeding Almost exclusive: breast milk with water supplement Partial/mixed breastfeeding	Aged 6–71 months dmft Rampant caries = caries affecting 1 or more maxillary incisors with or without involvement of primary molars Caries = caries affecting tooth/teeth exclusive of maxillary anterior tooth/teeth No caries	Significant predictors of dmft: Duration of breastfeeding (p = 0.002) & form of breastfeeding [exclusive breastfeeding] (p = 0.03) No significant association b/w form of breast feeding and rampant caries or caries. No sig association b/w duration of breastfeeding and caries or no caries – however significant association between duration of breastfeeding and rampant caries (p = 0.02)	None reported	
Folayan et al. (87) [3* Unsatisf]	Cross-sectional	Children attending the Child Dental Health Clinic of 2 hospitals in Nigeria	N = 205 Boys = 108 (52.7%) 1–5 years n = 91 6–10 years n = 88 11–16 years n = 26	Duration of breastfeeding Breastfeeding on demand or leaving the nipple in mouth overnight during night feeding. Duration of bottle feeding	Aged 1–16 years Rampant caries	No association found between rampant caries, duration of breast feeding (p = 0.13), form of breastfeeding (p = 0.84) or duration of bottle feeding (p = 0.07) in children aged 1–5 years	None reported	
Forsman et al. (51) [3* Unsatisf]	Cross-sectional study; 2 sites	(1) Vaxjo, Sweden; Children born 1962 and 1963; Data on infant feeding extracted from records in Children's Welfare Centre, Vaxjo (2) Gothenburg, Sweden Children born in 1964 Questionnaire	Vaxjo n = 726 Gothenburg n = 115	-Exclusive breastfeeding for first 5 months (B) -Exclusive water diluted infant dry milk formula for first 5 months of life (F)	Aged 4 years Dental caries defs and deft	Results reported in frequencies and t-tests No significant differences in caries between the B and F groups in both sites.	None reported	

Appendix (Continued)

References [NOS QA score]	Type of study/brief description	Study population/Country	Sample size (gender % given if reported)	Exposure definition	Outcome definition and age	Exposure estimate (95% CI)	Other variables included in the models as confounders	Interactions
Hallett et al. (52) [6* Very good]	Cross-sectional; Self administered questionnaire	Preschools; North Brisbane, Australia	N = 2515 Boys = 1307 (52%)	Duration of breastfeeding: None; <3 months; 3–6 months; 7–12 months; >13 months	Aged 4–5 years ECC- dmfs and dmft ≥ 1	Multivariate analysis Ref = no breastfeeding <3 months OR = 1.0 (0.7–1.3) (p = 0.9) 3–6 months OR = 0.7 (0.5–1.0) (p = 0.05) 7–12 months OR = 1.0 (0.7–1.4) (p = 0.9) >13 months OR = 1.5 (0.9–2.3) (p = 0.09)	Sleep with bottle (y/n); Sip from bottle (y/n); Ethnicity; Family income	
Hallonsten et al. (53) [3* Unsatisf]	Cross-sectional survey; 1981–1982 Comparative study of 4 groups (±breastfeeding and ± dental caries)	Child welfare centres (n = 48 centres); 3 counties in Sweden	N = 200	Breastfeeding Duration of breastfeeding	Aged 18 months Dental caries defs	No significant difference in defs of children with caries being breastfed and children with caries not being breastfed No analysis of association between defs and breastfeeding duration	None reported	
Haq et al. (54) [2* Unsatisf]	Cross-sectional	Recruited from hospitals, private dental clinics and public dental clinic, Dhaka, Bangladesh	N = 530	Feeding: Breast fed Bottle fed Mixed fed Breastfeeding duration: 6 months – 1 year 1–2 years 2–3 years	Aged 5 months – 6 years Dental caries dmft	No significant difference in caries between those breast fed, bottle fed or mixed fed. Longer duration of feeding (either breast, bottle or mixed fed) significantly associated with prevalence of caries.	Sweet drink intake analysed with each exposure	
Hardy (55) [1* Unsatisf]	Cross-sectional	Village communities in Greece	N = 225 Wholly breast fed = 159 Wholly bottle fed = 66	Breast fed Bottle fed	Aged 2–6 years Dental caries dmft	No significant difference in caries between the two groups.	None reported	
Harrison et al. (56) [4* Satisf]	Cross-sectional	Vietnamese migrants; Vancouver, Canada	N = 60 Boys = 31 (52%)	Breastfed Breastfeeding duration	Mean age 32.4 months ± 21.3 Dental caries – defs Nursing caries (≥2 maxillary teeth have decay)	Correlational statistics. No association between dental caries and nursing caries and breastfeeding.	None reported	
Holt et al. (57) [3* Unsatisf]	Cross-sectional	Maternal and child welfare centres in Camden and Islington Health Authority, London, UK	N = 555 Boys = 275 (49.5%)	Breast feeding No breastfeeding for >2 weeks = Wholly bottle fed	Aged 12 – 60 months Caries – visible cavity involving dentine Rampant caries – labial or palatal carious lesions involving ≥2 maxillary incisor teeth	A significantly higher proportion of children wholly breastfed (95%) were caries free compared with the proportion of children wholly bottle fed (82%) ($p < 0.01$)	None reported	
Hong et al. (58) [5* Good]	Cross-sectional	Singapore	190 children Boys = 98 (51.6%) Chinese = 60% Malay = 32% Other = 7%	Breast feeding till 10 months; > 10 months	Mean age = 36.3 months ± 6.9 Dental caries dmfs/dmft	Presence of dental decay: Adjusted Breastfeed <10 months (ref) breastfeed >10 months: RR = not significant [Results not shown] Risk for decayed and filled teeth (dt) Adjusted Breastfeed <10 months (ref) breastfeed > 10 months: mean ratio = 1.85 (1.12–3.05) p = 0.016 Risk for decayed and filled surfaces	Child racial group, frequency of sweets, importance of baby teeth, plaque on teeth	

