Review of the aetiology of Early Childhood Caries

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Abstract

Without a full understanding of the aetiology of Early Childhood Caries (ECC), it is not possible to recommend appropriate interventions to prevent ECC. The extensive literature on the aetiology of ECC has been reviewed. Potential risk factors range from those inherent in the individual, such as genetic profile, to the environment, which influences family choices and behaviour. These have been considered in ten groups: genetics, saliva, nutrition, enamel hypoplasia, oral flora, oral hygiene and dental plaque, breast-feeding, sugar in bottles, dietary sugar, and family behaviour and environment. All of these have been shown to be related to the occurrence of ECC, although some risk factors appear to be much more important than others, and there are strong interactions and synergies between them. Most emphasis has been put on high and frequent consumption of dietary sugars, infant feeding practices, poor removal of dental plaque, and formation of a dental plaque flora which is particularly conducive to caries development – the growth of this plaque is strongly encouraged by poor plaque control and a high sugar diet. Reasons for these caries-inducing behaviours lie in the family – their own experiences, circumstances and lifestyles. However, the family, or carers, are subject to strong pressures which shape belief, attitude and behaviour. The use, or lack of use, of fluoride has not been discussed in this review. The beneficial role of fluoride in caries prevention is well-known, and lack of use of fluoride should be seen as an important risk factor for ECC.

Keywords

Early childhood caries, ECC, Aetiology of Early Childhood Caries, Review of Early Childhood Caries

Introduction

Without a full understanding of the aetiology of Early Childhood Caries (ECC), it is not possible to recommend appropriate interventions to prevent ECC. Although the basics of the aetiology of dental caries are very well known – a tooth, plaque and dietary sugars – the aetiology of ECC is more complicated compared with caries development later in life, due to the strong influence of infant feeding practices and behaviour of the family, particularly the mother (or primary care giver).

There is extensive literature on the aetiology of ECC. This will be reviewed, looking first at the published reviews of aetiology of ECC, followed by an examination of information on the many potential risk factors for ECC. These potential risk factors range from those inherent in the individual, such as genetic profile, to the environment, which influences family choices and behaviour. These will be considered in ten groups (Table 1). All of these have been shown to be related to the occurrence of ECC, although it has to be appreciated that some risk factors appear to be much more important than others, and there are strong interactions and synergies between them.

Method

Literature to inform this review of aspects of Early Childhood Caries was obtained in several ways.

First, an electronic internet search was made through PubMed and ScienceDirect databases. The primary search term was 'early childhood caries'. Other keywords included tooth decay in young children, dental caries in young children, nursing caries. Other associated terms used in the search included: diagnosis, criteria, epidemiology, prevalence, aetiology, risk factor, prevention, treatment and oral health related quality of life. Eligible studies were included when they met the following criteria: (1) articles in English providing relevant information within the time period 1990 to 2015; (2) presenting evidence relevant to ECC according to the defined themes: epidemiology, aetiology, prevention and treatment; (3) considers dental caries or sequelae in early childhood. Concerning the exclusion criteria, studies were excluded from the review if they focused on either: (1) concerned with other age-groups or other diseases, (2) studies published in languages other than English. A total of 417 articles were identified through database searching; duplicates and references irrelevant to ECC were removed, reducing this list by about one third. Two conference books relevant to the situation in Asian countries were also included.

Second, nine journals were searched by hand: International Journal of Paediatric Dentistry, European Journal of Paediatric Dentistry, Pediatric Dentistry, Journal of Dentistry for Children, Journal Clinical Pediatric Dentistry, Community Dentistry Oral Epidemiology, Community Dental Health, Caries Research, Journal of Public Health Dentistry. How far back the hand-searches were made, depended on the journal: for most journals it covered 2000 to 2015, while for International Journal of Paediatric Dentistry, the search extended back to 1990.

Third, some back-tracking from the reference lists attached to publications so far discovered was carried out to identify any remaining key articles. This resulted in a database of 380 references on all aspects of ECC, covering the years 1993 to 2016. Out of this database, 227 publications were relevant to this review of the aetiology of ECC.

General Reviews of the Aetiology of ECC

The twenty-seven general reviews of the aetiology of ECC are indicated in the first column in Table 1. A major review of ECC took place at a conference in the USA, the proceedings of which were published in a supplement to Community Dentistry Oral Epidemiology, in 1998.[1] This established the definition and scope of aetiological factors in ECC. Diagnosis and reporting of ECC was discussed further in the reviews of Drury[2] and Ismail[3] in J Publ Health Dent, a year later. A very good earlier review by Litt,[4] presented models of aetiological pathways leading to ECC, including factors such as sugar, Streptococcus mutans (SM, an important bacterium in dental plaque), knowledge and behaviour. The most recent systematic review appears to be by Harris.[5] This review considered 77 studies worthy of analysis – Including 43 cross-sectional studies, 19 cohort studies, 8 case-control studies and 7 intervention studies. Topics covered included SM, diet, oral hygiene, enamel hypoplasia, and family factors. A more recent review by Gussy6 included 84 references and discussed aetiology and prevention of ECC, partly from an Australian perspective. It appears that each year the American Academy of Pediatric Dentistry reviews their policy documents; this includes ECC, and the latest (2013/4) is included in the list – they are not extensive reviews but they are authoritative. The list of references given by Seow[7] is particularly extensive and an excellent source of references (259 references listed) before this date. It should be noted that Seow added to this literature in another large article published in 2012 in Int J Paed Dent (103 references listed). This latter article considered family and environment factors, in detail. The review of Chaffee[8] provides information on the number of publications from various regions of the world, on 'early life feeding practice and ECC'. The recent review by Fontana[9] iscussed prediction of caries, through the knowledge of aetiological factors, concluding that the 'best predictor' is still past caries experience.

