Case definition, Aetiology and Risk assessment of Early Childhood Caries (ECC): A revisited review

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Abstract

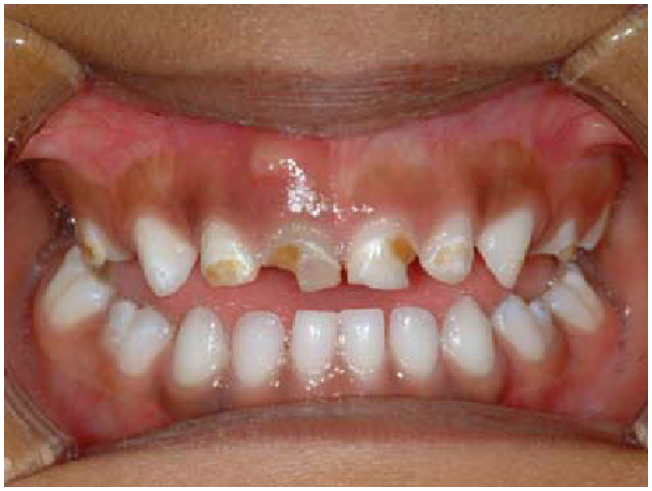
Aim: To provide a review of the existing literature on early childhood caries (ECC) with particular reference on the nomenclature, case definition, epidemiology, aetiology and risk assessment. **Methods:** An electronic search was used to identify and critically review papers that have been published and are pertinent to the above issues, and then evaluate and compile the reported evidence. **Results:** The term ECC has been adopted to more accurately describe dental caries that affects primary dentitions, replacing previously used terminology that associated the disease with the nursing habit. Suggested ECC case definition uses caries patterns as defining criteria, however, further refinement to include different clinical expressions of a varying severity is necessary. Significant percentages of preschool child populations are affected by ECC today, with the disease concentrating disproportionately in deprived families. Early colonization by mutans streptococci (MS) is associated with increased ECC development, with bacteria being transmitted in both vertically and horizontally. Dietary factors related to sugar consumption predispose to early MS colonization and establishment and increase the risk for ECC development, being part of the causal chain. Inappropriate bottle and breast-feeding behaviours also increase the risk, without showing a direct causal relationship. High risk children belong to ethnic minority groups and to low income families with poor parental behaviours and attitudes. **Conclusions:** Further high-quality studies are needed to explore the role bacteria other than MS may play in caries initiation and progression, elucidate the interaction of the saliva immune defense system with a potentially defective tooth, and investigate the effect distant behavioural factors have on the causal chain that leads to ECC development.

Introduction

Early childhood caries (ECC, Fig. 1), has been a major public health problem over many years and still continues today, affecting in many ways normal growth and development as well as social adaptation of young children. Despite the recent advances in understanding the interaction of factors that may be responsible for the development of the disease, dental caries in preschool children remains a problem for the dental clinician. Contemporary preventive methods and measures have been successful in only changing the wide-spread nature of the disease, which still affects significant parts of child populations with specific social and behavioural characteristics. Many aspects of ECC have not been adequately explored, i.e. which children will be affected, can initiation of dental caries be prevented, and what affects progression of the disease once it gets established. In this context, determining patient's risk status becomes one of primary importance.

The aim of this paper was to provide a narrative review of the current literature on ECC, focusing on aspects that are related to the nomenclature, aetiology and risk assessment. After critical evaluation and report of the existing data, conclusions will be drawn for each issue summarizing the available evidence.

Figure 1. ECC in an infant



Nomenclature and case definition of ECC

Dental caries in preschool children has long been recognized as a unique entity with distinguishing clinical characteristics. It was first identified as a distinctive pattern of carious lesions in the primary maxillary incisors of infants and toddlers associated with a nursing habit. Fass was the first in recent international literature to adopt the term ''nursing bottle mouth" to describe the condition [Fass, 1962]. Since then, terminology has been progressively refined to include the terms: baby bottle tooth decay, nursing bottle syndrome and nursing caries [Arkin, 1986; Ripa 1988]. All of the above terms focus on inappropriate nursing practices as the exclusive etiology of the condition. Although improper exercise

Key words: caries, preschool children, definition, etiology, risk factors

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of feeding practices may have a central role in the aetiology of many cases, it is definitely not the sole and not even the most important factor in caries development [Reisine and Douglass, 1998]. To avoid such inconsistencies and better reflect the multifactorial nature of the disease, the term early childhood caries (ECC) was suggested at a workshop held by the centers for Disease Control and Prevention [Kaste and Gift, 1995]. The rationale for using a term that encompasses a much broader meaning is the recognition of a disease that can affect primary dentitions, more than often in a non-typical way. Furthermore, it aims at addressing the existence of a variety of interacting factors that can potentially contribute to disease initiation and establishment.

Several clinical patterns of dental caries in preschool children have been proposed and used as case definitions of ECC [Milnes, 1996; Ismail and Sohn, 1999; Douglass et al., 2001]. Identification of well-defined caries patterns may be the result of a varying host response and different in nature and severity environmental conditions. The ECC case definition proposed at a workshop convened by the National Institute of Dental and Craniofacial Research (NIDCR) in 1999, used patterns of caries experience as defining criteria. It suggests two categories of caries in preschool children:

- **ECC** is defined as a the presence of 1 or more decayed (non-cavitated or cavitated lesions), missing (due to caries) or filled tooth surfaces in any primary tooth in a child aged < 6 years.
- **Severe ECC** is described separately for each age group: for children younger than 3 years of age, any smooth surface lesions; for children aged 3-5 years, 1 or more maxillary anterior lesion or a dmfs score of 4. 5 and 6 surfaces for ages 3, 4 and 5 years respectively [Ismail and Sohn, 1999; Drury et al., 1999].

