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Scientific Advisory Committee on Nutrition

Systematic review of evidence:

Carbohydrates and Oral Health

Contents

Carbohydrate and oral health

Term of reference

1. The oral health review is to address the third term of reference for the SACN Carbohydrates Working Group, "The evidence in respect to dietary carbohydrates and oral health".

Oral health endpoints

- Dental caries (including tooth loss)
- Periodontal disease
- Tooth wear (including dental erosion)
- Oral mucosal lesions (including oral cancer)

Dietary exposures

- Carbohydrate e.g. total carbohydrate, sugars (fructose, sucrose, lactose, glucose, lactose, galactose, maltose) disaccharides, monosaccharides, starch, resistant starch, oligosaccharides and inulin, non-milk extrinsic sugars, added sugars, soluble fibres (including guar gum, psyllium, beta glucans), non starch polysaccharides, dietary fibre (including cereal, fruit and vegetable), polyols (e.g. xylitol, mannitol and sorbitol).
- Dietary sources e.g. cereal, fruit, vegetables (including legumes), wholegrain (wheat, oats, rice, rye), sweets (including confectionary and candy), chewing gum, cakes and biscuits, carbohydrate/sugar containing drinks, jams and spreads, honey, milled flour, high fructose corn syrup, fruit juice, smoothies, yogurt, breastmilk/breastfeeding/infant feeding and probiotic drinks.
- Characteristics of carbohydrate or carbohydrate containing foods e.g. liquid vs. solid, viscosity, stickiness/oral residence time.
- Consumption patterns, e.g. frequency versus quantity and timing of consumption.

The COMA report on dietary sugars and human disease

2. The COMA report on dietary sugars and human disease (Department of Health, 1989) considered the available evidence, at that time, relating dietary sugars to risk of dental caries. Epidemiological studies, intervention studies, animal studies and experimental *in vitro* studies were considered. One prospective cohort study was available at that time (Rugg-Gunn *et al.*, 1984), which has been included in the dental caries section of this review, but the majority of the epidemiological evidence considered in the COMA report was from ecological, cross-sectional and case-control studies (as these types of study design are more prone to bias they have not been considered in this review). Prospective studies have been considered in this review, but not ecological, cross-sectional and case-control studies; also, animal studies and experimental *in vitro* studies have not been considered in this review. Three intervention studies were considered in the COMA report. Two of these have been included in Appendix 4 (Gustafsson *et al.*, 1954; Scheinin

et al., 1976), which considers controlled trials that did not report having been randomised and investigated digestible carbohydrate intake in relation to dental caries risk, while the other intervention study was a randomised controlled trial and has been included in the dental caries section of this review (Scheinin *et al.*, 1975).

Carbohydrate and oral health literature searches

3. Relevant publications were identified by searching Medline, Embase and CINAHL using the endpoint and exposure search terms listed in Appendix 1. The articles listed on Embase and CINAHL date back to 1980, while those on PubMed date back to 1952. Literature searches were performed from when the specified electronic databases began to January 2011. The references cited by articles identified in the searches as eligible for inclusion were hand searched. Only articles reported in English were included in the review, although the search was not restricted on language.

4. The number of potentially relevant studies of a particular study design (e.g. randomised controlled trials, prospective cohort studies, case-control studies, cross-sectional studies) were collated for each oral health endpoint.

5. All references identified in the searches were downloaded to the bibliographic software Endnote. The title and/or abstract of all references identified in the searches were screened for relevancy by a single assessor based on exposure/endpoint and inclusion/exclusion criteria. All articles that were potentially relevant were grouped together based on their study design, exposure and endpoint. A 10% random sample of the references identified as not relevant at the title and abstract stage was checked by an independent assessor.

6. Full text copies of the potentially relevant articles were obtained and considered by a single assessor to determine whether they were eligible for inclusion to the review. The reasons for any articles identified at the full text stage as ineligible were stated. Any articles for which the initial reviewer was uncertain as to their inclusion were sent to a Working Group Member for consideration/agreement.

Study quality assessment

7. A consideration of trial quality has been given in the associated commentary of the oral health section, based on the data extracted. Data were extracted from each publication on study design and location, sample size, duration of intervention/follow-up, number of endpoint cases and case definitions, case assessment methodology, population demographics, methods of dietary ascertainment and assessment, dietary intakes, adjustments for confounders (e.g. smoking status, fluoridation and other potential confounders were extracted), statistical analyses used and results. The methodologies used to define carbohydrate components were recorded and considered. For trials, data were extracted on whether a trial was described as randomised, level of blinding, the methods for generation of the allocation schedule and blinding, duration of intervention and whether there was a description of dropouts during the trial.

8. The criteria for judging risk of bias were based on the Cochrane Handbook. If insufficient information was reported, a judgement of 'unclear' (uncertain risk of bias) was given. A consideration of trial quality was given in the associated commentary of the oral health section, based on the data extracted. No scale for assessing study quality or risk of bias was employed. Sequence generation refers to the description of the method used to generate the allocation sequence in sufficient detail to allow an assessment of whether it should produce comparable groups. The allocation concealment refers to the description of the method used to conceal the allocation sequence in sufficient detail to determine whether intervention allocations could have been foreseen in advance of, or during, enrolment. The blinding of participants, personnel and outcome assessors refers to assessments of each main outcome (or class of outcomes) and describe the measures used, if any, to blind study participants and personnel from knowledge of which intervention a participant received. Incomplete outcome data refers to whether assessments were made for each main outcome (or class of outcomes) and the completeness and reporting of outcome data for each main outcome, including attrition and exclusions from the analysis.

Inclusion criteria

9. Only prevention studies in humans, including children and adults, were considered. For studies investigating the effect of infant feeding on oral health, only studies investigating dental outcomes between the ages of six months and two years were included. Prospective cohort studies and randomised controlled trials were included. Case-control or cross-sectional studies were not considered as they are prone to bias. Controlled trials that did not report having been randomised would only be considered when there were insufficient randomised controlled trials. Only articles published in peer-reviewed journals were included.

10. For epidemiological studies of dental caries, erosion or periodontal disease adjustment for smoking status in adults, brushing frequency and age (when cohorts included a range of ages) must have been conducted. For epidemiological studies of oral cancer adjustment for smoking status, alcohol consumption and age must have been conducted. For studies determining effects on the tooth surface, the duration/follow-up must have been for at least one year. For *in-situ* trials (such as those using blocks of enamel mounted in intra-oral appliances) the intervention duration must have been for at least one week. For experimental periodontal disease trials the intervention duration must have been for at least two weeks.

11. For epidemiological studies, the minimum information necessary to estimate the hazards ratio, relative risk or odds ratio associated with the endpoint and a corresponding measure of uncertainty (i.e., 95% confidence interval, standard error, variance, or P value as an indicator of the statistical significance of the estimate) were required for inclusion. In the case of multiple reports on the same population or subpopulation, estimates from the most recent or most informative report were considered.

12. When multiple risk ratios were presented in the original articles, the risk ratio and 95% CI that were adjusted for the most extensive confounding variables available were included.

Exclusion criteria

13. Single meal, single challenge or ecological studies, studies or trials in preterm infants, studies investigating effects relating to the treatment of disease or studies or trials of dietary interventions in conjunction with drug therapy or a non-carbohydrate component were excluded. Studies investigating carbohydrates in non-food items, such as medicines, mouth rinses or toothpastes were excluded. Published abstracts and articles in non-peer reviewed journals were also excluded.

Outcome measures

14. The outcome measures included were:

- Quantitative or qualitative clinical assessment of the progression/regression of caries in the deciduous or permanent dentition
- Quantitative or qualitative clinical assessment of tooth loss in deciduous or permanent dentition
- Quantitative or qualitative clinical assessment of plaque or gingivitis or both in deciduous or permanent dentition
- Quantitative or qualitative clinical assessment of enamel/dentine mineral loss in deciduous or permanent dentition
- Incidence of oral cancer or potentially malignant disorders - visible lesions that precede the majority of oral carcinomas

15. For the clinical assessments, the following dental indices were included: decayed, missing or filled teeth (DMFT/dmft) index; decayed, missing or filled tooth surfaces (DMFS/dmfs) index; root caries index (RCI); periodontal index; gingival index; calculus index; and plaque index (see the dental indices section below for details). Caries was assessed clinically with visible signs of change at the dentine level of diagnosis; however, if a combined clinical and radiological assessment was available it was also considered. The outcomes from other diagnostic tests including trans-illumination, laser fluorescence and electrical impedance measurements were considered if available. For a description of these indices please see table 1.

16. The deciduous and permanent dentitions have been considered separately.

17. Humans have two separate dentitions, the deciduous (colloquially known as “milk teeth”) and the permanent dentitions.

18. Deciduous teeth begin to erupt during the first year of life and the 20 teeth of the deciduous dentition are normally all present by the age of four. These are progressively shed during the “mixed dentition” phase when some deciduous and some permanent teeth are present. The period characterised as the “mixed dentition” occurs between about six and twelve years of age. The permanent dentition has 32 teeth with three molar teeth erupting behind the deciduous dentition as the jaws grow on each side and including 20 teeth (premolars, canines and incisors) that directly replace the deciduous teeth during the “mixed dentition” phase.

19. The permanent dentition starts to erupt into the mouth at the age of six with the first permanent molars erupting behind the deciduous dentition and the central incisors replacing their deciduous predecessors at or about this age. The eruption of the permanent dentition is usually complete by the early twenties, although the presence and pattern of eruption of the third permanent molars is variable within the population. Whilst there are up to 32 teeth in the complete permanent dentition the base used for many dental assessments is 28 as the third permanent molars are often missing or do not erupt into the mouth. In this circumstance during clinical studies only two molar teeth on either side of the upper and lower jaws are included in any assessment. If there are three teeth present then the most anterior two of the three are scored and the third ignored.

20. Micronutrient status can influence the structure of teeth in their developmental phase, but carbohydrates in the diet would only exert an effect after eruption when the teeth are exposed to the oral environment.

Data analysis

21. For all outcome measures, the data were insufficiently comparable to allow quantitative synthesis. The results from each study or trial have been tabulated, where available, and have been discussed in a narrative review.

Oral structures and their assessment

22. Teeth comprise two mineralised tissues enamel and dentine. The enamel provides the hard, insensitive, outer coating on the surface of the crown of the tooth. It is a non-vital tissue that is deposited during tooth formation but after eruption no further enamel can be laid down. It is the hardest tissue in the body with a mineral content of about 96%. In contrast, dentine is a vital tissue that forms the sensitive "core" of the crown of the tooth and the whole of the root of a tooth. Dentine undergoes continual change with age with increased levels of mineralisation of existing tissue and continued deposition in the dental pulp chamber ("the nerve"). When it is initially deposited dentine has levels of mineralisation similar to bone (70%).

23. The periodontium are the supporting structures of the teeth comprising the alveolar bone of the jaws (a specialised bony tissue that is only present because teeth are present), the connective tissue attachment between the alveolar bone and the root dentine and the soft tissue attachment of the gum which surrounds the tooth to the tooth itself. This attachment is unique in that it is the only place on the body where a structure of mesodermal origin passes through the ectoderm (skin) to function outside the body.

24. There are three major disease processes that affect oral health that could be impacted directly or indirectly by carbohydrates in diet, caries, periodontal disease and wear.

Dental Caries

25. Dental caries is the result of demineralisation of enamel and dentine in the presence of acid. The pH associated with decay is close to the "critical pH for demineralisation" of the tissue or about 5.5 for enamel and about 6 for dentine. The acids that induce demineralisation at this level are produced by the fermentation of dietary sugars, particularly sucrose, by acidogenic bacteria from the oral flora. Demineralisation from bacterially-derived acids (predominantly lactic acid) occurs during virtually every meal as natural sugars are present in virtually all foods. Saliva is, however, a very efficient remineralising solution allowing for repair of demineralised tissue. Tooth decay occurs when the frequency or extent of demineralisation in any one person's mouth exceeds the capacity of saliva to remineralise the tissue.

26. Enamel caries has two distinct phases. Initial demineralisation results in a lesion that occurs in and beneath the surface of the enamel without a breach in the enamel surface (cavitation). These non-cavitated lesions can be repaired/remineralised by the actions of saliva and through professionally applied "actives" that enhance the remineralisation process maintaining an intact tooth surface without restoration. As a consequence the health outcomes for non-cavitated lesions are managed by strategies that promote remineralisation and prevention rather than by preparing a cavity in the tooth and restoration.

27. Once the decay has extended sufficiently far through the enamel that it destroys significant amounts of the underlying dentine, the surface layer of the enamel is unsupported and breaks down resulting in a defect in the surface of the enamel and a "cavitated" lesion. Such lesions are not amenable to remineralisation and require operative intervention to remove the damaged tooth tissue and repair the defect with a restorative material (a "filling"). As a clinical outcome this is far inferior to being able to remineralise a non-cavitated lesion as restorations have a finite life-span so there is a continual cycle of repair and replacement once a restoration is required.

Dentine caries

28. This can take two forms. Caries occurs in dentine beneath enamel once the demineralisation has spread through enamel of the crown of the tooth. Effectively this is a progression of the enamel lesion rather than a new lesion. The demineralisation of dentine results in a significant weakening of its structure, undermining the enamel and allowing cavitation to occur. The root of a tooth solely comprises dentine. With increasing age and periodontal disease the root of the tooth becomes exposed in the oral environment and is at risk of decay (Curzon & Preston, 2004). This exposure may be related to physiological retraction of the gingiva or to damage related to oral hygiene habits and periodontal diseases or treatment (Touger-Decker & van Loveren, 2003). As noted above the critical pH for demineralisation of dentine is half a pH unit higher than that for enamel so these exposed dentine surfaces are more at risk of developing decay than adjacent enamel. The stoichiometry of dentine caries does not result in the equivalent of a developed but non-cavitated lesion that is seen in enamel.

29. In cross-sectional studies of older adults (Hix & O'Leary, 1976; Ravald *et al.*, 1986; Papas *et al.*, 1987; Fure & Zickert, 1990; Ravald & Birkhed, 1991; Faine *et al.*, 1992; Papas *et al.*, 1995a; Papas *et al.*, 1995b; Steele *et al.*, 2001), a higher sugar intake, especially in the form of liquids and sticky sugars, has been associated with an increased risk for root caries.

30. We were unable to identify any clinical trials that have addressed the relationships between dietary sugars intake and root caries.

Dental indices

31. In clinical studies and trials tooth decay can be measured in a number of ways as outlined in Table 1

Table 1. Dental indices for tooth decay

DMFT/dmft	This index records the number of **D**ecayed, **M**issing or **F**illed **T**eeth. The index is used for decay to the crowns of teeth ONLY. When recorded in lower case this index refers to the deciduous dentition and in upper case to the permanent dentition. It is a widely used index of decay activity that is valid when large numbers of teeth are present. However when small numbers of teeth remain as a result of extractions the **M** component dominates making it difficult identify change, particularly as teeth are extracted for a variety of reasons that may not solely relate to decay. Change can be expressed as the DMFT increment (the number of NEW decayed missing or filled teeth).
DMFS/dmfs	This index records the number of **D**ecayed, **M**issing or **F**illed tooth **S**urfaces. Each tooth is divided into 5 surfaces (Mesial, Occlusal, Distal, Buccal and Lingual) for the purposes of scoring, so the maximum DMFS score for a person would be 140 (28 teeth x 5 surfaces) The index is used for decay to the crowns of teeth ONLY. When recorded in lower case this index refers to the deciduous dentition and in upper case to the permanent dentition. It is a widely used index of decay activity that is valid when large numbers of teeth are present. However when small numbers of teeth are present the **M** component dominates (this is a greater problem for DMFS as 1 missing tooth results in 5 **M**issing surfaces) making it difficult identify change, particularly as teeth are extracted for a variety of reasons that may not solely relate to decay. Change can be expressed as the DMFS increment (the number of NEW decayed missing or filled teeth). This index is however more sensitive to site specificity of decay. The occlusal or biting surface of a tooth is more susceptible to decay than any of the "smooth" surfaces due to its tortuous anatomy. The Mesial and Distal surfaces of teeth are more commonly decayed than the buccal or lingual as it is the mesial and distal surfaces that contact adjacent teeth making plaque accumulation more of a problem as hygiene is more difficult in these areas
DMFT and particularly DMFS become increasingly unreliable as people age, both are susceptible to bias through missing teeth as explained above. However with age the **F**illed element also becomes less reliable. For example a tooth with a large filling involving 3 surfaces through decay may then have a crown placed by a dentist for sound clinical reasons. The DMFS score increases to 5 as a consequence of a treatment intervention that is independent of disease risk.	
ICDAS	The International Caries Assessment and Detection System is a consensus tool designed for epidemiological assessment of caries risk. It encompasses lesions on enamel that have cavitated and those that have not a full description of ICDAS can be found at http://www.icdas.org/ and in http://www.icdas.org/assets/downloads/Appendix.pdf . The system has a 7 point scoring range designed to give gradation of severity of carious lesions with 0 as no surface change, 1 and 2 as change in enamel only and 3 through 6 increasing severity of enamel breakdown and dentine involvement.
RCI	The **R**oot **C**aries **I**ndex is used to record decay on the roots of teeth either at a tooth or at a surface level (for this purpose the tooth root has 4 surfaces rather than 5 as there is no equivalent to the occlusal or biting

	surface on the tooth root). The RCI expresses the number of decayed teeth (or surfaces) as a proportion of the number of teeth with root surface exposed in the mouth. This is designed to reflect that not all teeth present in a mouth necessarily have exposed root dentine and overcomes the problem of missing teeth. However one issue is that it is assumed that any filled surfaces have been filled during the management of decay. This is a reasonable assumption for the crowns of teeth but not for the roots as restorations are also placed frequently to manage tooth wear.
Radiological scoring	Some epidemiological studies and RCTs include both clinical observation and radiological diagnoses of dental caries. Caries results in demineralisation of the enamel and/or dentine that is detectable on a dental radiograph as altered radiopacity (a carious lesion is relatively radiolucent). Radiographic diagnosis is more accurate on some tooth surfaces than a direct clinical assessment as it will show lesions that occur on surfaces of heath that are not visible on clinical inspection (notably the surfaces where the teeth touch together where early change is often invisible to direct vision). It is possible to classify lesions radiographically into those that occur in enamel only and those that extend into dentine, as well as the extent of penetration through the relevant tissue (for example Mejàre I 19xx). These outcomes are reported as either scores or scores within a tissue (so D2 is a lesion to level 2 in dentine)
Other diagnostic tools	Caries in enamel results in a change in the optical properties of the tissue with carious lesions being optically opaque compared with sound tissue. Fibre Optic Trans-Illumination (FOTI) uses a small, intense light system to trans-illuminate the tooth and detect areas of change in opacity that may be linked to decay. Enamel also fluoresces in specific wavelengths of incident light. The pattern of fluorescence is also affected by demineralisation and this has been used to develop the diagnostic tools of Quantitiative Laser fluorescence (QLF) and Diagnodent ®. Both give a numerical score to the fluorescence achieved from a surface allowing change to be monitored. Both are relatively effective for expose enamel surfaces but more limited on the surface between teeth and do not work at all well on dentine where the patterns of fluorescence are different. Enamel and dentine are hydrated tissues but enamel in particular has relatively high resistance to the passage of an electrical current. Demineralisation results in increased porosity and hence reduced resistance to current transmission. Electrical impedence measurements have been used as a diagnostic tool to monitor the development of demineralisation in both enamel and dentine.

Periodontal diseases

32. Periodontal diseases affect the gingiva and the supporting tissues of the teeth (the periodontium). They result in inflammation of the gingiva (gingivitis) and periodontium (periodontitis). Periodontitis results in progressive destruction of the bone support for a tooth and ultimately tooth loss. It is the most common reason for tooth loss in early adulthood. Gingivitis is thought to precede periodontitis, but there is no clear understanding why some patients progress from having gingivitis to periodontitis, the progression is by no means automatic, and is affected by the host response and by the bacterial flora of the mouth. In clinical studies and trials periodontal diseases can be measured in a number of ways as outlined in ***Table 2***.

33. As periodontal disease develops a cleft or pocket develops between the gum around the tooth and the surface of the tooth as the periodontium is damaged. The depth of this pocket can be measured using a variety of metal probes to estimate the severity of the disease.

34. Periodontal disease is characterised by "bursts" of activity as pocketing develops with periods of quiescence between. Each burst is associated with a specific inflammatory phase and probing of the pocket during such inflammatory change is associated with bleeding on probing. Such bleeding is a marker of disease activity rather necessarily than severity.

35. There is increasing awareness of an association between periodontal disease and a variety of systemic diseases, most notably with cardiovascular disease, both myocardial infarction and stroke, and with diabetes mellitus, particularly with type 2 diabetes mellitus. The mechanisms for these links are complex and are likely to be a mixture of common risk factors (for example periodontal disease is markedly aggravated by smoking) and specific interactions that are thought to be a result of the inflammatory process that is triggered by periodontal disease. Periodontal disease is a chronic disease process that results in ulceration of the lining of the periodontal pocket. This is virtually pain free in most people and the disease can progress for many years undetected as a consequence.

36. Inflammation of these pocket linings results in the presence of elevated circulating markers of inflammation such as C reactive protein and a host of others. This "hyper-inflammatory state" hypothesized as one of the key links between periodontal and systemic health (Ford *et al.*, 2010; Lalla & Papapanou, 2011).

Table 2. Dental indices for periodontal diseases

BPE	Basic Periodontal Examination This is a development of the WHO Community Index of Treatment Need (CPITN) and is similar to the Periodontal Scoring Record (PSR developed in the USA. All 3 tools use a specifically designed periodontal probe with a 1mm diameter ball end and black bands on the shaft of the probe, the first band lies between 3.5 and 5.5mm and the second between 7.5 and 9.5mm. Clinical evidence has shown that conventional personal oral hygiene can maintain periodontal health providing the pocket between the gum

	margin and the tooth is no deeper than 4 mm. If the pocket is deeper than 6mm then the overall treatment required for the tooth is likely to be more complex than for a shallower pocket. This tool breaks the mouth down into 6 areas or sextants 2 posterior and 1 anterior in each jaw. The worst score that is recorded by an examiner in each sextant is then recorded as that sextant's score for record purposes. It is widely used as a screening tool for disease severity.
Probing pocket depths	When a more detailed assessment of disease is required a probe marked in 1mm increments is used to measure the depth of periodontal pockets at 6 points round the surface of each tooth. Change in probing pocket depths is associated with disease activity or regression.
Bleeding Index	The proportion of teeth where bleeding is found on probing around the periodontal margin of the tooth
Periodontal Index	This is a composite index that tries to combine the signs of gingivitis and periodontitis each tooth is scored using 0,1,2,4,6 or 8 where: 0 is no disease, 1 and 2 relate to gingivitis, 4 is only used where a radiographic assessment is available, 6 is early pocketing round the tooth 8 is advanced destruction with loss of chewing function.
Plaque Index	Records the amount of plaque on the surface of a tooth with a 4-point scale: 0 no plaque 1 a thin film that can only be detected by scraping it together with an instrument 2 visible plaque deposits 3 an "abundance of soft matter" The original index used the scores on 6 teeth only as a screening tool, but it can be used to give a whole mouth score
Gingival Index	Plaque on the surface of a tooth produces inflammation of the gingival tissues. This is thought to progress to cause loss of attachment and periodontal disease. This index assesses the severity of the inflammatory response to plaque. It is important to measure both plaque and inflammation as on any given day a subject could clean their teeth better removing plaque. The gingival tissue response takes about14 days to develop fully but remains present for 2-3 days after the inflammatory challenge is removed. The inflammation is recorded using a 4-point scale: 0 normal tissues 1 mild inflammation, no bleeding on probing 2 moderate inflammation bleeds on probing 3 severe inflammation or ulceration tendency to spontaneous bleeding
Analysis of Periodontal, Plaque and Gingival indices is challenging. Whilst these measures use a numerical outcome it can be argued that they are not a linear scale (i.e. 2 is not twice as bad as 1, rather it is just different). Thus an approach which uses an average score may be flawed.	

Carbohydrate and dental caries

Introduction

37. Dental caries can be categorised according to its location on the tooth – smooth surface of the crown, pit and fissure of the crown, root or secondary where decay occurs around the edges of a dental restoration (filling) -, its extent -changes in enamel only or cavitation involving dentine for decay to the crowns of teeth- or the age of presentation - early childhood caries. The basic mechanism of dental caries is the same for all of classifications. Dental caries results from the interaction of specific bacteria with constituents of the diet within dental plaque. Acid production by bacteria embedded in dental plaque is a key aspect of the pathogenesis of dental caries (Bowen, 2002). Fundamentally, dental caries is biofilm (plaque)-induced acid demineralisation (loss of mineral) of enamel or dentine, mediated by saliva. Given time, the interaction of cariogenic microorganisms and digestible carbohydrates that can be fermented to organic acids (e.g. lactic, formic, acetic and propionic) by the oral microflora may induce demineralisation, which can progress to loss of tooth structure and cavitation.

38. In trials where subjects have worn enamel or dentine blocks contained within intra-oral appliances, the application of sucrose, and to a lesser extent glucose or fructose, has been shown to result in demineralisation. The effects of sucrose were shown to be dependent on dose and the frequency of application, as well as being militated against by fluoride administration (Lingstrom *et al.*, 1994; Cury *et al.*, 2000; Aires *et al.*, 2002; Ribeiro *et al.*, 2005; Aires *et al.*, 2006; Ccahuana-Vasquez *et al.*, 2006; Vale *et al.*, 2007).

39. A newly cleaned tooth surface is rapidly covered with a glycoprotein deposit referred to as pellicle. The pellicle is derived from salivary constituents that are selectively adsorbed onto the tooth surface. Components of the dental pellicle include albumin, lysozyme, amylase, immunoglobulin A, proline-rich proteins and mucins (Lussi *et al.*, 2004). The acquired pellicle may protect against erosion, and the formation of the pellicle is the first step in the formation of an oral microbial biofilm, termed dental plaque, which is attached to the tooth's enamel or root surface and embedded in an extracellular-polysaccharide matrix (Wood *et al.*, 2000).

40. The pellicle-coated tooth surface is first colonised by Gram-positive bacteria such as *Streptococcus sanguis, Streptococcus mutans,* and *Actinomyces viscosus* and then by Gram-negative species such as *Fusobacterium nucleatum, Prevotella intermedia*, and *Capnocytophaga* species. Bacterial surface molecules interact with components of the dental pellicle to enable the bacteria to attach or adhere to the pellicle-coated tooth surface and the Gram-negative species adhere to Gram-positive species already present in the existing plaque mass. Over 800 bacterial distinct species-level taxa have been detected in the oral cavity (Siqueira & Rocas, 2010).

41. Dental caries is associated with shifts in the microbial balance of the biofilm resulting in increased proportions of acid producing and acid tolerating bacteria, especially (but not exclusively) *mutans streptococci* and *lactobacilli*. The regular intake of digestible carbohydrate that can be fermented to acids by the oral microflora, or impaired saliva flow, produces persistent conditions of low pH within the biofilm, which selects for these cariogenic bacteria (Tenuta *et al.*, 2006; Marsh, 2010). Several trials have observed that sucrose-rich diets increase the proportions of *mutans streptococci* and *lactobacilli*, with a concomitant decrease in levels of *S. sanguinis* and other oral *streptococci* (De Stoppelaar *et al.*, 1970; Dennis *et al.*, 1975; Staat *et al.*, 1975). Sucrose, fructose and glucose are also substrates for extracellular polysaccharide production in dental biofilm, which promotes bacterial adherence to the tooth surface and contributes to the structural integrity of dental biofilms (Bowen, 2002; Tenuta *et al.*, 2006). Sucrose reduces the concentrations of calcium, inorganic phosphorus, and fluoride in the dental biofilm, which are important in maintaining the mineral equilibrium between the tooth and the oral environment (Paes Leme *et al.*, 2006). Low pH and the concentrations of these ions are critical factors during the de- and re-mineralisation processes in the saliva, biofilm and teeth milieu (Pearce, 1998; Pearce *et al.*, 2002). In contrast to digestible carbohydrates, polyols are practically non-fermentable by oral bacteria (Soderling, 2009) and at relatively high doses xylitol, in particular, appears to modify the composition of oral microflora, by reducing the proportion of certain strains of *mutans streptococci*, via the inhibition of lactate dehydrogenase (Maguire & Rugg-Gunn, 2003). The consumption of xylitol at physiological levels would be unlikely to lead to the inhibition of plaque micro-organisms.

42. Saliva contains the minerals calcium, inorganic phosphorus, and fluoride and is supersaturated with respect to hydroxyapatite, the main mineral of teeth. Thus, tooth mineral will not dissolve in saliva or plaque fluid (which is even more supersaturated than saliva during fasting), unless the saliva or plaque is acidified (Dawes, 2008). Bicarbonate in saliva is the main buffer against acid, but it is only really effective at high salivary flow rates because its concentration increases markedly with the flow rate. Acidification of the plaque results in the biofilm fluid becoming under saturated with respect to the enamel mineral, and demineralisation occurs (Paes Leme *et al.*, 2004).

43. The national surveys of Adult Dental Health have given a 10-yearly summary of the clinical condition of adults in the UK since 1978; the 2009 survey included data from England, Wales and Northern Ireland, but not Scotland. The proportion of adults who were edentate (no natural teeth) has fallen from 28 per cent in 1978 to 6 per cent in 2009. In 1978, 27 per cent of dentate adults had 18 or more sound and untreated teeth and by 2009, this had increased to 53 per cent. This improvement was seen across all age groups. A steady increase in the mean number of sound and untreated teeth is also observed; in 1978 dentate adults in England had 13.2 sound and untreated teeth on average, rising to 18.0 in 2009 (Steele & O' Sullivan, 2011).