It can be concluded from these review articles that several diverse factors are relevant in the aetiology of ECC. While dietary sugars remain central to the aetiology of ECC, the impact of dietary sugars can be modified considerably by factors such as genetics, structure of primary teeth, infant and child feeding habits, development of the dental biofilm, and tooth brushing with a fluoride-containing toothpaste. In turn, these factors will be strongly influenced by mother's health and well-being, poverty, education, societal influences, knowledge, attitude and behaviour. These factors will be considered individually in the next 10 sections, and considered together in a concluding section.

Genetics

This is a new field of research made possible by affordable genetic profiling: the three articles considering genetics are indicated in the second column of Table 1. The very recent article by Abbasoglu[10] is an important one. Information on diet and oral hygiene was obtained from 259 2 to 5 year-olds, in Turkey, and used as co-variates in multivariate analyses. These analyses showed several genotypes to be related to increased or decreased caries risk. Romanos[11] found weak correlations between polymorphisms in bone morphogenetic proteins (BMP) in DNA, harvested from buccal cells in 1731 Brazilian 3 to 5 year-olds, in relation to BMP2. These initial studies show the potential for understanding how genetics may affect caries susceptibility.

Saliva

This too is a fairly new area of research, made easier by newer methods of rapid analyses: eight publications which considered saliva are indicated in the third column of Table 1. Fonteles,[12] in a study of 78 1 to 6 year-old Brazilians, suggested the relationship between caries risk and salivary amino acids – proline levels were positively, and glycine levels negatively related to caries experience.

Jurczak[13] reported that histatin-5 and β-defensin-2 were positively related to dental caries. Two papers[14, 15] investigated salivary total antioxidant capacity (TAC) in saliva in relation to caries experience. Antioxidants are enzymes or similar compounds produced to counter inflammation: thus, TAC is a measure of inflammatory response. Both found higher levels of TAC in S-ECC (severe early childhood caries) and suggested its use as a marker of susceptibility to ECC. Another recent article[16] found that salivary protein profiles were different in S-ECC children compared with caries free (CF) children – 8 peptides being positively related and 3 peptides negatively related to ECC. Neves[17] reported that the use of pacifiers (unsweetened) was related to lower caries experience. While this type of study is very different from those mentioned above, the authors suggested that the increased salivary flow caused by sucking on unsweetened pacifiers is protective.

In summary, while differences in composition of saliva in relation to the occurrence of ECC have been recorded, their importance as a risk factor has not yet been demonstrated. TAC may be a marker of ECC but has not yet been shown to predict ECC. The microbial composition of saliva is likely to be much more important – see Oral Flora, below.

Nutrition

This section includes nutrition of the mother during pregnancy and early general nutrition of the child, but excludes infant feeding practices since these are discussed below. Thus, the scope is broad as can be seen in the 14 articles listed in the fourth column in Table 1. The issues are complicated since under-nutrition is linked to enamel hypoplasia (see below) which in turn may predispose to caries development. Health status during pregnancy and birth weight have been considered as potential risk factors for ECC. In a study of 495 0 to 18 month Thai infants, Thitasomakul[18] reported that lack of calcium supplementation and low milk consumption during pregnancy were related to increased incidence of ECC in the infants. In a study of vitamin D status during pregnancy, Schroth[19] found lower serum levels of 250HD to be related to increased risk of enamel hypoplasia and ECC in 133 1 year-old Canadians. Both low birth weight[20] and high birthweight (macrosomia)[21] have been linked to increased risk of ECC. The latter study was a particularly large 117,175 birth cohort in Japan: macrosomia being defined as >4000g. Results of studies relating infant's weight and height to incidence of ECC are mixed; some suggesting low weight/height is related to incidence of ECC[22] while others[23,24] reported no difference. A Brazilian study[20] recorded a U-shaped relation between ECC and child's weight (both under-weight and over-weight having higher caries experience). Children about to have a GA for tooth extraction are weighed and a blood sample taken. Four studies in Canada[25-27] and Iran[28] indicate that these children have sub-optimal nutrition status. However, low weight and poor nutritional status in children with ECC may be effect rather than cause. One publication on water fluoridation has been included[29] since it specifically mentions ECC: of course, there have been many other studies showing the effectiveness of water fluoridation at preventing caries in primary teeth (usually at age 5y) – see Rugg-Gunn and Do.[30]

In summary, the occurrence of ECC appears to be influenced by the nutritional status of the mother during pregnancy. The inverse relation between the child's nutritional status and ECC incidence may be cause or effect, or both. Most attention has been given to vitamin D, although calcium and iron have also been considered. The caries-protective role of fluoride in early life is well-established.

