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Early Childhood Caries and Nutritional Status of Children: A Review

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Abstract

Background: Early childhood caries (ECC) is a serious public health issue affecting children around the world. Severe symptoms and complications commonly found with ECC are adverse effects on health and growth retardation triggered by sensitivity, pain, and abscesses associated with decayed teeth, premature tooth loss, and insufficient food intake due to difficulty in chewing and keeping food in the mouth.

Objective: This article aims to provide an overview of the most recent and current evidence on the association between ECC and nutritional status with an aim to stimulate further research and to identify the impact of nutritional status on ECC and vice versa.

Methods: PubMed, Web of Science, and Google Scholar databases were used to search the studies conducted between 2016 and 2022. The included studies were searched using some keyword combinations and saved in Mendeley Desktop for review and referencing. All books, policy briefs, thesis/dissertations, and non-peer-reviewed articles were excluded, and 47 studies were selected for this narrative review.

Results: Many studies have identified long-term, frequent, and nocturnal bottle-feeding and breastfeeding as well as frequent consumption of sugary food and beverages as high-risk factors for ECC. Adverse nutritional status assessed by anthropometric measures, vitamin D status, and iron-deficiency anemia have been studied as risk factors for ECC.

Conclusions: Most of the prevailing studies are either case-control or cross-sectional studies, which are unable to provide strong evidence to prove the direction of causality. Thus, further prospective studies are needed to clarify the association between ECC and the nutritional status of children.

Keywords

early childhood caries, nutritional status, anthropometry, breastfeeding, iron-deficiency anemia, 25-hydroxyvitamin D

Introduction

Early childhood caries (ECC) is a form of dental caries and a serious public health issue that continues to affect infants, toddlers, and preschoolers all around the world.[1] According to World Health Organization (WHO), more than 530 million children under the age of 6 in the world suffer from dental caries of primary teeth.[2] Some studies have reported the prevalence of ECC among children globally as 46.2%,[3] 48%,[4] and 23% to 90%.[5] In addition, ECC prevalence has been reported variously as 79%, 37.2%, 98%, and 10.3% in Southeast Asia,[6] the European Union (EU),[7] some parts of Canada,[8] and Australia,[9] respectively. These high values for the prevalence of ECC among children indicate the gravity of this health issue.

Dental caries is caused by metabolic reactions that take place in dental plaque such as the interaction of bacteria and sugary foods on tooth enamel and it is mediated by saliva (Figure 1).[10,11] The initial stage of ECC is recognized as demineralized white-spot lesions in the maxillary incisors along the margin of the gingiva. If the disease progresses, the lesions quickly advance to obvious decay.[12,13] Carious lesions are visible on either the lingual or labial teeth surfaces or on

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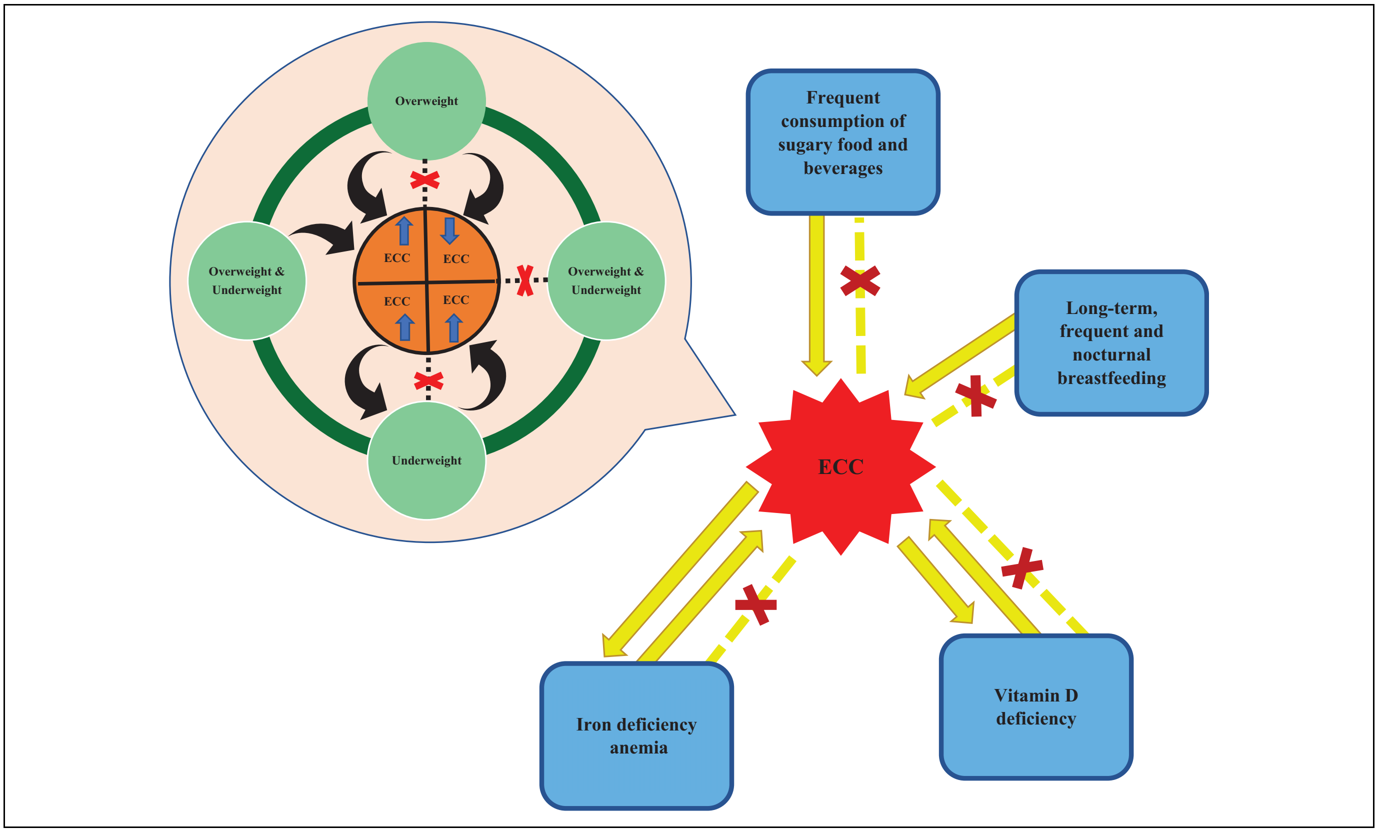

both.[14] Serious signs, symptoms, and complications commonly seen with ECC are sensitivity of teeth caused by thermal changes (cold or hot), pain, fever, abscesses associated with teeth, and difficulty in chewing, keeping food in the mouth for a longer time period and brushing, and longer-term health issues and growth retardation.[15] Therefore, the association between ECC-related oral health issues and general health or nutritional status has emerged as a research subject of growing interest.