44. The Children's Dental Health series of national surveys of children's oral health that have been carried out decennially since 1973 in England and Wales and in the whole of the UK since 1983 (Pitts *et al.*, 2006). Since 1973 the experience of obvious dentinal caries in permanent teeth has reduced in the specific age cohorts studied (eight, 12 and 15-year-olds): for 15-year-old children falling from 42% in 1983, to 30% in 1993 then to 13% in 2003. The experience of obvious dentinal caries in deciduous teeth, however, has remained unchanged over the same time period: at age five years obvious dentinal decay was 1.3 in 1983 and 1.4 in both 1993 and 2003.

45. The study characteristics for all prospective cohort studies have been considered in the first section, while the study characteristics for all randomised controlled trials have been considered in the following section. The results from both prospective cohort studies and randomised controlled trials have been considered together for each dietary exposure.

46. Most prospective studies and trials use the endpoint of frank cavitation as measured and examined by standard criteria to define dental caries (Radike, 1972), but some also include non-cavitated lesions, e.g. as defined by modifications of the World Health Organization standard methods and criteria (Scheinin *et al.*, 1985a).

Prospective cohort studies

47. Twenty six articles were identified as eligible (see Appendix 2 for studies excluded) (Rugg-Gunn *et al.*, 1984; Rugg-Gunn *et al.*, 1987; Burt *et al.*, 1988; Grytten *et al.*, 1988; Burt & Szpunar, 1994; Grindefjord *et al.*, 1995; Szpunar *et al.*, 1995; Grindefjord *et al.*, 1996; Mattila *et al.*, 1998; Tada *et al.*, 1999; Mattila *et al.*, 2000; Mattila *et al.*, 2001; Vanobbergen *et al.*, 2001; Levy *et al.*, 2003; Mariri *et al.*, 2003; Ruottinen *et al.*, 2004; Mattila *et al.*, 2005; Kallestal & Fjelddahl, 2007; Levine *et al.*, 2007; Ollila & Larmas, 2007; Sakuma *et al.*, 2007; Ismail *et al.*, 2008; Lim *et al.*, 2008; Ismail *et al.*, 2009; Tamaki *et al.*, 2009; Warren *et al.*, 2009). Two further articles were identified from cited references (Litt *et al.*, 1995; Leroy *et al.*, 2005).

48. A comparison was made between those studies that had not adjusted for oral hygiene and those that had; both of which produced similar findings. A limitation with the unadjusted studies was that most only performed bivariate analyses (some only t-tests) and most of the studies included in the report used multivariate analyses that had shown that factors reported as significant in univariate or bivariate analyses often failed to reach significance in multivariate analyses that adjusted for other factors (see Appendix 3).

49. Several of these articles reported on the same population cohort. Most of these articles reported different analyses of a cohort with the same length of follow-up, but for one cohort, followed for 10 years, several articles reported on factors affecting deciduous and then mixed and permanent dentition. Except for two articles on the Michigan Study (Burt *et al.*, 1988; Burt & Szpunar, 1994), which were superseded by a later article (Szpunar *et al.*, 1995), and one article on the Signal-Tandmobiel project (Vanobbergen *et al.*, 2001), which was superseded by a later article (Leroy *et al.*, 2005), all the other articles have been considered in the relevant sections below, grouped by the cohort on which they reported.

50. Two articles reported on a cohort recruited from around Newcastle (Rugg-Gunn *et al.*, 1984; Rugg-Gunn *et al.*, 1987); and two articles reported on a cohort recruited from Stockholm (Grindefjord *et al.*, 1995; Grindefjord *et al.*, 1996).

51. Four articles reported on the Finnish Family Competence Study (Mattila *et al.*, 1998; Mattila *et al.*, 2000; Mattila *et al.*, 2001; Mattila *et al.*, 2005), which followed-up a birth cohort, beginning at the mother's pregnancy, until the child was aged 10 years. Dental examinations were conducted at in the children at 3, 5, 7 and 10 years of age and parental questionnaires were used to assess potential risk factors for caries at 1.5, 3, 5 and 7 years of age.

52. Two articles reported on the Iowa Fluoride Study and adjusted for tooth brushing frequency (Levy *et al.*, 2003; Mariri *et al.*, 2003); one used a questionnaire to assess intakes and defined caries experience as cavitated (d2-3f) lesions (Levy *et al.*, 2003), while the other was a nested case-control study where cases of severe caries were defined as dmfs>6 and intakes determined by three-day food and drink diaries (Mariri *et al.*, 2003).

53. Three articles reported on a cohort of low-income African-American children from Michigan, USA (Ismail *et al.*, 2008; Lim *et al.*, 2008; Ismail *et al.*, 2009). One reported on factors affecting the risk of early childhood caries (as defined as a dmfs/dmft > 0 in the first 71 months of age) (Ismail *et al.*, 2008); another reported on factors affecting caries increment (as defined by increments for non-cavitated lesions (d_{1-2}), cavitated/dentinal lesions (d_{3-6}), filled and missing surfaces: d_{3-6}mfs and d_{1-6}mfs) (Ismail *et al.*, 2009). The third study from a subgroup of this cohort (children three years and older at baseline for whom follow-up data were collected; n= 403) examined change in consumption of sugar-sweetened drinks between baseline and follow-up in relation to caries increment (Lim *et al.*, 2008).

Prospective cohort study design

54. The study design details have been summarised on the basis of whether dental caries risk was investigated in deciduous (see **Table 3**) or mixed and permanent dentition (see ***Table 4***).

55. Eight studies investigated dental caries risk in deciduous dentition: four studies were conducted in North America, two in Europe and two in Asia. The length of follow-up ranged from one to six years. Cohort sizes ranged from 184 to 5107. Dietary assessment was by a simple questionnaire in most studies; one study used a three-day food diary in a sub-cohort analysis (Mariri *et al.*, 2003); while one used a food frequency questionnaire (Ismail *et al.*, 2008; Lim *et al.*, 2008; Ismail *et al.*, 2009). In relation to caries risk most studies investigated the frequency of sugar-sweetened drink or sweets (including confectionary and candy) consumption and infant feeding practices; one study investigated sugar consumption in relation to caries risk (Litt *et al.*, 1995).

56. Nine studies investigated dental caries risk in mixed and permanent dentition: one study was conducted in North America, seven in Europe and one in Asia. The length of follow-up ranged from one and a half to nine and a half years. Cohort sizes ranged from 66 to 2848. Dietary assessment was by a simple questionnaire in most studies; three studies used a three-day food diary (Rugg-Gunn *et al.*, 1984; Rugg-Gunn *et al.*, 1987; Ruottinen *et al.*, 2004; Levine *et al.*, 2007); while one used a food frequency questionnaire (Burt & Szpunar, 1994; Szpunar *et al.*, 1995). In relation to caries risk most studies investigated the frequency of sugar-sweetened drink, snack or sweets (including confectionary and candy) consumption; one study focused on infant feeding practices (Ollila & Larmas, 2007); four studies investigated sugar consumption (Rugg-Gunn *et al.*, 1984; Rugg-Gunn *et al.*, 1987; Szpunar *et al.*, 1995; Ruottinen *et al.*, 2004; Levine *et al.*, 2007) and one investigated starch consumption (Rugg-Gunn *et al.*, 1987).

57. It was unclear what was precisely meant by the exposure term 'sugar', when used in studies, as further details were not reported. Whether the term 'sugar' referred to a mixture of mono- and di-saccharides or individual mono- and di-saccharides, e.g. sucrose, was not defined. The exposure term 'sweets' includes the terms 'candy' or 'confectionary', but what was precisely meant by the term was unclear, as further details were not reported. The 'dietary components investigated' columns in **Table 3** and ***Table 4*** list the dietary exposures as described.

58. Most studies used questionnaires to assess dietary intake frequencies as defined as either dichotomised or categorical variables, which were then processed as ordinal data. Most of the studies provided limited information concerning the definition employed for the terms 'soft drink', 'sugar-sweetened drink' or 'sugar-containing drink'. Two studies did define 'sugar-sweetened drinks' as only including drinks with added sugar and not 100% fruit juices or milk (Lim *et al.*, 2008; Warren *et al.*, 2009), but most studies were unclear about exactly what was being referred to. The quantification of sugar-sweetened drink intake ranged from low, medium and high to daily, weekly or to yes or no.

59. Regression techniques (mainly multivariate logistic regression, but also zero-inflated negative binomial regression and Cox proportional hazards regression) were used in most studies to explore associations between one (dichotomous) outcome variable and two or more exposure variables (ordinal or categorical). The main aim of these studies was to define prediction models for dental caries risk based on a number of factors. These analyses tested for the relationships between variables controlling for the effects of other variables included in the model. A significant association in these analyses means that a particular independent variable was still significantly associated with a dependent variable when the effects of many other independent variables were controlled for in a statistical test or model involving one dependent variable and more than one independent variable. Two studies analysed survival curves for caries onset in molar teeth (the time elapsed from birth to when a dentist performed a restoration) to evaluate caries risk (Leroy *et al.*, 2005; Ollila & Larmas, 2007).

60. The confounders considered by the studies investigating carbohydrate and dental caries risk have been summarised in ***Table 5***. Several of the cohorts comprised populations of a single age and therefore did not adjust for age (Rugg-Gunn *et al.*, 1984; Grytten *et al.*, 1988; Mattila *et al.*, 2000; Ruottinen *et al.*, 2004; Leroy *et al.*, 2005; Kallestal & Fjelddahl, 2007; Levine *et al.*, 2007; Tamaki *et al.*, 2009).

61. The funding sources for all studies, where reported, were Governmental; 29% of studies did not report funding sources.

Table 3. Prospective cohort studies of carbohydrate intake and risk of dental caries in deciduous dentition

Study	Country	Sex	Baseline age (y)	Cohort size	Mean follow-Up duration (y)	Statistical method	Fluoride intake/ water content	Caries assessment and method	Dietary assessment method	Dietary components investigated	Funding source
Grytten et al., 1988	Norway	Mixed	6mth	231	30 mth	Multiple classification analysis	NR	dmfs: clinical assessment	Questionnaire - variables were collapsed into an additive index which was then divided into three categories in an ordinal scale: "Infrequent sugar consumption", "frequent sugar consumption", and "very frequent sugar consumption".	Soft drink and sweets consumption frequency (at 18 mth), sweetened comforter use (6 mth assessment)	NR
Grindefjord et al., 1995; Grindefjord et al., 1996	Sweden	Mixed	1	692 (2.5y); 786 (3.5y)	1.5 and 2.5	MLR	NR	dmfs: clinical assessment	Questionnaire - variables were analysed as dichotomised data	Sugar-containing drink and sweets intake frequency; prior to bed-time and night-time drink intake and breast feeding from 10 mths or more	Commission of Social Research; Swedish Ministry of Health; Swedish Patient Revenue Research Fund; Swedish Dental Society
Litt et al., 1995	USA	Mixed	4	184	1	Multidimensional causal model	NR	dmfs: clinical assessment	Care person interview - sugar intake assessed as 1 (never) to 5 (more than once a day) from a list of seven foods high in sugar content. Bottle with milk or juice to bed at night assessed as 0 (never) to 5 (every night).	Sugar intake and baby bottle use	National Institute of Health
Tada et al., 1999	Japan	Mixed	1.5	392	1.5	MLR	NR	dmft: clinical assessment	Questionnaire - variables were analysed as dichotomised data	Sweetened drink consumption (Yes or no); Sweet foods (Yes or no); Bottle feeding (Yes or no); Breast feeding (Yes or no)	NR
Levy et al., 2003; Mariri et al., 2003	USA	Mixed	6 wk-12 mth	291 (NCC, 39 cases and 39 controls	4-6	MLR	NR	dmfs; clinical examination	Questionnaire (NCC used 3-day diaries)- variables were analysed as ordinal data (NCC quantified intake amounts and frequency)	Quantity and frequency of sugar sweetened drink consumption (low, medium or high); soft/sports drink consumption (low, medium or high); 100% fruit juice/juice drink consumption; sweets consumption; sugar and starch consumption	National Institute of National Health, Institute of Dental and Craniofacial Research
Sakuma et al., 2007	Japan	Mixed	1.5	5107	1.5	MLR	water <0.1ppm	dmft; clinical examination	Questionnaire - drink and snacking variables were analysed as ordinal data; infant feeding practices analysed as dichotomised data	Daily frequency of sugar sweetened drink, sweets and snack consumption (seldom, once, twice, more than thrice); still breastfeeding, nursing bottle use (yes or no)	Shizuoka Prefecture Government
Ismail et al., 2008; Lim et al., 2008; Ismail et al., 2009	USA	Mixed	0-5	788	2	MLR; zero-inflated negative binomial regression	water 0.97 ppm	dmfs; clinical examination	FFQ - variables were analysed as ordinal data	Frequency of sugar sweetened carbonated drink consumption per week (none, 1 day, 2-6 days, every day or low, medium or high),	National Institute of Dental and Craniofacial Research; Delta Dental Fund of Michigan
Warren et al., 2009	USA	Mixed	0.5-2	212	1.5	Bivariate logistic regression	NR	dmft; clinical examination	Questionnaire - variables were analysed as dichotomised data	Daily frequency of sugar sweetened drink and night time bottle feeding	National Institute of Health

Decayed, missing and filled teeth (DMFT/dmft) index; decayed, missing or filled tooth surfaces (DMFS/dmfs) index; MLR, multivariate logistic regression; mth, month; y, year; NCC, nested case-control study

Table 4. Prospective cohort studies of carbohydrate intake and risk of dental caries in mixed and permanent dentition

Study	Country	Sex	Baseline age (y)	Cohort size	Mean follow-Up duration (y)	Statistical method	Fluoride intake/ water content	Caries assessment and method	Dietary assessment method	Dietary components investigated	Funding source
Rugg-Gunn et al., 1984; Rugg-Gunn et al., 1987	England	Mixed	Mean 11y, 7mth	405	2	Correlation coefficient; MLR, partial correlation analysis	Water <0.1mg F/l	DMFS (C3 grade), DMFT: clinical assessment, radiography	5 x 3d food diaries	Total, and between meal (snacking), sugars, sugar-sweetened drinks and starch. Food frequency - > 30min after meal and > 15 min after a snack	Medical Research Council
Szpunar et al., 1995	USA	Mixed	10-15	499	3	MLR	NR, but non-fluoridated area	DMFS: clinical assessment	4-9x 24 hour recall interviews	Total, and between meal (snacking), sugar. Interval between eating occasions was set at 20 min	NR
Mattila et al., 1998; Mattila et al., 2000; Mattila et al., 2001; Mattila et al., 2005	Finland	Mixed	1.5	1059 (3y); 828 (5 y); 1070 (7y); 1074 (10y)	1.5, 3.5, 5.5 and 8.5	MLR	NR	dmft/DMFT: clinical assessment	Questionnaire- variables were analysed as ordinal data	Sweets consumption at the ages of 3 and 5 years (daily, once a wk, twice a wk or once or twice a mth) and sugar consumption at the ages of 18 mths (none, once a week, daily) Drinking juice at night (18 mths)	Fund of Turku City Hospital
Ruottinen et al., 2004	Finland	Mixed	7 mth	66	9.5	repeated measures ANOVA	NR	dmft/DMFT; clinical examination and radiographs	3-day diaries, including FFQ of 52 sucrose-containing foods	Sucrose	NR
Leroy et al., 2005	Belgium	Mixed	7	4468	6	Multivariate survival analysis method and accelerated failure time model	NR	DMFS in 4 permanent molars; annual dental health records	Questionnaire - variables were analysed as dichotomised data	Daily use of sugar-containing drink (yes or no); sweets (daily or more or less than daily); sweet snack consumption (yes or no)	Catholic University Leuven; Unilever
Kallestal & Fjelddahl, 2007	Sweden	Mixed	12	2848	4	MLR - poisson	NR	dmfs/DMFS; clinical examination and radiographs	Questionnaire - variables were analysed as ordinal data	Sweets (never/seldom, often at 1 interview, often at 2-3 interviews)	Swedish Council for Social Research; Vardal Foundation
Levine et al., 2007	England	Mixed	7-11	437	4	MLR	water <0.3 ppm fluoride	DMFT; clinical examination	3 x 24-hour dietary recall and 3-day diaries	Frequency of non-milk extrinsic sugars (NMES) in foods, drinks (<2, 2-3, 4+ per day) and drinks/foods the hour before bed (<1 or 1+ daily)	Northern and Yorkshire Region Research and Development Unit
Ollila & Larmas, 2007	Finland	Mixed	2	183	7	Survival analysis method and Cox proportional hazards regression	NR	dmft/DMFT in 2 deciduous and 2 permanent molars; annual dental health records	Questionnaire - variables were analysed as dichotomised data	Breastfeeding 1 year or more; sweets more than once a week; night-time bottle-feeding	Finnish Dental Society Apollonia
Tamaki et al., 2009	Japan	Mixed	5-6	500	2.5	MLR	water not more than 0.8ppm	DMFT; clinical examination	Questionnaire - variables were analysed as ordinal data	Daily frequency of drinking sweet juice or sweet snacks (once, twice, thrice or four and more)	NR

Decayed, missing and filled teeth (DMFT/dmft) index; decayed, missing or filled tooth surfaces (DMFS/dmfs) index; MLR, multivariate logistic regression; mth, month; y, year.

Table 5. Confounders considered in prospective studies investigating dental caries risk[1]

Study	Age	Sex	Tooth-brushing habits	SES	Parent's education	Gingival index	Fluoride intake	Parent's dental health	Baseline caries prevalence	Antibiotic use	Ethnicity	Saliva streptococci mutans
Deciduous dentition												
Grytten et al., 1988			Y		Y		Y**	Y				
Grindefjord et al., 1995; Grindefjord et al., 1996	Y	Y	Y	Y	Y	Y	Y			Y	Y	Y
Litt et al., 1995	Y	Y	Y	Y							Y	Y
Tada et al., 1999		Y	Y									
Levy et al., 2003; Mariri et al., 2003	Y	Y	Y	Y	Y							
Sakuma et al., 2007	Y	Y	Y***	Y				Y				
Ismail et al., 2008; Lim et al., 2008; Ismail et al., 2009	Y	Y	Y	Y	Y			Y	Y			
Warren et al., 2009	Y	Y	Y		Y		Y ***					Y
Mixed and permanent dentition												
Rugg-Gunn et al., 1984		Y	Y	Y								
Rugg-Gunn et al., 1987	Y	Y				Y*						
Szpunar et al., 1995	Y	Y	Y	Y	Y		Y			Y		
Mattila et al., 1998; Mattila et al., 2000; Mattila et al., 2001; Mattila et al., 2005			Y	Y								
Ruottinen et al., 2004			Y	Y								
Leroy et al., 2005		Y	Y				Y**		Y			
Kallestal & Fjelddahl, 2007			Y	Y			Y				Y	
Levine et al., 2007			Y									
Ollila & Larmas, 2007	Y	Y	Y				Y**					
Tamaki et al., 2009		Y	Y***				Y					Y

* controlled for plaque quality and effectiveness of tooth brushing , ** fluoride tablet intake; ***determined toothpaste usage.
SES, social economic status.

[1] It is not appropriate to control for frequency or amount of sugars consumption because the effect of amount consumed needs to be known irrespective of how many times it is consumed and the effect of frequency needs to be known irrespective of how much is consumed

Randomised controlled trials

62. Thirteen articles were identified as eligible (see Appendix 2 for studies excluded). Two trials reported on caries incidence in relation to infant feeding practices (Kramer *et al.*, 2007; Feldens *et al.*, 2010) while the other eleven trials reported on caries incidence in children in relation to carbohydrate interventions (Steinberg *et al.*, 1972; Scheinin *et al.*, 1975; Finn *et al.*, 1978; Finn & Jamison, 1980; Glass, 1983; Frostell *et al.*, 1991; Beiswanger *et al.*, 1998; Alanen *et al.*, 2000b; Machiulskiene *et al.*, 2001; Szoke *et al.*, 2001; Oscarson *et al.*, 2006).

Randomised controlled trial design

63. A summary of the trial designs has been given in ***Table 6*** and **Table 7**. The trials have been separated on the basis of infant feeding practices or whether dental caries risk was investigated in deciduous (***Table 6***) or mixed and permanent dentition (**Table 7**). All trials employed a parallel design.

64. Controlled trials that did not report having been randomised, investigating digestible carbohydrate intake in relation to dental caries risk, have not been included in the main review, but have been considered in Appendix 4, as these were part of the COMA report on dietary sugars and human disease.

65. Two trials reported on the effectiveness of encouraging breastfeeding practices on deciduous dentition (Feldens *et al.*, 2010) and mixed and permanent dentition. (Kramer *et al.*, 2007). One was a cluster-randomised trial, conducted in Belarus and consisted of 13889 mother-infant pairs. The experimental intervention was based on the Baby-Friendly Hospital Initiative, which was developed by WHO and UNICEF to promote and support breast-feeding, particularly among mothers who have chosen to initiate breastfeeding (Kramer *et al.*, 2007). The primary outcome of this trial was breastfeeding incidence and the dental health outcome was one of many secondary outcomes subsequently reported. The infants are seen at one, two, three, six, nine and 12 months by paediatricians who completed a data form containing detailed information about infant feeding (Kramer *et al.*, 2007). The other trial was randomised at the individual level, was conducted in Brazil and consisted of 340 mother-infant pairs (Feldens *et al.*, 2010). The intervention involved nutritional advice administered through home visits within 10 days of the child's birth, on a monthly basis up to six months, and at eight, 10 and 12 months. Advice was given on infant feeding practices and reducing sugar intakes during the infant's first year of life. At six and 12 months nutrition students interviewed mothers and a dietary assessment was conducted using 24 hour dietary recall.

66. Two individually-randomised trials reported on dental caries risk in deciduous dentition

in relation to either a sucrose or fructose and glucose intervention (Frostell *et al.*, 1991) or a low dose xylitol lozenge intervention (0.5-1g/day) (Oscarson *et al.*, 2006). In the sucrose or fructose and glucose intervention trial, families were asked to buy specially prepared drinks, biscuits, breakfast cereals, marmalade, jam, ice cream, ketchup, sweets and table sugar, totalling 32 different food items, that were sweetened using either fructose and glucose or sucrose (Frostell *et al.*, 1991). The substitution was largely restricted to a number of sugar-rich between-meal products. The products were sold daily at public dental clinics at reduced prices and all purchases were registered. Only those children whose parents had purchased the products regularly and shown good co-operation during the whole experimental period were included in the analysis. Forty four children received either sucrose or fructose and glucose.

67. In the low dose xylitol lozenge intervention trial, children received one lozenge (0.48g xylitol) to take at bedtime after tooth brushing for the first six months; after six months the daily dosage was increased to two lozenges, one in the morning and one in the evening, for the remaining year of the trial intervention (Oscarson *et al.*, 2006). The lozenge intervention was stopped at three and a half years of age and the dental examination was conducted at four years of age. One hundred and thirty two children completed the trial.

68. One trial substituted sucrose for polyol in chewing gum and investigated the effect on one year dental caries increment in permanent dentition (Scheinin *et al.*, 1975). Subjects were instructed to consume three to seven sticks of chewing gum each day at spaced intervals and to record consumption during the trial: the mean consumption was four and a half sticks daily of the xylitol containing chewing gum (2.25g xylitol/day) and four sticks daily of the sucrose containing chewing gum (2g sucrose/day). The intake frequency of sucrose containing foods and liquids was assessed at the beginning and end of the trial: the mean daily frequency of sucrose intake was 4.2 times in the sucrose group and 4.9 in the xylitol group.

69. Six trials investigated the effect of polyol containing chewing gum (sorbitol, mannitol or xylitol) on dental caries risk in mixed and permanent dentition (Finn *et al.*, 1978; Glass, 1983; Beiswanger *et al.*, 1998; Alanen *et al.*, 2000b; Machiulskiene *et al.*, 2001; Szoke *et al.*, 2001). One of the trials also investigated the effect of lozenges containing either a xylitol-maltitol or xylitol-polydextrose mixture with 49% xylitol (Alanen *et al.*, 2000b). All of the trials had a no gum control and one also had an non-carbohydrate artificially sweetened (accesulfame/saccharin) chewing gum control (Machiulskiene *et al.*, 2001). The duration of trials ranged from two to three years and cohort size ranged from 272 to 1402. All of these trials were cluster-randomised except two that were randomised at the individual level (Finn *et al.*, 1978; Glass, 1983).

70. One trial was conducted in institutionalised mental health patients (Steinberg *et al.*, 1972). The patients received a total of 650ml/day for three years of either sugar-

sweetened carbonated soft drink or water, given between meals in two equal amounts. The type of sugar or its content in the soft drinks used was not reported. Patients had access to between-meal snacks and this was reported to be of a similar nature to that observed in non-institutionalised populations. The patient's access to oral hygiene was not reported.

71. Two trials were conducted in deaf and blind school children who resided at school for nine months of the year (Finn *et al.*, 1978; Finn & Jamison, 1980). In one of these trials (Finn *et al.*, 1978), two of the experimental groups received trimetaphosphate-containing chewing gum either with sucrose or sorbitol, while the other experimental group received sorbitol and mannitol-containing chewing only and the control group received no gum. The results from the trimetaphosphate-containing chewing gums have not been included as the carbohydrate intervention was in conjunction with a non-carbohydrate component that may have affected dental caries development. Both trials tried to ensure compliance through the three month period the children were not resident at the school, when study personnel visited the children to encourage parental cooperation and provide sufficient experimental foodstuffs. The other trial provided different breakfast foods to children : either sugar coated cereal containing approximately 42.1% sugar, a 28g portion of raisins or unsweetened canned fruit or a non-sugar coated cereal to which children could add table sugar as required (Finn & Jamison, 1980). There was no restriction on sugar containing foods eaten during the rest of the day.

72. The funding sources for the infant feeding trials were Governmental, while all other trials that reported funding sources involved at least some commercial funding; 23% of trials did not report funding sources.

Table 6. Trials of carbohydrate intake or infant feeding and risk of dental caries in deciduous dentition

Study	Trial design	Country	Fluoride	Age (y)	Subject characteristics	Caries assessment and method	Duration (y)	Follow-up (y)	Cohort size	Dietary assessment method or compliance determination	Intervention	Control intervention	Funding source
Infant feeding													
Kramer et al., 2007	Cluster randomised -parallel	Belarus	water not fluoridated	From birth	Breast-fed infants	dmft/DMFT; clinical assessment	1	6.5	13889 mother-infant pairs	At 1, 2, 3, 6, 9, and 12 months, paediatricians completed a data form containing detailed information about infant feeding	The promotion of breastfeeding	The control maternity hospitals and polyclinics continued the practices and policies in effect at the time of randomisation.	Canadian Institutes of Health Research
Feldens et al., 2010	Individual randomised - parallel	Brazil	water 0.7ppm	From birth	Infants, low SES	dmft; clinical assessment	1	4	340 mother-infant pairs	At 6 and 12 months nutrition students interviewed mothers on infant feeding practices and at 12 months 24 hour dietary recall	The promotion of breastfeeding and the reduction of sugar intakes during the infant's first year *	The control group received routine assistance by paediatricians in the health service	Brazilian National Council for Scientific and Technological Development
Deciduous dentition													
Frostell et al., 1991	Individual randomised - parallel	Sweden	NR	4	Preschool children	dmfs/dmft; clinical assessment and radiograph	2	-	44	All food purchases registered and a random sample evaluated by questionnaire	Sucrose-rich between meal products	Fructose and glucose - rich between meal products	Swedish Sugar Company; Swedish Odontological Patents Revenue Research Fund
Oscarson et al., 2006	Individual randomised - parallel	Sweden	NR	2	Preschool children	dmfs; clinical examination	1.5	0.5	132	Compliance checked by questioning parents	Low dose xylitol lozenge (0.5-1g/day)	No lozenge	NR

* The trial intervention also attempted to increase infant fruit and vegetable intake and reduce their night-time bottles use, but these aspects were not different between control and intervention groups.
NR, not reported; y, year; d, day

Table 7. Trials of carbohydrate intake and risk of dental caries in mixed and permanent dentition

Study	Trial design	Country	Fluoride	Age (y)	Subject characteristics	Caries assessment and method	Duration (y)	Cohort size	Dietary assessment method or compliance determination	Intervention	Control intervention	Funding source
Steinberg et al., 1972	Individual randomised parallel	USA	water 0.4ppm	8-21	Institutionalised mental health patients	DMFS/DMFT; clinical assessment and radiograph	3	567	All foods provided to patients and consumption supervised	650ml/day sugar-sweetened carbonated soft drink (sugar content not reported)	650ml/day water	Illinois Bottlers Association; National Institutes of Health, USA
Scheinin, 1975	Individual randomised - parallel	Finland	NR	mean 22.2	Dental and medical students	DMFS; clinical assessment and radiograph	1	102	5-day and 14-day food frequency questionnaire	Xylitol chewing gum Instructed to consume 3-7sticks/day. (Mean intake 2.25g/day; 4.5 sticks/day).	Sucrose chewing gum Instructed to consume 3-7sticks/day. (Mean intake 2g/day; 4 sticks/day)	NR
Finn et al., 1978	Individual randomised - parallel	USA	NR	range 5-16	Residential deaf and blind school children	DMFS/DMFT; clinical assessment and radiograph	2.5	272	Chewing gum consumed under the supervision for nine months each year	Sorbitol (50-70%) / mannitol chewing gum (3 sticks/day after meals)	No chewing gum	Warner-Lambert Co.; National Institutes of Health, USA
Finn & Jamison, 1980	Individual randomised - parallel	USA	NR	NR	Residential deaf and blind school children	DMFS/DMFT; clinical assessment	1.5	604	All foods provided to children and consumption supervised for nine months each year	sugar-coated breakfast cereal or unsweetened dried/canned fruit	non-sugar-coated breakfast cereal	NR
Glass, 1983	Individual randomised - parallel	USA	water not fluoridated	7-11	School children	DMFS/DMFT; clinical assessment and radiograph	2	540	Supervision by teachers at school	Sorbitol chewing gum (2 sticks/day)	No chewing gum	NR
Beiswanger et al., 1998	Cluster randomised -parallel	Puerto Rico	water =0.1 ppm	mean 11.7	School children	DMFS; clinical assessment and radiograph	3	2601	Classroom rosters of participation were kept and children instructed to return the outer wrappers from used sticks of gum. Over 3 years approximately a third of chewing sessions were supervised	Sorbitol (40 to 60 %), mannitol (4 to 15 %) chewing gum (3 sticks/day after meals)	No chewing gum	William Wrigley Jr. Co.
Alanen et al., 2000b	Cluster randomised -parallel	Estonia	NR	10	School children	DMFS; clinical assessment	2-3	740	Products consumed under the supervision of a teacher. intervention was only given during school hours	Xylitol containing sweets or chewing gum (5g/day); the sweets either contained a xylitol-maltitol or xylitol-polydextrose mixture with 49% xylitol	No xylitol products and no additional prevention outside routine care	Leaf Co.; Finnish Dental Association
Machiulskiene et al., 2001	Cluster randomised -parallel	Lithuania	Water <0.2ppm	9-14	School children	DMFS; clinical assessment and radiograph	3	602	Chewing gums consumed under the supervision of a teacher/parents; questionnaire completed by children	Xylitol or sorbitol chewing gum (5 sticks/day)	Acesulfame/saccharin sweetened gum or no chewing gum	Dandy A/S (Fertin A/S); Aarhus University Foundation, Nordic Council of Ministers
Szoke et al., 2001	Cluster randomised - parallel	Hungary	water not fluoridated	8-13	School children	DMFS; clinical assessment and radiograph	2	583	Chewing gum consumed under the supervision of a teacher and the return of gum wrappers from out-of-school chewing,	Sorbitol (65 %) / mannitol chewing gum (3 sticks/day after meals)	No chewing gum	William Wrigley Jr. Co.

