Dietary factors in the prevention of dental caries: a systematic review

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The aim of this study was, systematically, to evaluate the effect of dietary changes in the prevention of dental caries. A search and analysis strategy was followed, as suggested by the Swedish Council on Technology Assessment in Health Care (SBU). The search strategy for articles published in 1966–2003 was performed using electronic databases and reference lists of articles and selected textbooks. Out of 714 articles originally identified, 18 met the inclusion criteria for a randomized or controlled clinical trial—at least 2 years' follow-up and caries increment as a primary endpoint. This included the total or partial substitution of sucrose with sugar substitutes or the addition of protective foods to chewing gum. No study was found evaluating the effect of information designed to reduce sugar intake/frequency as a single preventive measure. It is suggested that the evidence for the use of sorbitol or xylitol in chewing gum, or for the use of invert sugar, is inconclusive. No caries-preventive effect was found from adding calcium phosphate or dicalcium phosphate dihydrate to chewing gums. The review clearly demonstrates the need for well-designed randomized clinical studies with adequate control groups and high compliance. □ *Dental caries; diet; sugars; sugar substitutes; systematic review*

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The role of diet as a key factor in the etiology of dental caries is currently well established. Even if many studies have failed to show a direct relationship between sugar consumption and levels of dental caries, there is overwhelming evidence that frequent consumption of fermentable carbohydrates is associated with the development of caries (1). One reason for the difficulty involved in demonstrating a strong relationship is the frequent use of fluoride, which has changed the impact of sugars (2).

Even though a large number of carbohydrates, such as sugars and starch, can be fermented by oral microorganisms (3), sucrose has been assigned special importance (4). Other important dietary factors are consistency, degree of retention, and content of cariostatic caries-protection factors (1). Among individual factors, intake frequency is the most important. This was first demonstrated in the Vipeholm study, where the relationship between a variety of sugar intakes and caries increment was observed (5). The importance of intake frequency versus the total consumption of fermentable carbohydrates is difficult to evaluate, as these are hard to distinguish from each other. An increase in either parameter often automatically results in an increase in the other. Although a strong correlation between the two has been found (6), most studies indicate that the frequency of eating is of greater etiological importance for caries than the total consumption of sugar (7, 8). However, the clearance rate and the overall consumption pattern are also important factors that may well explain differences in caries increment.

Together with the use of fluoride and optimal oral hygiene, the control of sugar intake makes an important contribution to the multifaceted strategy for caries prevention. Over the years, information and advice on the importance of sugars for the development of dental caries and advice on the reduction of the total sugar intake and/or reduction of the intake frequency have been given on both an individual and a group basis, and often to parents in order to improve dental health in their children (9).

Total or partial replacement of sucrose in the diet with sugar substitutes is another way to prevent dental caries. The most commonly used in Europe today are the caloric sweeteners xylitol, sorbitol, Lycasin® (hydrogenated starch hydrolysate), maltitol, and mannitol and the non-caloric sweeteners acesulfame-K, aspartame, cyclamate, and saccharin. They all share the following characteristics:

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they can only be fermented by oral microorganisms to a very small extent or not at all, resulting in very low or no acid production. They are currently replacing sugar in a wide range of products, such as sweeteners for coffee and tea, confectionery and chewing gum, medicine, and soft drinks. Invert sugar (hydrolyzed sucrose) is a commonly used sweetener for baby food (10, 11). Xylitol has been claimed to have anti-caries properties and thus to be superior to sorbitol, for example, as a sugar substitute (12, 13).

The addition of various food factors to the diet is another potential dietary measure to prevent caries. Different foods and food components have shown anti-cariogenic properties. Apart from those occurring naturally, such as calcium, phosphate, and casein in milk and cheese (14, 15) or polyphenols and flavenoids in tea (16), attempts were made particularly during the 1960s and 1970s to incorporate different phosphates (mainly dicalcium phosphate dihydrate) in various sugar-free chewing gums (17, 18).

The aim of this study was to systematically assess the clinical effect of various dietary measures used to prevent dental caries. It is one in a series of systematic reviews of methods for caries prevention performed by the Swedish Council on Technology Assessment in Health Care (SBU) (19).