Enamel Hypoplasia

Ever since the research by Mellanby in the UK, over 80 years ago, it has been recognised that enamel hypoplasia predisposes to caries development. Mellanby suspected vitamin D deficiency was the cause of enamel hypoplasia and increased susceptibility to dental caries. Considering more recent studies, it was mentioned in the section on nutrition that Schroth[27] reported that poor vitamin D status during pregnancy was related to increased prevalence of enamel hypoplasia and ECC in the child. The 17 papers indicated in the fifth column in Table 1 confirm this. There are some key papers. Alaluusua[31] gives a good introductory paper for a conference at which Caufield[32] presents the main paper. Caufield discusses many causes of enamel hypoplasia in primary teeth. He maintains that the rough hypoplastic enamel surface allows bacteria to adhere to enamel more easily (especially S. mutans), encouraging caries development. He feels hypoplasia to be such an important risk factor for caries that he uses the term 'Hypoplasia-associated severe early childhood caries' (HAS-ECC). The earlier study by Seow[33] in Brisbane is historically important, together with her study in 2009; she then supervised the cohort study of Plonka.[34] In Plonka's study, hypoplasia was a significant risk factor and, importantly, the hypoplasia was recorded before caries developed, since diagnosing the presence of hypoplasia, in cross-sectional studies, is not easy as caries may have destroyed the areas of hypoplasia. Two *in vitro* analyses of the structure of teeth either with or without ECC, indicated that ECC teeth were more porous[35] and had lower calcium, phosphorus concentrations and a lower Ca:P ratio,[36] than sound teeth.

In summary, there is good evidence that enamel hypoplasia is a risk factor for ECC. There is moderately strong evidence that poor nutritional status, particularly vitamin D, is a risk factor for enamel hypoplasia.

Oral flora (salivary and plaque bacteria)

As can be discerned from the 55 articles indicated in the sixth column of Table 1, there is a strong opinion that ECC is an infectious disease with bacterial specificity. In simplest terms, the mother infects the infant with Streptococcus mutans (SM). Nearly all of the 55 publications confirmed the strong relationship between the presence of SM in plaque (and saliva) and ECC. Two review articles [37,38] confirm the predominant role of SM. Eleven cohort studies have enabled recording of the acquisition of SM and subsequent ECC experience. Infants who develop ECC acquire SM at an early age.[37,39-41] The study of Pattanaporn,[42] working in a Chiang Mai hospital, found mode of birth delivery to be significantly related to MS colonisation and caries development (vaginal birth greater risk than C-section). Infants mainly acquire MS and other organisms from the mother by kissing and food-tasting. A habit common in some countries, e.g. Japan[43] and Myanmar,[44] is pre-chewing of foods, such as rice, by mother or grandmother. Caufield[45] proposed the term 'discrete window of infectivity' (19 to 31mo), but this is questioned in several of the papers listed in Table 1. For example, Tankkunnasombut[46] examined young children attending a Well Baby Clinic in Bangkok, and found SM colonisation in 5% of infants as young as 2 months old, before first tooth eruption (about 6 months). By the age of 27 months (about 20 teeth present), 32% were infected with SM. As indicated by Ersin,[47] a high sugar diet encourages SM growth. Identifying organisms in plaque has become easier with modern profiling techniques and it can be seen from the publications that SM is not the only organism to be closely associated with development of ECC. For example, Ma[48] identified 379 species in plaque and saliva of 60 3 to 4 year old Chinese children – 13 species in plaque and 2 in saliva were positively associated with ECC. Other relevant organisms are Lactobacillus (LB), Streptococcus sobrinus, Candida albicans and Veillonella. The combined presence of these organisms

may increase the likelihood of ECC development. For example, Saraithong[49] working in Chiang Mai, Thailand, reported that if both SM and S. sobrinus were present, caries prevalence was five times greater than if both were absent. There is growing interest in individual genotypes of these organisms. For example, Qiu[50] reported that Candida albicans genotype A was associated with lower caries experience, while genotype B was associated with higher caries experience. Papers that chart colonisation over time are particularly relevant.[34,51,52] Various quick tests have been proposed and tested, two old ones being Dentocult SM and Dentocult LB (from Finland). Researchers in Japan[43,53] have developed the Caries Activity Test (CAT) and Cariostat – these largely measure acid production – reporting their ability to predict caries development.

In summary, there is strong evidence that SM is closely associated with development of ECC. Other organisms in plaque and saliva may have a similar and complementary role but their relative importance appears to be less. The primary source of SM for the infant is the mother or carer. Identification of plaque organisms is becoming more rapid and less reliant on cultivation in the laboratory.

Oral hygiene and dental plaque

The conclusion from the review of the 57 articles indicated in the seventh column in Table 1 is quite straight-forward – dental plaque and poor oral hygiene are strong risk factors for ECC. Because they are closely linked, presence of plaque and oral hygiene/toothbrushing have been included in the same section. Several ways of quantifying plaque on teeth were used, such as the 'plaque index', but the conclusions were the same – more plaque, more caries. A recent review of this subject[37] confirms this conclusion. Toothbrushing is the principal way of reducing/removing plaque and should be done by the carer in infancy and childhood. In surveys of This type, it should be noted that toothbrushing activity was almost always obtained by questionnaire and can be subject to recall bias. Questions relate to: age when brushing began, who brushed the teeth, frequency of brushing, and age of toothbrush. The type of toothpaste has not been investigated in this review, as it is well known that fluoride-containing toothpastes are effective in caries prevention. Most studies were cross-sectional although a few[34] were longitudinal allowing plaque levels to be recorded before caries development. Several studies[54-61] indicated that the earlier the age toothbrushing began, the lower the incidence of ECC. Several studies[18,43,62-66] showed that toothbrushing by parent and carer was important in that it was related to lower incidence of ECC. As far as frequency of toothbrushing was concerned, while several studies showed the benefit of brushing at least twice per day, other studies showed no relation between frequency of toothbrushing and incidence of ECC. One study[67] reported that low toothbrushing frequency in the carer was passed on to the child, resulting in increased caries levels in the child. Carvalho[62] reported on toothbrushing both at home and at nursery in 2411 1 to 5 year-old Brazilian children. Both were important and the incidence of ECC was very much higher when the child was not assisted with toothbrushing at home and did not brush their teeth at nursery. The interaction between toothbrushing habits and sugar-consumption habits was studied by Stecksén-Blicks[68] and Masson[69] – they reported a synergistic effect of poor plaque control and high sugar consumption in relation to the development of ECC.