* The trial intervention also attempted to increase infant fruit and vegetable intake and reduce their night-time bottles use, but these aspects were not different between control and intervention groups.
NR, not reported; y, year; d, day

Risk of bias assessment

73. A summary of the risk of bias assessment has been given in Table 8.

Table 8. Risk of bias assessment

Study	Randomisation	Sequence generation	Allocation concealment	Blinding	Incomplete outcome data	Dropouts (%)
Kramer et al., 2007	Yes	Random number tables and coin flip	NR	Open to participants and personnel, but assessors blind	Missing outcome data balanced in numbers across groups and data analysed on intention to treat basis	18.5
Feldens et al., 2010	Yes	NR	Opaque, sealed envelopes	Open to participants and personnel, but assessors blind	Missing outcome data balanced in numbers across groups and data analysed on intention to treat basis	32
Frostell et al., 1991	Yes	NR	NR	Participants, personnel and assessors blind	Missing outcome data unlikely to be related to outcome	29
Oscarson et al., 2006	Yes	NR	NR	Open to participants and personnel, but assessors blind	Missing outcome data unlikely to be related to outcome	11
Steinberg et al., 1972	Yes	NR	NR	Open	No missing outcome data	0
Scheinin, 1975	Yes	NR	NR	NR	Missing outcome data unlikely to be related to outcome	2
Finn et al., 1978	Yes	NR	NR	Open to participants and personnel, but assessors blind	Missing outcome data unlikely to be related to outcome	31
Finn & Jamison, 1980	Yes	NR	NR	Open to participants and personnel, but assessors blind	Missing outcome data unlikely to be related to outcome	32
Glass, 1983	Yes	Computer generated	NR	Open to participants and personnel, but assessors blind	Unclear – not discussed	unclear
Beiswanger et al., 1998	Yes	NR	NR	Open to participants and personnel, but assessors blind	Missing outcome data balanced in numbers across groups and data analysed on intention to treat basis	46
Alanen et al., 2000b	Yes	NR	NR	Open to participants and personnel, but assessors blind	Missing outcome data unlikely to be related to outcome	23
Machiulskiene et al., 2001	Yes	NR	NR	Open to participants and personnel, but assessors blind; participants and personnel blind to different chewing gums	Missing outcome data unlikely to be related to clinical assessment outcome	39
Szoke et al., 2001	Yes	NR	NR	Open to participants and personnel, but assessors blind	Missing outcome data unlikely to be related to outcome	6

yes indicates low risk of bias; no indicates high risk of bias; NR, not reported

74. All trials reported being randomised. Allocation concealment was only reported in one

trial (Feldens *et al.*, 2010). The drop-out rate ranged from 6-46%, but missing outcome data were generally balanced in numbers across intervention groups, with similar reasons for missing data across groups. One trial did not report dropout rates (Glass, 1983). In one of the polyol containing chewing gum trials the highest dropout rate was from the no gum control group and specifically for the radiograph assessment (Machiulskiene *et al.*, 2001; Machiulskiene *et al.*, 2002);consequently, the radiograph results have not been included in the results section. Only three trials conducted data analysis on the basis of intention-to-treat (Beiswanger *et al.*, 1998; Kramer *et al.*, 2007; Feldens *et al.*, 2010), two of which employed infant feeding interventions.

75. Due to the nature of the interventions all trials, except one (Frostell *et al.*, 1991), were open to participants and personnel. All trials reported that assessors were blind to intervention allocation, except one trial that did not report on blinding (Scheinin *et al.*, 1975).

Results

76. The results from prospective cohort studies of carbohydrate intake and risk of dental caries in deciduous dentition have been summarised in ***Table 9***. The results from prospective cohort studies of carbohydrate intake and risk of dental caries in mixed and permanent dentition have been summarised in ***Table 11***. The results from trials of infant feeding and risk of dental caries in deciduous dentition have been summarised in ***Table 10***. The results from trials of carbohydrate intake and risk of dental caries in deciduous dentition have been summarised in ***Table 12***. The results from trials of carbohydrate intake and risk of dental caries in mixed and permanent dentition have been summarised in ***Table 13*** and the results of trials of polyol-containing chewing gum and risk of dental caries in mixed and permanent dentition, relative to a no gum control, have been summarised in ***Table 14***.

77. For both deciduous and mixed and permanent dentition, data on measures of dietary exposure, caries incidence/prevalence and risk assessment methods were insufficiently comparable to allow quantitative synthesis.

78. For the following dietary exposures no relevant articles were identified: glycaemic index and load, dietary fibre, non-digestible oligosaccharides and total carbohydrate.

Infant feeding practices and risk of dental caries

79. Low socioeconomic status has been associated with both an increased risk of childhood dental caries (Douglass *et al.*, 2004) and a shorter duration of breast feeding (Thulier & Mercer, 2009). Three of the studies investigating a relation between infant feeding practices and dental caries risk did not adjust for socioeconomic status (Tada *et al.*, 1999; Ollila & Larmas, 2007; Warren *et al.*, 2009) (see ***Table 5***).

80. Three cohort studies investigated breastfeeding (Grindefjord *et al.*, 1995; Tada *et al.*, 1999; Sakuma *et al.*, 2007), two investigated nursing bottle use (Litt *et al.*, 1995; Tada *et*

al., 1999) and two investigated night-time drink intake (Grindefjord *et al.*, 1995; Warren *et al.*, 2009) in relation deciduous dentition (see ***Table 9***). One cohort study investigated infant feeding in relation to mixed and permanent dentition (Ollila & Larmas, 2007) (see ***Table 11***).

81. In a cohort of Swedish pre-school children drink consumption prior to bed-time and at night-time, and breastfeeding for more than 10 months of age, were not found to be associated with caries prevalence, excluding non-cavitated lesions, at three and a half years of age (Grindefjord *et al.*, 1995).

82. One study in low-income preschool children observed that reported baby bottle use at night, containing either milk or juice, (assessed as 0 (never) to 5 (every night)) was not predictive of one year caries increment, excluding non-cavitated lesions (Litt *et al.*, 1995).

Table 9. Results of prospective cohort studies of carbohydrate intake and risk of dental caries in deciduous dentition

Study	Dental caries assessment measure	Mean caries increment (±SD)	% caries-free	% with caries	Dietary exposure	Reported association
Grytten et al., 1988	Caries prevalence at 3 years of age including non-cavitated lesions	NR	80	20	Soft drink, sweets and sweetened comforter use	Soft drink, sweets and sweetened comforter use were not associated with caries incidence at 36mths of age after adjustment for confounders; only mother's dental health was related . Multivariate data were reported as beta values only
Grindefjord et al., 1995; Grindefjord et al., 1996	Caries prevalence at 3.5 years of age excluding non-cavitated lesions	NR	71	29	2 or more sugar-sweetened drinks/day; 1 or more sweets/week; prior to bed-time and night-time drinks; and breastfeeding for more than 10mths	Consumption of sugar-sweetened drinks more than twice a day and consumption of sweets once or more a week were associated with a significantly increased risk of manifest caries; prior to bed-time and night-time drinks and breastfeeding for more than 10mths was not found to predict caries incidence in multivariate models
Litt et al., 1995	1 year caries increment excluding non-cavitated lesions	dmfs 1.8	42	58	Sugar, bedtime bottle use	No relationship was observed between sugar intake or bedtime bottle use and dmfs increment; baseline dmfs was the main predictor of dmfs increment.
Tada et al., 1999	1.5 year caries increment including non-cavitated lesions	dmft 1.60 (± 2.70)	NR	NR	Between meal sweet food or drink intake, and breast and bottle feeding	For all teeth no correlation was observed in multivariate model,; breastfeeding was related to increment in dmft for upper anterior and bottle feeding to increment in dmft in molar teeth.
Mattila et al., 2001	Caries prevalence at 5 years of age excluding non-cavitated lesions	dmft 2.9 (± 1.8)	72	28	Daily sugar consumption at the age of 18 months	Daily sugar consumption at the age of 18 months was significantly predictive of caries prevalence
Levy et al., 2003; Mariri et al., 2003	Caries prevalence at 4-6 years of age excluding non-cavitated lesions	NR	77	23	Quantity and frequency of sugar sweetened drink consumption; soft/sports drink consumption; 100% fruit juice/juice drink consumption; sweets consumption; sugar and starch consumption	Sugar sweetened drink consumption at 12-24 mths and soft/sports drink consumption at 12-24 mths were significantly predictive of caries experience in the whole cohort. In the nested case-control study, Quantity, but not frequency, of sugar sweetened drink consumption and frequency of starch consumption over four year period were significantly predictive of severe caries (dmfs≥6)
Sakuma et al., 2007	1.5 year caries increment excluding non-cavitated lesions	dmft 2.40 (± 1.17) to 3.01 (± 1.24)	NR	NR	Daily frequency of sugar sweetened drink and sweets consumption, breastfeeding at 1.5y and nursing bottle use at 1.5y	Daily frequency of sugar sweetened drink consumption, daily frequency of sweets consumption, breastfeeding at 1.5y and nursing bottle use at 1.5y were all significantly predictive of increased carried increment.
Ismail et al., 2008; Ismail et al., 2009; Lim et al., 2008	2-years caries increment including and excluding non-cavitated lesions	NR	39	61	Weekly consumption of sugar-sweetened carbonated drinks	Weekly sugar-sweetened carbonated drinks consumption was not significantly related to the transition in the proportion of early childhood caries to severe early childhood caries, but (2-6/wk) was predictive of caries increment. An increase from baseline to follow-up of consumption of sugar-sweetened carbonated drinks was significantly predictive of caries increment
Warren et al., 2009	Caries prevalence at 1.5 years follow-up excluding non-cavitated lesions	NR	75	25	Regular consumers of sugar-sweetened drinks Night time bottle feeding	Regular sugar-sweetened drink consumption, but not night-time bottle feeding, significantly predicted d2-3f caries experience after 18 months

SD, standard deviation; NR, not reported, y, year; d, day

83. One study in Japan reported that in children aged eighteen months being breastfed, as opposed to not breastfeeding (defined as yes or no), was related to increment in dmft, including non-cavitated lesions, for upper anterior teeth (OR 6.65; 95% CI 2.89-15.20) and being bottle fed (defined as yes or no) was related to increment in dmft, including non-cavitated lesions, in molar teeth (OR 1.98; 95% CI 1.13-3.49), but for all teeth no correlation was observed in a multivariate model for either exposure (Tada *et al.*, 1999).

84. Another study in Japan of children residing in 21 municipalities, divided into four groups reflecting urban and rural backgrounds (Sakuma *et al.*, 2007), observed that still breastfeeding or using a nursing bottle at one and a half years of age (defined as yes or no) were both associated with an increased one and a half year caries increment, excluding non-cavitated lesions: breastfeeding at one and half years had an OR 1.9 (95% CI, 1.2-3.0) to 2.2 (95% CI, 1.6-3.1) in the different groups and nursing bottle use one and half years had an OR 1.5 (95% CI, 1.2-1.7) to 1.8 (95% CI, 1.1-2.8) in the different groups.

85. A cohort study of low-income preschool children reported that night time bottle feeding (defined as yes or no) was not predictive of the prevalence of dental caries, excluding non-cavitated lesions, at one and a half years follow-up (OR 1.34; 95% CI, 0.40-4.50) (Warren *et al.*, 2009).

86. One cohort study in children aged two at baseline and followed-up for seven years investigated risk to mixed and permanent dentition in relation to infant feeding practices (defined as yes or no), and reported that breastfeeding for more than 12 months and night-time bottle feeding, though predictive in univariate analyses, were not predictive in multivariate analyses of caries development, excluding non-cavitated lesions, in two deciduous or two permanent molar teeth (Ollila & Larmas, 2007); survival curves for caries onset (the time elapsed from birth to when a dentist performed a restoration) in each of the molars was used to evaluate caries risk.

87. Two trials reported on the effect of practising exclusive and prolonged breastfeeding on deciduous dentition (Feldens *et al.*, 2010) and mixed and permanent dentition (Kramer *et al.*, 2007) (see ***Table 10***); both observed no increase on caries prevalence at follow-up relative to the control group.

88. In the Belarusian trial (Kramer *et al.*, 2007) the experimental intervention led to a substantial difference in the duration of breast-feeding that was maintained throughout the first year of follow-up: 72.7 vs. 60.0% were still breast-feeding at 3 months, 49.8 vs. 36.1% at 6 months, 36.1 vs. 24.4% at 9 months, and 19.7% vs. 11.4% at 12 months in the experimental versus control groups, respectively. The prevalence of exclusive breast-feeding was seven-fold higher in the experimental group at three months (43.3 vs. 6.4%), although low in both groups at six months (7.9 vs. 0.6%).

89. In the Brazilian trial (Feldens *et al.*, 2010) the intervention increased the duration of exclusive breastfeeding (18.8% more than six months) compared to the control group (8.2% more than six months). The intervention also resulted in a later introduction of sugar, lower frequency of dietary intake and a smaller probability of ingesting foods of high sugar or lipid density during the first year of life. The intervention reduced the proportion of children with caries (dmft≥1), excluding non-cavitated lesions, and severe

caries (dmft≥5) relative to the control (Feldens *et al.*, 2010). The number of affected teeth (decayed, cavitated or not, missing or filled) were also less (p=0.02) in the intervention group (mean 3.25, SD ± 4.25) than the control group (mean 4.15, SD ±4.57).

Table 10. Results of trials of infant feeding and risk of dental caries in deciduous dentition

Study	Caries determinant	Intervention	Control	Risk assessment	Adjustments	Results
Infant feeding						
Kramer et al., 2007	Proportion with total DMFT ≥1, excluding non-cavitated lesions	81.9 %	84.7 %	OR 1.0 (95% CI 0.7-1.5)	cluster-adjusted	The breastfeeding intervention had no significant effect on the DMFT numbers or proportions, either in the overall dentition or in the incisors.
	Proportion with total DMFT ≥2	75.8 %	78.3 %	OR 1.0 (95% CI 0.7-1.5)	cluster-adjusted	
Feldens et al., 2010	Proportion with total dmft≥1 excluding non-cavitated lesions	53.9 %	69.3 %	RR 0.78 (95% CI 0.65-0.93)	unadjusted	The breastfeeding and sugar reduction intervention significantly reduced the proportion of children with caries and severe caries
	Proportion with total dmft≥5	29.1 %	42.7 %	RR 0.68 (95% CI 0.5-0.92)	unadjusted	

OR, odds ratio; RR, risk ratio; NR, not reported.

Sugar intake and risk of dental caries

Deciduous dentition

90. Two cohort studies investigated the frequency of sugar consumption in relation to deciduous dentition (Litt *et al.*, 1995; Mattila *et al.*, 2000) (see ***Table 9***).

91. One study observed sugar consumption frequency at 18 months of age (assessed as none, once a week or daily) to be related to an increased caries prevalence, excluding non-cavitated lesions, at 5 years of age (OR 2.4; 95% CI, 1.4) (Mattila *et al.*, 2000); however, subsequent follow-ups and analyses of this cohort observed no relation of sugar consumption to caries increment between three and five years of age or to caries increment between seven and ten years of age in mixed and permanent dentition (Mattila *et al.*, 2001).

92. One study in low-income preschool children observed that sugar consumption frequency at four years of age (assessed as 1 (never) to 5 (more than once a day) from a list of seven foods high in sugar content) was not predictive of one year caries increment, excluding non-cavitated lesions (Litt *et al.*, 1995). In a multidimensional causal model baseline caries was predictive of caries increment and salivary *S. mutans* was predicted by baseline sugar intake.

Mixed and permanent dentition

93. Four cohort studies investigated sugar consumption in relation to the mixed and permanent dentition (Rugg-Gunn *et al.*, 1984; Rugg-Gunn *et al.*, 1987; Szpunar *et al.*, 1995; Ruottinen *et al.*, 2004; Levine *et al.*, 2007) (see ***Table 11***).

Table 11. Results of prospective cohort studies of carbohydrate intake and risk of dental caries in mixed and permanent dentition

Study	Dental caries assessment measure	Mean caries increment	% caries-free	% with caries	Dietary exposure	Reported association
Rugg-Gunn et al., 1984; Rugg-Gunn et al., 1987	2 year caries increment excluding non-cavitated lesions	DMFT 2.20 DMFS 3.63 DFS (fissure) 2.10	NR	NR	Frequency and quantity of sugars and starch	Sugar-sweetened drink and starch intake did not correlate with caries incidence. No correlation with DMFT increment or approximal surface caries. Total sugar intake was significantly related to fissure caries increment after adjustment for confounders. A separate adjustment for tooth-brushing (only 54% of the cohort provided information on this, n=219) did not attenuate the correlation. The overall caries increments in the cohort were low. For an increase in total sugars of 30g/day caries rose 0.36 DMFS (95%CI, -0.07-0.80).
Szpunar et al., 1995	3-year caries increment excluding non-cavitated lesions	DMFS boys 2.7; girls 3.1	NR	NR	Frequency and quantity total sugars (% Energy, g/d)	No relationship was observed between the frequency of eating high sugar foods and DMFS increment. Higher sugar (% energy and g/day) significantly increased the probability of caries on all surfaces, but only higher sugar (% energy) significantly increased the probability of pit and fissue and approximatal caries.
Mattila et al., 2001	3 year caries increment excluding non-cavitated lesions	dmft/DMFT 2.3 (SD±1.6)	41	59	Sweets consumption	Consumption of 1 or more sweets/week at age 3 was predictive of caries increment; this was significant in permanent, but not deciduous teeth. Sugar consumption and drinking juice at night at 18 mths were not predictive of caries increment.
Ruottinen et al., 2004	Caries prevalence at 10 years of age, excluding non-cavitated lesions	NR	NR	NR	High or low sucrose intake	A high sucrose intake associated with significantly increased caries experience
Leroy et al., 2005	Time elapsed from birth to caries restoration of first permanent molar teeth	NR	76-80	20-24	Sugar-containing drink and sweets consumption	No association with dietary variables and net caries increment on first permanent molars
Kallestal & Fjelddahl, 2007	4 year caries increment excluding non-cavitated lesions	DMFS 2.07	24	76	Sweets consumption	The frequent consumption of sweets at several examinations was significantly associated with an increased caries increment
Levine et al., 2007	Caries prevalence at age 11-15years excluding non-cavitated lesions	mean DMFT 0.82 at 11-15 years	NR	NR	Frequency of sugar consumption	Bedtime non-milk extrinsic sugars (NMES) consumption from drinks was significantly predictive of higher caries risk, but daily frequency of NMES in foods, drinks and foods the hour before bed were not predictive.
Ollila & Larmas, 2007	Time elapsed from birth to caries restoration of 2 deciduous and 2 permanent molar teeth	mean DMFT 1.1 at 10 years of age	NR	NR	Breastfeeding 1 year or more; sweets more than once a week; night-time bottle-feeding	Consumption of sweets more than once a week at age 2 was significantly predictive of earlier caries onset in both the primary molars studied and one of the two permanent molars studied; Breastfeeding more than 12 months and night-time bottle feeding were not predictive in the multivariate model.
Tamaki et al., 2009	2.5-years caries increment excluding non-cavitated lesions	DFT 0.256	85.2 no new incidence	14.8 new incidence	Daily frequency of drinking sweet juice and eating sweet snacks	No significant association with caries increment observed

SD, standard deviation; NR, not reported, y, year; d, day

94. One cohort study found no correlation between sugar consumption quantity (as assessed by five times three-day food diaries) and overall two year caries increment, excluding non-cavitated lesions, or approximal surface caries, but total sugar intake, and not frequency of sugar intake, was significantly related to fissure caries increment, excluding non-cavitated lesions, after adjustment for confounders (adjusted correlation coefficient of 0.142) (Rugg-Gunn *et al.*, 1984; Rugg-Gunn *et al.*, 1987). In a sub-cohort of subjects (n=219) for whom data were available, adjustment for tooth brushing frequency increased the strength of the correlation between fissure caries increment and total daily sugars (correlation coefficient 0.165); in the full cohort adjustment for gingival index was used to control for plaque quality and effectiveness of tooth brushing. The overall caries increment in the cohort was low and the correlation was weak. In a further sub-cohort analysis, a comparison of 31 children with the highest (92.5 percentile) and 31 children with the lowest (7.5 percentile) mean weight of daily sugar intake found that mean two-year DFS pit and fissure caries, but not overall DMFS, increment, excluding non-cavitated lesions, were significantly higher in the high sugar group (2.94 compared with 1.81, respectively) (Rugg-Gunn *et al.*, 1984).

95. Sugar consumption quantity (% total energy and g/day as assessed by four to nine twenty four hour dietary recall interviews) were both positively associated with three year dental caries increment, excluding non-cavitated lesions, in one cohort study, but no relationship was reported between the frequency of eating high sugar foods and three year dental caries increment (Szpunar *et al.*, 1995). Each additional five gram of sugars a day was associated with a one percent increase in the probability of developing caries. Those with a percent energy intake from sugar one standard deviation above the mean had twice the risk of developing approximal caries relative to those with percent energy intake from sugar one standard deviation below the mean. The overall caries increments in the cohort were low and the strength of its correlation with sugar consumption was weak.

96. One cohort study was conducted in a subgroup of children who were participants in the Special Turku Coronary Risk Factor Intervention Project, and for whom dietary intakes had been assessed using three-day food diaries (including 52 sucrose-containing foods) every six months from seven months age to seven years of age (Ruottinen *et al.*, 2004). The intervention involved dietary counselling to modify dietary fat intakes. Sixty six children were studied who had sucrose intakes in either the upper or lower five percentiles of the intake range. In the low sucrose group intakes ranged from a mean of 7.1g/d at 13 months of age to 32.5g/d at 10 years of age; in the high sucrose group intakes ranged from a mean of 16.6g/d at 13 months of age to 52.6g/d at 10 years of age. Sucrose intakes in the low sucrose group were below 10% total energy at all time points, while in the high sucrose group they were only above 10% total energy for all time points, except for at 13 months of age. A high sucrose intake was associated with increased caries prevalence, excluding non-cavitated lesions: a mean DMFT of 1.4 (SD± 2.0) in the high sucrose group compared with a mean DMFT of 0.5 (SD±1.1) in the low sucrose group.

97. One cohort study conducted in England observed no significant relationship between the frequency of non-milk extrinsic sugar containing food or drink consumption (as assessed by three twenty four hour dietary recall interviews and three-day food diaries) at age seven to eleven years and caries prevalence, excluding non-cavitated lesions, in the first permanent molar teeth at age eleven to fifteen years (Levine *et al.*, 2007). The overall caries prevalence in this cohort was low. The frequency of bedtime non-milk extrinsic sugar consumption from drinks at seven to eleven years of age was predictive of caries

prevalence in first permanent molar teeth at eleven to fifteen years of age (OR 1.92, no variance data given).

98. One trial investigated the effect of partially substituting sucrose-containing foods with fructose and glucose containing foods, mainly sugar-rich between-meal products, over two years in relation to dental caries risk in deciduous dentition (Frostell *et al.*, 1991). In comparison to the sucrose group (n=26), the fructose and glucose group (n=18) tended have a lower incidence of dental caries during the experiment period, but the difference was not significant (Frostell *et al.*, 1991) (see ***Table 12***).

Table 12. Results of trials of carbohydrate intake and risk of dental caries in deciduous dentition

Study	Caries determinant	Intervention	Control	Risk assessment	Adjustments	Results
Deciduous dentition						
Frostell et al., 1991	Mean 2-year dmfs including non-cavitated lesions	3.27	1.89	NR	unadjusted	A tendency for higher caries increment with sucrose as compared to fructose and glucose intervention, but not significant
	Mean 2-year dmft increment excluding non-cavitated lesions	1.62	0.39	NR	unadjusted	
Oscarson et al., 2006	Mean dmfs at 4 years of age, excluding non-cavitated lesions	0.38 (SD 1.05)	0.80 (SD 2.60)	p>0.05	baseline dmfs	A tendency for less caries in xylitol lozenge group as compared to control group, but the difference was not significant

NR, not reported; SD, standard deviation.

Starch intake and risk of dental caries

99. One study investigated starch consumption quantity in relation to mixed and permanent dentition (Rugg-Gunn *et al.*, 1987), but observed no significant correlation with two-year caries increment, excluding non-cavitated lesions.

100. One study investigated starch consumption frequency in relation to deciduous dentition. A nested case-control study within the Iowa Fluoride Study compared children with severe cavitated caries (dmfs≥6; n=39) to those without caries (n=39), including non-cavitated lesions, at follow-up and reported that increased starch eating frequency (four year average) was higher in those children with severe caries, OR 5.36 (95% CI, 1.28-22.40) (Mariri *et al.*, 2003); sugar and starch eating frequency combined was not different between groups.

Sugar containing foods and drinks intake and risk of dental caries

Deciduous dentition

101. Seven studies investigated the frequency of sugar- containing drink or sweets (including confectionary and candy) consumption in relation deciduous dentition (Grytten *et al.*, 1988; Grindefjord *et al.*, 1995; Grindefjord *et al.*, 1996; Tada *et al.*, 1999; Levy *et al.*, 2003; Sakuma *et al.*, 2007; Ismail *et al.*, 2008; Lim *et al.*, 2008; Ismail *et al.*, 2009; Warren *et al.*, 2009) (see ***Table 9***)

102. One study reported that the combined frequency of soft drink, sweets (assessed at 18 months of age) and sweetened comforter use (assessed at six month of age), used to define sugar consumption, was associated with caries experience, including non-cavitated lesions, at three years of age: 33% of those children who consumed soft drink, sweets and sweetened comforter use frequently developed caries compared to 13% of those who did

not consume soft drink, sweets and sweetened comforter use frequently (Grytten *et al.*, 1988). In a multivariate analysis, however, soft drink, sweets and sweetened comforter use ceased to be significantly associated with caries incidence at 36 months of age after adjustment for confounders: OR 1.20, no variance data given.

103. Two articles reported different analyses of a cohort of Swedish pre-school children investigating caries prevalence at three and a half years of age, excluding non-cavitated lesions, in relation to dietary exposures assessed at one year and two and half years of age (Grindefjord *et al.*, 1995; Grindefjord *et al.*, 1996). Dietary exposures at one year of age that were predictors of caries prevalence at three and a half years of age, excluding non-cavitated lesions, were consumption of two or more, relative to less than two, sugar-sweetened drinks a day and consumption of one or more, relative to less than one, sweets a week: OR 1.40 (95%CI, 1.09-1.79) and OR 1.49 (95%CI, 1.03-2.15), respectively. The dietary exposures at two and half years of age that were predictors of caries prevalence at three and a half years of age were the same dietary exposures that were predictive at one year of age, but the relationships were stronger: consumption of two or more, relative to less than two, sugar-sweetened drinks a day, OR 1.79 (95%CI, 1.00-3.15), and consumption of one or more, relative to less than one, sweets a week, OR 1.63 (95%CI, 1.04-2.55) (Grindefjord *et al.*, 1996).

104. One study observed no relation between-meal sweet food or sweet drink intake (both defined as yes or no), at one and half years of age, and one and half year caries increment, including non-cavitated lesions (Tada *et al.*, 1999).

105. In children aged one to two years of age, sugar sweetened drink consumption and soft/sports drink consumption (both assessed as low, medium or high) were predictive of caries prevalence, excluding non-cavitated lesions, at four to six years of age (OR 1.42 and OR 1.45, respectively; no variance data given) (Levy *et al.*, 2003). A nested case-control study within this cohort compared children with severe cavitated caries (dmfs≥6; n=39) to those without caries (n=39), including non-cavitated lesions, at follow-up and reported the quantity, but not frequency, of sugar-sweetened drink consumption over the four year period was predictive of severe caries development (OR 1.26; 95% CI, 1.02-1.55) (Mariri *et al.*, 2003); neither the quantity nor the frequency of 100% fruit juice/juice drink was predictive of severe caries development. Sweets consumption frequency (assessed as low, medium or high) was also not reported to be predictive of severe caries development.