Nevertheless, the nature of this association continues to be controversial, both with regard to its underlying mechanisms and the direction of effect and context is likely to be important.[16] Many studies have provided evidence for an association between ECC and the subsequent nutritional status and growth of children. Some studies have found that dental caries is negatively associated with the growth and health of children, likely due to the pain and inflammation associated with dental caries which result in poor dietary intake as well as the stagnation of growth and development.[17,18] Other studies have reported a correlation between dental caries and being overweight, which is likely due to high sugar consumption, frequent night feeds, changes in salivary flow, and immune responses, although, some other studies have found no correlation between them.[19-21] It also has been observed that the presence of malnutrition may also affect the salivary composition and flow of children, consequently leading to more caries.[22] On the other hand, there is also evidence that poor nutritional status such as being underweight, stunted, and malnourished might result in the progress of dental caries, although not all studies have found an association between poor nutritional status and ECC.[23-25]

However, the association of ECC with nutritional status, eating habits, breastfeeding, bottle-feeding, vitamin D status, and iron-deficiency anemia (IDA) have not been reviewed, altogether. Furthermore, recent evidence sheds new light on the controversy of the association between ECC and nutritional status. Thus, these factors highlight the importance and timeliness of this review. This narrative review, therefore, aims to discuss the most recent evidence on the association between ECC and nutritional status, focusing on studies published in the last 6 years and will focus specifically on the association between ECC and adverse nutritional status assessed by anthropometric measures, eating habits, breastfeeding practices, vitamin D status, and IDA.

Methods

To be included in the current review, studies had to report on the association between ECC, assessed by decayed, missing, and filled teeth (dmft) or decayed, missing, and filled surfaces (dmfs) indices, and the nutritional status of children assessed by means of anthropometric measurements, eating habits, breastfeeding practices, vitamin D status, and IDA. Studies

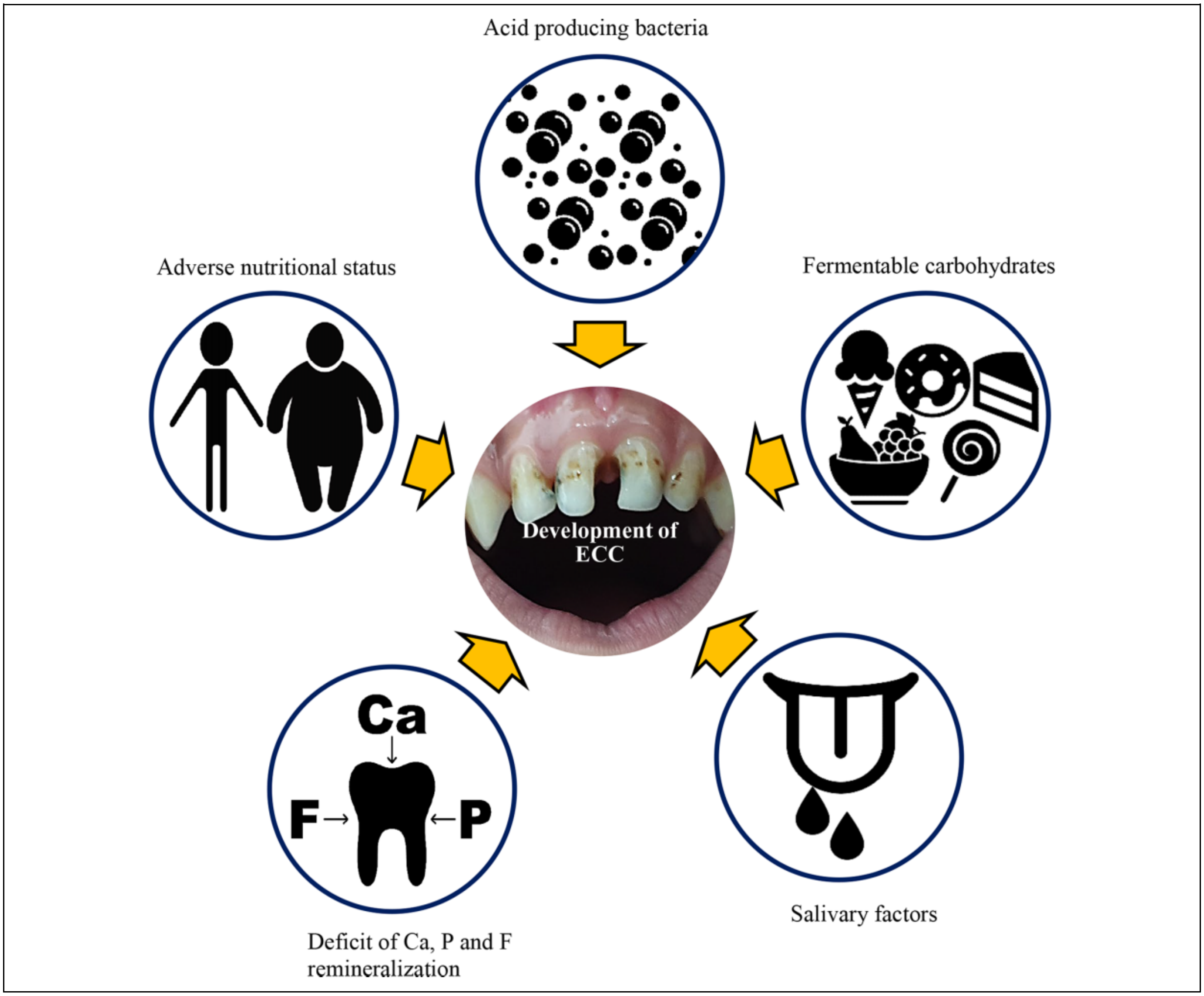

Figure 1. Major causative factors for triggering the development of early childhood caries (ECC). The susceptible host (with adverse nutritional status, nutrient deficiencies, salivary factors, etc), acid-producing microorganisms, and substrate (saliva and fermentable carbohydrates) are major risk factors for the development of dental caries.

were included in this review if they were conducted with children <7 years and were written in English only. All books, policy briefs, thesis/dissertations, and non-peer-reviewed articles were excluded from this review. First, a computerized search of related databases was conducted: PubMed, Web of Science, and Google Scholar from 2016 to 2022. The keywords such as "early childhood caries," "undernutrition," "overnutrition," "breastfeeding," "vitamin D deficiency," and "iron deficiency anemia" were used in varying combinations. Second, reference lists from relevant reviews on the association between ECC and the nutritional status of children[26,27] were scrutinized for potential additional studies. Finally, reference lists of all selected papers were examined for potentially applicable additional articles. A total of 47 studies were eligible for inclusion in this narrative review. The information on sample size, sample origin, gender and age (of the sample), study design (cross-sectional/case–control, longitudinal), year of assessment, and associations between variables were collected. Then, studies were categorized into anthropometric measurements, eating habits, breastfeeding practices, vitamin D status, and IDA and reviewed regarding their overall findings. Information regarding sample characteristics, study design, and main findings is presented in Table 1.