Material and methods

Search strategies

Relevant studies were identified by searching the Medline and Cochrane Library databases (1966 to November 2001 with a later update in July 2003). The search was done by an information specialist at SBU using the following search terms: 'food habits', 'diet', 'dietary carbohydrates', 'xylitol', 'sorbitol', 'mannitol', 'maltitol', 'lycasine', 'palatinose', and 'dental caries'. A total of 714 records were identified and printed (abstract or full-text article if an abstract was missing), and during the second stage relevant records were selected independently by two of the authors. Letters, editorials, and grey literature, as well as obviously irrelevant literature, were excluded.

A total of 109 articles were selected. An article was ordered in full if at least one of the two reviewers considered the study to be potentially relevant according to the basic criteria for inclusion that had been set in advance: randomized or controlled clinical trials (RCT or CCT) with coronal caries increment in the primary (Δdmfs/t) or the permanent (ΔDMFS/T) dentition as a primary endpoint and with a follow-up time of at least 2 years. At this stage, some cross-sectional studies were included. Articles in Swedish, Danish, Norwegian, English, German, French, Italian, and Spanish were considered. Review articles within the field and articles of general interest were also included. For studies in which more than one paper had been published on the same material at different times, only the last publication based on the longest follow-up period was included. Reference lists of these papers as well as from textbooks were hand-searched for additional relevant studies not found in the database search. In this way another 19 studies were identified. A total of 128 articles were thus selected. Of these, 3 were RCTs and 28 CCTs and they were included for further evaluation. Six were review papers and the rest were excluded for the reasons given in Table 1 (refs. 9, 11, 20–122).

Table 1. Excluded studies with the main reason for exclusion

Reason for exclusion	Reference number
Control group missing	22
Description of method	51, 77
Double publication	83, 102, 103
Field trial	26
Follow-up	59, 60, 82
High attrition rate	43, 52
Less than 24 months	41, 84, 107
No intervention	9, 21, 23, 27–31, 33–40, 42, 44–46, 49, 50, 53, 54, 56, 57, 63, 64, 70–73, 85–90, 93–98, 104–106, 108–111, 114–116, 118–121
Other endpoint	55, 65, 67, 68, 74, 75, 78, 79, 81, 91, 92, 99, 112, 113, 117, 122
Prevention program	11, 20, 25, 32, 47, 48, 66, 69
Retrospective study	62
Summary	58, 76, 80
Underway results	24, 61, 100, 101

Evaluation of papers and level of evidence

Of the 31 articles, 1 RCT and 17 CCTs fulfilled the final criteria for inclusion and were read independently by the 2 reviewers using a data extraction form that had been previously tested. The external and internal validity of each study was assessed and the studies were graded with a score of A–C according to predetermined criteria (Table 2). In the event of disagreement between the reviewers the article was discussed within the whole group in order to reach consensus. Based on the evaluated papers, the final level of evidence was judged according to the protocol of the SBU (123) (Table 3).

Results

Of the 18 articles included for evaluation of evidence, 7 reached level B and were used as a basis for conclusions (Tables 4 and 5). A few studies reported on the effect of caries-preventive programs in which recommendations for reduced sugar intake, optimal oral hygiene, and the frequent use of fluoride had been combined (11, 20, 25, 32, 66, 69). However, no studies were identified in which the effect of a reduced sugar intake on caries prevalence was studied separately. Furthermore, no studies could be found in which the caries-preventive effect of the total or

Table 2. Criteria for grading. For grade A, all criteria had to be fulfilled. Papers were rated with grade B or C when at least one of the criteria was met

Grade A	Large RCT, randomization by subject and described ≥3-year duration Study group representative, inclusion criteria described Stratified by age, sex, social group and caries frequency before allocation Double-blind and independent operators Attrition rate ≤10% per year, explained Defined methods for caries diagnosis Diagnostic reliability tests described Bias or confounders taken into account
Grade B	RCT or CCT 2- to 3-year duration Randomization by class/school and described Double- or single-blind Attrition rate ≤10% per year, not explained Group control satisfactory
Grade C	CCT 2-year duration Small single-blinded study Attrition rate >10% per year, not explained Several non-calibrated examiners Group control less satisfactory

partial exchange of dietary sugars for non-caloric sweeteners had been evaluated. In all the remaining studies, the effect of the total or partial substitution of sucrose with the caloric sweetener invert sugar or the sugar alcohols sorbitol and xylitol as well as addition of protective factors to chewing gum/candies had been investigated.

