Turku sugar studies XVIII

Incidence of dental caries in relation to 1-year consumption of xylitol chewing gum

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A longitudinal study was carried out in order to evaluate the caries incidence as affected by partial substitution of dietary sucrose (S) with xylitol (X), the effects of S- or X-containing chewing gums being compared during one year. The material comprised initially 102 young adults, predominantly dental and medical students, divided randomly into S- and X-groups. During the study 2 subjects were excluded, one due to lack of cooperation, the other not being allowed to enter the assigned S-group due to excessive caries prevalence. The subjects consumed 4.0 chewing gums per day in the S-group and 4.5 in the X-group. The frequency of sucrose intake was 4.2 times per day in the S-group, and 4.9 in the X-group. The caries incidence, assessed independently by clinical and radiographical means, expressed as the mean increment of decayed, missed and filled tooth surfaces, was 2.92 in the S-group, and —1.04 in the X-group. The corresponding values, when considering additionally the secondary caries reversals, were 3.76 in the S-group, and 0.33 in the X-group. The caries incidence was also expressed in combined quantitative and qualitative terms by considering in addition to the above parameters, also the changes in lesion size. The caries activity index thus calculated was 4.96 in the S-group, and 0.88 in the X-group. The results show a profound difference in the caries increment rate between the two experimental groups. The findings clearly indicate a therapeutic, caries inhibitory effect of xylitol.

Key-words: Xylitol; sucrose; dental caries incidence; prevention of dental caries

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Nearly complete substitution of dietary sucrose by xylitol has been shown to yield a dramatic reduction of the incidence of dental caries (*Scheinin, Mäkinen & Ylitalo*, 1974, 1975; *Scheinin & Mäkinen*, 1975). The magnitude of this effect necessitates further studies in relation to partial substitution of sucrose through low amounts of xylitol. A longitudinal study was thus carried out in order to evaluate the caries incidence in man as affected by sucrose (S) or xylitol (X) chewing gum consumption.

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MATERIAL AND METHODS

The initial material comprised 102 subjects, 28 males and 74 females. The mean age was 22.2 years, the subjects being predominantly dental and medical students. Before commencement of the actual study, the clinical material was first examined with regard to the dental conditions and dietary habits.

The registration of the dental conditions was carried out clinically and radiographically as described earlier (*Scheinin, Mäkinen & Ylitalo*, 1974). The dietary habits were analyzed during a 5-day period according to *Nizel* (1972). The material was subsequently divided at random into the future S- and X-groups.

The subjects were instructed to maintain their regular dietary habits and oral hygiene procedures. An ample supply of S- or X-chewing gum, weighing per stick 3.0 g, the compositions appearing in Table I, was given to each participant. Instructions were further given to consume between 3 to 7 sticks per day at spaced intervals, and to keep a complete record of the consumption during the projected full study year. The dietary habits were further checked before termination of the study during a 14-day period. By taking into account also the preceding 5-day period, information of the frequency of S-containing products was available for a total of 19 days.

RESULTS

Immediately after pooling it was recognized through an uninvolved examiner, that one subject with extreme caries prevalence and activity was allotted to the S-group. The subject was consequently not allowed to participate in the study. In addition, one further subject was later excluded, due to lack of co-operation.

Table I. *Composition (in %) of the sucrose- and xylitol-containing chewing gums*

	Sucrose	Xylitol
Gum base	26.0	26.0
Sucrose	50.0	0.0
Xylitol	0.0	50.0
Sorbitol	6.0	6.0
Other polyols	14.5	14.5
Flavours and water	3.5	3.5
	100.0	100.0

Table II. *The mean values and standard deviations of the clinical and radiographical registrations, age and sex of the subjects at the beginning of the study*

	Sucrose		Xylitol	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.
C 1	8.98	5.43	9.62	5.63
C 2	1.28	2.09	1.68	2.76
CS 1	2.00	2.18	2.20	2.38
CS 2	0.84	1.72	1.02	1.80
CR 1	2.84	2.13	2.74	2.01
CR 2	1.48	1.99	1.56	2.18
CSR 1	0.26	0.63	0.26	0.77
CSR 2	0.20	0.45	0.14	0.40
$D_{clin}MFS$	43.44	17.77	46.12	20.53
D_{rtg}	4.78	2.99	4.70	2.92
FS	28.82	15.05	28.96	14.69
M	0.38	1.04	0.66	1.31
DMFS	48.22	17.60	50.82	20.98
Age ♂ (n 13)	23.1	2.6	22.0	0.9
♀ (n 37)	22.0	2.9	22.1	1.7