Appendix (Continued)

References [NOS QA score]	Type of study/brief description	Study population/Country	Sample size (gender % given if reported)	Exposure definition	Outcome definition and age	Exposure estimate (95% CI)	Other variables included in the models as confounders	Interactions
						(ds) Adjusted Breastfeed <10 months (ref) breastfeed > 10 months: mean ratio = 2.32 (1.44–3.70) p = 0.001		
Iida et al. (59) [5* Good]	Cross-sectional National Health and Nutrition Examination Survey	Children aged 2–5 years USA	N = 1576 Boys = 793 (50.3%)	*History of BF* = ever BF; *Overall BF duration* = age when child completely stopped BF or being fed breast milk; *Exclusive BF duration* = Age when child was first fed something other than breast milk or water; *Full BF duration* = Age when child was first fed formula, milk or solid foods on a daily basis	Aged 2–5 years Dental caries *ECC* = presence of any dfs on any primary tooth *S-ECC* = presence of any dfs on any maxillary incisor	ECC – Adjusted Hx of BF: aOR = 0.97 (0.63–1.49) p = 0.89 S-ECC – Adjusted Hx of BF: aOR = 0.83 (0.49–1.40) p = 0.47 No statistically significant associations between of exclusive breastfeeding duration or full breastfeeding duration	Birth weight; Age; Gender; Race/ethnicity; Poverty status; Maternal age at child's birth; Maternal history of smoking during pregnancy; History of hospital admission; Time since last dental visit	Race/ethnicity Poverty status
Johansson et al. (60) [3* Unsatisf]	Cross-sectional	Preschool children presenting for well children visits at paediatric clinic in Boston Medical Centre, USA	N = 1206 Boys = 622 (51.6%)	Breastfeeding continues after falling asleep	Aged 6 months – 5 years Dental caries deft	Children breast fed when sleeping had significantly higher deft (1.48) cf children who were not (0.61) p = 0.0003 Those bottle fed in bed or at nap time did not have a significantly higher deft (0.53) those who did not (0.64) p = 0.233	None reported	
Livny et al. (61) [3* Unsatisf]	Cross-sectional	Children in Jahalin Bedouin community, Jerusalem	N = 102 Boys = 56 (54.9%)	Breastfeeding only Breastfeeding and bottle feeding	Aged 12–36 months Dental caries dmft	No significant associations between feeding practices and caries/no caries	None reported	
Majorana et al. (62) [4* Satisf]	Cross-sectional Questionnaire	Children aged 24—30 months Brescia, Italy	N = 2450 Males = 1181 (49.3%)	Exclusive breastfeeding Moderate-high mixed feeding (58–99% breast milk) Low mixed feeding (1–57% breast milk)	Aged 24—30 months Caries – dmfs ICDAS score for severity	Moderate and high caries was not observed in subjects exclusively breast fed, whereas high caries severity level was predominant in children fed with formula OR = 6.75 (6.00–7.58) p < 0.01	None reported	
Masumo et al. (63) [5* Good]	Cross-sectional	Manyara (high fluoride rural area) and Kampala (low fluoride urban area), Uganda	Child-caretaker pairs Manyara n = 1221 Boys = 616 (50.5%) Kampala n = 816 Boys = 414 (50.7%)	Current breastfeeding (yes/no) Breastfeeding duration	Aged 6–36 months Dental caries ECC = dmft Decayed (dt) – cavitated dt = absent or present	Breast feeding status was not significantly associated with ECC in multiple variable models Manyara: Currently breastfeeding aOR = 0.8 (0.30–2.17) p = NS Kampala Currently breastfeeding aOR = 1.4 (0.70–2.79) p = NS Significantly higher prevalence of caries in children breast fed 25–36 months compared to those breastfed 6–12 or 13–24 months	Age; Plaque score; Enamel hypoplasia; Teeth present; Sugar consumption; Number of teeth present	