Total substitution

The only study in which the effect of the total substitution of sucrose has been evaluated is the 'Turku sugar study' (137). Three groups of dental students and dental personnel, who volunteered for the various groups, consumed a diet sweetened with sucrose, fructose, or xylitol for a period of 25 months. No new carious lesions were found in the xylitol group and a 47% reduction in caries was found in the fructose group. The results in the xylitol group were explained by the almost complete substitution of sucrose in the diet, but also by an effect of xylitol in itself.

Table 3. Definition of evidence level (123)

Evidence level	Definition
1. Strong scientific evidence	At least 2 studies with high level of evidence (A) or a good systematic review
2. Moderate scientific evidence	One study with a high level of evidence (A) and at least 2 studies with a moderate level of evidence (B)
3. Limited scientific evidence	At least 2 studies with a moderate level of evidence (B)
4. Inconclusive scientific evidence	Fewer than 2 studies with a moderate level of evidence (B)

Partial substitution

Invert sugar used for the partial substitution of sucrose has been evaluated in a Swedish study (10), but, owing to methodological shortcomings, the study was graded as low level of evidence.

One common model for studying the caries-preventive effect of sorbitol/xylitol has been to add them to chewing gum or candies/lozenges. These products have been distributed to schoolchildren for daily and regular use during a period of 2–3 years, sometimes supervised by a schoolteacher. Twelve such studies were identified, none of them randomized at individual level (124–127, 129, 130, 132–136, 138). Instead, classrooms, schools, or households were used as the unit for randomization. Some of the studies were characterized as field studies (124, 132–134, 138), others as cohort studies (135, 136) or community intervention trials (127). Radiographs were used for caries diagnoses in three of the studies (125, 127, 133).

Candies and chewing gum with sorbitol

The effect of sorbitol substituted for sucrose in candies or chewing gum has been evaluated in three studies (125, 126, 130) of which two CCT were graded as moderate level of evidence (125, 126). In the study by Glass (126), no significant difference in caries incidence was found between the test group and a control group to which no gums were provided. In the study by Beiswanger et al. (125), the test group developed 7.9% fewer decayed, missing, and filled surfaces than the control group, who did not use chewing gum. In both studies the use of gum was partly supervised by schoolteachers. As the results are contradictory, no conclusion can be drawn about the use of sorbitol as a substitute for dietary sucrose.

Candies and chewing gum with xylitol, sorbitol, or carbamide

In the mid-1980s, the effect of adding xylitol to candies, chewing gum, drinks or toothpaste was evaluated in two WHO studies performed in French Polynesia and Hungary (133, 138). The caries-preventive effect of chewing gum with xylitol has since been evaluated in four studies (132, 134–136), all of which revealed a high caries-preventive effect in the gum groups with a caries reduction of between 30% and 70%. All six studies were graded as low level of evidence.

Three studies performed in recent years in Madagascar, Estonia, and Lithuania have been graded as moderate level of evidence (124, 127, 129). In a three-year CCT performed in Madagascar the effect of a chewing gum containing sorbitol-xylitol-carbamide was evaluated (129) in 7- and 11-year-old schoolchildren who used the test gums supervised by schoolteachers. Two control groups did not use chewing gum. All the children took part in a heavily supervised tooth-cleaning program at school and the caries increment was low (Table 4). After 3 years a statistically significant caries preventive effect could only

Table 4. Randomized clinical trials (RCT) and controlled clinical trials (CCT) graded as B (moderate level of evidence)