C = Primary caries*)
CR = Additional radiographic primary caries*)
CS = Secondary caries*)
CSR = Additional radiographic secondary caries*)
1 = Lesion without defect*)
2 = Lesion with defect*)
D_{clin} = Total number of clinically detected carious surfaces
D_{rtg} = Total number of additionally radiographically detected carious surfaces
M = Missed*)
F = Filled*)
S = Tooth surfaces*)

*) During the trial these symbols indicate the corresponding reversals.

The mean values and the standard deviations of the clinical and radiographical registrations at the commencement of the study, calculated for the final material of 100 subjects is given in Table II. The sex distribution was equal, each group consisting of 13 male and 37 female subjects. In addition to the variables given in the table, the height, weight and the wrist-girth of the subjects was also registered. There were, however, no significant differences between the prospective S- and X-groups, with exception of the value of missed teeth (M) which was significantly higher among the females in the X-group than in the S-group.

Table III. *Mean consumption of chewing gums per day during one year*

	Number of chewing gums per day								
	1	2	3	4	5	6	7	8	Total
Sucrose	0	5	10	19	15	1	0	0	197
Xylitol	1	1	5	19	16	5	2	1	226

$\chi^2 = 11.03$ D.F. = 7 $\alpha = 0.137$

The consumption of chewing gum, calculated as number of sticks per day is given in Table III. The mean consumption was 4.0 sticks per day in the S-group, and 4.5 correspondingly in the X-group, the difference between the groups being not significant.

The frequency of sucrose consumption, calculated as indicated in the »Material and Methods» section, appears in Table IV. The frequencies of sucrose consumption in both liquid and solid form, at and between meals, were consistently slightly higher in the X- than in the S-group, although the differences between the sugar groups were generally not significant (Table V). The mean daily frequency of sucrose intake was 4.2 times in the S-group, and correspondingly 4.9 in the X-group. On the other hand, when comparing the intake of S-containing products at the two follow-up periods, a decline in the consumption during the course of the study was regularly noticed and also found significant in the majority of instances Wilcoxon rank correlation test for dependent samples, Tables IV & V.

Table IV. *Sucrose intake during a 5-day period at the beginning, and a 14-day period at the end of the study. The consumption is expressed as the frequency per day per subject*

		Sucrose (n = 50)					Xylitol (n = 50)				
	Period	Min	Max	Md	$\bar{x}$	S.D.	Min	Max	Md	$\bar{x}$	S.D.
Liquid	5 d	0.0	3.0	0.80	0.87	0.82	0.0	4.0	0.70	1.10	1.12
at	14 »	0.0	3.2	0.21	0.45	0.65	0.0	2.4	0.29	0.49	0.57
meals	19 »	0.0	3.2	0.37	0.56	0.61	0.0	2.3	0.42	0.65	0.61
Liquid	5 »	0.0	3.8	0.60	1.16	1.16	0.0	4.4	1.30	1.46	1.15
between	14 »	0.0	2.5	0.50	0.67	0.63	0.1	3.9	0.64	1.03	0.91
meals	19 »	0.0	2.4	0.61	0.80	0.63	0.1	3.3	0.89	1.14	0.86
Solid	5 »	0.0	3.0	1.30	1.22	0.72	0.0	3.2	1.20	1.30	0.90
at	14 »	0.0	2.4	0.71	0.84	0.62	0.1	3.1	0.71	0.99	0.67
meals	19 »	0.0	2.1	0.84	0.94	0.55	0.2	2.8	0.92	1.07	0.58
Solid	5 »	0.0	8.6	2.10	2.35	1.59	0.6	8.8	2.20	2.50	1.47
between	14 »	0.0	5.9	1.54	1.74	1.28	0.2	4.5	1.79	1.92	0.93
meals	19 »	0.1	6.6	1.74	1.90	1.19	0.6	5.4	2.00	2.07	0.95

Table V. *Significance levels with regard to observed differences in the frequency of sucrose intake between observation periods, and between sugar groups (For numerical values, see Table IV)*