Appendix (Continued)

References [NOS QA score]	Type of study/brief description	Study population/Country	Sample size (gender % given if reported)	Exposure definition	Outcome definition and age	Exposure estimate (95% CI)	Other variables included in the models as confounders	Interactions
Mattos-Graner et al. (64) [4* Satisf]	Cross sectional	Children attending 9 public school nurseries, Sao Paolo, Brazil	N = 142	Duration of breastfeeding (0–3 months; 3–31 months); Frequency of breast feeding	Aged 1–2.5 years Dental caries ds (no missing or filled teeth were found)	Children never breastfed or breastfed to 3 months exhibited higher caries prevalence than children breastfed for longer period (X^2 = 4.11, $p < 0.05$)	None reported	
Nobile et al. (65) [3* Unsatisf]	Cross-sectional	Children in kindergartens in Southern Italy	N = 515 Boys = 262 (51%)	Occurrence and duration of breast feeding: History (yes/no); duration (≤4; 5–10; 11–19; ≥20 months) Bottle feeding – sleep with sweetened bottle or pacifier	Aged 36–71 months Dental caries ECC: ≥1 decayed, missing of filled teeth (dmft) S-ECC: In children <3 years = any sign of smooth surface caries; in children aged aged 3–5 years = 1 or more cavitated, missing or filled smooth surfaces in primary maxillary anterior teeth; or dmft ≥4 at age 3; dmft ≥5 at age 4; dmft ≥6 at age 5	Prevalence of ECC significantly increased with duration of breast feeding OR = 1.26 (1.01–1.57) p = 0.039 Prevalence of S-ECC significantly increased with breastfeeding OR = 2.06 (1.13–3.76) p = 0.019	Potential confounders included in the models but these are not specified. Possibly: Dental visit in previous year; Age; Mother's education level; Start using cup; Sleep with bottle or pacifier; Start toothbrushing; Maternal age at delivery; Mother's age	
Nunes et al. (66) [5* Good]	Cross-sectional	Preschool children; Low income families; Sao Luis, Brazil	N = 241 Non exposed n = 192 Exposed n = 49	Non-exposed = those breast fed for <12 months Exposed = those still breastfeeding at time of examination	Aged 18 – 42 months Mean age = 34.5 months Dental caries ECC, dmft	Prolonged breastfeeding not associated with ECC in this model. [Data not shown]	Child age; Nocturnal bottle feeding with infant formula; Daily sucrose consumption between main meals	
Perera et al. (67) [3* Unsatisf]	Cross-sectional	Children aged <60 months in a pediatric ward of a teaching Hospital; Sri Lanka	N = 285 Boys = 138 (48.4%)	Exclusive breastfeeding - breast milk up to 6 months Overnight feeding (bottle or breast)	Aged <60 months Dental caries deft	No significant difference in the deft of children exclusively breast fed and those not exclusively breastfed p = 0.28 Children fed overnight with breast milk had caries prevalence of 51.4% cf children not fed overnight (29%) OR = 2.54 (1.29–5.01) along with higher mean deft p = 0.001	None reported	
Prakash et al. (68) [4* Satisf]	Cross-sectional	Playschools and private hospitals Children aged 8–48 months Urban Bangalore, India	N = 1500	On-demand breastfeeding (not defined)	Age 8–48 months Dental caries	On demand breastfeeding and presence of caries X^2 = 17.71 p = 0.001	None reported	
Prakasha Shrutha et al. (69) [2* Unsatisf]	Cross-sectional	Children aged 3–5 years - Play homes/preschools in Kanpur District, India	N = 2000 Boys = 974 (48.7%)	Breastfeeding frequency 5 times 5–10 times >10 times Duration of breastfeeding <6 months 6 months–1 year 1–1.5 years 1.5–2 years Age bottle feeding introduced <6 months 6 months–1 year 1–2 years Not introduced	Age 3–5 years Dental caries dmft	Prevalence of dental caries showed inverse relationship with frequency of breastfeeding but not significant Caries prevalence increased with duration of breastfeeding and $p < 0.05$ Caries prevalence higher in children who were introduced to the bottle around 2 years of age $p < 0.001$	None reported	