In summary, the quantity of plaque recorded on teeth is positively related to incidence of ECC. Toothbrushing is the main way of removing/ reducing plaque. There is strong evidence that toothbrushing is related to lower occurrence of ECC. Early introduction of toothbrushing (before the first birthday), brushing by parent or carer, and brushing more than once a day are related to lower occurrence of ECC. The benefit of using a fluoride-containing toothpaste is very well documented.

Toothbrushing is not a substitute for a reduction in sugar consumption.

Breast-feeding

Thirty-eight articles discussing breast-feeding and the occurrence of ECC are indicated in the eighth column in Table 1. This is a contentious issue since breast-feeding is promoted strongly for the infant's general health and well-being. In many cultures, prolonging breast-feeding is an important method of birth-control. Another consideration is the cost of formula feed and the quality of water used to mix with the formula feed powder. WHO recommends exclusive breast-feeding until 6 months and complimentary breast-feeding up to two years of age. A good discussion of this can be found in the paper by van Palenstein Helderman[44] who describes a survey in Myanmar and presents a rather fatalistic attitude to ECC. In general, breast-feeding up to 12 months is not seen as a risk for dental caries, while continuing after 12 months increases risk. For example, the well-respected cohort Iowa study [94] found breast-feeding for 6 months protective after adjustment for confounding factors; Majorana[70] in Italy and Olatosi[71] in Nigeria found the same result. Another Italian study[72] found longer duration of breast-feeding (20 months) increased caries risk. In Japan, two studies identified breast-feeding beyond 18 months a risk for dental caries: Tanaka,[73] in a birth cohort study in Japan, found a cut-off at 18 months with low caries before then and high caries experience after that age, and Ibrahim,[43] also in Japan, reported increased caries experience in children breast - fed beyond 18 months. Turton,[54] in Cambodia, and Jain,[74] in India, reported that breast-feeding longer than 2 years was associated with increased incidence of ECC. In the Myanmar study of van Palenstein Helderman,[44] the cut-off age was 12 months, with caries risk increasing beyond that age.

While the above publications have considered breast-feeding, few have mentioned what the alternative to breast-feeding was. It is very likely that the alternative, during the first 6 months at least, was a formula feed, but was anything, such as sugar, added to that feed? One study in Nigeria, [71] which compared breast- and bottle-feeding directly, reported lower incidence of ECC in infants breast - fed for the first 6 months compared with infants fed by bottle. Superimposed on the consideration of duration of breast-feeding, is 'on-demand' breast-feeding, the frequency of breast-feeding, and nocturnal breast-feeding. These are seen as risk factors in several studies; for example, in the Thai cohort study of Thitasomakul,[18] where 495 infants were followed through to 18 months, 'on demand' feeding was associated with increased risk of ECC. In a study of 362 0 to 5 year-old Cambodian children, Turton[54] reported that 70% of the children were still sleeping with their mother at the age of 4 years. Apart from the interesting study of van Palenstein Helderman[44] in Myanmar, mentioned above, two other analyses are worth close study. First, by a group of paediatricians in Sri Lanka[75] who emphasised overnight feeding as a key risk factor. Second, the systematic review by Tham[76] from Melbourne, Australia. These authors concluded that: (a) breast-feeding up to 12 months of age was associated with lower risk of ECC, (b) breast-feeding more than 12 months was associated with increased risk of ECC, and (c) nocturnal breast-feeding was associated with increased risk of ECC.

In summary, the number of publications on this subject has increased considerably during the past few years; out of the 38 publications listed, seven were published in 2015 and nine in 2014. The research has been reviewed recently and thoroughly by Tham[76] and their conclusions, given above, provide the best summary.

Sugar in bottles

Although 'bottle feeding' was recorded in the 38 studies indicated in the ninth column in Table 1, an important difficulty in interpreting the information is that the content of the bottle was not always specified. In the 15 studies that did say that sugar was added to the feeding bottle [33,34,47,65,70,73,75,77-84] this was invariably related to increased risk of ECC. In the study by Majorana[70] in Italy, bottle-feeding with sugar added was associated with higher caries experience compared with breast-feeding. Avila[85] reported a systematic review of breast- versus bottle-feeding and concluded that breast-feeding was associated with lower caries experience. However, the contents of the bottle were not given. In a high proportion of the studies listed in the table, the effect of night-time use of a bottle was investigated and found to be strongly associated with increased caries experience. In some of the studies listed, multivariate analyses were used to control for confounding factors, but in many studies the analyses were univariate. Interpretation of these latter studies requires caution as 'bad habits' (e.g. use of sugar, poor toothbrushing) tend to occur in the same individuals. The 1999 article by Seow [33] describes a well-conducted cross-sectional study which found that sugared milk in a bottle at night-time a significant caries risk. One of the few studies to report the effect of juice or soft-drinks (not milk) in feeding bottles [86] found that use of these bottles at age 12 months was associated with increased caries experience at age 5 years. The list includes five cohort studies [21,34,73,84,86,87] (Chaffee [84] and Feldens [86] were the same study) in which feeding practices were recorded at a young age and subsequently related to the development of ECC. For example, in the Brazilian study of Chaffee,[84] ECC observed at examinations at age 5 years was related to diet which had been recorded at 6 and 12 months. In the cohort study of Peltzer[87] carried out in Han Province, Thailand, 597 children were followed from birth through to examination at age 36 months: sleeping with a bottle at 30 months was associated with increased risk of ECC. In three of these birth cohort studies[34,73,84,86] sugar in a bottle was recorded and found to be associated with higher caries experience.