	Between observation periods*)		Between sugar groups, days**)		
	Sucrose	Xylitol	5	14	19
Liquid at meals	+++	+++	Φ	Φ	Φ
Liquid between meals	++	+	Φ	+	+
Solid at meals	+++	Φ	Φ	Φ	Φ
Solid between meals	+	+++	Φ	Φ	Φ

$p \leq 0.05$ +
$p \leq 0.01$ ++
$p \leq 0.005$ +++

Φ = not significant

*) Wilcoxon-test
**) Mann-Whitney U-test

Table VI. *Analysis of examiner error based on duplicate clinical registrations of dental caries at the beginning of the study*

n = 100	Min	Max	Md	Total	$\bar{x}$	S.D.
O — C_1	0	4	0	77	0.77	1.06
C_1 — O	0	4	1	78	0.78	0.88
O → C_2	0	2	0	3	0.03	0.22
C_2 → O	0	1	0	1	0.01	0.10
F → CS_1	0	3	0	21	0.21	0.54
CS_1 → F	0	3	0	31	0.31	0.60
F → CS_2	0	0	0	0	0	0
CS_2 → F	0	1	0	1	0.01	0.10
C_1 → C_2	0	2	0	9	0.09	0.32
C_2 → C_1	0	1	0	9	0.09	0.29
CS_1 → CS_2	0	2	0	6	0.06	0.28
CS_2 → CS_1	0	1	0	3	0.03	0.17
r_2*)	0.000	0.077	0.015	1.813	0.018	0.016
O	43	136	93	9161	91.61	20.61
C_1	0	25	8	846	8.46	5.28
C_2	0	11	0	138	1.38	2.38
CS_1	0	8	1	170	1.70	2.10
CS_2	0	7	1	91	0.91	1.60
F	1	76	28	2910	29.10	14.98
M	0	6	0	89	0.89	1.45

*) ratio between disagreements and agreements, see Table VII.

The results from the clinical and radiographical registrations of dental caries appear in Tables VI—XI. The examiner error, estimated on the basis of the set of duplicate clinical examinations carried out at the beginning of the study, appears through the information given in Tables VI & VII.

According to the recommendations of COCSTOC (1973), the reproducibility (r) of the clinical registrations was also examined through the expression $r = a/b$, where a = the mean number of surfaces per subject with disagreements as to caries status on two successive examinations, and b = the mean number of surfaces per

Table VII. *Reproducibility of clinical caries registrations expressed in terms of numbers of disagreements and agreements in diagnosis*

I/II	0	C_1	C_2	CS_1	CS_2	F	M_S	Σ
O	9161	77	3					9241
C_1	78	846	9					933
C_2	1	9	138					148
CS_1				170	6	31		207
CS_2				3	91	1		95
F				21		2910		2931
M_S							445	445
Σ	9240	932	150	194	97	2942	445	14000

r_1 = ratio between no of disagreements and agreements for carious surfaces only
r_2 = ratio between no of disagreements and agreements for carious, filled and intact surfaces

$$r_1 = \frac{239}{1245} = 0.19 \qquad \text{S.D. } 0.38^*)$$

$$r_2 = \frac{239}{13316} = 0.018 \qquad 0.016^*)$$

Mean disagreements per subject	= 2.39	2.08
Mean agreements per subject (carious surfaces only)	= 12.45	8.39
Mean agreements per subject (carious, filled and intact surfaces)	= 133.17	7.27

*) based on individual ratios (corresponding mean values $r_1 = 0.28$, $r_2 = 0.018$)

Table VIII. *Total number (top) and cumulative increment in the number of decayed, missed and filled tooth surfaces (DMFS and Δ DMFS-indices) during one year of sucrose or xylitol chewing gum intake*

	Sucrose				Xylitol			
Months	R_S	Md	$\bar{x}$	S.D.	R_X	Md	$\bar{x}$	S.D.
0	11—90	48.0	48.22	17.60	5—94	49.0	50.82	20.98
6	13—93	47.5	49.36	17.98	6—94	48.0	50.54	20.73
12	14—94	50.0	51.14	17.10	6—96	47.5	49.78	21.11
0— 6	—5— 9	1.0	1.14	2.34	—10— 4	0.0	—0.28	2.26
0—12	—3—12	3.0	2.94	3.02	— 9— 4	—1.0	—1.04	8.72

subject consistently diagnosed as carious on two successive examinations. These calculations appear in Table VII.