If we view the nomenclature currently being used in a critical way we can underline several weaknesses. The term ECC does not accurately describe several aspects of the disease such as risk factors, characteristics of the condition and prevention. Objections to the term raised by a number of authors also include the inability to define the age of the children affected and to express its rampant nature [Horowitz, 1998; Davies, 1998]. In the mind of many clinicians and researchers reflects a clinical situation of rampant caries in young children, affecting labial/lingual surfaces of primary maxillary incisors. This pattern of caries development is characteristic of severe ECC and has long been used as case definition in studies and in the clinical setting. Severe ECC has been used in studies to describe conditions previously known as nursing caries. However, detecting only proximal lesions in maxillary incisors is also indicative of severe ECC. Severe ECC has several unique characteristics in clinical appearance as the disease progresses: many teeth are affected; lesions develop rapidly, often soon after teeth emerge and they occur in tooth surfaces that usually are at low risk of caries development. The sequence of tooth emergence that leads to a different timing and duration of exposure may be responsible for the differences noted in the sequence and frequency of carious involvement of different teeth [Horowitz, 1998]. First primary molars are more frequently affected compared with second molars, as they emerge approximately 1 year ahead of second molars.

Taking into account all the existing arguments on the nomenclature debate we can state that the term ECC is not ideal, but it is comprehensive enough to sufficiently describe the disease. Regarding case definition of ECC, efforts that have been made to approach different clinical patterns in a systematic way have reached no consensus. Disagreement in defining criteria makes study design problematic and questions reliability study results, since comparison of reports is being hampered. Further refinement of the case definition to include different clinical expressions of the disease with a varying severity, number and type of involved teeth could be of particular use, especially when designing epidemiological, risk assessment or interventional studies.

Summary. Early childhood caries (ECC) is a disease identified on the basis of its clinical picture. It is defined as the presence of one or more carious teeth in a child of preschool age. In particular, the presence of at least one smooth surface lesion in very young children (<3 years old) or multiple lesions in older preschool children are indicative of severe ECC. Additional research to further refine the definition would help resolve several issues that concern the extent, severity and varying age related clinical expression of the disease.

Methods

The strategy that was used for the electronic search, was as follows. The PubMed database was searched using as criteria the words:

dental caries,

child,

nomenclature or definition or epidemiology,

aetiology or bacteria or microorganisms or diet or sucrose or sugar or saliva or hypoplasia or malnutrition,

risk or bottle or breast or ethnic or minority or deprived or poor or socioeconomic status or family or parents,

prediction or experience or history or microbiologic testing or oral hygiene or toothbrushing, dental clinician.

First, the abstracts of the identified studies were assessed to determine whether they met the selection criteria and then a full copy of all the papers relevant to the subject were reviewed. Abstracts of papers concerning any studies on the prevention of ECC were not considered in this review as they were the subjects of a separate paper previously published [Twetman, 2008].

Epidemiology of ECC

Despite the dramatic decline in the prevalence of dental caries in children in countries of the Western World, caries in preschool children remains a major problem, as it affects significant percentages of preschool populations, in both developed and developing countries.

Although there are numerous surveys conducted in preschool children worldwide, few of them can be considered national with large samples representative of the local population. Most of them have reported estimated values of caries experience at the age of 5 years (Table 1) [Haugejiorden and Birkeland, 2002; Poulsen et al., 2002; Oulis et al., 2005; Pitts et al., 2005]. However direct comparison of the numbers reported is difficult due to methodological differences regarding caries diagnostic criteria, calibration procedures and examination conditions.

Table 1. Dental caries experience among 5-year-olds as reported in European national surveys.

Country	Prevalence (%)	Mean dmft
England & Wales [Pitts et al., 2005]	39.6	1.55
Scotland [Pitts et al., 2005]	55.4	2.76
Norway [Haugejiorden et al., 2002]	38.9	1.50
Denmark [Poulsen et al., 2002]	29.0	1.00
Greece [Oulis et al., 2005]	42.8	1.77

Data on younger children are sparse and often lack adequacy in sample size and representativeness. Children at these ages are not readily accessible for examination and difficult to examine thoroughly. Furthermore, studies that have focused on prevalence of maxillary anterior caries have reported rates ranging between 1% and 12% [Louie et al., 1990; Barnes et al., 1992; O'Sullivan et al., 1994]; however, in developing countries and in disadvantaged groups the prevalence could be as high as 70% [Kelly and Bruerd, 1987; Broderick et al., 1989]. These data should be viewed with caution, since the definition of maxillary anterior caries varies and no standardized criteria have been used. In addition, several of these surveys have used high-risk groups as study populations. What longitudinal studies conducted in Scandinavia have shown, however, is that caries experience measured in children at the age of 2.5-3 years increases dramatically as preschool children grow older [Grindefjord et al., 1993; Karjalainen et al., 2001].