Appendix (Continued)

References [NOS QA score]	Type of study/brief description	Study population/Country	Sample size (gender % given if reported)	Exposure definition	Outcome definition and age	Exposure estimate (95% CI)	Other variables included in the models as confounders	Interactions
Qadri et al. (70) [4* Satisf]	Cross-sectional survey	Children aged 3–5 years 20 kindergartens in Syria	N = 400 Boys = 191 (47.8%)	Feeding practices during infancy: predominately breastfed vs bottle fed.	Aged 3–5 years Dental caries dmft ECC	Logistic regression: Fully adjusted dietary practices (bottle vs breastfeeding) and (1) dmft OR = 0.61 (0.39–0.97) $p = 0.038$ (2) ECC OR = 0.27 (0.18–0.41) $p < 0.001$ Age was only significant factor associated with dmft and ECC	Models are adjusted but confounders included are not reported (possibly age, gender and dietary practices are the covariates).	
Retnakumari et al. (71) [3* Unsatisf]	Cross-sectional	Children attending immunisation clinic, day care centres – aged 12–36 months Kerala, India	N = 350 Male = 171 (48.9%)	Duration of breastfeeding: Night feeding only Present now ≤1 year 1–2 years >2 years Falling asleep with nipple in the mouth	Aged 12–36 months Dental caries defs	Significant association between caries severity and duration of breastfeeding (analysis not shown) Severity of decay higher in children who fell asleep with nipple in the mouth (OR 2.92, $p < 0.05$) [95% CI not reported]	None reported	
Rosenblatt et al. (72) [3* Unsatisf]	Cross-sectional	Pediatric clinic –two public maternity hospitals Recife, Brazil	N = 468 Boys = 222 (47.4%)	Feeding practices: Breast feeding Breast feeding + baby bottle sugared milk Baby bottle sugared milk Cup+ sugared milk	Aged 12–36 months Dental caries deft	No significant association between type of feeding and presence of caries	None reported	
Sankeshwari, (73) [3* Unsatisf]	Cross-sectional	Children aged 3–5 years; 20 preschools in Belgaum, India	N = 1250 Boys = 663 (59.4%)	Breastfeeding: history, duration, timing, frequency Bottle feeding: history, duration, timing, frequency, contents	Aged 3–5 years Dental caries – dmft (ECC)	Significant [unadjusted] associations (X^2) between lower prevalence of ECC and history of breastfeeding (yes/no: $p = 0.02$), duration of breastfeeding (6–24 months/ <6 months or >24 months: $p = 0.001$).	None reported	
Santos, (74) [2* Unsatisf]	Cross-sectional	Outpatients of the Pediatric University Hospital, Brazil	N = 80 Boys = 45 (56.3%)	Breastfeeding	Aged up to 36 months Dental caries	No significant associations were found between the prevalence of caries and nocturnal bottle- and breast-feeding.	None reported	
Sayegh et al. (75) [4* Satisf]	Cross-sectional	Kindergartens in Amman, Jordan	N = 1140 Boys = 582 (51.1%)	Infant feeding practice: Breastfeeding Bottle feeding Both Duration Frequency (on demand)	Aged 4–5 years Dental caries Dmft Incisors; incisors and canines; molars; incisors, canines and molars	Breast feeding duration >18 months or never (grouped together) – OR caries in any teeth = 1.5 (95% CI 1.1–2.1) $p < 0.05$ Breast feeding on demand cf not breast feeding on demand OR caries in any teeth = 1.8 (95% CI 1.3–2.5) $p < 0.05$	Characteristics included in stepwise regression: Age; Social class; Sleep with mother; Bottle feeding time; Use of comforter; Confectionery at bed or night time	
Sayegh et al. (76) [5* Good]	Cross-sectional	Kindergartens in Amman, Jordan	N = 1075 Boys = 553 (51.4%)	Breastfeeding/ Bottle feeding duration: <6–18 months >18 months Breastfeeding/ Bottle feeding frequency: Never; Not on demand; On demand	Aged 4–5 years Dental caries dmft Caries = dmft ≥1 Severe caries = dmft >4	Caries: Breastfeeding 18 months vs never – not significant [data not shown] Severe caries: Breast feeding > 18 months vs never breastfeeding OR = 2.3 (95% CI 1.1–4.8)	Characteristics included in the stepwise multiple logistic regression model: Dental plaque; Sleeping beside mother; Use of comforters; Confectionery; Marmalade/jam/honey/ halawi at breakfast or dinner	