The development of the total number of decayed, missed and filled tooth surfaces (DMFS-index), and the cumulative increment during the study (Δ DMFS-index) at the 6 and 12 months registrations are presented in Table VIII, which also gives the corresponding minimum and maximum individual values, medians, means and standard deviations of the experimental variables. Fig. 1 shows the corresponding development, the differences between the groups being significant after 6 months ($p < 0.006$) and highly significant after 12 months ($p < 0.001$).

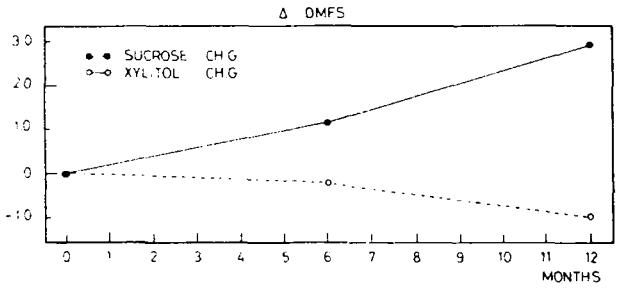

Fig. 1. Cumulative development of decayed, missed and filled tooth surfaces (Δ DMFS-index) during 12 months of sucrose or xylitol chewing gum intake.

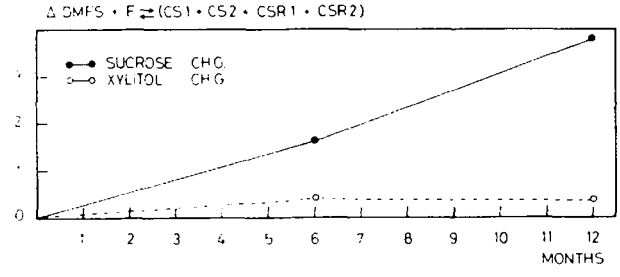

Fig. 2. Increment of decayed, missed and filled tooth surfaces and all new secondary caries reversals during 12 months of sucrose or xylitol chewing gum intake.

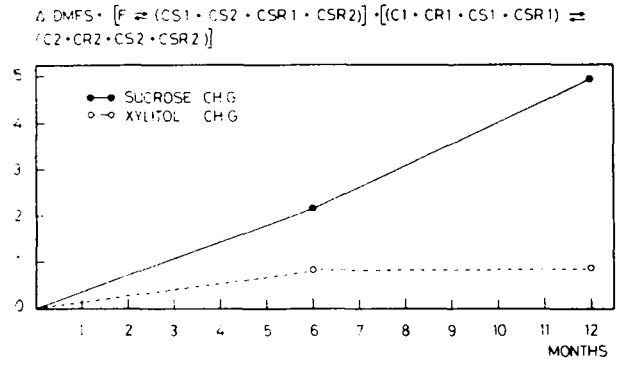

Fig. 3. Total caries activity after 12 months of sucrose and xylitol chewing gum intake. The cumulative development covers the increment of decayed, missed and filled tooth surfaces, all new secondary caries reversals, and the increment in lesion size of primary and secondary caries reversals.

Table IX. *Cumulative increment of quantitative reversals. Sum of increment in number of decayed, missed and filled tooth surfaces (ΔDMFS) and all secondary caries reversals (F ⇄ CS 1, F ⇄ CS 2, F ⇄ CSR 1, F ⇄ CSR 2)*

Months	Sucrose R_s	Md	$\bar{x}$	S.D.	Xylitol R_x	Md	$\bar{x}$	S.D.
0— 6	—3—12	1.0	1.62	2.86	—10— 9	0.0	0.44	2.91
0—12	—3—15	3.0	3.76	3.50	— 6—10	0.5	0.33	3.83