In summary, bottle-feeding is the alternative to breast-feeding in early life and is continued, for variable lengths of time, after weaning. Very little information on the contents of the bottle (e.g. formula or bovine milk) was given in the publications reviewed, although this information may be available in the wider medical literature. It would appear to be a common practice to add sugar to bottle feeds. Reasons for this practice were not given in the publications reviewed but, again, may be included in the wider medical literature. It is unclear if the custom of adding sugar to feeding bottles is more common in some countries, some social groups, or other groupings, than in others. In the small number of straight comparative studies, bottle feeding is associated with higher caries incidence compared with breast-feeding: however, it is unclear whether this difference was solely due to the addition of sugar to bottle feeds. A comparatively large amount of evidence indicates that sugar added to bottle feeds is strongly associated with increased incidence of ECC. Likewise, nocturnal feeding with a bottle is associated with increased caries incidence. The most useful information can be obtained from the five birth cohort studies.

Sugar

A total of 77 papers are indicated in the tenth column in Table 1. The form 'sugar' takes in the infant's/child's diet varies – for example, as candies, soda, sugary snacks, dummy dipped in syrup, medicines etc. The vast majority of these papers recorded that sugar consumption was associated with increased caries experience. A few reported no effect and one [88] reported 'non-exposure to

sugar snacks' to be associated with increased risk of ECC; although this was obtained by univariate analysis. Multivariate analyses were used in many of the more recent studies and nearly all of these showed positive relations between sugar consumption and caries experience. For reasons given in previous sections, cohort studies are a valuable source of information. There are reports on twelve cohort studies [18,39,56,59,84,86,89-95] investigating the relation between sugars consumption and ECC: all of these found caries experience to be related to sugar consumption, either as drinks or food. Importantly, one study,[96] in Japan, reported consumption of water to be associated with low caries risk. An American study [97] reported that milk was not associated with caries experience, while five studies [21,69,98-100] found milk consumption to be associated with decreased caries risk. While Al - Malik[58] reported that consumption of fruit juices was associated with increased incidence of ECC, five studies[69,89,98,101,102] reported that fruit juice was either associated with reduced incidence of ECC or reported no effect. A good analysis of the US NHANES (national) data and discussion regarding 100% fruit juice and the occurrence of ECC is given by Vargas.[102] In contrast, the study of Wulaerhan[103] of Ughur children in Kashgar, China, found 'fruit, sweet water and milk/yoghurt' to be associated with higher caries experience. In a cohort study in Umea, Sweden, Ohlund[93] reported lower caries experience in 4 year-old children who had consumed high amounts of cheese. Also from Umea, the paper by Stecksén–Blicks[104] describes an interesting interaction (strongly additive) between sugar consumption and poor toothbrushing habits. Only one study,[105] in Italy, mentioned 'sweetened baby pacifiers' – their use was associated with increased caries incidence. In only two publications was sugar in medicines discussed[106,107] – in both cases, their long-term use was related to increased incidence of ECC: this topic has been well-reviewed elsewhere. Locally in SE Asia, studies have been undertaken in Thailand,[18] Vietnam[108] and Lao PDR [61] – in all three, sweets/candies and sweetened soft drinks were associated with higher incidence of ECC.

In summary, there seems to be little doubt that sugars added to the diets of infants and young children are associated with incidence of ECC. These added sugars may be in the form of drinks (bottles and soft drinks), foods (sweets, candies, biscuits), applied to pacifiers/dummies, and given as medicines. This evidence comes from many types of study (birth cohort and cross-sectional) and from a wide spectrum of countries and cultures. In contrast, plain milk, fruit and fruit juice (all of which contain sugars naturally) are not associated with ECC or are associated with lower incidence of ECC. One study reported that consumption of plain water was associated with lower incidence of ECC.

Family, behaviour and environment

Although sugar intake, poor tooth cleaning, and dental plaque with high levels of Streptococcus mutans, are rightly given prominence as primary risk factors (see above), reasons for these unfavourable behaviours need to be understood if preventive strategies are to be successful. An excellent review of these aspects of ECC risk has been published by Seow[109] 'Environmental, maternal, and child factors which contribute to early childhood caries: a unifying conceptual model'; it contains 103 references. As Seow says: "The rates of ECC are highest among the socially disadvantaged such as low socioeconomic groups and indigenous and ethnic minorities". A large proportion of the 75 articles indicated in the right-hand (eleventh) column in Table 1 report that a low level of education and low family income are associated with high prevalence of ECC.

Table 1. Aspects of Aetiology of ECC.