First author, year (reference)	Design		Test group[1] intervention		No. of subjects[2]	Age (years)	Follow-up (years)		Drop-outs (%)		Effect (Δdmfs/t, ΔDMFS/T)	Caries reduction (%)
Richardson (1972) (18)	RCT	*T1*	Chewing gum/sucrose + dicalcium phosphate dihydrate	*Tot*	850	7–12	2	*Tot*	23	*T1*	3.33/6.07	+7
		T2	Chewing gum/sugar-free							*T2*	3.25/5.47	+4
		C	No intervention							*C*	3.12/5.22	
Möller (1973) (128)	CCT	*T*	Chewing gum/sorbitol + calciumphosphate	*T*	174	8–12	2	*T*	7	*T*	5.6	10
		C	No intervention	*C*	166			*C*	9	*C*	6.2	
Glass (1983) (126)	CCT	*T*	Chewing gum/sorbitol	*T*	269	7–11	2	*Tot*	8	*T*	2.53/4.63	1
		C	No intervention	*C*	271					*C*	2.55/4.70	
Beiswanger (1998) (125)	CCT	*T*	Chewing gum/sorbitol	*T*	1318	11–14	3	*T*	50	*T*	8.03	8
		C	No intervention	*C*	1283			*C*	42	*C*	8.72	
Petersen (1999)[4] (129)	CCT	*T1*	Chewing gum/sorbitol + xylitol + carbamide	*T1*	149	7	3	*T1*	16	*T1*	1.12/0.77	26/21
		T2	Chewing gum/sorbitol + xylitol + carbamide	*T2*	201	11		*T2*	12	*T2*	0.97/1.01	30/22
		T3	Chewing gum/sorbitol + xylitol + carbamide	*T3*	85	11		*T3*	13	*T3*	1.06/1.10	23/15
		C1	No intervention	*C1*	139	7		*C1*	16	*C1*	1.52/0.98	
		C2	No intervention	*C2*	229	11		*C2*	9	*C2*	1.38/1.29	
Alanen (2000) (124)	CCT	*T1*	Chewing gum/xylitol	*T*	560	10	3	*T*	24	*T1*	1.87	58
		T2	Candies/xylitol							*T2*	2.77	37
		T3	Candies/xylitol							*T3*	1.72	61
		C	No intervention	*C*	180			*C*	19	*C*	4.42	
Machiulskiene (2001) (127)	CCT	*T1*	Chewing gum/xylitol	*T1*	126	9–14	3	*T1*	21	*T1*	8.1	35
		T2	Chewing gum/sorbitol	*T2*	118			*T2*	42	*T2*	9.0	27
		T3	Chewing gum/sorbitol + carbamide	*T3*	118			*T3*	25	*T3*	11.8	5
		T4	Chewing gum/control[3]	*T4*	120			*T4*	19	*T4*	8.3	33
		C	No intervention	*C*	120			*C*	33	*C*	12.4	

[1]T = Test, C = Control; Test product/sweetener + any other caries-preventive substance.
[2]Tot = total number of subjects at the start of the study.
[3]Sweeteners: acesulfame-K, saccharine, saccharine sodium.
[4]T1 chewed 3 times/day, T2 and T3 chewed 5 times/day. T1 is compared with C1, and T2 and T3 with C2.

Table 5. Randomized clinical trials (RCT) and controlled clinical trials (CCT) graded as C (limited value as evidence)