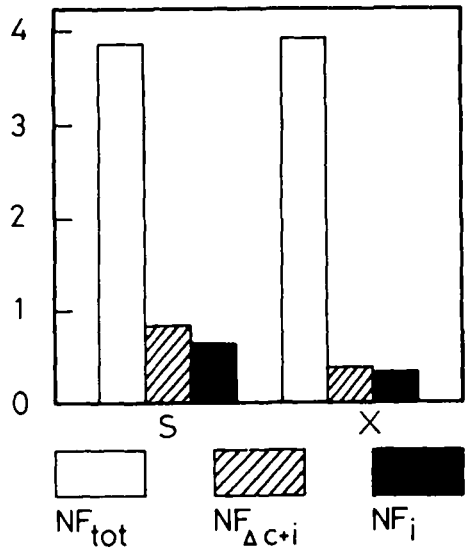

Fig. 4. Number of new filled surfaces after one year of selective sugar diets, a. Total number of new fillings, replacing caries at baseline examination, substituting positive caries reversals at subsequent examinations, and also at clinically and radiographically intact tooth surfaces. b. Number of new fillings replacing positive caries reversals, and at intact tooth surfaces. c. Number of new fillings at clinically and radiographically intact tooth surfaces.

The caries incidence during the study, calculated on the basis of the decayed, missed and filled tooth surfaces does not provide a complete description of the total quantitative development, particularly as the development of secondary caries remains obscured by those tooth surfaces already having been considered as filled. The caries incidence, when considering in missed and filled tooth surfaces (*Δ* DMFS), addition to the increment of decayed, also the secondary caries reversals (CS 1, CS 2, CSR 1 & CSR 2) in S- and X-groups was significant after 6 months ($p < 0.05$) and highly significant after 12 months ($p < 0.001$).

The caries incidence may also be expressed in combined quantitative and qualitative terms, by considering in addition to the total quantitative development (Table IX) also the qualitative development in terms of changes in the lesion size (C 1 ⇌ C 2, CS 1 ⇌ CS 2, CR 1 ⇌ CR 2, CSR 1 ⇌ CSR 2). The caries activity index thus calculated shows the total development in terms of all quantitative and qualitative changes (Table X and Fig. 3), the differences between the sugar groups being significant after 6 months ($p < 0.05$) and highly significant ($p < 0.001$) after 12 months.

There were no tooth extractions during the study, the development of new filled tooth surfaces being shown with regard to total number of new filled surfaces, substitution of caries reversals and intact surfaces (Table XI & Fig. 4).

DISCUSSION

Some of the inherent weaknesses in the first trial (*Scheinin, Mäkinen & Ylitalo*, 1974; *Mäkinen & Scheinin*, 1975) were overcome in the present study. These imperfections include the possibility of-

Table X. *Cumulative increment of quantitative and qualitative reversals. Sum of increment in number of decayed, missed and filled tooth surfaces (ΔDMFS), all secondary caries reversals (F → CS 1, F → CS 2, F → CSR 1, F → CSR 2), and increase in size of total clinical and radiographic reversals (C 1 ⇌ C 2, CS 1 ⇌ CS 2, CR 1 ⇌ CR 2, CSR 1 ⇌ CSR 2)*

Months	Sucrose R_s	Md	$\bar{x}$	S.D.	Xylitol R_x	Md	$\bar{x}$	S.D.
0— 6	—3—14	1.0	2.16	3.36	—11—10	0.0	0.84	3.35
0—12	—3—27	4.5	4.96	4.75	— 7—15	1.0	0.88	4.38

Table XI. *Development of new filled surfaces with regard to total number of new fillings, substitution of caries reversals and intact tooth surfaces*

New filled surfaces	Months	Sucrose R	Md	$\bar{x}$	S.D.	Xylitol R	Md	$\bar{x}$	S.D.
Substitution of baseline lesions,	0— 6	0—36	0	2.30	5.59	0—23	0	1.76	3.96
caries increment and intact surfaces	6—12	0—14	0	1.58	2.76	0—28	0	2.16	4.91
Total development, cumulative (NF_{tot})	0—12	0—36	2	3.88	6.07	0—30	1	3.92	6.39
Substitution of caries increment	0— 6	0— 3	0	0.34	0.75	0— 2	0	0.14	0.45
and intact surfaces	6—12	0— 6	0	0.50	1.05	0— 6	0	0.24	0.92
Total development, cumulative ($NF_{\Delta c + i}$)	0—12	0— 6	0	0.84	1.20	0— 6	0	0.38	0.99
Substitution of intact surfaces	0— 6	0— 3	0	0.34	0.75	0— 2	0	0.14	0.45
	6—12	0— 4	0	0.30	0.74	0— 6	0	0.20	0.90
Total development, cumulative (NF_i)	0—12	0— 4	0	0.64	0.96	0— 6	0	0.34	0.98

fered to the subjects on the strict sugar diets, to choose a specified sugar group, and the impractical approach aiming at a total substitution of sucrose through fructose or xylitol. In the present trial, involving a realistic partial substitution of sucrose through low amounts of xylitol, the subjects were assigned their groups on a random basis. Other weaknesses, e.g. the age of the subjects, remain common to both studies. From the viewpoint of incidence of dental caries, the selcetion of a young, homogenous age group would have been advantageous.