Dental caries experience is not evenly distributed throughout the entire preschool population. Despite the low mean caries levels reached in several western countries the disease has become increasingly polarized. About 10-15% of the children experience 50% of all caries lesions and 25-30% suffer 75% of lesions [Marthaler, 1990; Marthaler et al., 1996; Petersson and Bratthall, 1996]. Mean dft values of the whole population may be misleading regarding the size and severity of the problem, since children who have decay show dft values twice the value estimated for the whole population [Tinanoff et al., 2002]. More specifically, caries development is disproportionately concentrated in ethnic minority groups and low- income households. In the NHANES III, poor or near poor 2-5 year-olds have on average 3 times more carious lesions (dft) than non-poor children. More than half (55%) of low-income 5 year-olds had tooth decay, compared with one quarter of their more affluent peers. The majority of children with a significant burden of disease, irrespective of income status, remain without treatment [Tinanoff et al., 2002]. Similar results are reported from surveys in Australia, where 4-year-old children have on average 1.5 carious teeth, most of which remain untreated. The same study showed that 10% of those with some caries (66% were caries free) had more than 9 carious teeth [Armfield et al., 2003].

Summary. Epidemiological data from national surveys conducted in European countries show that significant percentages of the preschool child population are affected by ECC, confirming the widespread occurrence of the disease. Sparsity of data in very young children (below the age of 3) makes conduction of well-designed surveys in this age group imperative. ECC is unevenly distributed through the population, with the disease affecting disproportionately deprived families. Follow-up of the participating children and periodic registration of their caries status will elucidate on this disease over time.

Aetiology of ECC

Dental caries is a chronic infectious and transmissible disease that is modified by diet. It results from the interaction of various aetiological factors, each of which must be simultaneously present to initiate and progress the disease. The factors are (i) cariogenic microorganisms, (ii) fermentable carbohydrates (substrate) and (iii) susceptible tooth surface/host.

ECC is a form of dental caries, particularly virulent in many cases due to the presence of several unique characteristics in the mouths of young children. Factors such as the newly established bacterial flora, the immaturity of the host defense system, the low resistance of the newly emerged tooth surface, as well as extremes in the dietary substrate component may be responsible for accelerating the biological process of caries development in young children.

Cariogenic microorganisms. The most likely strain of bacteria implicated in the caries process in preschool children is mutans streptococci (MS). Several studies have shown elevated levels of S. mutans in both plaque and saliva of children with ECC. S. mutans plaque concentrations of an average of 30-40% were found in children with ECC, while the

S. mutans concentration in salivary flora reached the 10% level [van Houte et al., 1982; Berkowitz et al., 1984; Bone et al., 1987]. In another study, breastfed children with rampant decay were found to have S. mutans levels 100 times higher than caries free children [Matee et al., 1992]. Preschool children with high colonization levels of MS showed higher caries prevalence and a greater risk for development of new lesions compared with children with low levels [Thibodeau and O'Sullivan, 1996]. In a study with a randomly selected sample, after adjustment for age and ethnicity, children with a high MS level were 5 times more likely to have dental caries than children with a lower level [Milgrom et al., 2000].

More recent studies using sophisticated genetic methods that involve the sequencing of amplified 16S rRNA genes have identified numerous taxi of bacteria isolated from sound and carious tooth sites [Becker et al., 2002]. Some of these types had not been previously identified and their role is to be investigated. What these studies have shown is that apart of the strong relationship between MS and caries, other bacteria may be involved in the caries process. Actinomyces spp. and specifically A. gerensceriae were associated with caries initiation (white spot lesions) [Becker et al., 2002], while Bifidobacterium sp. was associated with deep caries lesions [van Houte et al., 1996]. In addition to these species, a number of other non-mutans streptococci that have acidogenic and aciduric properties were found to relate with caries [van Ruyven et al., 2000; Lingstrom et al., 2000]. In the light of these new data, the exclusive aetiological role of MS in the caries process is questioned. Other oral bacteria in the dental plaque may be involved in the caries initiation and progression. Nevertheless, the role of MS as good markers of the disease should not be underestimated.

Summary. MS is the strain of oral bacteria that has been repeatedly confirmed to associate with the caries process in preschool children. Recent research evidence point towards the involvement of other bacteria in the caries initiation and progression but their role needs further investigation.

Initial colonization with MS. Timing of initial MS colonization of the oral cavity in preschool children is critical for initiation and progress of dental caries. Kohler et al. [1988] found that 89% of children colonized with MS at the age of 2 had a mean dft index of 5, two years later, while only 25% of those with no detectable levels of MS at 2 years of age had caries experience two years later with a mean dft of 0.3. Alaluusua and Renkonen [1983] performed a longitudinal evaluation of MS colonization and dental caries in children 2-4 years old. The authors reported a higher dmfs score at the age of 4 in children with MS harboured at 2 years old, compared to children in whom colonization occurred later. Several longitudinal studies have investigated the time of initial detection of MS in infants and toddlers. Carlsson et al. [1975] using plaque samples found no detectable levels in pre-dentate infants while the percentage of infected children increased from 20% at the age of 2 to 84% at the age of 5. Masuda et al. using plaque samples reported 32% of 1 year-old children were tested positive for MS, while the respective percentage for 3 year olds was 69% [Masuda et al., 1979]. Caufield et al. [1993] using plaque, salivary and swab samples reported 25% of infected children at the age of 2 and 75% at the age of 3. Wan et al. showed that by 24 months of age 84% of children had been colonized by MS [Wan et al., 2003]. Obviously, direct comparison of the results reported is difficult due to differences in methodology, such as sampling techniques and differences in dietary habits, oral hygiene practices and maternal MS levels. Most of the studies report an initial colonization of the oral cavity during the first year of life, coinciding with the emergence of the first primary teeth. A "window of infectivity" between 19-31months of age for MS acquisition has been reported [Caufield et al., 1993]. However, its clinical value has been questioned by other studies, since evidence of MS colonization has been seen as early as the age of 10 months [Karn et al., 1998].