Results and Discussions

ECC and Adverse Nutritional Status Assessed by Anthropometric Measurements

Anthropometric measurements are used to assess the composition and proportions of the human body by taking quantitative measurements of the muscle, adipose tissue, and

Table 1. Current Studies on the Association Between ECC and Nutritional Status.

Author/s	Years	Country	Study design	Participants	Associations assessed with ECC	Main results
					Anthropometric measurements	
Athavale et al[28]	2020	LMIC—India	Mixed-methods study; cross-sectional study	959 children (male: 440 and female: 519), mean age: 3.7 years	Undernutrition (height-for-age, weight-for-age, and BMI-for-age)	Positive impact of ECC on the occurrence of undernutrition
Boustedt et al[29]	2020	HIC—Sweden	Prospective cohort study	208 children (male:105 and female:103), age: 6.5 years	BMI, waist circumference, fasting blood glucose, total cholesterol, triglycerides, high-density lipoprotein cholesterol, and low-density lipoprotein cholesterol	No significant correlation between ECC and BMI; no significant correlations between ECC and other studied risk factors of the metabolic syndrome; significant correlation between caries frequency and fasting blood glucose
Folayan et al[30]	2019	LIC—Nigeria	Cross-sectional study	370 children, mean age: 44.35 months	Underweight, overweight, wasting, stunting, and frequency of sugar consumption	Adjusted prevalence ratio (APR) of ECC were 7 times higher (6.88) in overweight children and 66% lower in stunted children (0.14) than in normal weight children; APR of ECC was zero in underweight children; sugar was a nonsignificant risk indicator for ECC
Folayan et al[31]	2020	LIC—Nigeria	Cross-sectional study	1549 children under 6 years	Undernutrition (wasting, stunting, and underweight), overnutrition, and frequency of sugar consumption in-between-meals	No significant association between nutritional status and the prevalence of ECC; positive association between frequency of sugar consumption and ECC
Janakiram et al[24]	2018	LMIC—India	Cross-sectional study	550 children (male: 288 and female: 262), 8-60 months	Undernutrition (weight-for-age)	Undernutrition was significantly associated with ECC
Kennedy et al[32]	2020	HIC—Canada	Cross-sectional study	150 children (52% female), mean age: 47.7 months	BMI	No association between dmfs score and BMI; over 42% were at risk for underweight, overweight, or obese
Madsen et al[33]	2017	HIC—Greenland	Cross-sectional study	373 children (male: 185, female: 188), 6 years old	BMI (thin, normal, overweight, and obese)	Clear propensity for higher caries prevalence in overweight and obese children
Ndekero et al[34]	2021	MIC—Tanzania	Cross-sectional study	831 children (male: 401 and female: 430), 3-5 years	Weight-for-age, height-for-age and weight-for-height, and total sugar exposure	Significant negative relationship between ECC and anthropometric measures indicated by weight-for-age; positive relationship between sugar exposure and ECC
Shen et al[35]	2019	UMIC—China	Longitudinal study	772 children (48.58% female), mean age: 50.82 months	Weight-for-age, height-for-age, sugar consumption, and breastfeeding	Significant negative association between dental caries and change in height-for-age; negative association between dental caries and weight-for-age; positive association between breastfeeding and dental caries; and between sugar consumption and dental caries

(continued)

Table 1. (continued)

Author/s	Years	Country	Study design	Participants	Associations assessed with ECC	Main results
So et al[36]	2017	UMIC—Ecuador	Cross-sectional study	1407 children (50.4% female), 0-6 years	Undernutrition (wasting, stunting, and underweight) and mouth pain interfering with eating and sleeping	Mouth pain interfering with sleeping was significantly associated with child malnutrition
					Breastfeeding practices and eating habits	
Achmad et al[37]	2018	LMIC—Indonesia	Cross-sectional study	356 children (48.1% female), 2-5 years	Frequency and duration of breastfeeding, using bottle until asleep, addition of sugar in the milk and bottle-feeding	Positive relation between addition of sugar in milk and ECC; positive association of longer breastfeeding, sing bottles at night to fall asleep, consuming confectioneries, and not eating vegetables with ECC
Bell et al[38]	2019	HIC—Australia	Prospective cohort study	1170 toddlers (46% female), 24-36 months	Dietary patterns and free sugars or energy intakes	No association between dietary patterns and dental caries; higher free sugars and energy intakes were risk factors for ECC
Bernabé et al[39]	2017	HIC—UK	Longitudinal study	1102 children (46.3% female), 1-4 years	Breastfeeding duration	Breastfeeding duration were not associated with caries trajectories of children aged 1-4 years
Carrillo-Díaz et al[40]	2021	HIC—Spain	Cross-sectional study	212 children (57.5% female), 2-4 years	Duration and frequency of breastfeeding and nocturnal breastfeeding and duration of co-sleeping	Significant association of duration of breastfeeding and co-sleeping with ECC; from 18 months onward breastfeeding at night was a risk factor for ECC
Chanpum et al[41]	2020	UMIC—Thailand	Cross-sectional study	513 children (53% female), 9-11 months	Frequency and breastfeeding duration in day and night time and breastfeeding to sleep	Breastfeeding to sleep was significantly associated with ECC
Dissanayaka and Gamage[42]	2020	LMIC—Sri Lanka	Cross-sectional study	104 children (51.2% female), 49-60 months	Consumption of sugary food, breastfeeding and bottle-feeding during sleep, adding sugar to feed, mouth washing after bottle-feeding	Consumption of sugary food such as biscuits and sugar containing milk products more than once daily, not washing the children's mouths after consuming sugary food, and breastfeeding during sleep were risk factors for ECC
Evans et al[43]	2013	HIC—USA	Cross-sectional study	808 children (54% male), 2-6 years old	Dietary intake of added sugar, sugar-sweetened beverages (SSB) and 100% fruit juice and eating frequency	SSB and added sugar play a significant role in S-ECC in children; no association between intake of 100% fruit juice and ECC
Feldens et al[44]	2018	UMIC—Brazil	Prospective cohort study	345 children (50% female), mean age: 8.1 $\pm$ 2.4 month	Duration of exclusive breastfeeding and daily frequencies of breastfeeding, bottle-use and intake of other food or drink	Positive association between high-frequency feeding in late infancy, including both bottle use and breastfeeding and ECC; no significant association between consumption of other foods or drinks more than 5 times/day and ECC
Hu et al[45]	2019	HIC—Singapore	Prospective cohort study	776 children (49% female), 24-36 months	Dietary patterns at 6-12 months and consumption of confectionary and SSB at 3 years old	Guidelines dietary pattern was protective for the development of ECC; no significant association with amount and frequency of SSB or confectionary consumption with ECC

(continued)

Table 1. (continued)