106. A study of children residing in 21 municipalities in Japan, divided into four groups reflecting urban and rural backgrounds (Sakuma *et al.*, 2007), observed that an increased one and a half year caries increment, excluding non-cavitated lesions, was predicted by daily frequency at eighteen months of age (assessed as seldom, once, twice or more than thrice) of sugar sweetened drink consumption (the odds ratios ranged from an OR of 1.2, 95% CI, 1.0-1.4 to an OR of 1.5, 95% CI, 1.3-1.7 between the four different groups) and daily frequency of sweets consumption (the odds ratios ranged from an OR of 1.4, 95% CI, 1.1-1.7 to an OR of 1.6, 95% CI, 1.3-2.1 between the four different groups).

107. Three articles reported on the consumption frequency of sugar-sweetened carbonated drinks (none, once a week, two-six times a week, every day) in a cohort of preschool low-income African-American children, with a high prevalence of dental caries, in relation to risk of dental caries (Ismail *et al.*, 2008; Lim *et al.*, 2008; Ismail *et al.*, 2009). The

transition over two years from having dental caries (dmfs≥1, including non-cavitated lesions) to having severe dental caries (dmfs ≥4 (age 3), ≥5 (age 4) and ≥ 6 (age 5) excluding non-cavitated lesions) was not significantly related to consumption frequency of sugar-sweetened carbonated drinks, but the prevalence of severe dental caries at follow-up was (OR 1.25, SD ±0.13) (Ismail *et al.*, 2008). Two year caries increment was higher in those children consuming sugar sweetened carbonated drink two-six times a week, but not once a week or every day, (incidence rate ratio 1.5, 95% CI, 1.1-2.0, including non-cavitated lesions and an incidence rate ratio 1.9, 95% CI, 1.3-2.9, excluding non-cavitated lesions) (Ismail *et al.*, 2009). Relative to those children with high fruit-juice or milk consumption at baseline and follow-up, an increase from baseline to follow-up of consumption of sugar-sweetened carbonated drinks (defined as either low, medium or high) was predictive of two year caries increment, excluding non-cavitated lesions (incidence rate ratio 1.75, 95% CI 1.16-2.64) and new filled teeth surfaces (incidence rate ratio 2.67, 95% CI 1.36 - 5.23) (Lim *et al.*, 2008); a high intake of soft drinks at baseline and two-year follow-up was not predictive of two year caries increment, but was predictive of new filled teeth surfaces during that time (incidence rate ratio 2.68, 95% CI 1.44 – 4.96).

108. A cohort study of low-income preschool children reported that those who regularly consumed sugar sweetened drinks (defined as yes or no) had a higher prevalence of dental caries, excluding non-cavitated lesions, at one and a half years follow-up (OR 3.04 (95% CI, 1.07-8.64) (Warren *et al.*, 2009).

Mixed and permanent dentition

109. Three trials investigated the effect of supplementing subjects with sugar-containing foods on dental caries increment in mixed and permanent dentition (Steinberg *et al.*, 1972; Scheinin *et al.*, 1976; Finn & Jamison, 1980) (see ***Table 13***).

110. A trial in mental health patients in the USA observed supplementation for three years with 650ml/day sugar-sweetened carbonated soft drink (sugar content not reported), given between meals in two equal amounts, to have no effect on the incidence of dental caries (DMFT or DMFS) (Steinberg *et al.*, 1972). It was reported that patients in the experimental group had higher DFS/DMFS scores for the buccal surfaces of maxillary anterior teeth and for the buccal and buccolingual surfaces of the mandibular posterior teeth. These teeth surfaces had the greatest contact with the soft drink.

111. One trial in dental and medical students investigated the effect of substituting sucrose with polyol in chewing gum on one year dental caries increment in permanent dentition in relation to a sucrose containing gum (Scheinin *et al.*, 1975). Chewing xylitol containing gum reduced caries increment relative to a sucrose-containing gum: the mean DMFS increment was 2.94 in the sucrose group and -1.04 in the xylitol group ($p<0.001$). The average decrease in DMFS increment in the xylitol group may have resulted partly from a change in the diagnostic level or partly from negative caries reversals, i.e. remineralisation. When secondary caries reversals were included in the analysis the mean DMFS increment was 3.76 in the sucrose group and 0.33 in the xylitol group ($p<0.001$).

112. A trial in deaf and blind school children provided different breakfast foods over eighteen months: either sugar coated cereal containing approximately 42.1% sugar as mainly sucrose, a 28g portion of raisins or unsweetened canned fruit (reported to be rich in

fructose) or a non-sugar coated cereal to which children could add table sugar as required (Finn *et al.*, 1978). There was no restriction on sugar containing foods eaten during the rest of the day. The mean 1.5 year dental caries increment was not different between any of the groups or for DMFS or DMFT, excluding non-cavitated lesions.

Table 13. Results of trials of carbohydrate intake and risk of dental caries in mixed and permanent dentition

Study	Caries determinant	Intervention	Control	Risk assessment	Adjustments	Results
Steinberg et al., 1972	Mean 3-year DMFS increment excluding non-cavitated lesions	12.2 (SD12.4)	10.3 (SD9.8)	NR	unadjusted	No effect of 650ml/day sugar-sweetened carbonated soft drink (sugar content not reported) on caries incidence
Scheinin, 1975	Mean 1-year DMFS increment excluding non-cavitated lesions	-1.04	2.94	p<0.001	unadjusted	Replacement of sucrose with xylitol in chewing gum significantly reduced caries increment
Finn & Jamison, 1980	Mean 1.5-year DMFS increment excluding non-cavitated lesions	3.13 (SD 3.57) sugar-coated breakfast cereal 2.64 (SD 2.57) dried/canned fruit	2.90 (SD 3.05) non-sugar-coated breakfast cereal		unadjusted	No difference in caries increment between children consuming sugar-coated breakfast cereal, unsweetened dried/canned fruit or non-sugar-coated breakfast cereal

NR, not reported; SD, standard deviation; SE, standard error.

113. Five studies investigated the frequency of sugar containing drinks or sweets (including confectionary and candy) consumption in relation to mixed and permanent dentition (Mattila *et al.*, 2001; Leroy *et al.*, 2005; Mattila *et al.*, 2005; Kallestal & Fjelddahl, 2007; Ollila & Larmas, 2007; Tamaki *et al.*, 2009) (see ***Table 11***).

114. One study reported that although in a univariate analysis the daily consumption of sugar containing drinks and sweets (defined as yes or no) at age seven were both predictive of caries risk at six years, multivariate analyses failed to observe a significant association; baseline caries, plaque index and tooth brushing were the only factors predictive of caries risk (Leroy *et al.*, 2005). Survival curves for caries onset in permanent molar teeth (the time elapsed from birth to when a dentist performed a restoration) were used to evaluate caries risk.

115. Two articles reported on the Finnish Family Competence Study (Mattila *et al.*, 2001; Mattila *et al.*, 2005), which followed-up a birth cohort, beginning at the mother's pregnancy till the child's age of 10 years. Consumption of sweets more than once a week (compared with hardly ever or once a week) at age three (but not age five) was predictive of caries increment, excluding non-cavitated lesions, between seven and ten years in mixed and permanent dentition (OR 2.7; 95% CI, 1.5-4.8) (Mattila *et al.*, 2001). Those children with the poorest dental health in the cohort, as defined as dmft/DMFT of 5 or more (n=314) at 10 years of age, were associated with more frequent consumption of sweets (daily or twice a week) OR 5.5, 95% CI 1.6-19.2 (Mattila *et al.*, 2005).

116. One study reported that at age twelve sweets consumption several times a day at more than one examination (compared with several times a day at one examination or never/seldom) was predictive of increased four year caries increment, excluding non-cavitated lesions (rate ratio 1.05; 95% CI, 1.00-1.10) (Kallestal & Fjelddahl, 2007); when the caries increment included non-cavitated lesions in proximal surfaces, the rate ratio increased to 1.09 (95% CI 1.02-1.17).

117. A cohort study in children aged two at baseline and followed-up for seven years investigated risk to mixed and permanent dentition in relation to sweets consumption

more than once a week (defined as yes or no) (Ollila & Larmas, 2007). Survival curves for caries onset in two deciduous or two permanent molar teeth (the time elapsed from birth to when a dentist performed a restoration) were used to evaluate caries risk. Consuming sweets more than once a week was predictive of earlier caries onset in both the deciduous molars studied and one of the two permanent molars studied in multivariate analyses of caries development, excluding non-cavitated lesions (Ollila & Larmas, 2007): hazards ratio of 3.80 for the permanent molar and hazards ratios of 6.83 and 8.18 for the two deciduous molars studied (no variance data given). The mean survival time for the two deciduous molars was 7.3 years for those reporting sweets consumption more than once a week and 10.1 years for those reporting sweets consumption less than once a week.

118. A study of children aged five to eight at baseline observed a non-significant trend for both the daily frequency of eating sweet snacks or drinking sweet juice (defined as once, twice, thrice or four or more times a day) to be associated with higher two and half year caries increment, excluding non-cavitated lesions (OR 1.27, 95% CI 0.82-2.01 and 1.36, 95% CI 0.96-1.91, respectively) (Tamaki *et al.*, 2009).

Polyol intake and risk of dental caries

119. One trial examined the effect of supplementation with a low dose polyol (0.5-1g xylitol /day) lozenge for two years on in deciduous dentition caries prevalence, excluding non-cavitated lesions, at four years of age in relation to a no lozenge control (Oscarson *et al.*, 2006). The mean dmfs (±SD) for the polyol group was 0.4 (±1.1) and for the control group was 0.8 (±2.6), but the difference was not significant (P value not given) (see ***Table 12***).

120. Six trials investigated the effect of polyol containing chewing gum on dental caries increment in mixed and permanent dentition in relation to a no gum control (Finn *et al.*, 1978; Glass, 1983; Beiswanger *et al.*, 1998; Alanen *et al.*, 2000b; Machiulskiene *et al.*, 2001; Szoke *et al.*, 2001) (see ***Table 14***). Most trials instructed subjects to chew the gums after meals. One of the trials also investigated the effect of sweets containing either a xylitol-maltitol or xylitol-polydextrose mixture with 49% xylitol (Alanen *et al.*, 2000b). One trial had an accesulfame/saccharin sweetened chewing gum control as well as a no gum control (Machiulskiene *et al.*, 2001).

121. Two trials investigated the effect of a sorbitol only containing chewing gum on caries risk relative to a no gum control. No effect of a sorbitol containing chewing gum (two sticks/day; dose not reported) relative to a no gum control on 2-year caries increment was observed in one trial (Glass, 1983). The diagnosis of caries did not include non-cavitated lesions. The other trial observed a 55% reduction in two- and a 27% reduction in three-year caries increment with a sorbitol containing chewing gum (five sticks/day; 2.9g

polyol/day) relative to a no gum control (Machiulskiene *et al.*, 2001). When non-cavitated lesions were excluded from the analysis there was no statistically significant reduction in the three-year caries increment, but there was a 45% reduction in the two-year increment of cavitated lesions for the sorbitol containing chewing gum relative to the no gum control.

Table 14. Results of trials of polyol-containing chewing gum and risk of dental caries in mixed and permanent dentition

Study	Caries determinant	Intervention	Control	Risk assessment	Adjustments	Results
Finn et al., 1978	Mean 2.5-year DMFS increment excluding non-cavitated lesions	5.44 (SD 6.36)	4.99 (SD 5.61)	NR	unadjusted	No effect of sorbitol/mannitol chewing gum relative to no gum on 2.5-year caries increment
	Mean 2.5-year DMFT increment excluding non-cavitated lesions	3.23 (SD 3.42)	3.13 (SD 3.05)	NR	unadjusted	
Glass, 1983	Mean 2-year DFT increment excluding non-cavitated lesions	2.53 (SD 2.46)	2.55 (SD 2.71)	NR	unadjusted	No effect of sorbitol chewing gum relative to no gum on 2-year caries increment
	Mean 2-year DFS increment excluding non-cavitated lesions	4.63 (SD 4.79)	4.70 (SD 5.79)	NR	unadjusted	
Beiswanger et al., 1998	Mean 3-year DMFS increment excluding non-cavitated lesions – all subjects	8.00 (SD 5.98)	8.58 (SD 6.51)	p=0.018	cluster-adjusted	Chewing sorbitol/mannitol containing gum significantly reduced caries incidence relative to no gum control.
	Mean 3-year DMFS increment excluding non-cavitated lesions – high risk subjects	8.59 (SD 6.02)	9.39 (SD 6.51)	p=0.003	cluster-adjusted	
Alanen et al., 2000b	Mean 3-year DMFS increment including non-cavitated lesions	2.10 (SD 2.55)	4.42 (SD 4.36)	p<0.001	age, gender, baseline DMFS, cluster	All xylitol containing gum and sweets both significantly reduced caries incidence relative to no gum control to a similar degree.
Machiulskiene et al., 2001	Mean 3-year DMFS increment including non-cavitated lesions	Sorbitol gum 9.0 (95% CI 7.4-10.6) Xylitol gum 8.4 (95% CI 6.8-9.3)	Control gum 8.1 (95% CI 6.7-9.9) No gum 12.1 (95% CI 10.7-14.2)	NR	adjusted for age, gender, no. erupted surfaces and baseline DMFS.	Sorbitol, xylitol and control gums all significantly reduced DMFS increment (all stages) relative to no gum control to a similar degree. For DMFS cavitated stages no significant differences between groups were observed
	Mean 3-year DMFS increment, excluding non-cavitated lesions	Sorbitol gum 5.0 (95% CI 3.6-5.7) Xylitol gum 3.3 (95% CI 2.7-4.2)	Control gum 4.0 (95% CI 3.3-5.2) No gum 5.2 (95% CI 4.2-6.4)	NR	adjusted for age, gender, no. erupted surfaces and baseline DMFS.	
Szoke et al., 2001	Mean 2-year DMFS increment, including non-cavitated lesions	1.95 (SE 0.16)	2.91 (SE 0.16)	p=0.008	baseline DMFS	Sorbitol/mannitol chewing gum significantly reduced caries incidence relative to no gum control.
	Mean 2-year DMFS increment, excluding non-cavitated lesions	0.81 (SE 0.10)	1.33 (SE 0.11)	p=0.018	baseline DMFS	

NR, not reported; SD, standard deviation; SE, standard error.

122. Three trials investigated the effect of a sorbitol and mannitol containing chewing gum on caries risk relative to a no gum control. One trial in deaf and blind children reported no effect of a sorbitol and mannitol containing chewing gum (three sticks/day; 50-70 % sorbitol; dose not reported) on two and a half year caries increment, excluding non-cavitated lesions, relative to a no gum control (Finn *et al.*, 1978). Another trial observed a 6% reduction in two- and an 8% reduction in three-year caries increment with a sorbitol and mannitol containing chewing gum (three sticks/day; 40-60 % sorbitol; 4-15 percent mannitol; dose not reported) relative to a no gum control (Beiswanger *et al.*, 1998). The diagnosis of caries did not include non-cavitated lesions. The other trial observed a 33% reduction in two-year caries increment with a sorbitol and mannitol containing chewing

gum (three sticks/day; 65 % sorbitol; dose not reported) relative to a no gum control (Szoke *et al.*, 2001). When non-cavitated lesions were excluded from the analysis there was a 39% reduction in the two-year increment of cavitated lesions for the sorbitol and mannitol containing chewing gum relative to the no gum control.

123. Two trials investigated the effect of a xylitol containing chewing gum on caries risk relative to a no gum control. One of these trials also investigated the effect of xylitol containing sweets on caries risk relative to a no gum control (the sweets either contained a xylitol-maltitol or xylitol-polydextrose mixture with 49% xylitol overall) and observed equivalent reductions in three year caries increment, including non-cavitated lesions, for both xylitol containing chewing gum and sweets (each provided 5g xylitol/day) of 54% and 33-59%, respectively (Alanen *et al.*, 2000b). The other trial observed no significant reduction in two-year caries increment, and a 35% reduction in three-year caries increment, including non-cavitated lesions, with a xylitol containing chewing gum (five sticks/day; 2.9g polyol/day) relative to a no gum control (Machiulskiene *et al.*, 2001). When non-cavitated lesions were excluded from the analysis there was no statistically significant reduction in the two-year caries increment, but there was a 35% reduction in the three-year increment of cavitated lesions for the xylitol containing chewing gum relative to the no gum control.

124. One of the trials also investigated the effect of polyol containing sweets on caries increment and reported that polyol containing sweets had the same effect as a polyol containing gum on reducing caries increment compared to a no gum control (Alanen *et al.*, 2000b).One trial observed acesulfame/saccharin sweetened chewing gum to reduce three-year caries increment, including non-cavitated lesions, relative to the no gum control to a similar extent as observed for sorbitol and xylitol containing gum (Machiulskiene *et al.*, 2001). When non-cavitated lesions were excluded from the analysis there was no statistically significant reduction in caries increment. It is unclear, therefore, whether any observed effects on caries increment were due to the polyol component of the chewing gums or to the actual chewing of the sugar-free gums themselves stimulating salivary flow (Stookey, 2008). One trial that observed both xylitol containing chewing gum and sweets to produce similar reductions in caries increment, attributed the main preventive role to the xylitol component and not to the chewing effect alone (Alanen *et al.*, 2000b), but as sucking also stimulates salivary secretion (Dawes, 2008) and this trial did not investigate the effect of sweets containing non-carbohydrate sweetening compounds, it remains unclear whether it is the polyol component that is responsible for the preventive effect. The observed caries reduction in response to sugar-free gum chewing after meals could be ascribed to saliva stimulation throughout the chewing process, the lack of sucrose and the inability of bacteria to metabolise polyols into acids, but available evidence does not necessarily support a direct effect caused by sorbitol or xylitol.

Summary

Infant feeding

125. The prospective studies' dietary assessment of infant feeding practices was very limited, e.g. whether a child or infant was being breastfed at a certain age was often defined by yes or no. The terms 'breastfeeding' and 'bottle feeding' were extremely poor descriptors of dental carbohydrate exposure because they said nothing about frequency of feeding, diurnal pattern of feeding, ingestion of other carbohydrates in the weaning diet and concurrent dental hygiene practices. Other terms such as 'using a nursing bottle' or 'baby bottle use at night' were also often used, but it was unclear whether these terms were describing the same thing. The term 'bottle feeding' may have meant using a bottle and teat, but it was not reported whether this differentiated between, for example, use of a bottle with teat and a cup with a spout as opposed to the use of a plain cup. The assessment of infant feeding practices, therefore, limits the conclusions that can be drawn from these studies.

126. Two studies reported that children being breastfed at eighteen months of age had an increased risk of caries development in deciduous dentition (Tada *et al.*, 1999; Sakuma *et al.*, 2007), as did children who were still being bottle fed (Tada *et al.*, 1999; Sakuma *et al.*, 2007). Being breastfed for more than more than ten months of age was not observed to be associated with an increased caries risk in deciduous dentition in one study (Grindefjord *et al.*, 1995); while another observed being breastfed for more than more than twelve months of age was not predictive of caries development in deciduous or permanent molar teeth (Ollila & Larmas, 2007).

127. Consumption of drinks prior to bed-time and night-time drinks (Grindefjord *et al.*, 1995) or baby bottle use at night (Litt *et al.*, 1995; Warren *et al.*, 2009) were not observed to be associated with caries risk in deciduous dentition. Night-time bottle feeding was also reported not to be predictive of caries development in deciduous or permanent molar teeth (Ollila & Larmas, 2007).

128. Two trials reported on the effect of encouraging exclusive and prolonged breastfeeding on deciduous dentition (Feldens *et al.*, 2010) and mixed and permanent dentition (Kramer *et al.*, 2007); both trials increased the proportion of women exclusively breastfeeding after six months, but observed no increase on caries prevalence at follow-up relative to the control group.). The intervention in one trial (Feldens *et al.*, 2010), also included a later introduction of sugar, lower frequency of dietary intake and a smaller probability of ingesting foods of high sugar or lipid density during the first year of life, which resulted in a reduction in caries risk in deciduous dentition at follow-up.

Sugar

129. In prospective cohort studies, it was unclear what was precisely meant by the exposure term 'sugar', as further details were not reported. Whether the term 'sugar' referred to a mixture of mono- and di-saccharides or individual mono- and di-saccharides, e.g. sucrose, was not defined.

130. Two cohort studies reported sugar consumption frequency in relation to dental caries risk

in deciduous dentition, but provided little evidence of an association (Litt *et al.*, 1995; Mattila *et al.*, 2000). Three cohort studies reported that the frequency of sugar consumption was not related to caries risk in mixed and permanent dentition (Rugg-Gunn *et al.*, 1984; Rugg-Gunn *et al.*, 1987; Szpunar *et al.*, 1995; Levine *et al.*, 2007). A higher total sugar consumption was reported to be associated with increased risk of dental caries in three cohort studies (Rugg-Gunn *et al.*, 1984; Rugg-Gunn *et al.*, 1987; Szpunar *et al.*, 1995; Ruottinen *et al.*, 2004), but caries increments in the study populations were low and any correlation with sugar consumption was weak. It has been noted that caution is required when interpreting correlation coefficients using discrete data, such as the DMFT/S index, in relation to continuous data, such as daily intake of sugar (Appleton *et al.*, 1986). The correlation coefficient between observed values of the continuous and counting variables decreased as the measurement error increased, the slope of the relationship decreased, and the number of counts decreased. This could have led to considerably smaller estimates of the correlation coefficient than would have been obtained from continuous data.

131. One trial reported that the partial substitution of sucrose for its constituent monosaccharides tended to reduce dental caries in deciduous dentition, but this was not significant (Frostell *et al.*, 1991).

132. The evidence linking the development of dental caries to sugars consumption is relatively weak. The relationship between sugars consumption and dental caries is very complex as it is moderated by a combination of the quality of personal oral hygiene practiced by individuals, their inherent susceptibility to developing decay, and a background of preventative measures that have reduced caries incidence worldwide. Caries develops slowly and most commonly on surfaces of teeth that are difficult to see and where diagnosis is complex and subjective. Caries also occurs in a small minority of the population (generally about 80% of caries develops in 20% of the population). Most studies do not select for caries susceptibility of individuals at baseline and for ethical reasons have to include a full range of caries prevention advice in all study groups. The impact of these complex variables is profound.

133. In a recent example, not related to nutrition, a well designed clinical trial with four study arms, two in high risk populations and two in low produced a null outcome because the impact of a novel preventative dental material in high caries risk individuals was completely masked by complete lack of effect in the low risk arms where the control groups didn't develop any disease (Papas *et al.*, 2012). In a commentary on this outcome it was noted that design of studies, specifically targeting high caries risk individuals would be critical to success in identifying links with this disease because of its complex aetiology (Milgrom & Tanzer, 2012). Such studies have yet to be undertaken in detail in relation to sugars and dental caries

Starch

134. Only two studies reported on the relationship between starch intake and dental caries risk. One reported no relation of the quantity of starch consumed to caries risk in mixed and permanent dentition (Rugg-Gunn *et al.*, 1987), while the other reported that increased starch eating frequency was higher in those children with severe caries in deciduous dentition (Mariri *et al.*, 2003).

Sweets and sugar containing drinks

135. As noted above, in prospective cohort studies it was unclear what was precisely meant by the exposure term 'sugar'. The exposure term 'sweets' (including confectionary and candy) was similarly unclear, as details were not reported.

136. Six studies investigated the relation of the frequency of sugar-sweetened drinks intake to dental caries risk in deciduous dentition. Five of these studies reported a higher frequency of intake to be associated with an increased risk (Grindefjord *et al.*, 1995; Grindefjord *et al.*, 1996; Levy *et al.*, 2003; Sakuma *et al.*, 2007; Ismail *et al.*, 2008; Lim *et al.*, 2008; Ismail *et al.*, 2009; Warren *et al.*, 2009). In these studies the OR ranged from 1.2 (95% CI, 1.0-1.4) for sugar-sweetened drinks intake more than thrice daily compared to seldom daily (Sakuma *et al.*, 2007), to OR 3.04 (95% CI, 1.07-8.64) for daily sugar-sweetened drinks intake compared to less than daily (Warren *et al.*, 2009). One study reported no relation of the frequency of sugar-sweetened drinks intake to dental caries in deciduous dentition (Tada *et al.*, 1999) (no OR reported).

137. One study investigated the relation of the frequency of combined soft drink, sweets and sweetened comforter use intake to dental caries in deciduous dentition and reported no significant relation (OR 1.2, no variance data given) (Grytten *et al.*, 1988).

138. Four studies investigated the relation of the frequency of sweets intake (including confectionary and candy) to dental caries risk in deciduous dentition. Two of these studies reported a higher frequency of intake to be associated with increased risk (Grindefjord *et al.*, 1995; Grindefjord *et al.*, 1996; Sakuma *et al.*, 2007). In these studies the OR was 1.40 (95%CI, 1.09-1.79) for sweets intake of once or more weekly, relative to less than once weekly (Grindefjord *et al.*, 1995), and OR 1.4 (95% CI, 1.1-1.7) for sweets intake more than thrice daily compared to seldom daily (Sakuma *et al.*, 2007). The two other studies reported no relation of the frequency of sweets intake to dental caries risk in deciduous dentition (Tada *et al.*, 1999; Mariri *et al.*, 2003) (no OR reported in either study).

139. Overall, cohort studies mostly reported that higher frequencies of intake of sugar-containing drinks increased the risk of caries in deciduous dentition. Reported associations between the frequency of sweets intake and risk of caries in deciduous dentition were less consistent.

140. Two studies investigated the relation of the frequency of sugar-sweetened drinks intake to dental caries risk in mixed and permanent dentition. Both reported no significant relation of sugar-sweetened drinks intake to dental caries in mixed and permanent dentition (Leroy *et al.*, 2005; Tamaki *et al.*, 2009). Of these studies, one reported an OR of 1.27 (95% CI 0.82-2.01) for an intake frequency of four or more times daily compared to once daily (Tamaki *et al.*, 2009), while the other reported no association of daily intake compared with less than daily intake on survival curves for caries onset in permanent molar teeth (the time elapsed from birth to when a dentist performed a restoration) (Leroy *et al.*, 2005).

141. Five studies investigated the relation of the frequency of sweets intake (including

confectionary and candy) to dental caries risk in mixed and permanent dentition. Three reported a higher frequency of intake to be associated with increased risk (Mattila *et al.*, 2001; Kallestal & Fjelddahl, 2007; Ollila & Larmas, 2007). Two of these studies reported OR ranging from 1.05 (95% CI, 1.00-1.10) for sweets intake several times daily compared to never/seldom (Kallestal & Fjelddahl, 2007), to OR 2.7 (95% CI, 1.5-4.8) for intake of sweets more than once a week compared with once a week or less (Mattila *et al.*, 2001). The other study reported that consuming sweets more than once a week was predictive of earlier caries onset in both the deciduous molars and one of the two permanent molars studied (Ollila & Larmas, 2007). Two studies reported no significant relation of the frequency of sugar-sweetened drinks intake to dental caries risk in mixed and permanent dentition. Of these studies, one reported an OR of 1.36 (95% CI 0.96-1.91) for an intake frequency of four or more times daily compared to once daily (Tamaki *et al.*, 2009), while the other reported no association of daily intake, compared with less than daily intake, on survival curves for caries onset in permanent molar teeth (the time elapsed from birth to when a dentist performed a restoration) (Leroy *et al.*, 2005).

142. Overall, two cohort studies reported no association between the frequency of sugar-containing drink intake and risk of caries in mixed and permanent dentition. Of the five studies investigating the relation of the frequency of sweets intake (including confectionary and candy) to dental caries risk in mixed and permanent dentition, three reported that a higher frequency of sweets intake was associated with an increased risk in mixed and permanent dentition.

143. Three trials investigated the effect of supplementing subjects with sugar-containing foods on dental caries increment in mixed and permanent dentition, but overall the results were inconsistent. Two trials reported on the effect of supplementing subjects resident in institutions with either sugar-containing carbonated soft drinks, given between meals in two equal amounts (Steinberg *et al.*, 1972), or sugar containing breakfast cereals (Finn & Jamison, 1980) on the risk of dental caries, but neither reported an effect: there was no statistical difference in incremental DMFT and DMFS scores between experimental and control groups in either trial. The substitution of sucrose with polyol in chewing gum, however, resulted in a marked reduction in dental caries after one year in permanent dentition in one trial (Scheinin *et al.*, 1975): incremental DMFS scores increment were 2.94 in the sucrose group and -1.04 in the xylitol group ($p<0.001$). The average decrease in DMFS increment in the xylitol group may have resulted partly from a change in the diagnostic level or partly from negative caries reversals, i.e. remineralisation. When secondary caries reversals were included in the analysis the mean DMFS increment was 3.76 in the sucrose group and 0.33 in the xylitol group ($p<0.001$).

Polyols

144. Most trials of sugar-free polyol-containing chewing gums have demonstrated a caries reducing effect relative to no gum control groups (Finn *et al.*, 1978; Glass, 1983; Beiswanger *et al.*, 1998; Alanen *et al.*, 2000b; Machiulskiene *et al.*, 2001; Szoke *et al.*, 2001). It is unclear, however, whether it was the polyol component that was responsible for the preventive effect.

Carbohydrate and periodontal disease

145. Periodontal diseases, including gingivitis and periodontitis, are serious infections that, left untreated, can lead to looseness and loss of the tooth. Periodontal disease is a chronic bacterial infection that affects the soft tissue and bone supporting the teeth, both of which are vital to maintaining a functioning dentition. It is thought that plaque-induced gingivitis and periodontitis are a continuum of the same chronic inflammatory condition that affects the supporting structures of the teeth. While individual susceptibility to both gingivitis and periodontitis varies it is acknowledged that gingivitis may precede periodontitis (Steele & O' Sullivan, 2011).