The prevailing concept so far has been that MS generally require a non-shedding surface such as the tooth to colonize. More recent data on MS colonization in children have confirmed their presence in the mouth of pre-dentate infants [Wan et al., 2003]. In a study using DNA probe technology MS were detected in 70% of tongue scraping samples in children 6-18 months old [Tanner et al., 2002]. These data indicate that the tongue may function as a potential microbial reservoir for tooth colonization; however, the clinical significance of MS acquisition in pre-dentate infants remains unclear. Furthermore, the stability of MS genotypes detected at the time of initial colonization is questionable, since studies showed that some strains remained stable in the mouth for many years while other genotypes could not be recovered in later years [Emanuelsson and Thornqvist, 2000; Kohler et al., 2003; Klein et al., 2004].

What all studies have shown is that the prevalence of infection with S.mutans increases with age in preschool children.

Summary. Research data indicate that early colonization by mutans streptococci may be associated with increased risk for caries development in preschool children.

Most studies report an initial colonization during the first year of life, with the infection level of MS increasing, as children grow older. Mutans streptococci may be present in predentate children, but its clinical significance is to be investigated.

Transmission of MS. Genotypes of MS isolated from infants indicate that the source of the MS infection in children is predominantly from their mothers via vertical transmission [Kohler et al., 1988; Li and Caufield, 1995], and that saliva is the principal vehicle by which transfer of S.mutans may occur [Mattos-Graner et al., 2001; Klein et al., 2004]. MS strains isolated from mothers and their babies exhibited similar phenotyping profiles or chromosomal DNA patterns [Li and Caufield, 1995; Gronroos et al., 1998; Emanuelsson and Thorn-

qvist, 2000; Kohler et al., 2003; Klein et al., 2004]. However, detection of genotypes that are not found in children's mothers or other family members indicates that MS and/or S. sobrinus may also be acquired from other sources [Emanuelsson et al., 1998; Klein et al., 2004]. There is evidence for a horizontal mode of transmission, as S.mutans isolated from nursery school children and genotyped with PCR showed identical genotypes [Mattos-Graner et al., 2001]. Also, similarity in MS strains in mother, father and child when MS acquisition occurs after the age of 5 (using bacteriocin typing) has been reported [van Loveren et al., 2000].

In a longitudinal study in infants after tooth eruption, factors significantly associated with MS colonization included frequent exposure of the infant to sugared food products, frequent snacking, taking sweetened drinks to bed, and sharing foods with adults. A number of maternal factors including high levels of maternal MS, poor oral hygiene, low socioeconomic status and frequent snacking were also contributory to MS colonization. In contrast, non – colonization was associated with multiple courses of antibiotics and tooth brushing [Wan et al., 2003]. In another study, mother's DMFS score; education and feeding habits were strongly associated with the colonization of caries-related microorganisms and ECC [Ersin et al., 2006]. There is also evidence that maternal salivary levels of MS are associated with MS infection rates in their children aged 4-5 years old [Kohler et al., 1988]. A concentration of 10^5CFU (colony forming units) of MS/ml of maternal saliva was associated with 52% of their children infected at the age of 6-18 months, while only 6% of the children were found infected when the maternal concentration was $<10^3$[Berkowitz et al., 1981].

Summary. The mother is the major primary source of MS infection for children, with saliva being the principle vehicle of transfer. Factors related to infant feeding practices such as frequent exposure to sugar, frequent snacking, taking sweetened drinks to bed, sharing foods with adults, as well as maternal caries status, oral hygiene and dietary habits predispose to early MS colonization and establishment of high MS counts; vertically transmission is the main route. Therefore, preventive measures focusing on mother's oral health should be implemented as well as not sharing spoons with a child Evidence for horizontal transmission may be also important, due to socioeconomic changes in Western culture ie. use of day care facilities when both parents are employed.

Substrate. Dietary sugars (primarily sucrose, but also fructose and glucose) and other fermentable carbohydrates (i.e refined flour) play a significant cariogenic role in the caries process. Sucrose is considered the only sugar that, when metabolized by bacteria, leads to production of dextrans, which subsequently enable bacteria to adhere firmly to the tooth surface and also inhibit diffusion properties of plaque [Mikkelsen, 1996; Tinanoff and Palmer, 2000].

The frequency of sucrose intake may be related to the development of ECC in children. In preschool children, two studies have shown that the total weight of sugar in children's diet was not predictive of caries development [Marques and Messer, 1992; McMahon et al., 1993]. However, frequent sugar consumption, particularly in between meals has been reported to be associated with caries development in preschool children [Pannio et al., 1993; Stecksen-Blicks and Holm, 1995]. In one study assessing indicators associated with caries experience at the age of 7 years, multiple logistic regression analysis showed that the daily use of sugar containing drinks between meals was significantly associated with caries, with an odds ratio of 1.38. In the same study, the use of more than 2 between meal snacks was significantly related to caries experience with an odds ratio of 1.22 [Vanobbergen, 2001]. Four cohort studies following preschool children from the age of 1 up to 5 years found that daily consumption of sugar-containing drinks, especially during night and daily sugar intake acted as independent risk factors in the development of ECC [Grindefjord et al., 1996; Wendt et al., 1996; Rodrigues and Sheiham, 2000; Karjalainen et al., 2001]. Another three case control studies showed that frequent snacking, especially soft drinks and sweetened foods were significantly associated with ECC [Hallonsten et al., 1995; Al Ghanim et al., 1998, Ye at al., 1999]. In addition, consumption of sugared drinks and presence of visible plaque accumulation were associated with prevalence of caries experience in preschool children, in a recent study [Declerck et al., 2007].