Author/s	Years	Country	Study design	Participants	Associations assessed with ECC	Main results
Kubota et al[46]	2020	LMIC—Cambodia	Cross-sectional study	121 children (male: 67, female: 54), mean age: 25.18 months	Breastfeeding before and after 18 months, night-time breastfeeding, bottle-feeding, and sugary food and beverage intake	Significant associations between ECC and breastfeeding, night-time breastfeeding and bottle feeding after 18 months; significant associations between ECC and sugary food and beverage intake
Obradović et al[47]	2020	UMIC—Bosnia and Herzegovina	Cross-sectional study	192 children (male: 99 and female: 93), 0-24 months	Higher meal frequency, breastfeeding/bottle-feeding at night and frequency of sugary food, and salty crisps intake	Positive association of meal frequency, breastfeeding/bottle-feeding at night and frequency of sugary food/salty crisps intake with ECC
Olczak-Kowalczyk et al[48]	2020	MIC—Poland	Cross-sectional study	656 children (52.3% male), 0-3 years	Nocturnal drinking of sweet beverages by the over 12-month-old child and feeding the child during the first 2 years of age with sweet foods	S-ECC was linked with consumption of sweetened food within the first 2 years of age and nocturnal drinking of sweet beverages by the over 12-month-old child
Percival et al[49]	2019	HIC—Trinidad and Tobago	Cross-sectional study	342 children (49.1% female), 36: 67 months	Duration and frequency of breast feeding and bottle-feeding, sleeping while breast- or bottle-feeding, feeding at night or early morning, adding sweetener to bottle contents, and frequent soft drink intake	All assessed parameters (feeding practices) were significantly associated with ECC
Peres et al[31]	2017	UMIC—Brazil	Longitudinal study: Birth cohort	1303 children, 0-5 years	Duration of breastfeeding, bottle-feeding at night, and sugar consumption	Prolonged breastfeeding enhanced the risk of having dental caries; high sugar consumption was associated with a risk of having S-ECC
Samaddar et al[50]	2021	LMIC—India	Case–control study	200 children (male: 185, female: 188), 3-5 years	Sugar exposure and likely to buy food items based on convenience and availability by parents	High-dietary sugar exposure was correlated with ECC; parents of children with ECC were likely to buy foods for their children based on convenience and availability
Setiawati et al[51]	2017	LMIC—Indonesia	Cross-sectional study	429 children, 6-24 months	Breastfeeding and nonbreastfeeding	Significant negative relationship between breastfeeding and prevalence of ECC
Ugolini et al[52]	2018	HIC—Italy	Cross-sectional study	563 children (49% female), 3-5 years	Consumption of sugared beverages and frequency	Drinking sugared beverages at least once a day was significantly associated with both ECC and S-ECC
Van Meijeren-van Lunteren et al[53]	2021	HIC—Netherlands	Prospective cohort study	4146 children (50.6% female), 1-6 years	Breastfeeding duration; nocturnal bottle-feeding	Prolonged breastfeeding (>12 months) and nocturnal bottle-feeding were significantly associated with dental caries; number of teeth affected by dental caries increased by 27%
Yardimci et al[54]	2021	UMIC—Turkey	Cross-sectional study	153 children (41.8% female), 30-71 months	Consumption of carbonated beverages, cariogenic foods, anticariogenic foods, fast foods	Positive correlations of the consumption of carbonated drinks or fast-food or added sugar with ECC; negative correlations of consumption of anticariogenic foods such as yogurt, milk, egg, and red meat with ECC; no correlation between vegetables and fruit consumption and ECC

(continued)

Table 1. (continued)

Author/s	Years	Country	Study design	Participants	Associations assessed with ECC	Main results
Zhang et al[55]	2020	UMIC—China	Cross-sectional study	1301 children (female 49.9%), 3-5 years	Frequency of bedtime sweet consumption and feeding method within 6 months of birth	Complete breastfeeding within 6 months of birth contributed to the high ECC risk of the 3-year-old group and high frequency bedtime sweet consumption contributed to that of the 5-year-old
					Vitamin D status	
Ahmed et al[56]	2020	UMIC—Iraq	Cross-sectional study	94 children (50% female), 2-6 years	Serum 25-hydroxy vitamin D level	Significant association between vitamin D levels and S-ECC
Chen et al[26]	2021	UMIC—China	Cross-sectional study	1510 children (45.83% female), 24-72 months	Serum 25(OH)D level	Negative correlation between 25(OH)D levels and the amount of caries in children
Chhonkar et al[57]	2018	LMIC—India	Case–control study	60 children (male: 39 and female: 21), 3-6 years	Serum 25(OH) vitamin D level	Statistically significant inverse correlation between vitamin D levels and S-ECC
Navarro et al[58]	2021	HIC—Netherlands	Prospective cohort study	5257 children (49.9% female), mean age: 6.17 years	Serum 25(OH)D concentrations at 18-24 weeks of pregnancy (prenatal), umbilical cord blood (perinatal) and in children	Only the 25(OH)D concentration in children, independent from prenatal and perinatal concentrations, was inversely associated with caries in primary teeth
Olczak-Kowalczyk et al[42]	2021	MIC—Poland	Cross-sectional study	1638 children (52.4% female), 3 years	Parental vitamin D supplementation	ECC prevalence was significantly lower in children receiving vitamin D; Association of parental vitamin D supplementation with the dmft score of children
Reed et al[59]	2017	HIC—USA	Case–control study	29 children (52% female), 3.6 $\pm$ 0.9 years	Maternal circulating vitamin D concentrations during pregnancy	Maternal mean 25(OH)D concentrations were generally lower for those children with enamel hypoplasia
Schroth et al[60]	2020	HIC—Canada	Prospective cohort study	175 children (48% female), mean age: 19.7 $\pm$ 8.1 months	25 hydroxyvitamin D (25(OH)D) content in umbilical cord blood	Inverse relationship between 25(OH)D levels and the number of decayed primary teeth
Seminario et al[61]	2018	HIC—USA	Cross-sectional study	276 children (50.4% female), mean age: 3.4 $\pm$ 1.5 years	Serum 25-hydroxy vitamin D level	Suboptimal 25-hydroxy vitamin D status was correlated with enhanced risk for ECC
Shah et al[62]	2021	LMIC—India	Case–control study	80 children (male: 47 and female: 33), 3-6 years	Serum 25(OH) vitamin D level	In case group, inadequate levels of vitamin D were positively correlated with caries status and in control group; absence of caries was significantly correlated with adequate levels of vitamin D
Singleton et al[63]	2019	HIC—USA	Prospective cohort study	57 children, 12-59 months	Cord blood (25(OH)D concentration	Significant negative correlation between cord blood 25(OH)D levels and dmft at 12-35 months
					Iron-deficiency anemia	
Abdallah et al[64]	2016	HIC—Saudi Arabia	Cross-sectional study	160 children (43.8% female), 3-6 years	Hemoglobin levels	Anemic children were more prone to dental caries in comparison to healthy children
Babu and Bhanushali[65]	2017	LMIC—India	Cross-sectional study	120 children (41% female), mean age: 6.32 years	Serum iron and ferritin levels	Inverse association between serum iron levels and dental caries; No association between serum ferritin levels and dental caries

(continued)

Table 1. (continued)