146. Gingivitis is the mildest form of periodontal disease. It causes the gums to become red, swollen, and bleed easily and is often caused by inadequate oral hygiene. Gingival bleeding on probing is one of the signs of plaque-induced gingivitis and generally indicates some level of gingival inflammation (Steele & O' Sullivan, 2011).

147. Untreated gingivitis can advance to periodontitis. With time, plaque can spread and grow below the gum line. Toxins produced by the bacteria in plaque irritate the gums. The toxins stimulate a chronic inflammatory response and the tissues and bone that support the teeth are broken down and destroyed. Gums separate from the teeth, forming pockets that become infected. As the disease progresses, the pockets deepen and more gum tissue and bone are destroyed. Eventually, teeth can become loose and may have to be removed. The progressive loss of the supporting structures of the teeth can be assessed by measuring periodontal pocketing and loss of periodontal attachment. Periodontal pocketing can be classified as mild, moderate and severe; mild periodontal pocketing reflects pocketing between 4mm and 6mm, moderate between 6mm and 9mm, and severe above 9mm. Loss of periodontal attachment is an indication of damage over a lifetime and takes into account gum recession (which often occurs alongside pocketing) (Steele & O' Sullivan, 2011).

148. The measurement of periodontal disease is only applicable to adults who have some teeth i.e. are dentate. The UK national surveys of Adult Dental Health reported the prevalence of periodontal disease in 1998 and 2009 (Steele & O' Sullivan, 2011); the 2009 survey included data from England, Wales and Northern Ireland, but not Scotland. Just over half the dentate adult population (54 per cent) demonstrated gingival bleeding in 2009. It was reported that 65 per cent of adults with visible plaque had gingival bleeding compared with only 33 per cent of adults who had no plaque. A similar pattern was observed for calculus (a form of hardened dental plaque also called tartar); 67 per cent of adults with calculus had gingival bleeding compared with 26 per cent of adults with no calculus. Since 1998 there has been an overall reduction in the prevalence of periodontal pocketing at 4mm or more from 55 per cent down to 45 per cent signifying an overall reduction in disease. For both higher thresholds (pockets of 6mm or more and 9mm or more), however, no decline in prevalence was observed between 1998 and 2009, and for pocketing at 6mm an overall increase from six per cent to nine per cent in 2009 was observed. In 2009, 66 per cent of adults aged 55 years or more had loss of periodontal attachment of 4mm or more, 21 per cent had LOA above 6mm and four per cent above 9mm.

149. The UK Children's Dental Health series of national surveys reported the prevalence of gingivitis in 1993 and 2003 (White & Lader, 2004). Periodontal pocketing and loss of attachment were not measured. Between 1993 and 2003 an increase in the proportion of

children affected by gingivitis was observed among five-, eight- and 12-year-olds. Among 15-year-olds, the proportion of children affected by gingivitis was similar in 2003 to 1993, with boys being more likely than girls to have gingivitis: 56% of 15 year old boys had some gingivitis compared to 48% of girls.

150. The accumulation of plaque and calculus has been shown to be a risk factor for periodontal disease. In several trials (mainly controlled trials that did not report having been randomised), where subjects were instructed to refrain from oral hygiene practices, plaque accumulation for up to one week was reportedly increased by higher exposure to sucrose (Kinoshita *et al.*, 1966; Mandel, 1966; Fry & Grenby, 1972; Grenby *et al.*, 1974; Grenby, 1975; Ashley & Wilson, 1977; Jalil *et al.*, 1983; Ooshima *et al.*, 1990; Tandon *et al.*, 1997), although, not all trials have observed this effect (Folke *et al.*, 1972; Staat *et al.*, 1975; Bergstrom & Airila-Mansson, 1992) and one trial that monitored plaque accumulation over 21 days also observed no effect of higher sucrose exposure (Gaengler *et al.*, 1986). Several trials (mainly non-randomized) have reported that sucrose was more effective than fructose or glucose alone in increasing plaque accumulation (Carlsson & Egelberg, 1965; Carlsson & Sundstrom, 1968; Scheinin & Makinen, 1971; Fry & Grenby, 1972; DuBois *et al.*, 1984).

151. Observations from prospective cohort studies have suggested that subjects with periodontal diseases have a higher risk of developing coronary heart disease and other cardiovascular diseases (Bahekar *et al.*, 2007; Humphrey *et al.*, 2008; Blaizot *et al.*, 2009).

Prospective cohort studies

152. No articles were identified as eligible (see Appendix 2 for studies excluded).

Randomised controlled trials

153. Two articles were identified as eligible (see Appendix 2 for studies excluded) (Harjola & Liesmaa, 1978; Sidi & Ashley, 1984).

Randomised controlled trial study design

154. A summary of the trial designs has been given in ***Table 15***. Both the trials investigated gingival bleeding in mixed and permanent dentition in relation to dietary exposures. One trial employed a parallel design and one a cross-over design. Both trials reported on sugar exposure in relation to gingival bleeding, with durations ranging from fourteen days to three weeks.

155. One trial investigating sugar exposure in relation to gingival state employed a control group that consisted of subjects instructed to continue chewing gum and eating sweets containing sucrose while the intervention group replaced these with polyol-sweetened products, such that the daily dosage was 12.2g xylitol and 8.2g sorbitol (Harjola & Liesmaa, 1978). A no sweets group was also included in the trial, but subjects were not randomised to this group and the results from this group have not been included. The visible plaque index (Ainamo & Bay, 1975) and gingival bleeding index were determined on the mesial, facial and lingual surfaces of six teeth. The oral hygiene practices of

subjects during the trial were not reported.

156. The other trial investigated sugar exposure in relation to gingival state and employed a control diet that consisted of avoidance of sugar-containing food and drink and also food rich in dietary fibre, as this had been shown in a pilot study to remove some of the bulk of the accumulating plaque (Sidi & Ashley, 1984). The experimental diet consisted of the control diet supplemented with nine boiled sweets with a minimum of one hour between each intake. The mean weight of the sweets was 5.17g and they were composed of 65% sucrose and 30% glucose (equating to 44.2g sugar daily). Subjects underwent a two week pre-experimental period of oral hygiene instruction and prophylaxis. Gingival bleeding was assessed following probing using a Michigan 'O' probe at the mesial and distal aspects of the six anterior teeth. The plaque index scores (Podshadley & Haley, 1968) were also determined. Throughout the trial subjects wore teeth guards on their lower anterior teeth during oral hygiene procedures so that these teeth were not exposed to the procedures.

157. Neither trial reported their funding sources.

Table 15. Carbohydrate intake and risk of periodontal disease trial design

Study	Trial design	Country	Age (y)	Subject characteristics	Periodontal disease assessment and method	Duration (days)	Cohort size	Dietary assessment method or compliance determination	Oral hygiene during intervention	Intervention	Control intervention	Funding source
Harjola & Liesmaa, 1978	Parallel	Finland	14-16	Secondary school students	Gingival bleeding index on six teeth; clinical assessment	14	47	Children provided with daily ration of polyol products	NR	Polyol (xylitol-sorbitol) sweetened chewing gun and sweets	Sucrose sweetened chewing gun and sweets	NR
Sidi & Ashley, 1984	XO – 1 week washout	England	19-23	Male dental students	Gingival bleeding score on six lower anterior teeth; clinical assessment	21	20	Subjects recorded food and drink consumed	Withdrawn, (Guard worn over lower anterior teeth)	Control diet with 9 between meal sweets daily. Comprised 65% sucrose, 30% glucose	Low sugar diet	NR

XO, cross-over; NR, not reported

Risk of bias assessment

158. A summary of the risk of bias assessment has been given in ***Table 16***.

Table 16. Risk of bias assessment

Study	Randomisation	Sequence generation	Allocation concealment	Blinding	Incomplete outcome data	Dropouts (%)
Harjola & Liesmaa, 1978	Yes	NR	NR	Open	No missing outcome data	0
Sidi & Ashley, 1984	Yes	NR	NR	Open to participants and personnel, but assessors blind	No missing outcome data	0

159. Both trials reported being randomised. Sequence generation and allocation concealment were not reported in any of the trials. There were no missing outcome data or dropouts in either of the trials.

160. Due to the nature of the interventions both trials were open to participants and personnel. One of the trials reported that assessors were blind to intervention allocation, but the other did not report on blinding.

Results

161. The findings from all trials of carbohydrate intake and risk of periodontal disease have been summarised in ***Table 17***. Data on dietary exposures and gingival bleeding indices were insufficiently comparable to allow quantitative synthesis.

162. For the following dietary exposures no relevant articles were identified: glycaemic index and load, dietary fibre, non-digestible oligosaccharides, polyols, starch, infant feeding, soft drinks and total carbohydrate.

Sugar

163. Two trials reported on sugar exposure in relation to periodontal disease (see ***Table 17***).

Table 17. Results of trials of carbohydrate intake and risk of periodontal disease

Study	Intervention	Intervention duration (d)	Periodontal disease index	Control (mean±SD)	Intervention (mean±SD)	Results
Harjola & Liesmaa, 1978	Replacement of sucrose containing-with polyol containing-sweets	14	Gingival bleeding index	46.65±16.45	16.37±11.74	Replacement of sucrose with polyol significantly reduced gingival bleeding index
Sidi & Ashley, 1984	44g sucrose/glucose-containing sweets/day	21	Gingival bleeding score on probing	2.00±1.86	3.25±2.19	Sucrose/glucose supplementation significantly increased gingival bleeding on probing

164. In school children, the replacement of sucrose with polyol in chewing gum and sweets reduced gingival bleeding index after two weeks, while in those who continued to consume sucrose sweetened chewing gum and sweets no change in gingival bleeding index was reported (Harjola & Liesmaa, 1978). The replacement of sucrose with polyol in chewing gum and sweets also resulted in lower visible plaque index after two weeks, which was unchanged in the sucrose group.

165. In the other trial, mean gingival bleeding scores on probing increased over the duration of the trial in both study periods, but the increase was more in the sugar supplemented period (Sidi & Ashley, 1984). At the end of the intervention period of three weeks, bleeding scores were higher after the sugar supplemented period than the control period ($p=0.042$). After one week the mean plaque index scores were higher in the sugar supplemented period than the control period, but after three weeks there was no difference between groups. As noted in the introduction, most of the studies that have reported sucrose to increase plaque accumulation had intervention periods of one week or less.

Summary

166. Available evidence was limited to a small number of trials. One trial reported that increasing sugar exposure frequency (mainly sucrose) between meals, in the form of sweets, resulted in increased gingival bleeding; the other trial reported that substituting sugar (mainly sucrose) with polyol between meals, in the form of sweets, resulted in decreased gingival bleeding.

Carbohydrate and tooth wear

167. No articles were identified that investigated the relationship between carbohydrate intake and tooth wear (including dental erosion). Articles were identified that investigated the relationship between acidic foods and drink intake and tooth wear (including dental erosion). These have been considered in detail in Appendix 5.

Carbohydrate and oral cancer

168. In the UK and most other countries, oral cancer is more common in men than women. The risk of developing oral cancer increases with age and in the UK the majority of cases (87%) occur in people aged 50 or over. The most important aetiological factors for oral cancer are tobacco usage and excess consumption of alcohol, and these factors combined are thought to account for about three-quarters of oral cancer cases in Europe (La Vecchia *et al.*, 1997). It is possible that studies investigating the relation of alcohol consumption to oral cancer risk may have some degree of residual confounding due to carbohydrate being present in alcoholic drinks. The assessment of alcohol intakes in these studies has probably included some carbohydrate components, e.g. sugars in beers, wine and mixers such as soft drinks, but these exposures have not been reported separately from alcohol and could possibly influence the outcome measure. Studies of alcohol intakes and oral cancer risk have not been included in this review as the carbohydrate content of alcoholic drinks were unlikely to have been reported, which would limit the conclusions that could have been drawn.

169. Oral cancers comprise cancer of the lip, tongue, mouth, oropharynx, piriform sinus, hypopharynx and other ill-defined sites. In the UK, about a third of oral cancers are diagnosed in the mouth cavity and a similar proportion on the tongue. Cancers of the oropharynx, piriform sinus and hypopharynx together account for a further quarter of cases, while lip, the least frequent type of oral cancer, accounts for 6% (Welsh Cancer Intelligence and Surveillance Unit, 2009; Northern Ireland Cancer Registry, 2010; Office for National Statistics, 2010; ISD Scotland, 2011). More than 90% of oral malignancies are squamous cell carcinomas (Daley & Darling, 2003).

170. The age standardised incidence of oral cancer in British males stayed at around 7 per 100,000 males between 1975 and 1989, but since then, the rate has steadily increased to reach 11 per 100,000 in 2007, an increase of more than 50% since 1989. While female oral cancer rates have remained significantly lower than male rates, their incidence trends have been similar with an average increase of 3% each year since 1989 (Welsh Cancer Intelligence and Surveillance Unit, 2009; Northern Ireland Cancer Registry, 2010; Office for National Statistics, 2010; ISD Scotland, 2011). There has been a rise in the incidence of the oral cancer subsite oropharyngeal squamous cell cancer – specifically of the lingual and palatine tonsils – which has been associated with human papillomavirus infection (Marur *et al.*, 2010). Oral cavity cancers appear unrelated to human papillomavirus infection and include cancer of the tongue, gum, floor of mouth, palate, and other mouth. In the UK, between 1983 and 2002 human papillomavirus related oral cancer subsite cancer incidence increased annually be 3.8%, while human papillomavirus unrelated oral cancer subsite cancer incidence increased by 1.4% (Curado *et al.*, 2007).

Prospective cohort studies

171. One article were identified as eligible (see Appendix 2 for studies excluded) (Ren *et al.*, 2010).

Prospective cohort study design

172. The study design details have been summarised in ***Table 18***. The study was conducted in North America. The length of follow-up was six years. The cohort size was 481563. Dietary assessment was by food frequency questionnaire. The study investigated carbonated soft drink intake in relation to oral cancer incidence. Carbonated soft drink intake was defined in terms of how many 12oz cans were consumed, but no information was provided on whether this included polyol-, artificial sweetener - or sugar-containing soft drinks or all of these. Cox proportional hazards regression was used to explore associations. The funding source for the study was Governmental. The confounders adjusted for by the study has been summarised in ***Table 19***.

Table 18. Study design of prospective cohort studies of carbohydrate intake and risk of oral cancer

Study	Cohort	Country	Sex	Age (y)	Oral cancer cases	Cohort size	Mean follow-up duration (y)	Statistical analysis	Dietary assessment method	Carbohydrate components investigated	Funding source
Ren et al., 2010	NIH-AARP Diet and Health Study	USA	Mixed	50-71	392*	481563	6	Cox proportional hazards regression model	124-item food frequency questionnaire	Carbonated soft drinks (12ounce cans/day)	National Institutes of Health, USA

NR, not reported; * included only squamous cell carcinomas

Table 19. Confounders adjusted for in prospective studies investigating carbohydrate intake and risk of oral cancer

Study	Age	Sex ~	BMI	Energy	Smoking	Alcohol	PA	Ethnicity	Education	Meat	Fruit	Vegetable
Ren et al., 2010	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

PA, physical activity

Table 20. Results of prospective studies investigating carbohydrate intake and risk of oral cancer

Study	Sex	Outcome	Carbohydrate components investigated	Comparison	Oral cancer RR	Oral cancer P for trend	Oral and pharyngeal cancer RR	Oral and pharyngeal cancer P for trend	Reported association
Ren et al., 2010	Mixed	Oral cancer	Carbonated soft drink intake	Q1 none vs. Q4 one or more cans per day	0.77 (0.54-1.09)	0.31			No significant association observed

* Variance data not reported; NR, not reported

Results

173. The results from the prospective cohort study of soft drink intake and risk of oral cancer have been summarised in ***Table 20***.

174. Reported data on measures of dietary exposure, cancer type and incidence and risk assessment methods were insufficient to allow quantitative synthesis. For the following dietary exposures no relevant articles were identified: glycaemic index and load, dietary fibre, non-digestible oligosaccharides, total carbohydrate, polyols and infant feeding.

Carbonated soft drink intake

175. One prospective study investigated carbonated soft drink intake in relation to oral cancer risk, but no information was provided a to whether this included all drinks sweetened with sugar, polyol or artificial sweeteners. The prospective study, in the USA, reported that carbonated soft drink intake (12 ounce cans/day) was not associated with oral cancer incidence, or any of the other upper aerodigestive tract cancers investigated (Ren *et al.*, 2010). Carbonated soft drinks were commonly consumed by cohort members with only 12 % who drank none , 31% drank one or less cans a week, 41% drank two to six cans a week and 16% drank at least one can a day. No linear relationship was observed: compared with those who drank no carbonated soft drinks the hazard ratios (95% CI) for drinking one or less cans a week, two to six cans a week and at least one can a day were 0.62 (0.46-0.85), 0.66 (0.49-0.89) and 0.77 (0.54-1.09), respectively.

Summary

176. Available evidence was limited to one prospective study, which reported no relation of carbonated soft drink intake to oral cancer risk.

Conclusions

Dental caries

Infant feeding practices

177. Available evidence was limited to a small number of studies and trials, with often very limited assessments of infant feeding practices. The evidence was insufficient to allow firm conclusions, but an increased risk of dental caries was only observed in two Japanese studies when either breastfeeding or bottle feeding was continued until infants were aged eighteen months or more.

Sugar

178. Cohort studies reported the quantity of sugar consumed was reported to be associated with an increased caries risk in mixed and permanent dentition in three cohort studies, but the caries increments in the study populations were low and the correlation with sugar intake was weak. Cohort studies reported no association between the frequency of sugar intake and dental caries risk in either deciduous or mixed and permanent dentition. It has been noted that caution is required when interpreting correlation coefficients using discrete data, such as the DMFT/S index, in relation to continuous data, such as daily intake of sugar (Appleton *et al.*, 1986). The correlation coefficient between observed values of the continuous and counting variables decreased as the measurement error increased, the slope of the relationship decreased, and the number of counts decreased. This could have led to considerably smaller estimates of the correlation coefficient than would have been obtained from continuous data.

179. Controlled trials that did not report having been randomised (see Appendix 4) observed that the removal or substitution of sucrose from the diet resulted in a reduction in dental caries increment. In these trials the addition of sucrose to the diet at mealtime, e.g. in food or drinks, appeared to have little impact on dental caries increment. One non-randomised trial in mental health patients receiving little, if any, oral hygiene suggested that intake of sucrose in a form regarded as having a high tendency to be retained on the tooth surface resulted in increased caries incidence. This trial also suggested that intake of sucrose containing foods between meals, especially in a form regarded as having a high tendency to be retained on the tooth surface, resulted in increased caries incidence.

180. The evidence linking the development of dental caries to sugars intake is relatively weak. The relationship between sugars intake and dental caries is very complex as it is moderated by a combination of the quality of personal oral hygiene practiced by individuals, their inherent susceptibility to developing decay, and a background of preventative measures that have reduced caries incidence worldwide. Caries develops slowly and most commonly on surfaces of teeth that are difficult to see and where diagnosis is complex and subjective. Caries also occurs in a small minority of the population (generally about 80% of caries develops in 20% of the population). Most studies do not select for caries susceptibility of individuals at baseline and for ethical reasons have to include a full range of caries prevention advice in all study groups. The impact of these complex variables is profound.

181. In a recent example, not related to nutrition, a well designed clinical trial with four study arms, two in high risk populations and two in low produced a null outcome because the impact of a novel preventative dental material in high caries risk individuals was completely masked by complete lack of effect in the low risk arms where the control groups didn't develop any disease (Papas *et al.*, 2012). In a commentary on this outcome it was noted that design of studies, specifically targeting high caries risk individuals would be critical to success in identifying links with this disease because of its complex aetiology (Milgrom & Tanzer, 2012). Such studies have yet to be undertaken in detail in relation to sugars and dental caries

Sugar containing foods and drinks

182. Prospective cohort studies generally reported that higher frequencies of intake of sugar-containing drinks increased the risk of dental caries in deciduous dentition, but reported associations with frequencies of sweets intake (including confectionary and candy) were inconsistent.

183. Two cohort studies reported no association between the frequency of sugar-containing drink intake and risk of caries in mixed and permanent dentition. Of the five studies investigating the relation of the frequency of sweets intake (including confectionary and candy) to dental caries in mixed and permanent dentition three reported that a higher frequency of sweets intake (including confectionary and candy) was associated with an increased risk in mixed and permanent dentition.

184. Three trials investigated the effect of supplementing subjects with sugar-containing foods on dental caries increment in mixed and permanent dentition. One reported no effect of sugar-containing carbonated soft drinks, given between meals, on caries risk, while another reported no effect of modifying the sugar content of breakfast cereals on caries risk. The replacement of sucrose with polyol in chewing gum was observed to reduce caries increment.

Polyols

185. Most trials of sugar-free polyol-containing chewing gums have demonstrated a caries reducing effect relative to no gum control groups. It is unclear, however, whether it was the polyol component or the action of chewing gum (which stimulates salivary output) that was responsible for the preventive effect.

Tooth wear including dental erosion

186. Prospective cohort studies of acidic food and drink intake and risk of tooth wear provided some evidence that a higher consumption of dietary acids may result in more tooth wear (see Appendix 5). *In situ* trials demonstrated that consumption of fruit juices (e.g. orange juice and apple and blackcurrant juice) and acidic soft drinks and sports drinks (whether artificially sweetened or sugar sweetened) resulted in a progressive loss of enamel and dentine from dental blocks. No direct comparison between artificially sweetened soft drinks and sugar sweetened soft drinks on dental erosion was conducted in the trials included. Individuals showed a large degree of variation in response to the erosive

challenge ranging from almost negligible erosion to large degrees of erosion, reflecting the multi-factorial nature of dental erosion.

Periodontal disease

187. Available evidence was limited to a small number of trials. One trial reported that increasing sugar, mainly sucrose, exposure between meals, in the form of sweets, resulted in increased gingival bleeding, while the other trial reported that substituting sugar, mainly sucrose, with polyol, in the form of sweets, between meals resulted in decreased gingival bleeding.

Oral cancer

188. Available evidence was limited to one prospective study, which reported no relation of carbonated soft drink consumption to oral cancer risk.

Appendix 1. Search terms

Literature search details

189. The literature search was conducted in January/February 2011:

- Medline identified 13348 unique articles
- Embase identified 14830 unique articles
- Cinahl identified 1390 unique articles

190. After the removal of duplicates, 18102 unique articles were identified. Details of the search terms used have been given in Appendix 1.

Oral health endpoint search terms

Free-text search terms (* denotes wildcard):

#1: (dental or tooth or teeth or enamel or root*) AND (decay* or caries or carious or white adj spot* or plaque or remineral* or demineral*)
#2: (periodont* or gingivitis or (gingiva* adj inflamm*) or (gingiva* adj bleed*) or (gingival* adj pocket) or (gingiva* adj attachment)
#3: stomatitis or (mouth adj4 ulcer*) or (oral adj4 ulcer*) or (oral adj4 candidiasis) or (aphthous adj4 ulcer*) or (mouth adj4 aphthae) or (oral adj4 aphthae)
#4: (mucositis adj4 oral)
#5: (tooth adj4 wear) or ((tooth or dental or teeth or enamel) and (erosion or abrasion))
#6: halitosis or (mouth adj4 odour) or (mouth adj4 odor) or (mouth adj4 malodour) or (mouth adj4 malodor) or (breath adj4 malodour)
#7: (bottle adj3 caries) or (bottle adj3 decay*) or (nursing and (decay or caries)) or (bottle adj3 decay) or ((early adj3 childhood) and (caries or decay))
#8: ((tooth adj6 scaling) or (teeth adj6 scaling) or (dental adj6 scaling))
#9: ((tooth adj6 scale*) or (teeth adj6 scale*) or (dental adj6 scale*))
#10: (supragingival* adj (scaling or scale*)) or (subgingival* adj (scaling or scale*))
#11: ((scale* adj6 polish*) or (scaling adj 6 polish*) or (root adj6 plane) or (root adj6 planed) or (root adj6 planing))
#12: ((root adj4 plane*) or (root adj4 planing) or (scale* adj4 polish*) or (scaling adj4 polish*)
#13: ((cancer* or tumour* or tumor* or neoplasm* or malignan* or carcinoma* or metatast* or dysplasia*) adj5 (oral* or intra-oral* or gingival* or oropharyn* or mouth* or tongue* or cheek or gum or palatal or palate or intraoral)).

#14:in conjunction with relevant thesaurus terms below #1 or #2 or #3 or #4 or #5 or #6 or #7 or #8 or #9 or #10 or #11 or #12 or #13

Medline Mesh terms:

#15: Exploded Dental Caries or Tooth Demineralization or Dental Plaque or Dental

Scaling or Oral Health or Stomatognathic Diseases or Dental Prophylaxis or Periodontics or Periodontal Diseases or Preventive Dentistry or Halitosis or Mouth Neoplasms or Gingival Neoplasms or Palatal Neoplasms or Tongue Neoplasms or Oropharyngeal Neoplasms

Embase Emtree terms:

#16: Exploded Dental Caries or Mouth Disease or Tooth Disease or Tooth Plaque or Periodontics or Periodontal Diseases or Preventive Dentistry or Dental care or Halitosis or Mouth Tumor or Gingiva Tumor or Jaw Tumor or Tongue Tumor or Oropharynx Tumor

Cinahl thesaurus terms:

#17: Dental Caries or Tooth Demineralization or Dental Plaque or Dental Scaling or Oral Health or Stomatognathic Diseases or Periodontics or Periodontal Diseases or Preventive Dentistry or Halitosis or Dental Prophylaxis or Mouth Neoplasms or Gingival Neoplasms or Palatal Neoplasms or Tongue Neoplasms

Dietary carbohydrate exposure search terms

The terms used for the colo-rectal function aspect of the carbohydrate report (given below) were used in conjunction with additional terms specific for oral health aspect:

Additional terms to be included:

Free text terms: “smoothie*” OR “juice*” OR “sweet*” OR “snack*” OR “raisin*” OR “sultana*” OR “yoghurt” OR “yogurt” ((“sport*” OR “acid*” OR “soft” OR “probiotic”) AND (“drink*” OR “drink*”))

Exploded Mesh terms: “drinks” OR “yogurt” OR “fruit”

Infant feeding free text terms: Breast fed OR Breast feed OR Breast feeds OR Breast feeding OR Bottle fed OR Bottle feed OR Bottle feeds OR Bottle feeding OR Infant feed OR Infant feeds OR Infant feeding OR Infant nutrition OR Formula fed OR Formula feed OR Formula feeds OR Formula feeding OR Infant diet* OR Early nutrition; exploded Mesh terms: Breast feeding OR Bottle feeding OR Milk, human OR Infant nutritional physiological phenomena ; exploded Embase terms: Breast feeding OR Breast milk OR Bottle feeding OR Infant feeding OR Infant nutrition OR Artificial milk

Colo-rectal function carbohydrate exposure search terms:

Food free-text terms: "refined grain" OR (("cake*" OR "biscuit*" OR "cookie*" OR "confectionery") AND ("diet" OR "intake")) OR ((“soda” OR “carbonated” OR “sweet*” OR “sugar*”) AND (drink* OR drink*)) OR “soft drink” OR “whole grain*” OR “wholegrain*” OR “grain*” OR “whole meal” OR “wholemeal” OR “wheat” OR “rice” OR "cereal*" OR “oat*” OR “porridge” OR “rye*” OR “barley” OR “bread*” OR “vegetable*” OR “fruit*” OR “bean*” OR “prune*” OR “legume*” OR “potato” OR

“maise” OR “honey” OR “jam*” OR “flour” OR “milk” OR “dairy”

exploded MeSH terms: Diet, Cariogenic OR “candy” OR “carbonated beverages” OR “cereals” OR “fabaceae” OR “bread”

General **carbohydrate** terms: exploded Emtree terms “CARBOHYDRATE DIET” OR “CARBOHYDRATE INTAKE” OR “STARCH” OR “Polysaccharides” OR “pasta” OR exploded MeSH terms “DIETARY CARBOHYDRATES” OR “STARCH” OR” Polysaccharides” OR CINAHL exploded “DIETARY CARBOHYDRATES” OR “Polysaccharide” OR free-text terms “carbohydrate*” OR “starch*” OR “polysaccharide*”

Sugars terms: exploded Emtree terms “SUGAR INTAKE” OR “SUCROSE” OR “FRUCTOSE” OR “LACTOSE” OR “GALACTOSE” OR “Maltose” OR “Isomaltose” OR “carbonated drinks” OR exploded MeSH terms “DIETARY SUCROSE” OR “FRUCTOSE” OR “LACTOSE” OR “GALACTOSE” OR “candy” OR “carbonated beverages” OR “Isomaltose” OR “Maltose” OR CINAHL thesaurus terms “DIETARY SUCROSE” OR “FRUCTOSE” OR “LACTOSE” OR “candy” OR “carbonated drinks” OR free-text terms “sugar*” OR “sucrose” OR “fructose” OR “lactose” OR “galactose” OR “maltose” OR “disaccharide*” OR “monosaccharide*”

Polyol terms: exploded Emtree terms “Polyol” OR “SUGAR ALCOHOL” OR “SORBITOL” OR “XYLITOL” OR exploded MeSH terms “SUGAR ALCOHOLS” OR “SORBITOL” OR “XYLITOL” OR CINAHL thesaurus terms “SORBITOL” OR “XYLITOL”OR exploded “SUGAR ALCOHOLS” OR free-text terms “polyol*” OR “sorbitol” OR “maltitol” OR “isomalt” OR “ xylitol” OR “erythritol” OR “lactitol” OR “mannitol” OR “polyglycitol”