First author, year (reference)	Design		Test group[1] intervention		No. of subjects[2]	Age (years)	Follow-up (years)		Drop-outs (%)		Effect (Δdmfs/t, ΔDMFS/T)	Caries reduction (%)
Finn (1967) (17)	CCT	*T1*	Chewing gum/sugar free	*Tot*	606	6–18	30 months	*Tot*	31	*T1*	2.52/4.58	19
		T2	Chewing gum/sucrose + dicalcium phosphate dihydrate							*T2*	2.52/4.50	19
		C	Chewing gum/sucrose							*C*	3.10/5.60	
Scheinin (1976) (137)	CCT	*T1*	Diet/xylitol	*T1*	52	27.5	2	*T1*	10	*T1*	0.0	100
		T2	Diet/fructose	*T2*	38			*T2*	8	*T2*	3.8	47
		C	Diet/sucrose	*C*	35			*C*	6	*C*	7.2	
Finn (1978) (131)	RCT	*T1*	Chewing gum/sorbitol	*T1*	138	5–16	30 months	*T1*	35	*T1*	5.44	+9
		T2	Chewing gum/sorbitol + trimetaphosphate	*T2*	131			*T2*	35	*T2*	4.07	18
		T3	Chewing gum/sucrose + trimetaphosphate	*T3*	33			*T3*	42	*T3*	4.73	5
		C	No intervention	*C*	154			*C*	28	*C*	4.99	
Banoczy (1981) (130)	CCT	*T*	Candies/sorbitol	*Tot*	535	3–12	3	*Tot*	52	*T*	3.09	45
		C	Candies/sucrose							*C*	5.60	
Frostell (1981) (10)	CCT	*T*	Diet/invert sugar	*Tot*	151	3	2	*Tot*	20	*T*	2.91/5.39	17
		C	No intervention							*C*	3.51/8.31	
Scheinin (1985) (138)	CCT	*T1*	Candies-toothpaste/xylitol	*T1*	394	6–11	3	*T1*	29	*T1*	4.2	46
		T2	Milk-toothpaste-water/ fluoride	*T2*	378			*T2*	30	*T2*	6.5	16
		C	No intervention	*C*	218			*C*	33	*C*	7.7	
Isokangas (1988) (132)	CCT	*T*	Chewing gum/xylitol	*T*	212	11–12	2	*T*	19	*T*	1.1	45
		C	No intervention	*C*	154			*C*	1	*C*	2.0	
Kandelman (1988) (133)	CCT	*T1*	Chewing gum + candies/ xylitol	*T1*	240	6–12	32 months	*T1*	32	*T1*	4.58	36
		T2	Chewing gum + candies/ xylitol	*T2*	161			*T2*	32	*T2*	4.37	39
		C	No intervention	*C*	345			*C*	43	*C*	7.19	
Kandelman (1990) (134)	CCT	*T1*	Chewing gum/xylitol	*Tot*	574	8–9	2	*Tot*	52	*T1*	2.09	66
		T2	Chewing gum/xylitol + sorbitol							*T2*	2.39	61
		C	No intervention							*C*	6.06	
Mäkinen (1995) (135)	CCT	*T1*	Chewing gum/xylitol	*T1*	580	10	40 months	*T1*	37	*T1*	0.3–0.5	–
		T2	Chewing gum/sorbitol	*T2*	136			*T2*	12	*T2*	0.7	
		T3	Chewing gum/xylitol + sorbitol	*T3*	281			*T3*	38	*T3*	0.5–0.6	
		T4	Chewing gum/sucrose	*T4*	137			*T4*	20	*T4*	1.2	
		C	No intervention	*C*	143			*C*	38			
Mäkinen (1996) (136)	CCT	*T1*	Chewing gum/xylitol	*Tot*	510	6	2	*Tot*	16	*T1*	0.35–0.53	–
		T2	Chewing gum/sorbitol							*T2*	0.44–0.70	
		T3	Chewing gum/xylitol + sorbitol							*T3*	0.48–0.50	
		C	No intervention									

[1] T = Test, C = Control; Test product/sweetener + any other caries-preventive substance.
[2] Tot = total number of subjects at the start of the study.

be demonstrated on occlusal surfaces in the younger children.

In a field study in Estonia (124), the caries-preventive effect of adding xylitol to candies as well as to chewing gum has been studied in 10-year-olds who chewed candies or gum three times a day supervised by schoolteachers. After 3 years, the 'xylitol groups' had a significantly lower incidence of caries than the control groups (who were not provided with candies or chewing gum).

In a CCT performed in Lithuania, the caries-preventive effect of different chewing gums was evaluated in groups of 9- to 14-year-olds (127). Supervised by schoolteachers, the following interventions were tested: sorbitol gum, sorbitol/carbamide gum, xylitol gum, control gum, and no gum. The results showed that after 3 years the incidence of caries was lower to a statistically significant degree in all test groups—apart from the group chewing a gum with sorbitol/carbamide—compared with the no-gum group. The sorbitol group had a high attrition rate and the results for this group must be interpreted with caution. The xylitol group displayed a caries reduction of 35%, while the corresponding figure for the control group was 33%. This indicates that a considerable part of the caries-preventive effect of chewing sugar-free gum could be related to an effect of chewing. To date, this study is the only one in which a control gum has been used.