Preschool children with chronic diseases are often given liquid medicines high in sucrose for extended periods of time. One case control study found that these children showed a fourfold increase in dmfs compared to healthy children [Roberts and Roberts, 1979].

Summary. Dietary factors significantly associated to ECC are related to frequency, timing and amount of sugar consumption. Specific dietary factors include daily sucrose intake, night–time meal/drinks, frequent consumption of sugary drinks (particularly juice) and carbonated drinks, amount and frequency of sweet consumption, high number of eatings/drinkings per day.

Milk. Bovine milk has been studied as a potential cariogenic dietary agent in several experimental designs, in animals. Stephan [1966] showed that milk given to rats along with a non-cariogenic diet did not produce caries. When it was combined with a cariogenic diet including 66% sucrose, a low caries effect was found. In another study with rats, Bowen and Pearson [1993] reported no difference in caries development between bovine milk, 4% lactose, lactose-reduced milk and distilled water. When sucrose was added to milk, there was an increase in caries development, but significantly lower compared to the same amount of sucrose in water.

Furthermore, milk has been shown to rank as the least acidogenic drink (minimum pH 6.3) among 54 snack foods and drinks tested, being less acidogenic than 5% glucose or lactose. The addition of sucrose or lactose to milk increased pH changes [Edgar et al., 1975]. In vitro studies indicate that several milk proteins such as different forms of casein have significant anti-caries properties. Casein is a potent inhibitor of the adhesion of S.sanguis and S.sobritus to saliva – coated hydroxyapatite or to bovine enamel [Neeser et al., 1994]. Casein also prevents subsurface enamel demineralization and significantly reduces smooth surface and fissure caries development in rats by 55% and 46% respectively, compared to control teeth treated with water [Reynolds et al., 1995]. In vitro studies also show that unmodified cow's milk or human breast milk are not significantly acidogenic or cariogenic unless carbohydrates are added [Erickson and Mazhari, 1999].

Animal studies indicate that milk acts more as a cariostatic rather than a cariogenic agent, while epidemiological studies suggest a negative or neutral relationship between the consumption of cow's milk and dental caries. However, sugars added to milk increase cariogenicity [WHO Technical Report Series 916, 2003].

Regarding infant formulae, most of them have shown to be acidogenic in vitro, favouring caries development [Sheikh and Erickson, 1996; Erickson et al., 1998]. This is particularly true for soya infant formulae due to the high glucose concentration. Soya infant formulae have a low buffering capacity compared to cow's milk formulae, partly related to the absence of casein.

Host factors

Saliva. Saliva acts as a protective factor against dental caries development by providing the main defense system for the host. Saliva buffers plaque acids through activation of the carbonic acid- bicarbonate and phosphate – proteins system [Tenovuo and Lumikeri, 1991]. It also mediates antimicrobial activities by selectively allowing colonization of bacteria on the tooth surface, and through activation of several antimicrobial systems (i.e. lysozyme, lactoferrin, peroxidase enzymes) [Seow, 1998]. Both pH buffering capacity and antimicrobial properties as well as the clearance of foods are closely related to saliva flow rates. Feeding practices that include daily sucrose intake at night when the saliva flow rate is low probably increases the caries risk for the infant [Scheneyer et al., 1956].

The main immune defense system against cariogenic bacteria is provided by salivary secretory immunoglobulin (s-IgA) and serum and gingival crevicular fluid immunoglobulins (IgG). Reports from clinical studies on the effect of immunoglobulins on caries development have come up with conflicting results, since high and low caries scores have been associated with similar immunoglobulins levels in saliva [Challocombe, 1980; Bolton and Hlava, 1982; Gregory et al., 1986]. Immunological studies in young children also face several problems such as the immaturity of the immune system and the instability of the bacterial flora. Furthermore, there is a lack of human studies that show an effective and consistent response of the salivary immune system to bacterial antigens.

Summary. Saliva flow rate related to pH buffering capacity, antimicrobial properties and clearance of foods from the oral cavity might be important. Sugar feeding practices at night, when saliva flow rate is low, may increase the caries risk for infants and toddlers.

Tooth structure. Enamel continues to undergo enamel maturation following emergence of teeth into the mouth. A tooth is most susceptible to caries development immediately after emergence and until final maturation is completed. Therefore, primary tooth enamel is particularly vulnerable to bacteria acid attack immediately after emergence. Besides suboptimal maturation of enamel in a newly erupted tooth, the presence of hypoplastic or hypomineralized lesions is indicative of development defects. In a controlled study, enamel hypoplasia was strongly related with elevated MS counts in 3 and 4 – year old Chinese children [Li et al., 1994].