Non-digestible oligosaccharide terms: exploded Emtree terms “PREBIOTIC AGENT” OR “FRUCTAN” OR “INULIN” OR “FRUCTOSE OLIGOSACCHARIDE” OR “GALACTOSE OLIGOSACCHARIDE” OR “RAFFINOSE” OR mannans OR “oligosaccharides” OR exploded MeSH terms “FRUCTANS” OR “INULIN” OR “RAFFINOSE” OR mannans OR “oligosaccharides” OR CINAHL thesaurus terms “PREBIOTICS” OR “oligosaccharides” OR free-text terms “prebiotic*” OR “inulin” OR “fructan*” OR “raffinose” OR "polydextrose" OR “oligosaccharide*”

NSP/dietary fibre terms: Exploded Emtree terms “DIETARY FIBER” OR “ISPAGULA” OR “BETA GLUCAN” OR “STERCULIA” OR “KARAYA GUM” OR “BULKING AGENT” OR “BRAN” OR “WHEAT BRAN” OR “GUAR GUM” OR “ARABINOXYLAN” OR “PECTIN” OR “HEMICELLULOSE” OR “Alginic acid” OR “carageenan” OR “cellulose” OR “methylcellulose” OR “lignin” OR “carboxymethylcellulose” OR “plant gum” OR “gum Arabic” OR “gum tragacanth” OR “cereal” OR “legume” OR “bread” OR exploded MeSH terms “DIETARY FIBER” OR “PSYLLIUM” OR “BETA-GLUCANS” OR “STERCULIA” OR “KARAYA GUM” OR “PECTINS” OR “Alginates” OR “carrageenan” OR “cellulose” OR “methylcellulose” OR “lignin” OR “carboxymethylcellulose” OR “plant gums” OR “gum Arabic” OR “tragacanth” OR “cereals” OR “fabaceae” OR “bread” OR CINAHL thesaurus terms “DIETARY FIBER” OR “PSYLLIUM” OR “alginates” OR “cellulose” OR “cereals” OR “bread” OR “legumes OR free-text terms “complex carbohydrate*” OR “unavailable

carbohydrate*" OR "resistant starch*" OR "amylose" OR "psyllium" OR "sterculia" OR "karaya gum" OR "bulking agent" OR "husk" OR "bran" OR "ispaghula" OR "roughage*" OR "raw starch" OR "cellulose" OR "hemicellulose" OR "pectin" OR "arabinoxylan*" OR "plant gum*" OR "guar gum" OR "beta-glucan*" OR (("non-starch" OR "nonstarch" OR "low-digestible" OR "non-digestible " OR "nondigestible" OR "indigestible") AND ("polysaccharide*" OR "carbohydrate*")) OR (("fibre*" OR "fiber*") AND ("dietary" OR "plant" OR "high" OR "crude" OR "insoluble" OR "soluble")) OR "alginate" OR "xanthan" OR "carageenan" OR "methylcellulose" OR "hydroxymethylcellulose" OR (("acacia" OR "arabic" OR "bean") AND "gum")

Glycaemic index and load: exploded Emtree terms "GLYCEMIC INDEX" OR "GLYCEMIC LOAD" OR "GLUCOSE BLOOD LEVEL" OR exploded MeSH terms "GLYCEMIC INDEX" OR "BLOOD GLUCOSE" OR CINAHL thesaurus terms "GLYCEMIC INDEX" OR "BLOOD GLUCOSE" OR ((index OR load) adj3 glycaemic) OR ((index or load) adj3 glycemic) OR ((sugar* OR glucose) adj3 blood)

Appendix 2. Articles excluded at full-text stage

Carbohydrate and dental caries

Prospective cohort studies

191. The initial search identified 64 articles, which were assessed as full-text articles for eligibility. Of these 38 were excluded for the following reasons:

- No relevant dietary exposure data reported (nine articles) (Dummer *et al.*, 1990a; Dummer *et al.*, 1990b; Papas *et al.*, 1995b; Domejean-Orliaguet *et al.*, 2006; Southward *et al.*, 2006; Marshall *et al.*, 2007; Southward *et al.*, 2008; Yoshihara *et al.*, 2009; Arnadottir *et al.*, 2010)
- Review article (three articles) (Papas *et al.*, 1989; Billings & Kopycka-Kedzierawski, 2004; Burt, 2004)
- Follow-up period less than 12 months (Thitasomakul *et al.*, 2009)
- Dental caries assessment was self-reported (Kuusela *et al.*, 1997)
- Not adjusted for tooth brushing frequency (seventeen articles) (Persson *et al.*, 1985; Silver, 1987; Wilson & Ashley, 1989; Holbrook, 1993; MacEntee *et al.*, 1993; Holbrook *et al.*, 1995; Wendt & Birkhed, 1995; Rodrigues *et al.*, 1999; MacKeown *et al.*, 2000; Petti & Hausen, 2000; Karjalainen *et al.*, 2001; Campain *et al.*, 2003; Marshall *et al.*, 2003; Pienihakkinen *et al.*, 2004; Bruno-Ambrosius *et al.*, 2005; Marshall *et al.*, 2005; Law & Seow, 2006)
- Retrospective study design (van Palenstein Helderman *et al.*, 2006)
- Data reported in previous article (Hackett *et al.*, 1987)
- No longitudinally data reported (five articles) (Sundin, 1990; Sundin & Granath, 1992; Sundin *et al.*, 1992; Jamieson *et al.*, 2010b; Jamieson *et al.*, 2010a)

Randomised controlled trials

192. The initial search identified 71 articles, which were assessed as full-text articles for eligibility. Of these 58 have been excluded for the following reasons:

- Intervention in conjunction with non-carbohydrate components e.g. fluorides, tooth brushing etc. (eight articles) (Moller & Poulsen, 1973; Petersen & Razanamihaja, 1999; Aaltonen *et al.*, 2000; Hausen *et al.*, 2007; Hietasalo *et al.*, 2008; Meurman *et al.*, 2009; Milgrom & Tut, 2009; Mohebbi *et al.*, 2009)
- Non-carbohydrate intervention (three articles) (Slack *et al.*, 1972; Karjalainen *et al.*, 1997; Scheiwe *et al.*, 2010)
- Data reported in previous article (four articles) (Scheinin, 1976; Makinen *et al.*, 1996b; Machiulskiene *et al.*, 2002; Szoke & Banoczy, 2005)
- Comparison trial with no relevant control (five articles) (Rowe *et al.*, 1974; Wilson, 1979; Alanen *et al.*, 2000a; Kovari *et al.*, 2003; Thorild *et al.*, 2006)
- Review article (five articles) (Anderson & Hujoel, 2001; Bretz, 2002; Tsao & Morgan, 2005; Bader, 2007; Edelstein, 2010)

- No relevant outcome data (three articles) (Thorild *et al.*, 2004; Haresaku *et al.*, 2007; Fontana *et al.*, 2009)
- A controlled trial evaluating the effectiveness of a school break-time policy to reduce obvious decay experience and sugar snacking, but at follow-up sugar snacking was the same in both control and intervention groups (Freeman & Oliver, 2009)
- Follow-up period less than 12 months (Milgrom *et al.*, 2009)
- Controlled trials not reporting randomisation and follow-up studies (twenty seven articles) (Gustafsson *et al.*, 1954; King *et al.*, 1955; Dunning & Hodge, 1971; Frostell *et al.*, 1974; Scheinin *et al.*, 1976; Banoczy *et al.*, 1981; Barmes *et al.*, 1985; Scheinin & Banoczy, 1985a; Scheinin & Banoczy, 1985b; Scheinin *et al.*, 1985b; Rekola, 1987; Isokangas *et al.*, 1988; Kandelman *et al.*, 1988; Isokangas *et al.*, 1989; Rekola, 1989; Kandelman & Gagnon, 1990; Isokangas *et al.*, 1991; Isogangas *et al.*, 1993; Makinen *et al.*, 1995a; Makinen *et al.*, 1995b; Makinen *et al.*, 1996a; Makinen *et al.*, 1998; Hujoel *et al.*, 1999; Isokangas *et al.*, 2000; Peng *et al.*, 2004; Honkala *et al.*, 2006; Stecksen-Blicks *et al.*, 2008)
- Preliminary results at 1 years follow-up from a trial included below with 4 years follow-up (Feldens *et al.*, 2007)

Carbohydrate and tooth wear (including dental erosion)

Prospective cohort studies

193. The initial search identified three articles. All three were eligible for inclusion.

Randomised controlled trials

194. The initial search identified 33 articles, which were assessed as full-text articles for eligibility. Of these 20 have been excluded for the following reasons:

- Controlled trials that did not report having been randomised (five articles) (Thomson, 1990; Lussi *et al.*, 1997; Honorio *et al.*, 2008; Rios *et al.*, 2008; Hannig *et al.*, 2009)
- Comparison trial with no relevant control (seven articles) (Wennerholm *et al.*, 1994; Hunter *et al.*, 2000; Attin *et al.*, 2005; Rios *et al.*, 2006; Rios *et al.*, 2009; Honorio *et al.*, 2010; Lodi *et al.*, 2010)
- Inappropriate control - a progressive loss of enamel was observed in specimens exposed to the water control, which was attributed to mechanical or chemical process or measurement error by the authors (Hunter *et al.*, 2003)
- No relevant outcome data (seven articles) (Gedalia *et al.*, 1991a; Gedalia *et al.*, 1991b; Steinberg *et al.*, 1992; Gedalia *et al.*, 1995; Cury *et al.*, 1997; Goncalves *et al.*, 2006; de Mazer Papa *et al.*, 2010)

Car*bohydrate and periodontal disease*

Prospective cohort studies

195. The initial search identified two articles, which were assessed as full-text articles for eligibility. Both of these were excluded for the following reasons:

- No relevant dietary exposure data reported (Yoshihara *et al.*, 2009)
- Data were not adjusted for tooth brushing frequency (Merchant *et al.*, 2006), although the study did adjust data for the smoking status and age

Randomised controlled trials

196. The initial search identified 13 articles and one additional article was identified from cited references. These were assessed as full-text articles for eligibility. twelve of these were excluded for the following reasons:

- Controlled trials that did not report having been randomised (four articles) (Von der Fehr *et al.*, 1970; Longhurst & Berman, 1973; Jalil *et al.*, 1983; Gaengler *et al.*, 1986)
- No relevant control (three articles) (Gazi, 1991; English *et al.*, 2004; Staab *et al.*, 2009)
- Control group not randomly assigned (Podshadley & Haley, 1968)
- Intervention less than two weeks (four articles) (Cheraskin *et al.*, 1965a; Cheraskin *et al.*, 1965b; Cheraskin *et al.*, 1966; Cheraskin *et al.*, 1967)

Carbohydrate and oral cancer

Prospective cohort studies

197. The initial search identified seven articles, which were assessed as full-text articles for eligibility. Six of these were excluded for the following reasons:

- No relevant dietary exposure data reported (three articles) (Day *et al.*, 1994; Kjaerheim *et al.*, 1998; Boeing *et al.*, 2006)
- Head and neck cancer incidence reported, but no separate analysis for oral cancer reported (George *et al.*, 2009)
- Upper aerodigestive tract cancer incidence reported, but no separate analysis for oral cancer reported (two articles) (Chyou *et al.*, 1995; Kasum *et al.*, 2002)

Randomised controlled trials

198. No articles were identified as eligible in the initial search

Appendix 3. Carbohydrate and dental caries – articles not adjusting for tooth brushing frequency

Prospective cohort study design

199. Fifteen articles were included, that had previously been excluded on the basis that they did not adjust for tooth brushing frequency (Persson *et al.*, 1985; Silver, 1987; Wilson & Ashley, 1989; Holbrook, 1993; Holbrook *et al.*, 1995; Wendt & Birkhed, 1995; Rodrigues *et al.*, 1999; MacKeown *et al.*, 2000; Petti & Hausen, 2000; Karjalainen *et al.*, 2001; Campain *et al.*, 2003; Marshall *et al.*, 2003; Pienihakkinen *et al.*, 2004; Bruno-Ambrosius *et al.*, 2005; Marshall *et al.*, 2005; Law & Seow, 2006).

200. Two articles reported on the Iowa Fluoride Study (Marshall *et al.*, 2003; Marshall *et al.*, 2005), which was also reported on by two studies already included (Levy *et al.*, 2003; Mariri *et al.*, 2003) that included a subset of subjects for which tooth brushing frequency data were available and reported on the dietary exposures sugar-sweetened beverage and soft/sports drink intake. The two articles that reported on the Iowa Fluoride Study without adjustment for tooth brushing frequency (Marshall *et al.*, 2003; Marshall *et al.*, 2005) examined dietary exposures (total and between-meal sugar-sweetened and sugar-free beverage intake and foods rich in sugars or starches) through age one to five years in relation to caries experience between four to seven years of age.

201. One study was in a cohort already included in the dental caries and carbohydrate report: participants in the Special Turku Coronary Risk Factor Intervention Project where the intervention involved dietary counselling to modify dietary fat intakes. (Karjalainen *et al.*, 2001). The study already included was conducted in a subgroup of children who were participants in the Special Turku Coronary Risk Factor Intervention Project (Ruottinen *et al.*, 2004).

202. The study design details have been summarised on the basis of whether dental caries risk was investigated in deciduous (see **Table 21**) or mixed and permanent dentition (see ***Table 22***). Two studies were conducted in America, ten in Europe and one in Africa and two in Australia. The length of follow-up ranged from one to six years. Cohort sizes ranged from 36 to 593. Dietary assessment was by a simple questionnaire in five studies; three studies used food frequency questionnaires, four studies used three to four-day food and beverage diaries and four studies used twenty four hour dietary recall interviews either alone or in conjunction with food diaries. Three studies reported that subjects were caries free at baseline (Wendt & Birkhed, 1995; Petti & Hausen, 2000; Law & Seow, 2006). The funding sources for all studies, where reported, were Governmental; 33% of studies did not report funding sources.

203. Most studies employed unadjusted bivariate statistical comparisons, but four studies employed multivariate logistic regression analysis (Rodrigues *et al.*, 1999; Petti & Hausen, 2000; Marshall *et al.*, 2003; Pienihakkinen *et al.*, 2004; Marshall *et al.*, 2005) and one employed a proportional hazards model (Campain *et al.*, 2003). The other confounders considered in these studies have been summarised in ***Table 23***.

Table 21. Prospective cohort studies of carbohydrate intake and risk of dental caries in deciduous dentition

Study	Country	Sex	Baseline age (y)	Cohort size	Mean follow-Up duration (y)	Statistical method	Fluoride intake/ water content	Caries assessment and method	Dietary assessment method/question asked	Dietary components investigated	Funding source
Persson et al., 1985	Sweden	Mixed	1	275	2	Stepwise discriminant analysis	Water 0.3mg/L	dmfs: clinical assessment	Eight-category food frequency questionnaire	26 types of foods or dishes including soft drinks, sweets, cakes	Swedish Patent Revenue Fund
Holbrook, 1993	Iceland	Mixed	4	110	1 and 2	NR	NR	dmfs; clinical assessment	Questionnaire - variables were analysed as dichotomised data	Frequency of sugar-containing food and drink intake of > 30 times a week or sweets consumption more than twice a day or sugar consumption after teeth brushing before bed	Icelandic Council of Science; Swedish Patent Revenue Fund
Holbrook et al., 1995	Iceland	Mixed	5	43	15 mth	Student's *t*-test	Water 0.04mg/l	dmfs; clinical assessment	Questionnaire comprising five multiple choice questions to determined consumption on previous working day	Frequency of sugar-containing food and drink intake and between-meal snacks	University of Iceland Research Fund; Swedish Patent Revenue Fund Mitsui Sugar Company
Wendt & Birkhed, 1995	Sweden	Mixed	1	593	2	Chi-squared and Fisher' exact test	NR	dmfs; clinical assessment and radiographs	Questionnaire - variables were analysed as dichotomised data	Infant feeding practices: breast fed (defined as for more than two months); still breast feeding at 1 year of age; sugar-containing feeding bottle consumption; and weekly frequency (less than weekly or weekly or more) of sugar containing food and drink (soft drink; fruit soup, sweets, ice cream and biscuits)	Jönköping County Council Research Fund; Swedish Patent Revenue Fund, Swedish Dental Society
Rodrigues et al., 1999	Brazil	Mixed	3	510	1	Multivariate logistic regression	NR	dmfs; clinical assessment	2 x 3-days weighted inventory at nurseries and 24-hour recall and food frequency questionnaire at home	Sugar, weight and frequency	CAPES
MacKeown et al., 2000	South Africa	Mixed	1	259	4	Correlation coefficient	NR	dmfs; clinical assessment	Semi-quantitative food frequency questionnaire	Total weight of available carbohydrate, dietary fibre and added sugar	NR
Karjalainen et al., 2001	Finland	Mixed	37 mth	135	36 mth	Students *t*-test	water 0.3 ppm	dmft; clinical assessment	4-day food diaries	Carbohydrate and sucrose intake (weight and % energy)	NR
Marshall et al., 2003; Marshall et al., 2005	USA	Mixed	6 wks	400	4.5-6.8	Multivariate logistic regression	NR	dmfs/t; clinical assessment	15 x 3-day food and beverage diaries – variables were analysed a categorical data (nonuser, low medium or high)	Total and between-meal sugar-sweetened and sugar-free beverage consumption and foods rich in sugars or starches. Food frequency defined by 30min intervals	National Dairy Council; the National Institute for Dental and Craniofacial Research; General Clinical Research Centers
Pienihakkinen et al., 2004	Finland	Mixed	2	226	3	Multivariate logistic regression	NR	dmfs; clinical assessment	Questionnaire - variables were analysed as ordinal data	Sweets consumption (once a week or less, several times a week or daily use)	NR
Law & Seow, 2006	Australia	Mixed	35 mth	28	2	ANOVA	NR	dmfs; clinical assessment	3-day diet history - variables were analysed as dichotomised data	Frequency of between meal sugar-containing snacks (sugared snack or non-sugared snack consumption; snack consumption less than 3/day or 3 or more/day)	National Health and Medical Research Council of Australia; Australian Dental Research Foundation

Decayed, missing and filled teeth (DMFT/dmft) index; decayed, missing or filled tooth surfaces (DMFS/dmfs).

Table 22. Prospective cohort studies of carbohydrate intake and risk of dental caries in mixed and permanent dentition

Study	Country	Sex	Baseline age (y)	Cohort size	Mean follow-Up duration (y)	Statistical method	Fluoride intake/ water content	Caries assessment and method	Dietary assessment method/question asked	Dietary components investigated	Funding source
Silver, 1987	England	Mixed	3	161	6	Correlation coefficient	NR	dmft/DMFT: clinical assessment	Questionnaire- variables were analysed as dichotomised data	Infant feeding practices: breast fed (defined as for more than one month) and/or sweetened or unsweetened bottle use	Hertfordshire Area Health Authority
Wilson & Ashley, 1989	England	Mixed	11-12	84	2 and 3	Correlation coefficient	NR	DMFS: clinical assessment	24 hour recall	Number of, and sugar intake from, between meal snacks containing more than 10% sugar	Medical Research Council
Petti & Hausen, 2000	Italy	Mixed	6-7	304	2	Multivariate logistic regression	NR	dmft/DMFT; clinical assessment	24 hour recall - variables were analysed as dichotomised data	Frequency of sucrose-containing between-meal snacks (less than 2/day or 2 or more /day)	NR
Campain et al., 2003	Australia	Mixed	12-13	504	2	Proportional hazards model	NR	DMFS; clinical assessment	4-day food diaries and 24 hour recall	Cluster analysis of high medium and low sugar and starch combinations	NR
Bruno-Ambrosius et al., 2005	Sweden	Female	12	162	3	Students *t*-test	NR	DMFS; clinical assessment	12 x 15 item questionnaire - variables were analysed as dichotomised data	Frequency of between meal snacks, soft drinks/fruit juice and sweets (several times a day or several times a week and less)	County Council of Halland, Sweden

Decayed, missing and filled teeth (DMFT/dmft) index; decayed, missing or filled tooth surfaces (DMFS/dmfs).

Table 23. Confounders considered in prospective studies investigating dental caries risk

Study	Age	Sex	Tooth-brushing habits	SES	Gingival bleeding	Plaque index	Fluoride intake	Parent's dental health	Baseline caries prevalence	Saliva streptococci mutans
Deciduous dentition										
Rodrigues et al., 1999	Y	Y		Y					Y	
Marshall et al., 2003; Marshall et al., 2005	Y	Y					Y			
Pienihakkinen et al., 2004					Y	Y	Y		Y	Y
Mixed and permanent dentition										
Petti & Hausen, 2000						Y*	Y**			Y
Campain et al., 2003									Y	

* plaque index considered a clinical measure of children's oral hygiene ** tablets and mouthrinses

Table 24. Results of prospective cohort studies of carbohydrate intake and risk of dental caries in deciduous dentition

Study	Dental caries assessment measure	Mean caries increment	% caries-free	% with caries	Dietary exposure	Reported association
Persson et al., 1985	Caries prevalence at age 3 years	NR	84	16	26 types of foods or dishes including soft drinks, sweets, cakes	Children with caries consumed more sucrose-rich foods than children without caries; the most discriminating variables were cakes, butter, bread and sweet soup consumption.
Holbrook, 1993	Caries prevalence at ages 5 and 6 years	NR	34 at 6 years of age	66 at 6 years of age	A frequency of sugar-containing food and drink intake of more than 30 times a week or sweets consumption more than twice a day or sugar consumption after teeth brushing before bed.	Children who had a frequency of sugar-containing food and drink intake of more than 30 times a week or sweets consumption more than twice a day or sugar consumption after teeth brushing before bed had significantly higher caries scores and lower numbers of caries-free teeth at both the one and two-year follow-ups, than children who did not
Holbrook et al., 1995	Caries prevalence at age 6 years	NR	19	81	Frequency of sugar-containing food intake and between meal snacks per day	Children with dmfs values of 3 or more had more significantly more frequent intakes of sugar-containing foods, and between meal snacks, than children with dmfs values of less than 3
Wendt & Birkhed, 1995	Caries prevalence at age 3 years	NR	73	27	Infant feeding practices: breast fed (defined as for more than two months); still breast feeding at 1 year of age; sugar-containing feeding bottle consumption and weekly frequency (less than weekly or weekly or more) of sugar containing food and drink (soft drink; fruit soup, sweets, ice cream and biscuits)	The development of caries at age 3 years was significantly higher in those children who were either breast fed (defined as for more than two months), still breast fed at 1 year of age, consumed sugar-containing feeding bottle or whose intake frequency of sugar containing food and drink (soft drink; fruit soup, sweets, ice cream and biscuits) was weekly or more.
Rodrigues et al., 1999	1-year caries increment	NR	NR	NR	Frequency and weight of sugar intake	Adjusted odds ratio 2.75 for caries increment according to weight of sugar consumption at nursery ≤ 32.66g/day compared with >32.66g/day. Adjusted odds ratio 4.29 (95CI 1.72-10.71) for caries increment according to frequency of sugar consumption at home and at nursery 5 times or more a day compared with 1-2.9 times a day
MacKeown et al., 2000	4-year caries increment	NR	37.8	62.2	Total weight of available carbohydrate, dietary fibre and added sugar	No statistically significant associations between dmfs incidence and any of the nutrient variables
Karjalainen et al., 2001	Caries prevalence (dmft ≥1)	0.94 (±1.93)	72	28	Total weight or % energy of carbohydrate and sucrose intake	In comparison with children without caries, those with caries had significantly higher sucrose intakes (weight and % energy), but carbohydrate intakes (weight and % energy) were not different between groups.
Marshall et al., 2003 Marshall et al., 2005	Caries prevalence (defined as $d_{2\text{-}3}$)	NR	74	26	Total and between-meal sugar-sweetened and sugar-free beverage consumption and foods rich in sugars or starches. Food frequency defined by 30min intervals	High soft drink consumption was significantly associated with increased caries prevalence, either when assessed as total, with meals or as between meals events. 100% fruit juice consumption was not associated with caries risk and sugared beverage intake at 2 years of age only was significantly associated with increased caries risk. High consumption of beverages with added sugar between meals was significantly associated with increased risk of caries. High snacking events, but not meals, were significantly associated with increased caries risk High sugar or starch exposure at meals was significantly associated with a reduced risk of caries, while high sugar exposure between meals was significantly associated with increased risk
Pienihakkinen et al., 2004	2-year caries increment	NR	77	23	Sweets consumption	Daily sweets consumption was significantly associated with an increased risk of developing caries
Law & Seow, 2006	Caries prevalence	NR	78	22	Frequency of between meal sugar-containing snack consumption	Children who developed caries were significantly more likely to consume sugar-containing snacks and have a daily consumption frequency of 3 or more than those who remained caries-free

OR, odds ratio; IRR, incidence rate ratio; sd, standard deviation; NR, not reported, y, year; d, day

Table 25. Results of prospective cohort studies of carbohydrate intake and risk of dental caries in mixed and permanent dentition

Study	Dental caries assessment measure	Mean caries increment	% caries-free	% with caries	Dietary exposure	Reported association
Silver, 1987	Caries prevalence at age 8-10 years	NR	NR	NR	Infant feeding practices	Children who had been breastfed only or had no sugar added to their feeds had a significantly higher proportion of caries-free permanent molars at age 8-10 years and a significantly lower proportion with dmft/DMFT ≥5 than children whose parents reported sweetened feeding bottle or comforter use during infancy.
Wilson & Ashley, 1989	2-year caries increment	3.2 (SD±3.84)	NR	NR	Number of, and sugar intake from, between meal snacks containing more than 10% sugar	2-year caries increment was significantly correlated with both the number of, and sugar intake from, between meal snacks containing more than 10% sugar.
	3-year caries increment	5.3 (SD±6.6)	NR	NR		3-year caries increment was not significantly correlated with either the number of, or sugar intake from, between meal snacks containing more than 10% sugar.
Petti & Hausen, 2000	2-year caries increment	0.68 (SD±1.16)	64	36	Frequency of sucrose-containing between-meal snacks	Frequency of sucrose-containing between-meal snacks correlated with caries increment, but was not significantly associated with caries incidence in a multiple logistic regression analysis including fluoride intake, plaque index and multiple salivary *Mutans Streptococcal* counts
Campain et al., 2003	2-year caries increment	0.98	62	38	Cluster analysis of high medium and low sugar and starch combinations	The low sugar-high starch food intake cluster was significantly associated with increased risk of caries (RR 1.23; 95% CI 1.06-1.43), but all other combinations of low, medium or high sugar and starch intakes were not associated with caries risk.
Bruno-Ambrosius et al., 2005	3-year caries increment	DMFS 2.1 (SD±3.0) DMFT 1.1 (SD±1.6)	27	73	Snacks, soft drinks/fruit juice and sweets consumption	Consuming sweets and snacks or soft drinks/fruit juices several times a day was not significantly associated with risk of developing caries

OR, odds ratio; IRR, incidence rate ratio; sd, standard deviation; NR, not reported, y, year; d, day

Results

204. The findings from all prospective cohort studies of carbohydrate intake and risk of dental caries in deciduous dentition have been summarised in ***Table 9***. The findings from all prospective cohort studies of carbohydrate intake and risk of dental caries in mixed and permanent dentition have been summarised in ***Table 25***.

Infant feeding

205. One study investigated the relationship between infant feeding practices and deciduous dentition. In infants who were caries-free at one year of age, those that developed caries by three years of age were more likely to have been either breast fed (defined as for more than two months), breast fed at one year of age, consumed a sugar-containing feeding bottle or had a frequency of intake of sugar containing food and drink (soft drink; fruit soup, sweets, ice cream and biscuits) that was weekly or more (Wendt & Birkhed, 1995).

206. One study investigated the relationship between infant feeding practices assessed at three years of age and mixed and permanent dentition. Children who had been breastfed only or had no sugar added to their feeds had a higher proportion of caries-free permanent molars at age 8-10 years and a lower proportion with dmft/DMFT ≥5 than children whose parents reported sweetened feeding bottle or comforter use during infancy (Silver, 1987). Sweetened feeding bottle or comforter use by the child was correlated with a lower proportion of caries-free permanent molars (correlation coefficient of -0.19) and a higher proportion with a high caries rate (dmft/DMFT ≥ 5; correlation coefficient of -0.22).

Sugar

207. Three studies investigated the relationship between sugar intake and deciduous dentition (Rodrigues *et al.*, 1999; MacKeown *et al.*, 2000; Karjalainen *et al.*, 2001). A study of low socioeconomic three-year old children attending nurseries in Brazil that had, or had not, adopted dietary guidelines on sugar intake, investigated the association between sugar intake and one-year dental caries increment (Rodrigues *et al.*, 1999). At baseline there was no significant difference in dental caries levels between children from nurseries adopting (mean dmfs=3.21±6.44) and not adopting (dmfs=2.75±5.39) dietary guidelines. The study reported that those children attending nurseries adopting these guidelines had significantly lower sugar intakes and caries increments than those attending nurseries not adopting sugar intake guidelines. Weighed intake inventories were performed at the nurseries and the adjusted odds ratio for caries increment according to weight of sugar intake at nursery, less than or equal to 32.66g/day compared with more than 32.66g/day, was 2.75 (95% CI I 1.29-5.85). The adjusted odds ratio for caries increment according to frequency of sugar intake at home and at the nursery, 5.0 times or more a day compared with 1.0-2.9 times a day, was 4.29 (95CI 1.72-10.71).

208. A study investigating intake of available carbohydrate, dietary fibre and added sugar in one year old children reported no significant correlation for any of the variables with four year caries increment. The general linear models analysis showed no statistically significant effects on dmfs increment of any of the nutrient variables (MacKeown *et al.*, 2000).

209. One study assessed sucrose and carbohydrate intakes in children at three years of age. In comparison with children without caries, those who with dental caries at six years of age had higher sucrose intakes (weight and % energy), but carbohydrate intakes (weight and % energy) were not different between groups (Karjalainen *et al.*, 2001). The mean sucrose intake of 3 year old children who developed caries by 6 years of age was 10.2% energy (SD±3.1), while that of caries-free children was 8.9% energy (SD±3.4).