Author/s	Years	Country	Study design	Participants	Associations assessed with ECC	Main results
Bansal et al[66]	2016	LMIC—India	Cross-sectional study	60 children (45% female), 2-6 years	Hemoglobin, corpuscular volume, corpuscular hemoglobin and packed cell volume	S-ECC was strongly associated with the anemia due to iron deficiency
Deane et al[67]	2018	HIC—Canada	Case–control study	266 children (48.9% female), mean age: 40.8 $\pm$ 14.1 months	Serum ferritin and hemoglobin, 25(OH)D levels in blood, BMI	Combined deficiencies of vitamin D and anemia were more predominant in children with S-ECC; children with S-ECC had higher BMI z-scores and lower serum hemoglobin and ferritin levels
Jayakumar and Gurunathan[68]	2017	LMIC—India	Case–control study	114 children, <72 months	Serum ferritin level	Children with ECC showed lower ferritin levels than ECC-free children; S-ECC group had lower ferritin levels than mild and moderate ECC groups
Nara and SameenaParveen[69]	2021	LMIC, India	Cross-sectional study	102 children, 2-5 years	Complete blood count, serum iron, total iron binding capacity, percent transferrin saturation and serum ferritin of iron deficient pregnant women and children	Children with S-ECC had significantly low ferritin status and lower hemoglobin levels when compared with caries free controls
Sajjanar et al[70]	2021	LMIC—India	Cross-sectional study	1332 children (52.5% female), 2-5 years	Anemia (red blood cell count, hemoglobin, haematocrit value, corpuscular volume, corpuscular hemoglobin) and iron-deficiency (serum iron, transferrin, iron binding capacity)	Significant correlation between ECC and anemia; No significant differences in iron-deficiency status

Abbreviations: BMI, body mass index; HIC, high-income country; LIC, low-income country; LMIC, lower middle-income country; MIC, middle-income country; S-ECC, severe early childhood caries; UMIC, upper middle-income country.

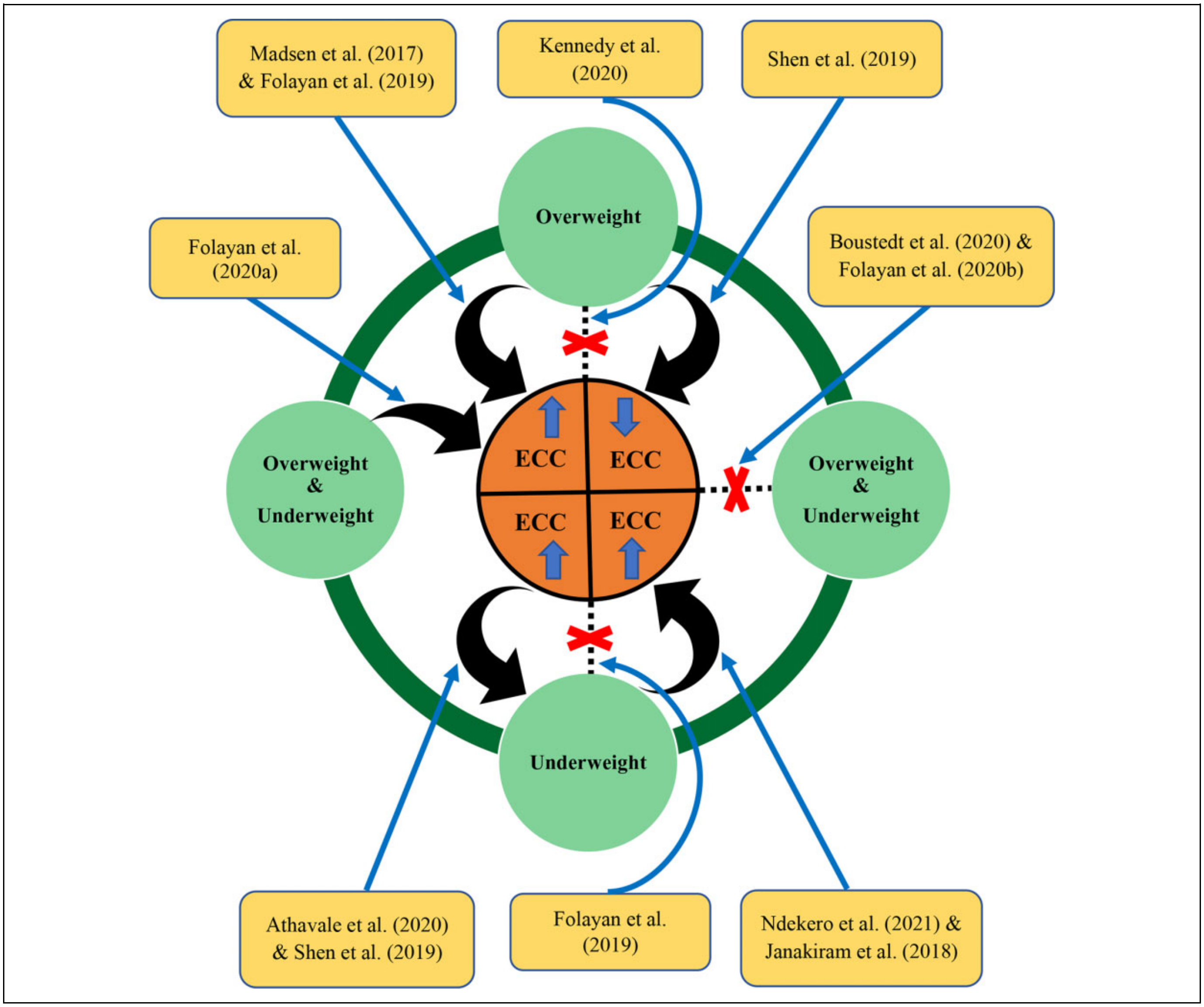

Figure 2. Associations between early childhood caries (ECC) and weight status. Research findings on the association between ECC and children being underweight/overweight are controversial and bidirectional. Some authors found that the incidence of ECC increased when the children were overweight or underweight while some authors argued that there was no relation. Some authors investigated that high ECC status can result in underweight. Another study reported that being overweight can reduce the incidence of ECC.

bone. The fundamental components of anthropometry are weight, height, body mass index (BMI), skinfold thickness, and body circumferences (hip, limbs, and waist).[23] There are several anthropometric indicators for assessing children's inadequate growth such as wasting, stunting, and being underweight. Wasting, stunting, and being underweight are defined as low weight-for-height, low height-for-age, and low weight-for-age, respectively. Moreover, both BMI and mid-upper arm circumference are commonly used, viable nutritional indices to assess undernutrition and overnutrition in children.[71] Underweight children below the age of 5 are those with a weight-for-age <-2 standard deviations (moderate) and -3 standard deviations (severe) from the median weight-for-age.[72] Overweight and obesity can be defined as the accumulation of excessive or abnormal fat which may impair health. According to WHO, children under 5 years of age with overweight are recognized by having weight-for-height >2 standard deviations above the WHO child growth standards median, while having more than 3 standard deviations defines children having obesity.[73]