Appendix (Continued)

References [NOS QA score]	Type of study/brief description	Study population/Country	Sample size (gender % given if reported)	Exposure definition	Outcome definition and age	Exposure estimate (95% CI)	Other variables included in the models as confounders	Interactions
Serwint et al. (77) [3* Unsatisf]	Cross-sectional	Hospital based pediatric clinic, California, USA	N = 110 Boys = 55 (50%)	Ever breast fed Bottle feeding was primary interest	Aged 18–36 months Dental caries: Caries Non-caries	Ever breast fed and caries OR = 2.9 (95% CI 0.9–9.9) p = 0.08 – borderline significance.	Controlled for familial characteristics: Maternal cavities; Mother aims to keep teeth by age 65; Child drank fluoride water; fluoride supplements; Brush child's teeth	
Slabsinskiene et al. (78) [3* Unsatisf]	Cross-sectional Subset questionnaire Children with no caries n = 40 Children with S-ECC n = 40	Kindergartens in 10 counties in Lithuania	n = 80	Duration of breast feeding: ≤12 months >13 months	Aged 2.5–3.5 years Dental caries dmft/dmfs No caries S-ECC	In children who breastfed beyond 13 months the risk of developing S-ECC was high OR = 10.0 (95% CI 1.28–78.12)	None reported	
Songo et al. (79) [2* Unsatisf]	Cross-sectional	Dental units of five hospitals or private clinics in Kinshasa, Democratic Republic of Congo	N = 158 Boys = 79 (50%)	Breast feeding: Exclusive Mixed with bottle Bottle feeding only	Aged 4–6 years Dental caries - dmft	Children being exclusively breast fed or have both bottle and breast presented with lower caries levels OR = 0.16 (95% CI 0.04–0.66)	None reported	
Tanaka et al. (80) [5* Good]	Cross-sectional	Public health centre Fukuoka City, Japan	N = 2056 Boys = 1087 (52.9%)	Breastfeeding duration regardless of exclusivity: <6 months 6–11 months 12–17 months ≥18 months	Aged 3 years Dental caries dmft >1	Adjusted Prevalence Ratios (95% CI) Breastfeeding duration (months) *<6* PR = 1 *6–11* PR = 0.79 (0.6–1.05) *12–17* PR 0.86 (0.66–1.13) *≥18* PR 1.66 (1.33–2.06) Breastfeeding for 18 months or longer significantly associated with higher prevalence of dental caries	Adjusted for: gender; Toothbrushing frequency; Use of Fluoride; Regular dental check-ups; Between meal snack frequency; Maternal smoking during pregnancy; Exposure to environmental tobacco smoke at home; Parental education levels	
Tiano et al. (81) [3* Unsatisf]	Cross-sectional	Public day care centres in 2 municipalities in Brazil	N = 68	Breast feeding duration ≤12 months 13 months +	Aged 18–36 months Dental caries CCL = cavitated carious lesions ECC = any stage of carious lesion	CCL prevalence is significantly associated with duration of breastfeeding (p = 0.02) ECC prevalence is not associated with duration of breastfeeding	Not reported	
Tyagi (82) [1* Unsatisf]	Cross-sectional	Kindergartens in Davangere, Karnataka, India	N = 813 Boys = 395 (48.6%)	Duration of breast feeding: 3–9 months 10–12 months 13–24 months 25–42 months	Aged 2–6 years Dental caries dfs	Mean dfs increases with duration of breast feeding, but not statistically significant	Not reported	