Reference	ECC Review articles	Genetics	Saliva	Nutrition	Enamel hypoplasia	Oral flora	Oral hygiene and dental plaque	Breast - feeding	Sugar in bottles	Sugar	Family behaviour and environment
Das (2016) [36] Int J Paed D					★						
Turton (2016) [54] Eur Arch Paed D							★	★		★	
Abbasoglu (2015) [10] Caries Res		★					★			★	
AbdelAziz (2015) [101] Ped D										★	
Avila (2015) [85] PLoS One								★	★		
Baggio (2015) [110] BMC Oral H											★
Birungi (2015) [126] PLoS One								★			
Chaffee (2015) [84] CDOE									★	★	
Correa-Faria (2015) [127] Int J Paed D					★		★				★
de Souza (2015) [121] Eur J D.											★
Folayan (2015) [128] BMC OH										★	
Fontana (2015) [9] Ped D	★										
Ghazal (2015) [89] CDOE										★	
Hao (2015) [39] Caries Res						★				★	
Jain (2015) [74] JODDD							★	★	★		
Jurczak (2015) [13] Biol Res			★								
Kato (2015) [129] BMJ Open								★			
Khanh (2015) [108] Am J Publ H										★	
Liang (2015) [130] Oral H Prev D											★
Lim (2015) [90] CDOE										★	
Ma (2015) [48] PLoS One						★					
Nakayama (2015) [131] J Epi.							★	★		★	
Nakayama (2015) [124] J Pub H D										★	★
Narrenthran (2015) [35] Caries Res					★						
Neves (2015) [17] J Clin Paed D			★			★					
Paglia (2015) [132] Eur J Ped D								★			
Peltzer (2015) [87] BMC O H									★		★
Qiu (2015) [50] BMC Oral H.						★					

Table 1. Aspects of Aetiology of ECC (continued).

Reference	ECC Review articles	Genetics	Saliva	Nutrition	Enamel hypoplasia	Oral flora	Oral hygiene and dental plaque	Breast - feeding	Sugar in bottles	Sugar	Family behaviour and environment
Romanos (2015) [11] Caries Res		★									
Saraithon (2015) [49] Cl Oral Inv						★					
Si (2015) [16] Caries Res			★								
Tham (2015) [76] Acta Paed								★			
Wigen (2015) [91] Acta Od Scand							★			★	
Winter (2015) [59] Clin Oral Inv							★			★	★
Yokomichi (2015) [21] PLoS One				★			★		★	★	★
Zaki (2015) [98] Int J Paed D										★	
Albino (2014) [133] J Pub H D											★
Aminabadi (2014) [55] Caries Res							★				★
Batliner (2014) [134] J Pub H D											★
Bissar (2014) [60] Clin Oral Inv							★	★	★		★
Carvalho (2014) [62] Caries Res							★		★	★	★
Chaffee (2014) [135] Ann Epid.								★			
Chaffee (2014) [8] J Oral Dis	★										
Chaffee (2014) [40] JDR						★					
Congiu (2014) [105] J Pub H D									★	★	★
Congiu (2014) [136] O Health Pr D	★										
dos Santos (2014) [20] BMC				★							
Duijster (2014) [119] CDOE											★
Gao (2014) [137] Ped D						★	★				
Gilbert (2014) [138] J Oral Micr.						★					
Han (2014) [139] CDOE										★	
Hong (2014) [29] Int J Paed D							★	★		★	
Hong (2014) [94] Ped D				★	★			★		★	★
Hsieh (2014) [67] As Pa J P H							★				
Jabin (2014) [140] J Clin Diag Res											★
Koo (2014) [141] Future Microb						★					

Table 1. Aspects of Aetiology of ECC (continued).

Reference	ECC Review articles	Genetics	Saliva	Nutrition	Enamel hypoplasia	Oral flora	Oral hygiene and dental plaque	Breast - feeding	Sugar in bottles	Sugar	Family behaviour and environment
Krisdapong (2014) [142] A P J Pub H											★
Li (2014) [143] Int J Mol Sci.						★					
Mahjoub (2014) [15] Caries Res			★								
Majorana (2014) [70] BMC								★	★		★
Masumo (2014) [144] Acta Od Scand					★		★			★	
Nobile (2014) [72] BMC								★	★		★
Nunes (2014) [63] BMC Publ H							★	★		★	
Olatosi (2014) [71] J West Afr Coll Surg.								★	★		
Peng (2014) [145] Int J Paed D				★							★
Perera (2014) [75] Asia Pac J Clin Nutr								★	★		
Piovesan (2014) [146] J Pub H D											★
Reyes-Perez (2014) [147] J P H D				★							
Schroth (2014) [148] Pediatr				★	★						
Stecksén-Blicks (2014) [111] Acta Od Sc											★
Torriani (2014) [149] Caries Res											★
Vargas (2014) [102] JADA										★	
Wulaerhan (2014) [103] BMC Oral .							★			★	★
Xu (2014) [150] PLoS One						★					
Am Acad Ped (2013/4) [151] Am Acad Ped	★										
Am Acad Ped (2013/4) [152] Am Acad Ped	★										
Alanzi (2013) [153] Ped Dent		★									
Bhoomika (2013) [24] J Clin Ped D				★							
Feldens (2013) [154] Caries Res											★
Leong (2013) [37] Int J Paed D						★	★	★	★	★	★
Masumo (2013) [88] Acta Od Sc								★		★	
Menon (2013) [115] Int J Paed D							★				★

Table 1. Aspects of Aetiology of ECC (continued).

Reference	ECC Review articles	Genetics	Saliva	Nutrition	Enamel hypoplasia	Oral flora	Oral hygiene and dental plaque	Breast - feeding	Sugar in bottles	Sugar	Family behaviour and environment
Naidu (2013) [155] BMC										★	
O'Keefe (2013) [156] Evid-based D	★										
Pani (2013) [157] Int J Dent											★
Pattanaporn (2013) [42] CDOE						★					
Plonka (2013) [34] Caries Res					★	★	★		★		★
Schroth (2013) [26] BMC				★							
Schroth (2013) [27] BMC				★							
Smith (2013) [158] J Ped Nursing	★										
Tanaka (2013) [73] Ped Dent								★	★		
Tao (2013) [51] Arch O Biol						★					
Whitney-Evans (2013) [159] J Acad Nut Diet										★	
Alaluusua (2012) [31] JDR					★						
Caufield (2012) [32] JDR					★	★					
Hughes (2012) [160] Ped D						★					
Masumo (2012) [161] BMC					★			★		★	★
Nunes (2012) [162] CDOE							★	★		★	
Plutzer (2012) [163] Int J Ped											★
Prakash (2012) [77] Eur J D							★	★	★	★	
Qadri (2012) [164] Quint Int								★	★		
Sadeghi (2012) [28] D Res (Iran)				★							
Seow (2012) [109] Int J Paed D											★
Subramaniam (2012) [64] Cont Clin D							★	★	★	★	
Wong (2012) [56] Int J Paed D							★		★	★	★
Yang (2012) [165] Arch O Biol						★					
Zhang (2012) [166] Arch O Biol						★					
Zhou (2012) [22] Caries Res				★	★	★	★				★

Table 1. Aspects of Aetiology of ECC (continued).