Many studies have been carried out to investigate the correlation of ECC experience with anthropometric measurements of children (Table 1). Current literature on the association of ECC with being either undernourished or overnourished is controversial and inconclusive (Figure 2). Variations of these findings in different countries might also result from other variables such as diverse dietary patterns, food security parameters, genetic factors, oral hygiene practices, and physicochemical characteristics of drinking water including fluoride content.[33,34,74]

A meta-analysis of 14 studies by Chen et al[26] showed no differences in dental caries between abnormal- and normal-weight children in low- and middle-income countries. However, a significantly higher prevalence of dental caries was found among overweight children in high-income countries.[26] Since then, a significant association between being overweight/obese and the prevalence of ECC has been suggested by several authors.[30,73] A meta-analysis by Manohar et al[75] indicated that overweight and obese children had a higher prevalence of ECC than children with normal weight. However, there are several other confounding variables associated with both ECC and being overweight/obese such as lifestyle, genetic, and geographical factors.[33] The opposite relationship was seen by Shen et al[35] who found that children in China with higher weight-for-age had lower progression of dental caries, based on findings of a longitudinal study. Additionally, Kennedy et al[32] reported that there was no association between being overweight and the prevalence of ECC, in a cross-sectional study in Canada.

Ndekero et al[34] demonstrated a direct negative correlation between weight-for-age and ECC in a cross-sectional study in Tanzania, although they found no correlation between ECC and height-for-age or weight-for-height. Janakiram et al[24] also reported a significant relationship between being underweight and ECC. They found that the children with borderline nutrition and undernutrition had 2 and 3 times the odds of having ECC, respectively, compared to the children with normal nutritional status. However, Folayan et al[30] found that the prevalence of ECC among underweight children in Nigeria was zero, with no correlation between them. In addition, the prevalence of ECC in stunted children was significantly lower than in children who had normal weight. However, these 3 studies are cross-sectional studies that are unable to determine the direction of causality.

To show how inconsistent the findings of these studies related to ECC and nutritional status are, the findings of Folayan et al,[76] Boustedt et al,[29] and Folayan et al[77] can be compared. Folayan et al[76] reported, based on an ecological study in Nigeria, that being underweight and being overweight/obese were both significantly associated with the prevalence of ECC. However, in a prospective study in Sweden, Boustedt et al[29] found that there was no association between ECC prevalence and either being underweight or overweight. It was reflected by not having significant differences in dmft indices among normal weight, underweight, overweight, and obese children. Moreover, Folayan et al[77]reported that ECC was associated with neither under- nor overnutrition, which was assessed cross-sectionally through wasting, stunting, and underweight nutritional indicators.

On the contrary, several authors have brought forth pieces of evidence for the association of poor nutritional status among children with their ECC experience. For example, Athavale et al[28] have provided cross-sectional evidence for an association between undernutrition and ECC. According to the findings, each tooth of children with deep decay increased additional 10% odds having undernutrition, measured through anthropometric measures such as height-for-age, weight-for-age, and BMI-for-age. In addition, a longitudinal finding of Shen et al[35] fell in line with the above argument. They reported that the higher the incidence of dental caries, the lower the weight and height of children gained. So et al[36] cross-sectionally illustrated the impact of ECC on malnutrition. According to the findings, each unit rose in the incidence of mouth pain, associated with ECC enhanced the odds of being underweight (1.27) and decreased the odds of being overweight (0.76). The risk factor for poor nutritional status was measured by stunting, wasting, and being underweight. This study suggested that sleep disruption by mouth pain is also an indicator of severe early childhood caries (S-ECC). In addition, Deane et al[67] reported that children with S-ECC had higher BMI z-scores than those who were caries-free.

The findings have highlighted the double burden of ECC and poor nutritional status in developing countries, which should be prioritized and addressed to avoid the negative impact on the general well-being and growth of children. For that, poor nutritional status in one area can be used as a marker for poor nutritional status in another area within the region.

Eating Habits and ECC

Cariogenic diet is one causative factor for ECC.[78] Moreover, constant sipping or grazing of food and beverages, particularly sugary food is correspondingly caries promoting.[43] American Dental Association has also identified frequent exposure to sugar-containing snacks or beverages between meals and non-spill cups or bottles containing added or natural sugar frequently or at bedtime as risk factors associated with ECC.[79] In addition, several authors have reviewed excessive sugar consumption as a risk factor for ECC (Table 1).[80,81] Variations of these findings might also have resulted from other variables such as diverse oral hygiene practices, genetic factors, socioeconomic conditions, and physicochemical characteristics of drinking water including fluoride content in different countries.[82]

A positive correlation between sugar consumption and the occurrence of ECC has been reported in several cross-sectional studies[31,34,43,76] and one longitudinal study.[35] Folayan et al[77] further explained that consumption of sugar in between meals 3 or more times a day was twice as anticipated to have ECC than the consumption of sugar less often in between meals. These findings emphasize the urgent need of disseminating accurate and appropriate information on total sugar exposure and dietary recommendations. According to Evans et al[43] and Kubota et al,[46] the frequent consumption of added sugars from foods and sugar-sweetened beverages (SSB) is strongly correlated with causing S-ECC in children from low-income ethnically diverse families. Each added serving of SSB increased 14% and 139% odds of having S-ECC as derived from a 24-hour diet recall and food frequency questionnaire, respectively.[43]

Ugolini et al[52] reported that children with poor oral hygiene status who drank sugared beverages at least once a day had a higher risk of ECC and S-ECC than the children with satisfactory oral hygiene status who drank sugared beverages at least once a day and even the children with poor oral hygiene status who drank sugared beverages less than once a day. Sugar consumption was found to be correlated with the ECC burden in the EU member states after analyzing the systematic data obtained from the Food and Agriculture Organization of the United Nations.[7] Obradović et al[47] and Olczak-Kowalczyk et al[48] also observed a strong correlation between the occurrence of ECC and prominent risk factors such as consumption of sweetened food within the first 2 years of age (odds ratio [OR] = 2.96) and nocturnal drinking of sweet beverages by the over-12-month-old child (OR = 1.95). However, all these studies are cross-sectional studies that are quite unable to determine the independent and actual effect of the particular phenomenon.

A high frequency of sweets consumption before bedtime was associated with an increased risk for ECC, as detected by Percival et al,[49] Zhang et al,[55] and Samaddar et al,[50] through cross-sectional study designs. According to Percival et al,[49] bottle-feeding, added sweeteners to bottle contents, sleeping while bottle-feeding, and frequent consumption of soft and sports drinks were strongly associated with ECC. Dissanayaka and Gamage[83] confirmed that finding regarding the frequent intake of sweetened milk/powdered milk. Zhang et al[55] further explicated that ECC in the later stage (5 years old) of deciduous dentition was primarily associated with dietary patterns, particularly sugar-eating habits (OR = 3.22). Samaddar et al[50] elaborated that the cases (children with ECC) of the case–control study had significantly greater sugar exposure by 1.8 times in comparison with controls (children without ECC). Additionally, when comparing the attitudes of parents toward sugar snacking by children, the parents of the cases were prone to buy food items depending on convenience and availability, in comparison to controls by 2.5 times. Achmad et al[37] stated that consuming sweetened snacks and candy twice or more chance of having a higher incidence of ECC (76.9%-85.1%) among children.