The presence of enamel hypoplastic defects has been associated with perinatal conditions such as premature birth and low birth weight, as well as with malnutrition and illness. A prevalence of developmental defects that exceeded 62% of preterm infants with very low birth weight was reported in a controlled study [Seow et al., 1987]. Malnutrition has been associated with aetiology of enamel hypoplasia (structural and opacities) in a cross-sectional study in 2-6 year old Saudi males [Rugg-Gunn, 1998]. Using multivariate modelling to control for potential confounders, both enamel hypoplasia and malnutrition were related with an increased caries experience. A randomized controlled study of 1,344 rural 3-5 years old Chinese children showed a strong association between enamel hypoplasia and caries prevalence, using also control for possible confounding [Li et al., 1996]. In a longitudinal, case controlled study, enamel hypoplasia was related to birth weight of the children, since 67% of very low birth- weight children had hypoplastic defects compared to only 10% of normal birth- weight children [Lai et al., 1997]. In the same study increased caries prevalence was reported among the very low birth weight children. A longitudinal study in Peru, adjusting for delayed eruption of teeth, suggested that a single, prolonged, mild to moderate malnutrition episode in the first year of life may result in higher primary dentition caries rates [Alvarez et al., 1993].

It is characteristic that most of the above studies have used samples of children from deprived populations in developing countries, with increased prevalences of enamel hypoplasia. Therefore, caution is needed if one tries to apply this evidence into well-nourished child populations with good health care, in developed countries.

Summary. Although there are a few studies that have confirmed enamel hypoplasia as a significant independent risk factor for caries, a causal relationship has not been established. However, since enamel hypoplastic defects may be associated with premature, low birth weight infants and undernourished toddlers that usually belong to deprived populations, such children should be receiving special dental care.

ECC risk assessment

In medical science "risk" may be defined as the probability that a particular outcome will occur due to the presence of specific risk factors or after exposure to a particular action or event. In the case of dental caries, risk factors are environmental, behavioural or biological factors confirmed by temporal sequence, usually in longitudinal studies, which it presents, directly increase the probability of a disease occurring, if absent or removed, it reduces the probability. Risk factors are part of the causal chain, or they expose the host to the causal chain [National Institutes of Health Consensus Development Conference, 2001].

Infant dietary practices

Bottle feeding. To investigate the potential relationship between feeding practices and early childhood caries several clinical studies have been carried out with various experimental designs. Most of the studies that examined reported bedtime bottle use in children with and without maxillary anterior caries have shown increased percentages of bottle use in both groups. In some of the studies a significant relationship between nighttime bottle use and presence of maxillary anterior caries was found [Johnsen, 1982; Marino et al., 1989; Schwarz et al., 1993; Weinstein et al., 1992], while others did not show a significant relationship [Derkson and Ponti, 1982; Albert et al., 1988; Serwint et al., 1993; Febres et al., 1997].

Most of these studies either did not use a detailed questionnaire regarding bedtime bottle use or they did not report it. Three studies have taken into account bottle use in greater detail. In the first one, among the 47 preschool children with more than 3 carious maxillary incisors 66% slept overnight with the bottle, while among the 20 caries free children none had slept with the bottle, the difference being statistically significant [Johnsen, 1982]. In the second study, 48% of the 33 children with maxillary anterior caries experience fell asleep with the bottle, while only 8% of the 123 caries free children had the same habit, a difference that was statistically significant [Schwarz et al., 1993]. A third study reported on the night-time bottle use in 260 3-5 year old children with nursing caries and 130 without caries experience - 95% of the nursing caries group used the bottle at night while the respective percentage in the caries free children was 85%, which was not statistically significant [Oulis et al., 1999].

Most of the above studies did not use random samples and were carried out in patients attending dental offices or in minority groups, with samples not representative of the population. Therefore, although there is some evidence that nighttime use of the bottle, especially when it is prolonged and on demand, is associated with ECC development, night-time bottle use also shows a high prevalence among preschool children without caries. In addition, methodological weaknesses such as exclusion from the study design of potential confounding factors and reliance on parental recall when using detailed questionnaires requires extrapolation of results to the general population only with caution.

Two case control studies found that bottle-feeding with sweetened milk to be a significant risk factor for ECC development, along with frequent consumption of soft drinks, sweet liquids and sweet foods [Al Ghanim et al., 1998; Ye et al., 1999]. One cross-sectional study found that sleeping with the bottle and duration of bottle use were not related to ECC [Milgrom et al., 2000], while, another cross-sectional study showed that going to sleep with the bottle, sipping from the bottle during the day, duration of bottle feeding beyond 12 months and sweetened bottle contents were significant risk factors [Hallet and O'Rourke, 2002].

Summary. Inappropriate bottle–feeding behaviours (i.e. nocturnal bottle feeding on demand, sweetened contents) increase the risk of caries development, rather than bottle-feeding solely. A direct causal relationship between bottle–feeding and ECC is difficult to substantiate. Other dietary habits, such as frequent snacking and consumption of soft drinks and sweet liquids, often mask the bottle-feeding effect or may be stronger determinants for caries development.