In two of these studies of moderate evidence, a statistically significant caries preventive effect was shown after adding xylitol to chewing gum/candies. In one of them the effect was almost equivalent to the effect in the control group, which makes the results inconclusive.

Protective factors

Studies of the caries-preventive effects of certain additives in chewing gums date back to the 1960s and the 1970s before fluorides were widely used and when the prevalence of caries was still high.

The caries-preventive effect of dicalcium phosphate dihydrate added to sugar-free and sucrose-containing chewing gums was studied (17, 18), as well as the effect of calcium phosphate added to sorbitol chewing gum (128) and trimetaphosphate added to sorbitol/mannitol and sucrose-containing chewing gums (131). Heterogeneous age groups and a considerable number of dropouts characterize the studies by Finn et al. (17, 131) and only Richardsson et al. (18) and Möller & Poulsen (128) have been graded as moderate level of evidence. Little or no significant effects were shown, except in the study by Möller & Poulsen (128), in which a 10% reduction in caries incidence was reported in the test group. The agents used are no longer available.

Discussion

Information to patients about the importance of reducing the amount of sugar in the diet or reducing intake frequency is a commonly used caries-preventive measure. However, no studies could be identified in which the effect of this kind of information had been evaluated, which confirms the findings reported by Kay (139). Thus, there is no evidence today to suggest that information to reduce sugar intake is an effective activity.

None of the 12 studies in which sorbitol or xylitol was tested as a substitute for sucrose was considered to have a high level of evidence and only 5 were considered to have a moderate level. In 1 of the 3 studies in which xylitol was evaluated, a caries reduction of 37% to 61% was reported when the daily intake of xylitol was 5 g during a period of 3 years (124). In the other two studies (one with a daily intake of 3 g xylitol, the other 0.09–0.15 g), the effect was lower (127, 129).

'Sugar-free chewing gum' with sorbitol or xylitol as a substitute for sucrose has been available for a number of years and currently dominate the market. While the caries-preventive effect has been primarily attributed to low or no acid production, the effect of chewing *per se* should not be ignored. All gums—sugared and unsugared—stimulate the flow of saliva, which leads to an increase in the buffering effect, as well as enhancement of remineralization and increased clearance of sugars from the mouth (140). It has been claimed that it would be difficult to obtain acceptance for a control chewing gum (136) and the effect of chewing has therefore not been measured in previous studies. However, in the study by Machiulskiene et al. (127) a control gum with a non-caloric sweetener was used. The effect was close to that produced by adding xylitol to the chewing gum and points towards the need for further studies.

Some of the studies have been performed in countries with a high caries incidence and high sugar consumption (124, 127, 135, 136), and in some studies access to dental care has been limited (135, 136), which makes it difficult to generalize the results.

The results of the five studies evaluating sorbitol or xylitol, and with a moderate level of evidence, are too limited to enable conclusions to be drawn. This should not be interpreted as meaning that a reduction in sugar in the diet would not be beneficial, but it is obvious that more studies are needed, even though the complexity of these studies should not be underestimated. Furthermore, the findings do not rule out the possibility that the use of products with sorbitol or xylitol instead of sucrose may have a caries-reducing effect. The size of this effect, the daily doses needed to achieve it, and the period during which the products should be used are still unclear.

In conclusion, this systematic review has not identified any studies in which the effect of information designed to reduce sugar intake/frequency was evaluated. No caries-preventive effect from the use of invert sugar rather than sucrose, or from adding calcium-phosphate or dicalcium phosphate dihydrate to chewing gums, has been demonstrated. Studies showing a caries-preventive effect from using sugar alcohols as a substitute for sucrose in chewing gums or candies/lozenges cannot be generalized and are too few to allow conclusions to be drawn. The hypothesis that xylitol has a superior role as a sugar substitute has not been verified. Well-designed randomized clinical studies with high compliance are needed to demonstrate the role of sorbitol and xylitol in caries prevention.

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