Conversely, Folayan et al[30] indicated that consuming sugar between meals 3 times a day or more had no impact on the occurrence of ECC. Likewise, Bell et al[38] illustrated no associations between dietary patterns, high sugar, and energy intakes and ECC, after conducting a prospective study using 1170 children over a period of 3 years. They further described a possible explanation for observing a weak association between dietary patterns and ECC, as 24-36 months of age was too early to detect the influence of poor diet including high free sugar and energy intakes. Hu et al[45] also prospectively found no significant association between the quantity and frequency of SSB and confectionary consumption and the occurrence of ECC among 3 years old children. Percival et al[49] found no relation between snacking on sweet and savoury snacks between meals and ECC, irrespective of the frequency, though 44% of children had caries out of those who were observed to snack between meals (87.3%). Children who snacked on fruits between meals showed a lower incidence of ECC. Therefore, several prospective studies have shown that there is no association between sugary food consumption and ECC. More weight should be given to these findings since prospective studies can provide strong evidence and illustrate the strength of an association between a health issue and putative causative factors.

Diets of children are considered, Hu et al[45] stated that different infant dietary patterns at 6 to 12 months of age resulted in changes in the severity of ECC at 2 to 3 years of their lives. According to this prospective study which has carried out using 776 children, following the guideline dietary pattern (weaning guidelines of WHO), compared to other dietary patterns (predominantly breastmilk, easy-to-prepare foods, and noodles in soup and seafood) at 6 months was protective against the development of ECC.[45] The cross-sectional findings of Yardimci et al[54] also fell in line with the above hypothesis. They demonstrated that consumption of high protein-containing foods (meat, eggs) and beverages (milk, dairy products), starchy foods, and low-carbonated beverages had positive and preventive effects on ECC. Moreover, they stated that healthy consumption patterns such as the Mediterranean-style diet offer a defensive effect against ECC; nevertheless, the fast-food-style Western diet brings about dental caries in children. According to Achmad et al[37] children who did not consume vegetables were more prone to ECC (77.9%), compared to children who consumed vegetables as a habit. Obradović et al[47] found that higher meal frequency, having more than 8 meals per day was strongly correlated with the prevalence of S-ECC, according to cross-sectional observations.

Breastfeeding Practices and ECC

The recommendation of WHO and UNICEF is exclusively breastfeeding infants for the first 6 months of their life. After 6 months, safe and adequate supplementary food should be provided to the child while continuing breastfeeding for 2 years or beyond.[84] However, the query of the linkage between prolonged breastfeeding and caries on primary teeth which is caused by tooth decay has become a focus of heated argument.[85] It has been prospectively examined that the lactose content in breast milk increased over the period (ie, from 64.5 g/L, 2 months to 66.9 g/L, 12 months).[53] Considering the risk–benefit ratio, it has been mentioned that the benefits of long-term breastfeeding for child health outweighed the risk of caries.[86] Therefore, the findings on the association between breastfeeding and ECC are different or even controversial (Table 1). Discrepancies in these findings in different countries might also have arisen from other variables such as diverse weaning practices, genetic factors, socioeconomic conditions, oral hygiene practices, and physicochemical characteristics of drinking water including fluoride content.[31,53,87]

Some studies have reported that exclusively breastfed children in the first 6 months were prone to have a higher incidence of ECC.[35,55] However, Shen et al[35] further observed in their longitudinal study that children who breastfed longer were less likely to be overweight or obese, less susceptible to diabetes later in life, and perform better in intelligence quotient tests. ADA and DQA,[79] Percival et al,[49] and Dissanayaka and Gamage[83] argued that frequent and nocturnal breastfeeding led to a higher prevalence of ECC, based on cross-sectional findings. Long-term breastfeeding, especially after 12 months, was identified as a risk factor associated with ECC,[48,53,79] especially before and during sleep.[48] In addition, breastfeeding in the early morning was found to be a causal effect on ECC.[49] Carrillo-Díaz et al[40] reported that, when the mother co-slept and breastfed the child at night, babies tended to breastfeed frequently without waking the mother. Therefore, the mother was unable to do the oral cleaning, after the feeding which resulted in the onset and progress of carious lesions. Moreover, it was found that infants who continued to breastfeed for 18 months or more, nevertheless sleeping independently without continuous breastfeeding at night, had a relatively lower rate of dental caries than those who co-slept.[40]

Kubota et al[46] also explained that among child-rearing factors, breastfeeding, and night-time breastfeeding after 18 months were significantly associated with ECC. Achmad et al[37] reported that the caries number was 75.2% in the group which breastfed for more than 12 months. However, according to this cross-sectional study, there was no significant difference in the caries number of the group of children who drank milk at different frequencies. On the contrary, Feldens et al[44] prospectively examined that ECC prevalence and experience increased with daily frequency of breastfeeding and bottle-feeding at 38 months of age. The prevalence of S-ECC was nearly 2 times larger in the second or third quantiles of the feeding frequency comparable to the first, whereas 3 or 4 times higher in the 4th or 5th quantiles. Thus, high priority should be given to the prospective findings of Feldens et al[44] in terms of the causality of ECC which were collected from 345 children over a period of 38 months.

Though the impact of frequency and duration of breastfeeding during day and night time on ECC was assessed cross-sectionally by Chanpum et al[41] and Dissanayaka and Gamage,[83] only the breastfeeding to sleep and oral cleaning practices after breastfeeding were significantly associated with ECC prevalence and caries experience. Obradović et al[47] authenticated the above finding indicating that breastfeeding or bottle-feeding at night was significantly associated with S-ECC among children aged birth to 24 months. As investigated by Peres et al,[31] children breastfed ≥24 months had a 2.4 times higher risk of S-ECC than children breastfed for <12 months. In contrast to that, Setiawati et al[51] stated that children who were not breastfed had a 4 times greater risk to suffer from ECC compared to children who were breastfed. Van Meijeren-van Lunteren[53] found that there was no association between being exclusively breastfed or having ever been breastfed within the first 4 months and dental caries, using a prospective study design. In addition, some authors have argued that there was no association between breastfeeding duration and childhood caries.[39]

Vitamin D Status and ECC

Vitamin D plays a vital role in the development of oral bone, dentin, and enamel and the sustaining of good oral health.[61,88,89] Many studies have been carried out to investigate the role of 25(OH)D in the maintenance of good oral health and the association of 25(OH)D concentration in the body with ECC (Table 1). Dissimilarities among these findings might also result from other variables such as diverse dietary patterns, breastfeeding, genetic factors, oral hygiene practices, socioeconomic conditions, and physicochemical characteristics of drinking water including fluoride content in different countries.[42,60,63]

Singleton et al[63] and Schroth et al[60] prospectively examined an inverse relationship between the umbilical cord blood 25(OH)D concentrations and ECC. It was found that children with deficient cord blood vitamin D levels (25(OH)D <30 nmol/L) had mean dmft score 2 folds higher compared to children with nondeficient vitamin D levels in cord blood at 12 to 35 months of age, showing the potential causality of low vitamin D levels to ECC. However, a significant association could not be found between cord blood vitamin D levels and ECC at the age of 36 to 59 months since dmft scores were not significantly different among children with deficient and nondeficient cord blood 25(OH)D.[63] Though the inverse association between cord 25(OH)D levels and decayed tooth score was observed by Schroth et al,[60] a significant difference between the ECC status of infants in an intervention (giving 2 oral doses of 50 000 IU of vitamin D in mothers' second and third trimesters) and control groups was not observed.