Breast feeding. Regarding the potential relationship of prolonged or at will breast-feeding and ECC, only few studies were undertaken and most were of poor quality. Poorly defined variables, exclusion of confounding factors such as the use of complementary sweetened foods and fluids, as well as the use of non – random samples are some of the methodological weaknesses. One study using both children with maxillary anterior caries and caries-free children reported that 22% of children with caries experience had been breast-fed at night until at least 6 months of age, while the respective percentage among caries free children was 6% [Febres et al., 1997]. Two case control studies showed that nocturnal breast-feeding for 6-12 months was a significant risk factor for ECC development [Matee et al., 1994; Ye et al., 1999]. On the contrary, two studies in 2-5 year old children with a more detailed questionnaire on breast feeding practicing did not report a significant relationship between breast-feeding and ECC [Al-Malik et al., 2003; Dye et al., 2004]. Another case control study also did not show breast-feeding as a significant risk factor for ECC development [Hallonsten et al., 1995].

Although the literature results are contradictory, caution is needed as frequent and on-demand night breast-feeding when it is prolonged may be implicated in ECC development [AAPD, 2003].

Summary. Prolonged breast–feeding (beyond 12 months) ad lib during the night may increase caries risk. However, establishment of breast-feeding as a single, independent caries risk factor cannot be supported by the current studies.

Minorities. There is evidence that certain ethnic minority groups exhibit high rates of ECC. In the Third National Health and Nutrition Examination Survey (NHANES III), 87% of non-Hispanic Whites, 78% of non-Hispanic blacks and 68% of Mexican-Americans were found to be caries experience frees [Kaste et al., 1996]. In the same national survey, non- Hispanic preschool children had a mean dft of 0.67, African – Americans 1.04 and Mexican-Americans 1.71 [Vargas et al., 1998]. Three studies that used populations with large ethnic minority groups as study populations found a significantly higher odds ratio for ECC development among non-Caucasian children compared to Caucasians, especially among those with a native American, Asian or Hispanic origin [Shiboski et al., 2003; Hallet and O'Rourke, 2003; Psoter et al., 2006]. Increased rates of ECC have been reported in ethnic minority groups in European countries also, such as England and Sweden [Silver, 1992; Grindefjord et al., 1993]. In Sweden, caries risk in children of immigrant background was three times higher than non-immigrant children [Grindefjord et al., 1993]. Factors that have been suggested as risk indicators for ECC development in these groups include access to dental care cost of care, child rearing practices, as well as parents' concern for oral health. As many risk factors have been studied in ethnic minority groups, extrapolation of these risk assessment models to the general population should be done with caution.

Summary. ECC is particularly prevalent in ethnic minority groups and specific social and behavioural determinants are considered responsible. Such variables may include low family income and caregiver's education level, a disrupted family environment (e.g single parent, extended parents) and cultural/ behavioural patterns specific to ethnic group (e.g feeding practices, brushing frequency, parental dental visit frequency).

Socioeconomic Status (SES). SES has been widely studied in different age groups in association to dental caries experience. However, in the preschool age group few studies have investigated this relationship. Dental caries prevalence was studied in a population of preschool children aged 5 months to 4 years old. It was found that caregivers' level of education and reported family income were negatively associated with ECC [Tang et al., 1997]. A cross-sectional study of dental caries experience among 4-5 year old children reported a significant linear increase in caries prevalence with decreasing SES, as measured by annual family income [Hallet and O'Rourke, 2003].

In a study analyzing the socio-demographic characteristics of paediatric dental caries, (NHANES III), the prevalence of preschool children with at least one decayed or filled tooth was negatively associated with the income level, showing a five times increase in caries prevalence among children from families with the lowest income level compared to the highest income group [Vargas et al., 1998].

Family-related factors. One study that investigated, among others, possible family factors associated with poor dental health of preschool children found a significantly higher odds ratio for the following variables: low frequency of parental tooth brushing, positive parental caries experience history, cohabitation as marital status and young age of the mother at childbirth [Mattila et al., 2005]. Another study explored the association between parental smoking and caries experience in preschool children, taking into account the child's oral health related behaviour and SES. The authors reported a significant relationship between parental smoking behaviour and caries experience in 5-year old children, after adjusting for the other evaluated variables [Leroy et al., 2007].

Summary. Family income as well as low parental knowledge and limited life skills factors feature as a significant risk factor for ECC in several risk assessment models. A strong relation of ECC to poverty makes the design of preventive programs that can be realistically applied to deprived child populations, one of primary importance.

ECC risk prediction

History of previous caries experience. Previous caries experience expressed as the baseline DMFS score is the single most powerful predictor of future dental caries development [Hausen, 1997]. Several studies using previous caries experience alone or combined with other risk predictors such as MS, saliva flow rate and buffer capacity in multi-factorial prediction models have shown that preschool children with a history of dental caries should be considered at high risk for future caries development [Demers et al., 1992; Reisine et al., 1994; Birkeland et al., 1997]. In these prediction studies, each variable is tested for its future caries predictive ability by estimating sensitivity and specificity levels – sensitivity and specificity should have a total of 160 for a variable to be considered as a reliable caries predictor [Hausen, 1997]. None of the aforementioned variables reached the desired level of 160, with previous caries experience being the only variable which approached this level.

Children with lesions such as white spot lesions should also be classified in the high-risk category since they are indicative of present caries activity in the mouth. Also, hypoplastic lesions or stained and sticky pits and fissures in primary molars, should be evaluated as high-risk determinants [Steiner et al., 1992; Li et al., 1996]. A low number of sound primary molars was the most consistent predictor of high caries increment, followed by high numbers of pre-cavity lesions (discoloured pits and fissures and white spots on smooth parts of buccolingual surfaces [Steiner et al., 1992]. Children who develop caries in primary teeth in early childhood tend to develop additional caries in late primary denti-

tion [Hallonsten et al., 1995; O'Sullivan and Tinanoff, 1996]. Caries in maxillary anterior teeth in particular, is associated with increased caries risk in other primary teeth [O'Sullivan and Tinanoff, 1993].