210. Three studies investigated the relationship between sugar intake and mixed and permanent dentition (Wilson & Ashley, 1989; Petti & Hausen, 2000; Campain *et al.*, 2003). One study reported that two-year caries increment was correlated with both the number of, and sugar intake from, between meal snacks containing more than 10% sugar at eleven to twelve years of age, but that this ceased to be significant for three-year caries increment. Neither of the dietary between meal sugar variables were significantly different between low and high risk individuals, as defined as a DFS of less than 5 or 5 or more respectively (Wilson & Ashley, 1989).

211. A study of children aged six to seven years at baseline reported that while the frequency of sucrose-containing between-meal snacks (less than twice daily compared with two or more times daily) correlated with caries increment (0.13 correlation coefficient), this ceased to be significant in a multiple logistic regression analysis including fluoride intake, plaque index and multiple salivary *Mutans Streptococcal* counts (Petti & Hausen, 2000).

212. A study of children aged twelve to thirteen reported that a low sugar-high starch food intake cluster was associated with increased risk of dental caries (RR 1.23; 95% CI 1.06-1.43), but all other combinations of low, medium or high sugar and starch intakes were not associated with caries risk (Campain *et al.*, 2003). The low sugar-high starch food intake cluster was also associated with increased risk of pit and fissure surface caries (RR 1.27; 95% CI 1.09-1.47), but not smooth surface caries risk. All other combinations of low, medium or high sugar and starch intakes were not associated with risk of pit and fissure surface caries or smooth surface caries.

Sugar containing food and drink

213. Six studies investigated the relationship between the frequency of intake of sugar containing food and drink and caries risk in deciduous dentition (Persson *et al.*, 1985; Holbrook, 1993; Holbrook *et al.*, 1995; Marshall *et al.*, 2003; Pienihakkinen *et al.*, 2004; Marshall *et al.*, 2005; Law & Seow, 2006). A study of children aged one at baseline reported that those children with caries at three years of age consumed more sucrose-rich foods than children without caries. The most discriminating variables between those children with and without dental caries were cakes, butter, bread and sweet soup intake.

214. Children who had a frequency of sugar-containing food and drink intake of more than 30 times a week or sweets intake of twice a day or sugar intake after teeth brushing before bed at age four had higher caries scores and lower numbers of caries-free teeth at both the one and two-year follow-ups, than children who had lower intake frequencies (Holbrook, 1993).

215. Another study in Iceland reported that children who developed three or more carious lesions (including initial caries) after 15 months had higher initial intake frequencies, at age five, of sugar-containing foods (5.1/day compared with 2.1/day) and more between meal snacks (4.5/day compared with 1.4/day) than those children who developed less than three carious lesions (Holbrook *et al.*, 1995).

216. Two articles reported on the Iowa Fluoride Study (Marshall *et al.*, 2003; Marshall *et al.*, 2005). High soft drink consumption (at ages one through to five) was associated with increased caries prevalence, either when assessed as total (OR 3.8; 95% CI 1.7-8.5), with meals (OR 3.2; 95% CI 1.5-7.1) or as between meal events (OR 2.5; 95% CI 1.2-5.1). One hundred percent fruit juice consumption was not associated with caries risk and sugar-containing beverage intake at two years of age only was significantly associated with increased caries risk. High between meal consumption of beverages with added sugar (at ages one through to five) was associated with increased risk of caries (OR 3.6; 95% CI 1.5-8.7). High total snacking events, but not meals, were associated with increased caries risk (OR 2.2; 95% CI 1.0-4.9). High sugar or starch exposure at meals was associated with a reduced risk of caries (OR 0.4; 95% CI 0.2-0.8 and OR 0.5; 95% CI 0.2-1.0 respectively), while high sugar exposure between meals was associated with increased risk (OR 2.8; 95% CI 1.2-6.7).

217. In preschool children aged two, daily sweets consumption, compared with once a week or less or several times a week, was associated with an increased risk of developing caries at age five (OR 3.6; 95% CI 1.5-8.7) (Pienihakkinen *et al.*, 2004).

218. A small study of children initially caries-free, reported that those children who developed caries (n=8) were more likely to consume sugar-containing snacks, have a daily consumption frequency of three or more and brush their teeth less often than those children who remained caries-free (n=27) (Law & Seow, 2006).

219. One study investigated sweets and snack consumption in relation to mixed and permanent dentition. In adolescent girls, consuming sweets and snacks several times a day (unadjusted OR 5.5; 95% CI 0.7-46.1) or soft drinks/fruit juices (unadjusted OR 1.2; 95% CI 0.5-2.9) several times a day were not significantly associated with risk of developing caries in permanent teeth at age 15 (Bruno-Ambrosius *et al.*, 2005).

Summary

220. A limitation with the studies considered in this appendix was that most only performed bivariate analyses (some only t-tests). Most of the multivariate analyses performed in studies that did adjust for toothbrushing frequency (see the Carbohydrate and dental caries report section) observed that factors reported as significant in univariate or bivariate analyses often failed to reach significant in multivariate analyses that adjusted for other factors.

Infant feeding

221. Available evidence was limited to two studies: one in relation to deciduous dentition and the other in relation to mixed and permanent dentition. The evidence was inconsistent and insufficient to allow firm conclusions.

Sugar

222. Three studies investigated the relationship between sugar intake and deciduous dentition. Two of which observed that higher sugar intake was weakly associated with increased caries risk, while the other observed no association.

223. Three studies investigated the relationship between sugar intake and mixed and permanent dentition. These studies mainly reported little or no association between sugar intake and caries risk.

Sugar containing food and drink

224. Six studies investigated the relationship between the frequency of intake of sugar containing food and drinks and caries risk in deciduous dentition. All of these reported that higher frequencies of sugar containing foods or drinks were associated with increased caries risk. The one study that investigated the frequency of sweets and snack consumption in relation to mixed and permanent dentition reported no significant association.

Appendix 4. Controlled trials that did not report having been randomised investigating digestible carbohydrate intake in relation to dental caries risk

225. Five articles were identified as relevant (Gustafsson *et al.*, 1954; King *et al.*, 1955; Dunning & Hodge, 1971; Frostell *et al.*, 1974; Scheinin *et al.*, 1976). A summary of the trial designs has been given in **Table 26**. Four of the trials investigated dental caries risk in mixed and permanent dentition and one in deciduous dentition, in relation to dietary exposures. Three trials supplemented subjects with sucrose and two substituted sucrose with polyol. All trials employed a parallel design.

226. A trial was conducted in patients resident in a mental health institution in Sweden, where the commonest types of mental disease were described as idiocy and imbecility (Gustafsson *et al.*, 1954). Saliva stimulation with paraffin was possible in only 40% of patients and the proportion of patients in each experimental group in whom saliva stimulation was possible appeared fairly even. Eighty two of the 436 patents had their teeth brushed regularly; these patients were mainly female and were concentrated in two experimental groups: those receiving sugar enriched bread and those receiving 24 toffees daily. The trial was conducted between 1947 and 1951. Until 1950, the routine dental treatment that patients received mainly consisted of tooth extraction with most of the cavities being left untreated; from 1950, cavities were filled at as part of any dental treatment. The trial was conducted in two phases each lasting two years. During the first phase patients received vitamin supplements as well as the different carbohydrate supplements. During the first phase patients received sucrose in amounts equivalent to twice the national average intake and in the second phase this was approximately the same as the national average intake. The control group was the same throughout both phases and received saccharine in place of added sucrose in the first phase resulting in an intake of sucrose of one gram per day. The control diet in the first phase was low in all carbohydrates (130g/day) and patients received 150g margarine per day to provide sufficient dietary energy. In the second phase the control group received 70g/day added sucrose (total carbohydrate 370g/day) and 40g/day margarine, which was described as being roughly representative of the average national dietary composition.

227. The experimental diets supplemented the control diet used in each phase (with the exclusion of the margarine) with carbohydrate in different forms. Sugar, mainly sucrose, was added to foods and drinks either at meals or in-between meals in the form of sweets and either in a food form more, or less ,likely to be retained on the teeth. In the first phase patients received sweets after breakfast and lunch in two halves, while in the second phase a quarter of the allocated sweets were given four times a day at least an hour before or after meals or snacks. The number of patients assigned to each group ranged from 39 to 62. Morbidity due to tuberculosis decreased throughout the trial and there was also a tendency for mortality due to tuberculosis to decrease.

228. One article reported on two trials in children residing in foster homes in London, Liverpool and Sheffield (King *et al.*, 1955). A trial in London was conducted in children aged two to four years of age and a trial in Sheffield and Liverpool was conducted in children aged four to fourteen years of age. The experimental groups received an additional 89g/day sugar compared with the control group, which was added to the children's meals and drinks (tea and cocoa). Most of the children dropped out from the London trial before two years duration (n=391 at one year and 82 at two years), mainly due to adoption, so only the results after the first year have been included. This also affected the Sheffield and Liverpool trials, which had a duration of 18 and 24 months, respectively, but a policy of 'boarding out' the children resulted in large numbers of dropouts after the first year, so only the results after the first year have been included.

229. A trial in the USA in school-based mental health facility investigated the effect of supplementation for two years with 1 pint/day chocolate flavoured milk formula sweetened with sugar (approximately 30g/day), relative to a whole milk control group and a saccharine sweetened control milk. It was not reported when the milk was consumed. The patients were not supervised to ensure they received the designated 1 pint/day, but it was stated that approximately three out of four did so. Attendants were unavailable to brush the teeth of the patients on a regular basis (Dunning & Hodge, 1971).

230. A trial in Sweden in preschool children aimed to assess the effect of the substitution of sucrose-containing sweets for polyol-containing sweets (sweetened with a mixture of polyols) on caries incidence over two years (Frostell *et al.*, 1974). Parents were instructed to purchase sweets, sugar and polyol containing, in participating shops. This was monitored using a coupon system and while this was sufficient to assess compliance to the allocated intervention, it was insufficient to determine the amount of sweets consumed by individual children. Also, sweets bought for children in other stores not participating in the investigation was only registered by about half of parents. An issue with regard to compliance was the lack of variety in the polyol-containing sweets and the assortment of sweets had to be changed at intervals. Separate analyses were performed for all children and those children whose parents had purchased the products regularly and shown good co-operation during the whole experimental period.

231. A trial in adolescents and adults in Finland almost completely substituted dietary sucrose with either fructose or a polyol, xylitol, for two years and investigated the effect on mean DMFS increment (Scheinin *et al.*, 1976). The subjects were provided with an assortment of foodstuffs sweetened with either sucrose, fructose or xylitol. Using distribution and control systems, the subjects were handled and controlled so that an almost comparable consumption of the products was achieved throughout the trial. The mean individual monthly intake of sucrose, fructose and xylitol was 2.2, 2.1 and 1.5 kg, respectively (which equates to 72, 69 and 49g/day, respectively). The highest daily amounts of sucrose, fructose and xylitol per person varied between 200–400 g. The cooperation of the subjects completing the study in the fructose or xylitol groups was 97 %, expressed as the intake frequency of the correct sugar (Makinen & Scheinin, 1976).

232. Only one trial reported its funding source, which was Governmental; 80% of trials did not report funding sources.

Table 26. Trial design

Study	Trial design	Country	Fluoride	Age (y)	Subject characteristics	Caries assessment and method	Duration (y)	Cohort size	Dietary assessment method or compliance determination	Intervention	Control intervention	Funding source
Gustafsson et al., 1954	Parallel and XO – 1 month washout	Sweden	water 0.4ppm	mean 31.9	Institutionalised mental health patients	DMFS/DMFT; clinical assessment and radiograph	2	436	All foods provided to patients and consumption monitored	Phase 1 300g/day sucrose at meals in food and drinks; 345g/day sucrose in bread at one meal; 70g/day sugar in caramel sweets between meals and 200g/day sucrose solution; 60g/day sugar in toffees between meals and 200g/day sucrose solution; 120g/day sugar in toffees between meals and 150/day sucrose solution.	Low carbohydrate basal diet 130g/day carbohydrate; no added sucrose; 140g/day margarine	NR
							2	436		Phase 2 75g/day sucrose at meals in drinks; 345g/day sucrose in breads consumed at all meals; 30g/day sugar in chocolate 4 times between meals; 75g/day sugar in caramel sweets between meals; 75g/day sugar in toffees between meals;	Basal diet 270g/day carbohydrate; 70g/day added sucrose; 75g/day margarine	
King et al., 1955	Parallel	England	NR	2-14	Institutionalised children	dmfs/DMFS of molars; clinical assessment	1	391 aged 2-4; 371 aged 4-14;	All foods provided to subjects and consumption monitored	89g/day sucrose in meals and drinks	No additional sucrose	NR
Dunning & Hodge, 1971	Parallel	USA	NR	9-25	Children and young people in a school-based mental health facility	dmfs/DMFS; clinical assessment	2	430	All foods provided to patients	1 pint /day Chocolate flavoured milk formula with sugar (approximately 30g/day)	1 pint/day Chocolate flavoured milk formula sweetened with saccharine or whole milk	NR
Frostell et al., 1974	Parallel	Sweden	water 0.2ppm	3-6	Preschool children	dmfs/dmft; clinical assessment and radiograph	2	225	All food purchases registered and a random sample evaluated by questionnaire	polyol-containing sweets (no dose reported)	sucrose-containing sweets (no dose reported)	Swedish Medical Council and Patent Resources Fund For Odontologic Prophylaxis Research
Scheinin et al., 1976	Parallel	Finland	NR	mean 27.5	Adolescents and adults	DMFS; clinical examination and radiograph	2	125	All foods provided to subjects and consumption monitored	Polyol (xylitol; 49g/day) or fructose (69g/day) sweetened foods	Sucrose (72g/day) sweetened foods	NR

NR, not reported; XO, cross-over.

Risk of bias assessment

233. A summary of the risk of bias assessment has been given in **Table 27**.

Table 27. Risk of bias assessment

Study	Randomisation	Sequence generation	Allocation concealment	Blinding	Incomplete outcome data	Dropouts (%)
Gustafsson et al., 1954	No	-	-	Open	Missing outcome data unlikely to be related to outcome	31
King et al., 1955	No	-	-	Open	Missing outcome data unlikely to be related to outcome	Unclear
Dunning & Hodge, 1971	No	-	-	Open to participants and personnel, but assessors blind	Missing outcome data unlikely to be related to outcome	Unclear
Frostell et al., 1974	No	-	-	Open to participants and personnel, but assessors blind	Missing outcome data unlikely to be related to outcome	50
Scheinin et al., 1976	No	-	-	Open to participants and personnel, but assessors blind	Missing outcome data unlikely to be related to outcome	8

234. None of the trials reported being randomised, so there was no sequence generation or allocation concealment. Due to the nature of the interventions all trials were open, but three reported that the dental assessors were unaware of the group or product allocations. In the three trials in institutionalised subjects the different treatments were prospectively allocated to different dormitories, homes or institutions (Gustafsson *et al.*, 1954; King *et al.*, 1955; Dunning & Hodge, 1971). A trial in adolescents and adults prospectively divided subjects partly on individual preference into the three experimental groups, with a view that this would improve compliance (Scheinin *et al.*, 1976). The trial in preschool children did not report on how the children were allocated to the experimental groups (Frostell *et al.*, 1974).

235. For two trials it was not possible to calculate the proportion of dropouts as the numbers entering the trials were not reported, although the reasons for dropping out were discussed and the proportion of dropouts later in the trials were relatively high (King *et al.*, 1955; Dunning & Hodge, 1971). In two other trials there was a high proportion of dropouts over two years, 31-50% (Gustafsson *et al.*, 1954; Frostell *et al.*, 1974), while in one other trial the proportion was relatively low over two years, 8% (Scheinin *et al.*, 1976).

236. Overall, the risk of bias appeared relatively high for these trials.

Results

237. The findings from all trials of carbohydrate intake and risk of dental caries have been summarised in **Table 28**. Many of the articles did not report variance data.

Table 28. Results

Study	Caries determinant	Intervention description	Intervention	Control	Adjustments	Results
Gustafsson et al., 1954 Phase 1	Number of new carious surfaces/person/year including non-cavitated lesions	300g/day sucrose at meals in food and drinks	0.43	0.27		The intervention had no significant effect on caries incidence
		345g/day sucrose in bread at one meal	0.32			The intervention had no significant effect on caries incidence
		70g/day sugar in caramel sweets between meals and 200g/day sucrose solution	1.92			The intervention had a significant increase in caries incidence
		60g/day sugar in toffees between meals and 200g/day sucrose solution	3.03			The intervention had a significant increase in caries incidence
		120g/day sugar in toffees between meals and 150/day sucrose solution	4.02			The intervention had a significant increase in caries incidence
Gustafsson et al., 1954 Phase 2		75g/day sucrose at meals in drinks	0.74	0.50		The intervention had no significant effect on caries incidence
		345g/day sucrose in breads consumed at all meals	1.30			The intervention had a significant increase in caries incidence
		30g/day sugar in chocolate s between meals	1.17			The intervention had a significant increase in caries incidence
		75g/day sugar in caramel sweets between meals	3.02			The intervention had a significant increase in caries incidence
		75g/day sugar in toffees between meals	3.18			The intervention had a significant increase in caries incidence
King et al., 1955	Percentage of new carious surfaces/year including non-cavitated lesions	89g/day sucrose added to meals and drinks	4.2	3.9		The intervention had no significant effect on caries incidence in children aged 2-4 years
	Percentage of new carious surfaces on deciduous molars/year including non-cavitated lesions	89g/day sucrose added to meals and drinks	6.3	4.3 aged 4-6		The intervention had no significant effect on caries incidence in children aged 4-10 years
			3.6	7.4 aged 7-10		
	Percentage of new carious surfaces on permanent molars/year including non-cavitated lesions	89g/day sucrose added to meals and drinks	29.0	18.8 aged 7-10		The intervention had no overall significant effect on caries incidence in children aged 7-14 years
			24.3	20.0 aged 11-14		
Dunning & Hodge, 1971	Mean 2-year surface caries increment including non-cavitated lesions	473ml/day Chocolate flavoured milk formula with sugar (approximately 30g/day)	6.63	5.26	age, past dental caries experience and number of teeth at risk.	The intervention caused a significant increase in caries incidence
Frostell et al., 1974	Mean 2-year dmfs increment including non-cavitated lesions	Partial substitution of sucrose-containing sweets for polyol-containing sweets	5.97 (SD 5.36)	6.95 (SD 7.28)		The intervention had no significant effect on caries incidence
Scheinin et al., 1976	Mean 2-year DMFS increment excluding non-cavitated lesions	Almost complete substitution of dietary sucrose for polyol	0.0 (SD 5.4)	7.2 (SD 5.7)		The intervention caused a significant decrease in caries incidence
		Almost complete substitution of dietary sucrose for fructose	3.8 (SD 4.1)			The intervention caused a significant decrease in caries incidence

SD, standard deviation.

238. In a trial conducted in patients resident in a mental health institution in Sweden, the effect of the amount, frequency and form of dietary sugar on two year caries increment, including non-cavitated lesions, was investigated (Gustafsson *et al.*, 1954). The trial was conducted in two two-year phases. When the data were analysed as time series data it was observed that the phase one control diet, in with nearly all added sucrose was removed and contained 30g/day sugars, reduced caries incidence to almost nil, and that caries incidence subsequently increased on the phase 2 control diet, which was representative of the average national diet composition and contained 70g/day added sucrose.

239. Analysis between groups of caries incidence during the intervention periods revealed that when sugar was consumed with the meal and in a form regarded as having a low tendency to be retained on the tooth surface there was no statistical difference between groups and their respective control group. In phase one these groups included 300g/day sucrose at meals in food and drinks and 345g/day sucrose in bread at one meal and in phase two the 75g/day sucrose at meals in drinks.

240. When sucrose was consumed in a form regarded as having a high tendency to be retained on the tooth surface, as in the phase two group 345g/day sucrose in breads consumed at all meals, there was a significant increase relative to the respective control group in the caries incidence. This was generally observed to be of a greater extent when the sugar was consumed between meals also: in phase one these groups included 70g/day sugar in caramel sweets between meals and 200g/day sucrose solution, 60g/day sugar in toffees between meals and 200g/day sucrose solution and 120g/day sugar in toffees between meals and 150/day sucrose solution. In phase two these groups included 30g/day sugar in chocolate s between meals, 75g/day sugar in caramel sweets between meals and 75g/day sugar in toffees between meals.

241. Overall, large amounts of sugar eaten at meal time and in a form regarded as having a low tendency to be retained on the tooth surface had little effect on caries incidence, while much smaller amounts of sugar eaten between meals in a form having a high tendency to be retained on the tooth surface were sufficient to increase caries incidence.

242. In children living in residential homes in England aged two to four years who received an additional 89g/day sucrose added to their meals and drinks, there was no difference in the percentage of non-carious teeth which developed caries over one year or the percentage of carious teeth as compared with the control group (King *et al.*, 1955). In children aged four to fourteen who received an additional 89g/day sucrose added to their meals and drinks, there was no difference in the percentage of new carious surfaces on deciduous or permanent molars as compared with the control group, except for children aged seven to ten years where the percentage was higher in the sugar group. Overall, the addition of 89g/day sucrose for one year to children's diets resulted in no effect on the initiation or progression of carious lesions in deciduous or permanent dentition.

243. A trial in a school-based mental health facility in the USA observed supplementation for two years with 1 pint/day chocolate flavoured milk formula sweetened with sugar (approximately 30g/day), relative to a whole milk control to have no effect on two-year caries increment, including non-cavitated lesions (Dunning & Hodge, 1971). When the group receiving 1 pint/day chocolate flavoured milk formula sweetened with sugar were compared to a saccharine sweetened control milk in another institution, a small increase in net caries increment over two years was observed ($P<0.05$).

244. A trial in preschool children in Sweden aimed to assess the effect of the substitution of sucrose-containing sweets for polyol-containing sweets on caries incidence over two years (Frostell *et al.*, 1974). The substitution of sucrose-containing sweets with polyol-containing sweets was only partial, as parents reported that children in the polyol group also consumed sweets containing sucrose (Frostell *et al.*, 1974). The proportion of polyol-containing sweets consumed in the polyol group ranged from 50 to 75%. There was no difference in the mean two-year dmft and dmfs increments, including or excluding non-cavitated lesions, between the polyol and sucrose groups. An analysis was also performed for those children whose parents had purchased the products regularly and shown good co-operation during the whole experimental period, but there were no significant differences between groups in caries increment. In a subgroup analysis of children with three or less carious surfaces at the beginning of the trial, the mean 2-year dmft, but not dmfs, increment, excluding non-cavitated lesions, was lower in the polyol group (dmft 2.13) than the sucrose group (dmft 3.11; $P<0.05$).

245. A trial in adolescents and adults in Finland almost completely substituted dietary sucrose with either fructose or a polyol, xylitol, for two years and investigated the effect on mean dental caries increment, excluding non-cavitated lesions (Scheinin *et al.*, 1976). Substitution of sucrose with xylitol reduced the two year caries increment relative to both the sucrose and fructose substitution groups ($P < 0.005$), while substitution of sucrose with fructose also resulted in a reduced caries increment relative to the sucrose group ($P<0.05$). When radiological assessments, new secondary caries reversals and increases in sizes of lesions were included in the assessment the same pattern of results was observed.

Summary

246. The removal or substitution of sucrose from the diet appeared to have resulted in a reduction in dental caries increment. The addition of sucrose to the diet at mealtime, e.g. in food or drinks, appeared to have little impact on dental caries increment. One trial in mental health patients receiving little, if any, oral hygiene suggested that consumption of sucrose in a form regarded as having a high tendency to be retained on the tooth surface resulted in increased caries incidence. This trial also suggested that consumption of sucrose containing foods between meals, especially in a form regarded as having a high tendency to be retained on the tooth surface, resulted in increased caries incidence.

Appendix 5. Dietary acids and tooth wear (including dental erosion)

Introduction

247. Teeth wear in function, as a consequence there would be an expected increase in wear with increasing age of the individual. There are also some intrinsic and extrinsic variables, however, that increase the rate of tooth wear. These can act as individual factors but most likely act in combination during any wear process.

248. There are three types of wear described in the dental literature.

249. Abrasion, in which tooth substance is removed by the abrasive action of an external substance or device, for example a "smoker's toothpaste" or incorrect use of interdental cleaning aids.

250. Attrition in which tooth substance is removed as a consequence of teeth rubbing together in contact, effectively polishing each other, but when combined with a clenching or tooth grinding habit this can result in rapid destruction of teeth.

251. Erosion in which tooth substance is removed as a consequence of its dissolution by acids from either foods or regurgitated gastric content. This type of wear is different to caries because the acids are not generated in the mouth and it occurs at lower pH than the caries process (typically pH of less than 3 compared with 5.5 or 6 for enamel and dentine respectively for caries). As a consequence of the more aggressive acid attack, the sub-surface demineralisation that characterises dental caries does not occur, rather the tooth surface simply dissolves. The dissolution of mineral from either enamel or dentine results in a residual softened surface that can then be worn away much more rapidly by attrition from tooth-to-tooth contact or by contact with the lips, cheeks and tongue or by toothbrushing, or by hard fibrous foods during chewing. In terms of the study of wear this process would more accurately be described as corrosion, but is universally described as erosion in the dental literature.

252. Dental erosion is a multi-factorial condition in which an interplay between chemical (e.g. food acidity and its calcium, phosphorus and fluoride content), biological (e.g. salivary flow, buffering capacity and acquired pellicle) and behavioural factors (e.g. oral hygiene and eating and drinking habits) underlies large inter-individual variation (Lussi & Jaeggi, 2008).

253. The patterns of wear produced by these three different mechanisms have some characteristic features, so for example when wear occurs on a surface of a tooth that cannot be in contact with another, it can't be produced by attrition. So some attribution of ear mechanisms can be made based on appearance of the teeth. These will tend to be more accurate in younger people where a "pure" mechanism may have been acting for a short period of time. In adults this linkage is much more difficult to make as a single observation will show the outcomes of a lifetimes function and wear.

254. The Children's Dental Health series of national surveys of oral health reported the prevalence of tooth wear (including dental erosion) in 1993 and 2003. A comparison between the two Children's Dental Health surveys of 1993 and 2003 observed that there has been little change in the proportion of five-year-olds with tooth wear: 52% in 1993 and 53% in 2003. There was, however, an increase in the prevalence of tooth wear on permanent teeth, which was statistically significant at age 15 where 27% upper incisors had tooth wear palatally in 1993 compared to 33% in 2003 (Chadwick *et al.*, 2006).

255. The national surveys of Adult Dental Health reported the prevalence of tooth wear (including dental erosion) in 1998 and 2009 (Steele & O' Sullivan, 2011); the 2009 survey included data from England, Wales and Northern Ireland, but not Scotland. The prevalence of tooth wear in England has increased since the 1998 survey, when two thirds (66%) of the dentate population showed signs of wear compared with over three quarters (76%) in the 2009 survey. There have also been small increases in the proportion of adults with moderate wear, 11 per cent in 1998 compared with 15 per cent in 2009. The greatest increase was in the youngest three age groups; 15 percentage points, 10 percentage points and 13 percentage points for those aged 16 to 24, 25 to 34 and 35 to 44 years, respectively. For adults under the age of 65 moderate and severe tooth wear has increased since 1998, but for those aged 65 and over, there has been a small decrease. While the increase in moderate tooth wear was small, moderate tooth wear in 16 to 34 year olds was suggestive of rapid tooth wear.

256. The study designs for all prospective cohort studies have been considered in the first section, while the study designs for all randomised controlled trials have been considered in the following section. The results from both prospective cohort studies and randomised controlled trials have been considered together for each dietary exposure.

Prospective cohort studies

257. The initial search identified three articles, which were assessed as full-text articles. All three were eligible for inclusion (Lussi & Schaffner, 2000; Dugmore & Rock, 2004; El Aidi *et al.*, 2011).

Prospective cohort study design

258. The study design details have been summarised in ***Table 29***. All studies investigated tooth wear in mixed and permanent dentition. In one study (Lussi & Schaffner, 2000) the tooth wear indices (facial, oral and occlusal surfaces) were based upon diagnostic criteria used in a previous study (Lussi *et al.*, 1991). Another study assessed tooth wear using the criteria used in 1993 survey of Children's Dental Health (Dugmore & Rock, 2004): a Tooth Wear Index that recorded all three main types of tooth wear irrespective of aetiology (Smith & Knight, 1984). For the third study (El Aidi *et al.*, 2011) the criteria for the clinical assessment of tooth wear were a modification (van Rijkom *et al.*, 2002) of diagnostic criteria developed previously (Lussi, 1996).

259. Cohort sizes ranged from 55 to 1149 and the follow-up period ranged from two to six years. Dietary assessment was by a simple questionnaire in two studies and by food frequency questionnaire in the other (El Aidi *et al.*, 2011). All studies investigated consumption of acidic foods and drinks in relation to tooth wear. Multivariate logistic regression analysis was used in all studies to explore associations. The confounders considered by the studies investigating carbohydrate and dental caries risk have been summarised in ***Table 30***. Only one study reported its funding sources which were mainly commercial (El Aidi *et al.*, 2011); 67% of studies did not report funding sources.