Enamel hyperplasia (EH) is associated with vitamin D deficiency and is a serious risk factor for ECC. Thus, Reed et al[59] studied the association between maternal circulating vitamin D levels during pregnancy and EH in infants' teeth that developed in utero, using a case–control study. Enamel hyperplasia was found in 45% of the study sample and when compared to children without EH, maternal mean 25(OH)D levels were lesser for those with EH. Olczak-Kowalczyk et al[42] cross-sectionally studied the association between parental vitamin D supplementation and ECC in infants. Though the prevalence of ECC was significantly lower in children receiving vitamin D through parental supplementation when several confounders were included, the association between vitamin D supplementation and ECC was not significant.[42]

Many cross-sectional and case–control studies have reported serum vitamin D levels (25(OH)D) were significantly and inversely correlated with ECC.[56,57,61,62] Chhonkar et al[57] observed that out of 30 children with S-ECC (case group), 29 children had insufficient serum 25 (OH) vitamin D levels (<20 ng/mL). Seminario et al[61] stated that children with suboptimal vitamin D status (25(OH)D <75 nmol/L) were 2 times as likely to have ECC than the children with optimal vitamin D status. According to Shah et al,[62] all the children in the case group (with caries) had inferior serum 25(OH) vitamin D levels (<15 ng/mL), while the vitamin D status of the case and control groups were significantly different. In addition, Chen et al[90] illustrated that children with vitamin D deficiency (serum 25(OH)D $\leq$ 20 ng/mL) and insufficiency (20-30 ng/mL) had a significantly greater prevalence of ECC, compared to those with vitamin D sufficiency ($\geq$30 ng/mL). It was found that the 1 ng/mL decline in the 25(OH)D level increased the number of caries in children by 0.08, showing an inverse relationship between vitamin D status and ECC.

In contrast to the evidence for the impact of low vitamin D levels in the body on ECC, Deane et al[67] argued that children with ECC are more likely to have vitamin D deficiency as an adverse effect of ECC, through a case–control study. They observed that children with S-ECC were more susceptible to having low 25(OH)D levels (<50 or <75 nmol/L) than the caries-free control group. Contradictorily, Navarro et al[58] reported a weak association between serum 25(OH)D concentrations and caries risk in primary teeth, suggesting that children who were genetically susceptible to having inferior serum 25(OH)D concentrations did not have a higher risk of developing caries. Hence, genetic, environmental, and lifestyle/behavioral factors can be confounding the evidence for associations between vitamin D status and risk for caries development.[58] Higher importance can be given to the findings of this study since they have been observed prospectively using 5257 children over a period of 6 years.

Iron-Deficiency Anemia and ECC

Many studies have been carried out to provide evidence for the association between ECC and IDA (Table 1) because IDA is reported to be highly prevalent among children with ECC, besides ECC is reported to be highly prevalent among children with IDA.[27,91] Disparities among these findings might also be the result of other variables such as diverse dietary patterns, breastfeeding, food security parameters, genetic factors, oral hygiene practices, socioeconomic conditions, and physicochemical characteristics of drinking water including fluoride content in different countries.[65,74,92]

Many authors have reported significant associations between ECC and IDA.[76,93] Deane et al[67] and Sajjanar et al[70] found that children with ECC had low hemoglobin and ferritin contents compared to ECC-free children. Though ferritin contents were low in children with S-ECC, 70% of those with S-ECC had normal ferritin levels, thus IDA was quite deemphasized in this case–control study.[67] According to a cross-sectional study by Sajjanar et al,[70] children with high decayed, missing, and filled surfaces (dmfs) score ($\geq$35) had a 5.75-fold higher risk for anemia compared to those with low dmfs score (<35), showing a positive correlation. Bansal et al[66] and Jayakumar and Gurunathan[68] also showed that ECC is a risk marker for IDA, analyzing the serum ferritin level of children with severe, moderate, and mild ECC.[65] As cross-sectionally assessed by Bansal et al,[66] children with S-ECC were 10.77 folds more likely to have IDA than those without S-ECC. In addition, children with S-ECC had significantly low hemoglobin and packed cell volume, indicating S-ECC is a risk factor for anemia.

On the contrary, some authors have argued that the anemic condition of children is a risk factor for ECC, based on cross-sectional findings.[65,69] Babu and Bhanushali[65] stated that 31.7% of children had inferior serum iron levels (50 μg/dL) and 81.6% of them had caries, showing an inverse association between serum iron levels and caries. After observing the prenatal IDA conditions, Nara and SameenaParveen[69] reported that IDA is one of the main reasons for S-ECC. Confirming those findings, Abdallah et al[64] found that children with lower hemoglobin contents had significantly higher dmft scores than those with higher hemoglobin contents.

Conclusion

Current literature on the association between ECC and nutritional status is mostly bidirectional. The adverse nutritional status assessed by anthropometric measures, vitamin D status, and IDA have been identified as risk factors for ECC. In contrast to that, the impact of ECC on the incidence of adverse nutritional status assessed by anthropometric measures, vitamin D status, and IDA has been illustrated. Long-term, frequent, and nocturnal breastfeeding as well as frequent consumption of sugary food and beverages have been identified as high-risk factors for ECC in numbers of both prospective and cross-sectional studies, though some prospective studies have found weak associations. The strength of this review was including good quality 9 prospective cohort studies with justified sample size calculation, statistical tests with adequate statistical power, and assessment outcomes. Nevertheless, it is difficult to provide evidence for the associations due to these controversial findings along with the multiplicity of confounding factors such as genetic, demographic, lifestyle, and behavioral patterns. Most prevailing studies are either case–control or cross-sectional studies, which cannot provide strong evidence to prove the direction of causality. Thus, further studies are needed to clarify the association between ECC and the nutritional status of children, since prospective and authentic studies with well-founded statistical designs are scanty.

Author Contributions

Harshani Nadeeshani performed the literature search and wrote the original manuscript. Ruvini Liyanage, Ruwan Jayasinghe, Chandra Herath, and Sanath Thushara Kudagammana conceived the idea and edited the final version of the manuscript.

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