Using previous caries experience as a predictor of future ECC has two significant drawbacks. Clinical diagnosis of a caries free child at a young age is not a safe indicator of a low risk patient and does not preclude an already established caries process in the mouth. In addition, prediction is being made only after one or more teeth have been affected, thus, not satisfying the goal for primary prevention. The presence of pre-cavitated lesions (enamel caries) may be more useful as a predictor of future caries [van Palenstein Helderman et al., 2001].

In a longitudinal study with large sample size (3,303 children), several variables that had been confirmed as caries risk indicators in earlier cross-sectional analyses on the same data set were tested as prediction variables for future caries development in the first permanent molars. These variables included baseline oral health behaviour and socio-demographic factors, as well as baseline dmfs and plaque index. A stepwise logistic regression analysis showed that baseline dmfs ($p<0.001$) and plaque index ($p<0.01$) were highly significant for having a high caries increment in first permanent molars (between the ages of 7 and 10 years). Brushing less than once a day was also highly significant ($p<0.001$), as well as the daily use of sugar containing drinks between meals ($p<0.05$). Both variables were confirmed as risk indicators. Gender, age at start of brushing, regular use of systemic fluoride supplements and in between meal snacks were not confirmed as risk indicators. However, none of the socio-demographic or behavioural variables, including the confirmed risk indicators, had enough predictive power to be considered as risk predictors for identifying caries susceptible children (the model with the highest predictive power reached a sensitivity+specificity level of 131). Even the power of baseline dmfs was considered modest [Vanobbergen et al., 2001]. Therefore, although there are several risk indicators that from an aspect of causality and evidence base, if present, are responsible for an increase in caries incidence, they cannot be used as risk predictors, safely.

Summary. Previous caries experience (dmfs/DMFS) in a child has been found to be the best predictor of future dental caries. However, even the power of previous caries experience is considered modest.

Microbiological screening. Children with high salivary MS counts have higher caries prevalence and incidence than children with low MS counts [Thibodeau et al., 1993; Litt et al., 1995]. Also, early detection of MS in very young children has been associated with increased caries risk [Alaluusua, 1983; Mundorff et al., 1993; Anderson and Shi, 2006]. In a well-designed cohort study, Grindefjord and others [1996] evaluated a number of potential caries risk factors including several demographic variables, sugar consumption, oral hygiene and MS counts, in 1-year old children. The authors reported that the presence of MS at 1 year of age was the most effective predictor of caries at 3.5 years of age.

Microbiologic testing of MS counts in the dental office has been shown to be highly effective in correctly identifying children who will not develop caries, but not as effective in the correct identification of the children who will develop caries [Edelstein and Tinanoff, 1989]. It may be that this is one of the reasons why MS counts do not perform satisfactorily as single predictors of future dental caries [Hausen, 1997].

Summary. High salivary MS counts have been confirmed as significant risk factors for dental caries in preschool children. However, salivary MS counts cannot be used safely as a single predictor of future caries in children.

Oral hygiene – visible plaque. Studies investigating tooth-brushing habits in relation to caries experience in preschool children have reported contradictory results regarding tooth brushing frequency and age at which tooth brushing was started. The design of such studies is, in most cases, weak since they base their data on the parents' recall ability and also data are subject to response bias. Also, the quality of brushing as practiced is difficult to evaluate using a questionnaire. Visible plaque accumulation on primary teeth is a more reliable caries predictor. Studies have shown a positive correlation between visible plaque on primary teeth and caries risk [Alaluusua and Malmivtra, 1994; Roeters et al., 1995]. In one of these studies, the presence of visible plaque used as a single predictor classified correctly 91% of the children regarding caries risk [Alaluusua and Malmivtra, 1994].

Interestingly enough, intake of sweets >1xday and presence of visible plaque did not feature as independent risk factors in the development of ECC, in a cohort study involving 3-year old children. However, the two variables combined gave a 1.7 fold caries risk compared to children with neither habit [Karjalainen et al., 2001]. Furthermore, the study by Wendt and associates [1966] not only showed that visible plaque is a significant risk factor for ECC development, but also emphasized on the role of oral hygiene, since a risk behaviour such as giving a child a sugared drink when thirsty may be partly counteracted by good oral habits (no visible plaque) until the age of 3 years.

Summary. Variables related to tooth brushing cannot be used safely as predictors of future ECC development. Instead, presence of visible plaque is a more powerful predictor.

Perceived risk by dental clinician. Studies have shown that dental clinicians are reasonably able to predict caries risk in specific children by assessing clinically the patient and by using information from the dental history [Disney et al., 1992; Alanen et al., 1994]. Findings derived after a thorough clinical examination regarding past and present caries activity, gingival health and oral hygiene, as well as information gathered

from an interview with the parent are important in assisting the clinician to formulate a caries risk profile. In such an approach factors such as the experience, knowledge and clinical "feeling" are of primary significance for a successful prediction.

Conclusion

Further high-quality studies are needed to explore the role bacteria other than MS may play in caries initiation and progression. These studies should aim to elucidate the interaction of the saliva immune defense system with a potentially defective tooth, and investigate the effect distant behavioural factors have on the causal chain that leads to ECC development.

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