Reference	ECC Review articles	Genetics	Saliva	Nutrition	Enamel hypoplasia	Oral flora	Oral hygiene and dental plaque	Breast - feeding	Sugar in bottles	Sugar	Family behaviour and environment
Agarwal (2011) [167] Int J Paed D											★
Duran-Contreras (2011) [168] Eur J Paed D						★					
Hart (2011) [169] Int J D			★			★					
Kawashita (2011) [170] Int J D	★										
Kumar (2011) [14] Int J Paed D			★								
Kumarihamy (2011) [106] BMC Res Notes										★	
Li (2011) [99] Int J P D										★	
Lindemeyer (2011) [171] NY State D J											★
Mathur (2011) [172] Ped Dent J								★	★		
Ozer (2011) [78] Eur J Paed D									★		★
Tanner (2011) [52] JDR						★	★			★	
Zhou (2011) [173] Austral D J						★	★			★	★
Zhou (2011) [174] Int J Paed D						★					
Begzati (2010) [79] BMC						★			★	★	
Elfrink (2010) [175] Int J Paed D					★		★				★
Feldens (2010) [86] Caries Res								★	★	★	★
Johansson (2010) [176] Caries Res							★			★	★
Kanasi (2010) [177] Caries Res						★	★				
Masson (2010) [69] Br J Nut							★			★	
Meurman (2010) [92] Caries Res						★				★	★
Niji (2010) [53] Ped D						★	★			★	★
Palmer (2010) [97] Caries Res						★				★	
Parisotto (2010) [178] Arch O Biol						★	★			★	
Parisotto (2010) [38] Oral H Prev D						★					
Petti (2010) [179] J Dent	★										

Table 1. Aspects of Aetiology of ECC (continued).

Reference	ECC Review articles	Genetics	Saliva	Nutrition	Enamel hypoplasia	Oral flora	Oral hygiene and dental plaque	Breast - feeding	Sugar in bottles	Sugar	Family behaviour and environment
Senesombath (2010) [61] SE Asia J Trop Med P H.							★			★	
Tuli (2010) [180] Eur J Paed D	★										
Adeniyi (2009) [181] Int J Paed D											★
Alaki (2009) [182] Ped Dent	★				★						
Irigoyen-Camacho (2009) [183] J Clin P D											★
Choi (2009) [184] Int J Paed D						★					
Fonteles (2009) [12] Arch O Biol			★								
Ibrahim (2009) [43] Ped Dent J						★	★	★		★	
Jigjid (2009) [185] Com D Hlth						★		★		★	
Mitchell (2009) [41] Ped D						★					
Nunn (2009) [186] JDR										★	★
Nunn (2009) [187] J Pub H D											★
Seow (2009) [116] Caries Res					★	★	★			★	★
Tankkunnasombut (2009) [46] Ped Dent						★					
Thitasomakul (2009) [18] JDR				★			★	★		★	★
Uribe (2009) [188] Evid-Based D	★										
Warren (2009) [95] CDOE						★				★	
Coşulu (2008) [189] Int J P D						★	★	★		★	
Alaki (2008) [190] Ped D	★										
Declerck (2008) [191] CDOE							★			★	
Hong (2008) [23] J Pub H D				★							★
Ismail (2008) [120] Ped Dent										★	★
Maruyama (2008) [96] Ped D						★	★			★	
Mohebbi (2008) [192] CDOE								★	★	★	
Qin (2008) [80] Ped D						★			★	★	★

Table 1. Aspects of Aetiology of ECC (continued).

Reference	ECC Review articles	Genetics	Saliva	Nutrition	Enamel hypoplasia	Oral flora	Oral hygiene and dental plaque	Breast - feeding	Sugar in bottles	Sugar	Family behaviour and environment
Warren (2008) [193] J Pub H D						★	★				★
Du (2007) [194] Quint Int									★		★
Ferreira (2007) [195] Int J Paed D											★
Finlayson (2007) [117] CDOE											★
Kolker (2007) [100] Ped D							★			★	
Kramer (2007) [196] Caries Res								★			
Iida (2007) [125] Pediatrics								★			★
Ohlund (2007) [93] Caries Res						★				★	
Olak (2007) [197] Int J Paed D						★					
Schroth (2007) [198] Ped D											★
Tiberia (2007) [199] Ped D									★		
Williamson (2007) [113] Ped D											★
De Carvalho (2006) [200] Arch O Biol						★					
Clarke (2006) [25] Ped D				★							
Ersin (2006) [47] J Dent Ch						★	★		★		★
Gussy (2006) [6] J Paed Ch H	★										
Hallett (2006) [201] CDOE									★		★
Law (2006) [202] Ped D					★	★	★			★	
Psoter (2006) [203] J Pub H D											★
Tsai (2006) [204] CDOE							★			★	
Van Palenstein Helderman (2006) [44] JDR						★		★			
Tang (2005) [118] CDOE											★
Campus (2004) [65] Eur J Paed D							★		★	★	
Harris (2004) [5] Com Dent Hlth	★										
Kiwanuka (2004) [107] Int J Paed D							★			★	★
Nomura (2004) [205] Ped Dent J						★				★	

Table 1. Aspects of Aetiology of ECC (continued).