The inclusion of a non-chewing group, i.e. a second control group in the chewing gum study, would clearly have been an improvement, but for practical reasons such an arrangement was not possible.

From an opposite point of view, the solidity of the present long-term study may rest in the general arrangement, the clinical and radiographic findings, independently assessed, being supplemented through a number of biochemical and microbiological assays of plaque and saliva, the results of these studies being reported for separately.

The analysis of the method error, as appearing in Tables V and VI, was carried out on the basis of two sets of caries registrations at the beginning of the study. The spacing of the two sets was about three weeks, the subjects being examined in random order.

Although the presentation of the results has been done by showing the total quantitative and qualitative development, the calculation of the method error is based for all separate entries at the clinical registrations. The analysis shows (Tables VI & VII) that the C 1- and CS 1-lesions are the most important with regard to reversal in diagnosis; all other recordings are of secondary importance only.

In addition to expressing the reproducibility of the clinical registrations as the ratio between the number of disagreements and agreements for carious surfaces only (r_1, Table VII), it is also

given as the ratio between number of disagreements and agreements for carious, filled and intact tooth surfaces (r_2). The latter value, covering all tooth surfaces present, is considered to express the reproducibility in a comprehensive way. The values of $r_1 = 0.19$, and $r_2 = 0.018$, are given for comparison with future studies, and have obviously also to be compared with a similar analysis carried out in relation to the 2-year diet study (*Scheinin, Mäkinen & Ylitalo*, 1975). The values of r_1 and r_2, being considerably smaller in the present study than in the diet study, are explained through the introduction of a decision table eliminating the error arising from differing taxation of the location of primary and secondary carious lesions, situated in the border area of two adjacent tooth surfaces. The taxation of individual surfaces will otherwise appear arbitrary to a certain degree, resulting in that the number of disagreements is in fact too large. One can show it by the incidence of O → C 1 and C 1 → O lesions in the same tooth, but on different surfaces at consecutive caries registrations. This inflates the variations in the Δ DMFS-index to a certain degree. In addition to the above inflatory effect, the procedure suggested by COCSTOC (1973) has the additional weakness of not being directly related to the overall caries indices (DMFS & Δ DMFS).

The results on the incidence of dental caries, as affected through xylitol or xylitol chewing gum consumption, show sucrose in chewing gum to be definitely cariogenic. This finding is in accordance with a recent, so far unpublished study (*Glass*, 1975).

The very low incidence of dental caries, as observed in the X-group, was surprisingly of the same magnitude as previously observed in the 2-year trial involving strict X-diet (*Scheinin, Mäkinen & Ylitalo*, 1974). The present observations, in relation to partial substitution of sucrose by xylitol, further strengthen the previous findings (*Scheinin, Mäkinen & Ylitalo*, 1974, 1975) indicating a therapeutic, caries inhibitory effect of xylitol. It should be noted, however, that the present results were obtained in subjects with a moderate sucrose consumption and a satisfactory level of oral hygiene.

The overall development of the ΔDMFS-index, particularly the average decrease being about one surface per subject during the study year in the xylitol group, might be resulting partly from a change in the diagnostic level, partly from true negative caries reversals. These findings will be separately analysed, and the results presented separately. The essential observation seems to be the marked difference in the incidence of dental caries between the two experimental groups. It is also emphasized that the experimental model involved consecutive consumption of the xylitol chewing gum and the sucrose containing products. At present there are thus no indications of a caries-reducing effect occurring in relation to a mixture of xylitol and sucrose. In view of the findings and forthcoming reports belonging to the same series, it is suggested that the non- and anti-cariogenic properties of xylitol principally depend on its lack of suitability for microbial metabolism, and on the physico-chemical effects in plaque and saliva through low and repeated dosage of xylitol.

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