Vachirarojpisan et al. (83) [5* Good]	Cross-sectional	Health centres, U-Thon District in Suphan Buri Province, Thailand	N = 520 Boys = 272 (52.3%)	Method of feeding: Breast feeding Bottle feeding or mixed feeding	Aged 6–19 months Dental caries dmfs; dmft Intensity of ECC (I-ECC) = ratio of affected teeth (non cavitated + cavitated): erupted teeth	Bivariate analysis of *15–19 month* group: Significant association between breastfeeding and I-ECC (p = 0.018). Significant association lost in multivariate models that include all age groups.	Multivariate models controlled for: Age; Number of teeth present	
Vazquez-Nava et al. (84) [5* Good]	Cross-sectional study within prospective cohort study 2005	Children aged 4–5 years who had been longitudinally studied since 4 months of age.	N = 1160 Boys = 585 (50.2%)	Breast feeding Breast feeding >12 months & at night Bottle feeding	Aged 4–5 years Dental caries (assessed from 2 years of age) deft and defs	Significant association between breastfeeding beyond 12 months & at night and dental caries OR = 3.6 (2.51–5.16) p < 0.001	Not reported Not reported	

Appendix (Continued)

References [NOS QA score]	Type of study/brief description	Study population/Country	Sample size (gender % given if reported)	Exposure definition	Outcome definition and age	Exposure estimate (95% CI)	Other variables included in the models as confounders	Interactions
Wendt & Birkhed (85) [4* Satisf]	Cross-sectional study within prospective longitudinal study 3 time points: 1 year, 2 years, 3 years	Preschool children in Jonkoping, Sweden - comparison of Swedish children and immigrant children	Baseline n = 671 1 year n = 632 1 year caries free n = 629 2 years n = 298 2 years caries free n = 276 3 years n = 270 3 years caries free n = 210	Breast feeding: ≤2 months Still breast fed	Examined at 1 year, 2 years and 3 years of age Dental caries dmfs	Significantly more children with caries than without caries at the age of 3 had either been breast fed for ≤2 months or >12 months		
Yonezu et al. (86) [1* Unsatisf]	Cross-sectional	Infants attending preventive dental care programs at public health centres. Children have been or are being breastfed	N = 105	Bed time breast feeding	Aged 18 months Dental caries dft	Odds of caries at 24 months was significantly higher OR = 10.66 (2.23–50.96) for bedtime breast fed children than children not breast fed at bed time ($p < 0.05$)	None reported	

ECC = Early childhood caries; S-ECC = Severe early childhood caries; dmfs/t = decayed, missing, filled and extracted *deciduous* surfaces/teeth; defs/t = decayed, extracted due to caries, filled *deciduous* surfaces/teeth; DMFT = Decayed, Missing, Filled and Extracted *permanent* surfaces/teeth; ICDAS = International Caries Detection and Assessment System (Reference: ICDAS Foundation. What is ICDAS?. https://www.icdas.org/what-is-icdas, 9 March 2015).