Reference	ECC Review articles	Genetics	Saliva	Nutrition	Enamel hypoplasia	Oral flora	Oral hygiene and dental plaque	Breast - feeding	Sugar in bottles	Sugar	Family behaviour and environment
Rosenblatt (2004) [206] Int J Paed D								★		★	
Stevens (2004) [207] Eur J P D											★
Vachirarojpisan (2004) [208] CDOE						★					★
Carino (2003) [57] CDOE							★			★	
Ismail (2003) [209] Ped D	★										
Jin (2003) [210] J Pub H D										★	
Jose (2003) [211] Ped D							★			★	★
Shiboski (2003) [81] J Pub H D									★		★
Chan (2002) [212] Int J Paed D							★			★	★
Huntington (2002) [66] Ped D							★		★		★
Rosenblatt (2002) [213] J Dent Ch										★	
Tinanoff (2002) [214] Ped D	★										
Al-Malik (2001) [58] Int J Paed D							★			★	★
Maciel (2001) [215] Int J Paed D						★				★	
Tsai (2001) [123] Int J Paed D							★				★
Ansai (2000) [216] Ped Dent			★			★					
Rodrigues (2000) [217] Int J Paed D					★		★			★	
Tinanoff (2000) [218] J Publ H D	★										
Drury (1999) [2] J Pub H D	★										
Ismail (1999) [3] J Pub H D	★										
Oulis (1999) [219] Ped D									★		
Ramos - Gomez (1999) [82] J Dent Ch								★	★		
Seow (1999) [33] Ped Dent					★	★	★		★		
al-Ghanim (1998) [83] Int J Paed D							★		★	★	
Bowen (1998) [220] CDOE	★										
Davies (1998) [221] CDOE	★										

Table 1. Aspects of Aetiology of ECC (continued).

Reference	ECC Review articles	Genetics	Saliva	Nutrition	Enamel hypoplasia	Oral flora	Oral hygiene and dental plaque	Breast - feeding	Sugar in bottles	Sugar	Family behaviour and environment
Reisine (1998) [222] CDOE	★										
Seow (1998) [7] CDOE	★										
Tinanoff (1998) [223] CDOE	★										
Del Valle (1998) [224] J Dent Ch									★		
Peretz (1997) [225] Ped D											★
Tinanoff (1997) [226] Ped D	★										
Shantinath (1996) [114] Ped D									★		★
Litt (1995) [4] Publ H Rep	★					★				★	★
Stecksén-Blicks (1995) [104] Int J Paed D							★			★	
Todd (1994) [227] Int J Paed D								★			

Poor oral health of infants and children of immigrant families has been recorded in several countries.[60,110,111] A good investigation into reasons for this was published by Stecksén–Blicks,[111] with poor dietary and oral hygiene habits being important. The child's temperament has been considered by some researchers – there is a good recent study by Aminabadi[55] in Tabriz, Iran, where the Early Childhood Behaviour Questionnaire (designed by Putnam[112]) was used. This questionnaire is relevant for children aged 18 to 36 months and measures 18 traits: the nine traits which were positively related and the nine traits which were negatively related to ECC are listed. An infant's 'difficulty sleeping' is listed as a risk factor in two papers.[113,114] Mother's high levels of stress were mentioned by some[115,116] as a risk factor although some reports disagreed with this.[117,118] There was a good paper on 'family functioning' in relation to ECC by Duijster[119] with emphasis on the negative impact of poor organisation within the home. Carer's 'fatalistic oral health beliefs' were investigated and discussed by Ismail.[120] Single parenthood and age of the mother are other variables reported in the articles. The poor oral health of the mother was recorded as a risk factor for ECC in the infant in several studies.[37,121-123] Several studies reported that mothers who smoked was a risk factor for ECC in the infant/child.[21,70,124,125]

In summary, family attributes, dynamics and behaviour are drivers of the primary risk factors for ECC - sugar intake, feeding habits, poor tooth cleaning and acquisition of SM. These family risk factors are themselves driven by the environment in which the family lives. Unfavourable environmental factors include food availability and relative costs of foods, educational experience and finance, advertising, society cultures and customs. These factors need to be considered if progress is to be made in controlling the primary risk factors for ECC.

Concluding remarks

227 articles have been examined in this review of the aetiology of ECC. Potential risk factors for ECC have been grouped under 10 headings. The literature indicated that all ten were relevant risk factors. Although each has been considered separately, there are strong interactions between them. Most emphasis has been put on high and frequent consumption of dietary sugars, infant feeding practices, poor removal of dental plaque, and formation of a dental plaque flora which is particularly conducive to caries development – the growth of this plaque is strongly encouraged by poor plaque control and a high sugar diet. Reasons for these caries-inducing behaviours lie in the family – their own experiences, circumstances and lifestyles. However, the family, or carers, are subject to strong pressures which shape belief, attitude and behaviour. The use, or lack of use, of fluoride has not been discussed in this review. The beneficial role of fluoride in caries prevention is well-known, and lack of use of fluoride should be seen as an important risk factor for ECC. Vehicles for fluoride relevant to ECC are water, salt, milk, toothpaste, and varnish.

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