Table 29. Prospective cohort studies of acidic food and drink intake and risk of dental erosion

Study	Country	Sex	Baseline age (y)	Cohort size	Mean follow-Up duration (y)	Statistical method	Fluoride intake / water content	Dental erosion assessment and method	Dietary assessment method	Dietary components investigated/question asked	Funding source
Lussi & Schaffner, 2000	Switzerland	Mixed	26-50	55	6	MLR	NR	Tooth wear; clinical assessment	Questionnaire	Consumption of fruits, citrus fruits, fruit juice, apple juice, vegetables and yoghurt	NR
Dugmore & Rock, 2004	England	Mixed	12	1149	2	MLR	NR	Tooth Wear Index; clinical assessment	Questionnaire	Consumption of apples, oranges or grapefruit, other fruit, chips with vinegar or tomato sauce, chocolate or sweets (yes or no) Daily frequency of glasses/cans of the water, milk, tea/coffee, chocolate, squash, fruit juice or carbonated soft drink.	NR
El Aidi et al., 2011	The Netherlands	Mixed	mean 11.9	572	3	MLR	NR	Tooth wear; clinical assessment	Food frequency questionnaire every 6 months	Consumption on the previous day of acidic drinks, water, tea, dairy products, yoghurt products, milk products, acidic fruit and non-acidic fruit, sour vegetables, pickled vegetables, cheese, chewing gum, red sauces, curry, chilli sauce and white/yellow sauces	Radboud University Nijmegen, the Dutch Dairy Association, Dutch Sugar Bureau and Dutch Soft Drinks Association

MLR, multivariate logistic regression; mth, month; y, year.

Table 30. Confounders considered in prospective studies investigating acidic food and drink intake and dental erosion risk

Study	Age	Sex	Tooth-brushing habits	SES	Gingival index	Plaque index	Calculus	Fluoride intake	Baseline caries prevalence	Ethnicity
Lussi & Schaffner, 2000	Y		Y							
Dugmore & Rock, 2004			Y	Y	Y	Y	Y		Y	Y
El Aidi et al., 2011			Y			Y				

Randomised controlled trials

260. Thirteen articles were identified as eligible (see Appendix 2 for studies excluded) (Rugg-Gunn *et al.*, 1998; West *et al.*, 1998; Hughes *et al.*, 1999b; Hughes *et al.*, 1999a; West *et al.*, 1999; Hughes *et al.*, 2002; West *et al.*, 2003; Hooper *et al.*, 2004; West *et al.*, 2004; Hooper *et al.*, 2005; Venables *et al.*, 2005; Hooper *et al.*, 2007; Caglar *et al.*, 2008).

Randomised controlled trial design

261. A summary of the trial designs has been given for those trials investigating tooth wear in relation to soft drinks and fruit juices (see ***Table 31***). All trials had an *in situ* design whereby assessment of enamel or dentine blocks contained within intra-oral appliance was investigated. The wear was determined by surface profilometry.

262. The enamel or dentine blocks were exposed to dietary factors by either applying solutions ex vivo, once the intra-oral appliances were removed and then replacing them afterwards, or by exposing dental blocks to dietary factors *in vivo,* e.g. eating food or consuming drinks while the intra-oral appliance was being worn. In the trial where solutions were dipped onto the dental blocks, subjects were instructed to remove the intra-oral palatal appliances during meals.

263. All trials were cross-over in design with either no washout period or a washout period ranging from two days to one week. The experimental period ranged from seven to twenty one days. The funding sources were mainly commercial, reflecting product modifications to reduce the erosive potential of soft drinks.

264. One of the trials used a split-mouth intra-oral palatal appliance where the blocks on each side of the mouth were exposed to different test solutions (Rugg-Gunn *et al.*, 1998).

265. In a series of trials by the same authors investigating the effect of fruit juices and soft drinks on dental erosion (see ***Table 31***), intra-oral appliances were worn between 9am and 5pm and removed for one hour over lunch (West *et al.*, 1998; Hughes *et al.*, 1999b; Hughes *et al.*, 1999a; West *et al.*, 1999; Hughes *et al.*, 2002; West *et al.*, 2003; Hooper *et al.*, 2004; West *et al.*, 2004; Hooper *et al.*, 2005; Hooper *et al.*, 2007). In another trial, investigating the effect of a malt-based drink on dental erosion, intra-oral appliances were worn between 9am and 4pm and removed for one hour over lunch (Caglar *et al.*, 2008). In one trial investigating the effect of sport drink consumption on enamel loss when subjects participated in planned exercise, the intra-oral appliances were worn during the exercise period between 7:00am and 9:10am (Venables *et al.*, 2005).

266. Most of the trials investigated the effect of modifying soft drinks, by the addition of calcium compounds, to reduce their erosive potential, but this aspect has not been included in the review (Rugg-Gunn *et al.*, 1998; Hughes *et al.*, 1999b; Hughes *et al.*, 1999a; West *et al.*, 1999; Hughes *et al.*, 2002; Hunter *et al.*, 2003; West *et al.*, 2003; Hooper *et al.*, 2004; West *et al.*, 2004; Hooper *et al.*, 2005; Venables *et al.*, 2005; Hooper *et al.*, 2007). Several trials investigated the effect of juice drinks artificially sweetened with aspartame, acesulfame K and saccharin.

Table 31. Soft drink and fruit juice trial design

Study	Trial design	Country	Fluoride	Age (y)	Subject characteristics	Dental erosion method and exposure time	Duration (d)	Dietary assessment method	Basal diet	Intervention	Control intervention	Funding source
Rugg-Gunn et al., 1998	XO – no washout	England	NR	NR	11 adults	Bovine permanent incisor enamel mouth palatal appliances analysed by profilometer and scanning electron microscopy	7	NR	No restrictions – volunteers asked to maintain similar eating and drinking patterns during experimental periods	Dental blocks dipped with either artificially sweetened phosphoric acid-based cola drink or artificially sweetened citric acid-based orange drink for 15 minutes 4 times/d	Dental blocks dipped with distilled water 4 times/d	Proctor and Gamble Ltd.
West et al., 1998	XO – 1 wk washout	England	No tooth brushing allowed when appliance *in situ*	mean 24, range 20-30	10 adults	Human third molar teeth enamel in palatal appliances analysed by profilometer and surface microhardness	15	Compliance questionnaire completed each study day	Only tea, coffee or water could be consumed while the appliances were *in situ*	250ml orange juice 4 times/d	250ml mineral water 4 times/d	Smith-Kline Beecham Consumer Healthcare
Hughes et al., 1999a	XO – 2 ½ d washout	England	No tooth brushing allowed when appliance *in situ*	mean 28, range 20-34	12 adults	Human third molar teeth enamel in palatal appliances analysed by profilometer	15	Compliance questionnaire completed each study day	Only tea, coffee or water could be consumed while the appliances were *in situ*	250ml orange juice 4 times/d	250ml mineral water 4 times/d	Smith-Kline Beecham Consumer Healthcare
Hughes et al., 1999b	XO – 2 d washout	England	No tooth brushing allowed when appliance *in situ*	NR	15 adults	Human third molar teeth enamel in palatal appliances analysed by profilometer	15	Compliance questionnaire completed each study day	Only tea, coffee or water could be consumed while the appliances were *in situ*	250ml artificially sweetened orange drink or artificially sweetened apple and blackcurrant juice drink 4 times/d	250ml mineral water 4 times/d	Smith-Kline Beecham Consumer Healthcare
West et al., 1999	XO – no washout	England	No tooth brushing allowed when appliance *in situ*	mean 27, range 20-39	12 adults	Human third molar teeth enamel in palatal appliances analysed by profilometer	15	Compliance questionnaire completed each study day	Only tea, coffee or water could be consumed while the appliances were *in situ*	250ml orange juice or blackcurrant juice drink 4 times/d	250ml mineral water 4 times/d	Smith-Kline Beecham Consumer Healthcare
Hughes et al., 2002	XO – 2 d washout	England	No tooth brushing allowed when appliance *in situ*	mean 29, range 22-42	12 adults	Human third molar teeth enamel in palatal appliances analysed by profilometer and ultrasonication	10	Compliance questionnaire completed each study day, drinks were sipped under supervision	Only tea, coffee or water could be consumed while the appliances were *in situ*	250ml orange juice 4 times/d	250ml mineral water 4 times/d	GlaxoSmithKline Consumer Healthcare
West et al., 2003	XO – 2 d weekend washout	England	No tooth brushing allowed when appliance *in situ*	median 32, range 17-56	15 adults	Human third molar teeth enamel in palatal appliances analysed by profilometer	20	Compliance questionnaire completed each study day	Only tea, coffee or water could be consumed while the appliances were *in situ*	250ml artificially sweetened carbonated orange juice drink 4 times/d	250ml mineral water 4 times/d	GlaxoSmithKline Consumer Healthcare
Hooper et al., 2004	XO – no washout	England	No tooth brushing allowed when appliance *in situ*	Mean 33	21 adults	Human third molar teeth enamel in palatal appliances analysed by profilometer	15	Compliance questionnaire completed each study day	Only tea, coffee or water could be consumed while the appliances were *in situ*	250ml sugar sweetened citric acid-based sports drink 4 times/d	250ml mineral water 4 times/d	GlaxoSmithKline Consumer Healthcare

NR, not reported; y, year; d, day

Soft drink and fruit juice trial design continued

Study	Trial design	Country	Fluoride	Age (y)	Subject characteristics	Dental erosion method and exposure time	Duration (d)	Dietary assessment method	Basal diet	Intervention	Control intervention	Funding source
West et al., 2004	XO – no washout	England	No tooth brushing allowed when appliance *in situ*	mean 34	16 adults	Human third molar teeth enamel in palatal appliances analysed by profilometer	15	Compliance questionnaire completed each study day	Only tea, coffee or water could be consumed while the appliances were *in situ*	250ml artificially sweetened apple and blackcurrant juice drink 4 times/d	250ml mineral water 4 times/d	GlaxoSmithKline Consumer Healthcare
Hooper et al., 2005	XO –16hr overnight washout	England	No tooth brushing allowed when appliance *in situ*	range 19-45	10 adults	Human third molar teeth enamel in palatal appliances analysed by profilometer	10	Compliance questionnaire completed each study day, sipping of drinks was supervised	No other food and drink could be consumed while the appliance was *in situ*	1.5litres sugar sweetened citric acid-based sports drink consumed within 1 hour/d	1.5litres mineral water consumed within 1 hour/d	NR
Venables et al., 2005	XO – no washout	England	NR	mean 22	19 adults	Human third molar teeth enamel in palatal appliances analysed by profilometer	21	NR, sipping of drinks was supervised	No restrictions	1.4 litres sugar sweetened citric acid-based sports drink consumed within two hours, 5 days a week during planned exercise	1.4 litres mineral water consumed within 2 hours, 5 days a week during planned exercise	GlaxoSmithKline Consumer Healthcare
Hooper et al., 2007	XO – 2 d washout	England	No tooth brushing allowed when appliance *in situ*	18+	15 adults	Human third molar teeth enamel in palatal appliances analysed by profilometer	10	Compliance questionnaire completed each study day	No other food and drink could be consumed while the appliances were *in situ*	250ml artificially sweetened citric acid-based drink 4 times/d	250ml mineral water 4 times/d	GlaxoSmithKline Consumer Healthcare
Caglar et al., 2008	XO – no washout	Turkey	NR	range 21-23	10 adults	Human third molar teeth enamel in palatal appliances analysed by profilometer	10	NR	No other food and drink could be consumed while the appliances were *in situ*	250ml/d malt drink	250ml/d mineral water	NR

NR, not reported; y, year; d, day

Risk of bias assessment

267. A summary of the risk of bias assessment has been given in ***Table 32***.

268. All trials reported being randomised. Allocation concealment was not reported in any of the trials. One trial reported the method random sequence generation. Only two trials reported having any drop-outs, which ranged from 11-14%. The missing outcome data in these trials were balanced in numbers across intervention groups, with similar reasons for missing data across groups.

269. Due to the nature of the interventions all trials were open to participants since the volunteers were either able to identify the treatments by the flavour and consistency of the solutions or the intervention involved consumption of specific foods. All of the trials reported that the trials were blind with respect to the assessors.

Table 32. Risk of bias assessment

Study	Randomisation	Sequence generation	Allocation concealment	Blinding	Incomplete outcome data	Dropouts (%)
Rugg-Gunn et al., 1998	Y	Random number tables	NR	Open to participants and personnel, but assessors blind	No missing outcome data	0
West et al., 1998	Y	NR	NR	Open to participants and personnel, but assessors blind	No missing outcome data	0
Hughes et al., 1999a	Y	NR	NR	Open to participants and personnel, but assessors blind	No missing outcome data	0
Hughes et al., 1999b	Y	NR	NR	Open to participants and personnel, but assessors blind	No missing outcome data	0
West et al., 1999	Y	NR	NR	Open to participants and personnel, but assessors blind	No missing outcome data	0
Hughes et al., 2002	Y	NR	NR	Open to participants and personnel	No missing outcome data	0
West et al., 2003	Y	NR	NR	Open to participants and personnel	No missing outcome data	0
Hooper et al., 2004	Y	NR	NR	Open to participants and personnel, but assessors blind	Missing outcome data unlikely to be related to outcome	14
West et al., 2004	Y	Computer generated randomisation sequence	NR	Open to participants and personnel, but assessors blind	No missing outcome data	13
Hooper et al., 2005	Y	NR	NR	Open to participants and personnel, but assessors blind	No missing outcome data	0
Venables et al., 2005	Y	NR	NR	Open to participants and personnel, but assessors blind	Missing outcome data unlikely to be related to outcome	11
Hooper et al., 2007	Y	NR	NR	Open to participants and personnel, but assessors blind	No missing outcome data	0
Caglar et al., 2008	Y	NR	NR	Open to participants and personnel, but assessors blind	No missing outcome data	0

yes indicates low risk of bias; no indicates high risk of bias; NR, not reported

Results

270. Data on measures of dietary exposure or interventions used and risk assessment methods were insufficiently comparable to allow quantitative synthesis.

271. For the following dietary exposures no relevant articles were identified: glycaemic index and load, dietary fibre, non-digestible oligosaccharides, polyols, sugar, starch, infant feeding, carbohydrate rich foods and total carbohydrate.

Acidic foods and drinks

Prospective cohort studies

272. The findings from all prospective cohort studies of acidic food and drink consumption and risk of tooth wear have been summarised in ***Table 33***.

Table 33. Results from prospective cohort studies

Study	% with enamel loss at baseline	% with dentine exposed at baseline	% with enamel loss at follow-up	% with dentine exposed at follow-up	Dietary exposure	Reported association
Lussi & Schaffner, 2000	10-15*	3-8	30-51	8-26	Consumption of fruits, citrus fruits, fruit juice, apple juice, vegetables and yoghurt	Consumption of dietary acids was associated with significantly increased dental erosion
Dugmore & Rock, 2004	56	2	65	9	Consumption of apples, oranges or grapefruit, other fruit, chips with vinegar or tomato sauce, chocolate or sweets Daily frequency of glasses/cans of the water, milk, tea/coffee, chocolate, squash, fruit juice or carbonated soft drink	Carbonated soft drink consumption was significantly associated with increased tooth wear
El Aidi et al., 2011	32	NR	42	NR	Consumption on the previous day of acidic drinks, water, tea, dairy products, yoghurt products, milk products, acidic fruit and non-acidic fruit, sour vegetables, pickled vegetables, cheese, chewing gum, red sauces, curry, chilli sauce and white/yellow sauces	Consumption of alcoholic mixed drinks and sour vegetables and tooth grinding during sleep were significantly associated with increased erosive wear incidence. Consumption of yoghurt and milk products was negatively associated with the incidence of erosive wear. No significant association was observed between carbonated soft drink consumption and erosive wear incidence or progression

* Data given as ranges in the report; NR, not reported.

273. A small study in adults investigated the association between the consumption of erosive foodstuffs and tooth wear after six years follow-up (Lussi & Schaffner, 2000). An assessment of fruits, citrus fruits, fruit juice, apple juice, vegetables and yoghurt consumption was used to assess dietary acid ingestion. Multiple linear regression analysis revealed age and dietary acid consumption to explain 28% of the variability in the progression of tooth wear between baseline and follow-up. A subgroup analysis of subjects who accounted for most of the total tooth wear progression observed (about a third of cohort subjects) observed that, compared to the rest of the cohort, their intake of dietary acids and the hardness of their tooth brush bristles were significantly higher and the buffering capacity of their saliva significantly lower.

274. A study of twelve year old children followed-up at 14 years of age reported no significant associations with tooth wear regarding dental cleanliness, gingival health, eating apples, chips with tomato sauce or vinegar, citrus fruit, sweets or chocolate; or drinking coffee, chocolate or squash (Dugmore & Rock, 2004). Experience of caries and carbonated soft drink consumption were observed to increase the chances of tooth wear by around 50%, whilst an orthodontic anomaly, the presence of calculus or consumption of fruits other than apples or citrus types (OR 0.61; 95% CI 0.45-0.84) appeared to confer a protective effect. High consumption of carbonated soft drink was the principle factor associated with tooth wear, increasing by around 50% for each daily additional intake: carbonated soft drink consumption (yes compared with no) OR 1.46 (95% CI, 1.08 1.97); carbonated soft drink consumption (less than compared with three or more per day) OR 2.16 (95% CI, 1.46 3.18); and carbonated soft drink consumption (less than compared with four or more per day) OR 2.23 (95% CI, 1.41 3.54). All odds ratios were adjusted for all variables, both significant and non significant.

275. The relationship between a broad collection of food items and the incidence and progression of erosive tooth wear among adolescents was investigated in one study (El Aidi *et al.*, 2011). Incidence was defined as the percentage of subjects without tooth wear at baseline developing tooth wear over the course of the study. Progression was defined as the percentage of subjects with tooth wear at baseline showing an increase in severity score at the final examination. In multivariate analyses significant associations were observed between the incidence of erosive tooth wear and alcoholic mixed drinks (odds ratio, OR 1.82; 95% CI 1.03-3.23), sour vegetables (OR 1.16; 95% CI 1.02-1.32) and tooth grinding during sleep (OR 4.03; 95% CI 1.09-13.67). The intake of yoghurt products was negatively associated with the incidence of erosive wear (OR 0.79; 95% CI 0.66-0.94). Erosive wear was less likely to progress in subjects who consumed milk and yoghurt products (OR 0.89; 95% CI 0.82-0.97 and 0.76; 95% CI 0.60-0.98, respectively). Yoghurt, despite a low pH, has hardly an erosive effect *in vitro* due to its high calcium and phosphate content (Lussi *et al.*, 2004). Carbonated soft drink consumption was not associated with either the incidence (OR 1.03; 95% CI .0.99-1.08) or progression (OR 0.97; 95% CI .0.91-1.02) of erosive tooth wear and nor were any of the other acidic drinks investigated.

276. To test whether interaction between factors gave an added or reduced risk, both the incidence and progression model were extended with interactions between the combined acidic products (carbonated soft drink, fruit lemonade, lemonade squash, energy/sports drink, alcoholic mixed drink and sour vegetables) and biological factors. The interaction of acidic products and tooth grinding resulted in a significant extra risk (OR 1.20; 95% CI 1.01-1.42). Overall this study suggests that factors such as tooth grinding during sleep play a large role in tooth wear in the cohort studied. The consumption of carbonated soft drinks in this cohort (mean intake of 8.8 glasses/week) was lower than that observed in the Dugmore and Rock study where a positive association between carbonated soft drink and tooth wear was found: 40.9% of the 12-year-olds drank three or more glasses per day; by the age of 14 this increased to 45% (Dugmore & Rock, 2004). The prevalence of dental erosion in the cohort studied by Dugmore and Rock was also higher than that observed in the cohort studied by El Aidi *et al*.

Randomised controlled trials

277. The findings from all trials investigating the effect of acidic food and drink on tooth wear have been summarised in ***Table 34***. As many of the trials provide no variance data only the means for enamel erosion have been tabulated.

278. One trial investigated the effect on bovine enamel dental block demineralisation in response to either water, an artificially sweetened phosphoric acid-based cola drink (pH 3.1) or an artificially sweetened citric acid-based orange drink (pH 3.6) for 15 minutes four times a day for one week (Rugg-Gunn *et al.*, 1998). The exposure of enamel slabs to the phosphoric acid-based cola drink resulted in a deeper depth of enamel loss, as determined by profiling casts of the of the enamel slabs and scanning electron microscopy, compared with the distilled water control. There was no difference in depth of enamel loss between distilled water and the citric acid-based orange drink treatments. The finding that artificially sweetened phosphoric acid-based cola drink was more erosive to enamel than the artificially sweetened citric acid-based orange drink suggested that the pH of the drink may have been a factor.

Table 34. Results of trials investigating the effect of acidic food and drink on tooth wear

Study	Intervention	Control enamel lesion depth	Intervention enamel lesion depth	Results
Rugg-Gunn et al., 1998	artificially sweetened phosphoric acid-based cola drink	depth of loss of enamel 3.8µm	depth of loss of enamel 12.8 µm	The intervention significantly increased enamel surface loss
	artificially sweetened citric acid-based orange drink		depth of loss of enamel 5.9µm	No effect
West et al., 1998	orange juice	depth of gain of enamel 0.05 µm	depth of loss of enamel 2.77µm	The intervention significantly increased enamel surface loss
Hughes et al., 1999a	orange juice	depth of loss of enamel 0.19µm	depth of loss of enamel 2.54µm	The intervention significantly increased enamel surface loss
Hughes et al., 1999b	artificially sweetened orange drink	depth of loss of enamel 0.08µm	depth of loss of enamel 8.29µm	The intervention significantly increased enamel surface loss
	artificially sweetened apple and blackcurrant juice drink		depth of loss of enamel 2.04µm	The intervention significantly increased enamel surface loss
West et al., 1999	orange juice	depth of loss of enamel 0.05µm	depth of loss of enamel 1.70µm	The intervention significantly increased enamel surface loss
	sugar sweetened blackcurrant juice drink		depth of loss of enamel 2.75µm	The intervention significantly increased enamel surface loss
Hughes et al., 2002	orange juice	depth of loss of enamel 0.18µm	depth of loss of enamel 2.03µm	The intervention significantly increased enamel surface loss
West et al., 2003	artificially sweetened carbonated orange drink	depth of loss of enamel 0.11µm	depth of loss of enamel 4.92µm	The intervention significantly increased enamel surface loss
Hooper et al., 2004	sugar sweetened citric acid-based sports drink	depth of loss of enamel 0.01µm	depth of loss of enamel 3.91µm	The intervention significantly increased enamel surface loss
West et al., 2004	artificially sweetened apple and blackcurrant juice drink	NR	mean difference to control of depth of loss of enamel 4.67µm	The intervention significantly increased enamel surface loss
Hooper et al., 2005	sugar sweetened citric acid-based sports drink	depth of loss of enamel 0.04µm	depth of loss of enamel 4.08µm	The intervention significantly increased enamel surface loss
Venables et al., 2005	sugar sweetened citric acid-based sports drink	depth of loss of enamel 0.14µm	depth of loss of enamel 4.24µm	The intervention significantly increased enamel surface loss
Hooper et al., 2007	artificially sweetened citric acid-based drink	depth of loss of enamel 0.00µm	depth of loss of enamel 6.04µm	The intervention significantly increased enamel surface loss
Caglar et al., 2008	malt-based drink	depth of loss of enamel 0.26µm	depth of loss of enamel 0.59µm	The intervention significantly increased enamel surface loss

NR, not reported.

279. Three trials investigated the effect of one litre a day of orange juice (pH 3.7-3.9) consumed over fifteen days on dental erosion in relation to a water control (West *et al.*, 1998; Hughes *et al.*, 1999a; West *et al.*, 1999). All observed a progressive loss of enamel with time during the orange juice consumption period, but not the water consumption period, as determined by profiling the enamel slabs during the intervention period. After fifteen days the mean enamel loss ranged from 1.70 – 2.77µm following orange juice consumption, while water consumption had little effect on enamel loss, 0.05 – 0.19µm. One trial also performed a surface microhardness analysis of enamel that had either been exposed or not exposed to the oral environment (PVC tape was used to cover part of the enamel to prevent exposure during the experimental periods) (West *et al.*, 1998). There was no difference in demineralisation between the exposed and unexposed areas after the water consumption period, but following the orange juice consumption period the exposed enamel was significantly different from the unexposed enamel. The exposed-unexposed difference was greater for orange juice than for water (p=0.049).

280. One trial investigated the effect of one litre a day of orange juice (pH 3.3) consumed over ten days on dental erosion in relation to a water control (Hughes *et al.*, 2002). There was a progressive loss of enamel with time during the orange juice consumption period, but not the water consumption period, as determined by profiling the enamel slabs during the intervention period. After fifteen days the mean enamel loss was 2.03µm following orange juice consumption, while water consumption had little effect on enamel loss, 0.18µm. The mean softening depth of the enamel was determined using ultrasonication. Orange juice consumption resulted in a deeper softening depth of the enamel than water consumption.

281. The effect of one litre a day of artificially sweetened orange drink (pH 3.0) and an artificially sweetened apple and blackcurrant juice drink (pH 3.4) over fifteen days on dental erosion was investigated in relation to a water control (Hughes *et al.*, 1999b). A progressive loss of enamel with time was observed during the orange drink and apple and blackcurrant drink consumption periods, but not the water consumption period, as determined by profiling the enamel slabs during the intervention period. After fifteen days the mean enamel loss was 8.29µm following artificially sweetened orange drink and was 2.04µm following artificially sweetened apple and blackcurrant juice drink, while water consumption had little effect on enamel loss, 0.08µm.

282. Another trial also investigated the effect of an artificially sweetened blackcurrant juice drink (pH 3.6) over fifteen days on dental erosion in relation to a water control (West *et al.*, 2004). A progressive loss of enamel with time was observed during the apple and blackcurrant drink consumption periods, but not the water consumption period, as determined by profiling the enamel slabs during the intervention period. After fifteen days the mean difference in enamel loss between the artificially sweetened apple and blackcurrant juice drink and water consumption was 4.67µm ($p<0.001$).

283. The effect of one litre a day of sugar sweetened blackcurrant juice drink (pH 2.9) over fifteen days on dental erosion was investigated in relation to orange juice and a water control (West *et al.*, 1999). A progressive loss of enamel with time was observed during the blackcurrant juice drink consumption period, but not the water consumption period, as determined by profiling the enamel slabs during the intervention period. After fifteen days the mean enamel loss was 2.75µm following sugar sweetened blackcurrant juice drink consumption, while water consumption had little effect on enamel loss, 0.05µm.

284. Carbonated drinks are potentially more erosive than non-carbonated drinks due to the additional carbonic acid present. The effect of one litre a day of artificially sweetened carbonated orange juice drink (pH 3.1) over twenty days on dental erosion was investigated in relation to a water control (West *et al.*, 2003). A progressive loss of enamel with time was observed during the artificially sweetened carbonated orange juice drink consumption period, but not the water consumption period, as determined by profiling the enamel slabs during the intervention period (West *et al.*, 2003). After fifteen days the mean enamel loss was 3.19µm and after twenty days this was 4.92µm following artificially sweetened carbonated orange juice drink consumption, while water consumption had little effect on enamel loss, 0.11µm after twenty days.

285. The effect of one litre a day of sugar sweetened citric acid-based sports drink (pH3.2) over fifteen days on dental erosion was investigated in relation to a water control (Hooper *et al.*, 2004). A progressive loss of enamel with time was observed during the sugar sweetened citric acid-based sports drink consumption period, but not the water consumption period, as determined by profiling the enamel slabs during the intervention period. After fifteen days the mean enamel loss was 3.91µm following sugar sweetened citric acid-based sports drink consumption, while water consumption had little effect on enamel loss, mean erosion 0.01µm.

286. The effect of one and a half litres a day of sugar sweetened citric acid-based sports drink (pH3.2), consumed within one hour, over ten days on dental erosion was investigated in relation to a water control (Hooper *et al.*, 2005). A progressive loss of enamel at five and ten days duration was observed during the sugar sweetened citric acid-based sports drink consumption period, but not the water consumption period, as determined by profiling the enamel slabs during the intervention period. After ten days the mean enamel loss was 4.08µm following sugar sweetened citric acid-based sports drink consumption, while water consumption had little effect on enamel loss, mean erosion 0.04µm.

287. The effect of 1.4 litres sugar sweetened citric acid-based sports drink (pH3.2) consumed within two hours, five days a week during planned exercise on dental erosion was investigated in relation to a water control over twenty one days (Venables *et al.*, 2005).. After twenty one days, fifteen days of exposure, the mean enamel loss, as determined by profiling the enamel slabs, was 4.24µm following sugar sweetened citric acid-based sports drink consumption, while water consumption had little effect on enamel loss, mean erosion 0.14µm.

288. The effect of one litre a day of artificially sweetened citric acid-based drink (pH3.4) over ten days on dental erosion was investigated in relation to a water control (Hooper *et al.*, 2007). A progressive loss of enamel with time was observed during the artificially sweetened citric acid-based drink consumption period, but not the water consumption period, as determined by profiling the enamel slabs during the intervention period. After fifteen days the mean enamel loss was 6.04µm following artificially sweetened citric acid-based drink consumption, while water consumption had no effect on enamel loss, mean erosion 0.00µm.

289. The effect of 250ml a day of a malt-based drink (pH4.3) over ten days on dental erosion was investigated in relation to a water control. After ten days the mean enamel loss was higher (0.59µm) following artificially sweetened citric acid-based drink consumption, while water consumption had less effect on enamel loss, mean erosion 0.26µm.

290. In all trials a large degree of variation in enamel loss was observed, with some subjects showing negligible erosion and others showing large degrees of erosion, e.g. the range of responses in one trial in response to acidic soft drink consumption was 0.07µm to 22.06µm enamel erosion (Hooper *et al.*, 2007).

Summary

Acidic foods and drinks

291. Prospective cohort studies of acidic food and drink consumption and risk of tooth wear provided some evidence that a higher consumption of dietary acids may result in more tooth wear. *In situ* trials demonstrated that consumption of fruit juices (e.g. orange juice and apple and blackcurrant juice) and acidic soft drinks and sports drinks (whether artificially sweetened or sugar sweetened) resulted in a progressive loss of enamel and dentine from dental blocks. No direct comparison between artificially sweetened soft drinks and sugar sweetened soft drinks on dental erosion was conducted in the trials included. Individuals showed a large degree of variation in response to the erosive challenge ranging from almost negligible erosion to large degrees of erosion, reflecting the multi-factorial nature of dental erosion.

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