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Preventive Effect of Sugar-free Chewing Gum Containing Maltitol on Dental Caries *in situ*

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Abstract The preventive effect of chewing gum containing maltitol, xylitol, gum base, and sugar on remineralization were investigated. The clinical study consisted of 8 weeks' randomized, double blind, controlled, cross-over clinical trials including 24 healthy adults had chew gum. After each test week, remineralization effect was evaluated by measuring microhardness and scanning electron microscopy (SEM). Microhardness of experimental chewing gum containing maltitol or xylitol was significantly higher than that of sugar gum ($p<0.005$). Images of SEM showed the remineralization effect of gum containing gum base, maltitol, or xylitol compared with sugar gum. Maltitol and xylitol gums were more effective in remineralization than sugar gum. It was concluded that maltitol and xylitol can be used as sugar substitute to prevent dental caries.

Keywords: dental caries, sugar free gum, remineralization, microhardness, scanning electron microscopy (SEM)

Introduction

The development of sugar-free chewing gum has offered a non-cariogenic alternative for consumers. In contrast to sugared gum, chewing sugar-free gum results in the rise of plaque pH due to the effect of stimulation on the composition of saliva in the absence of significant acid production by plaque microflora (1,2). For this reason, Edgar and Dodds (3) stated that sugar-free gum 'approaches the ideal of a non-cariogenic sweetment'.

Sugar alcohols, a type of polyols, are commonly added to foods because of their lower caloric content than sugar; however, they are also, in general, less sweet, and are often combined with high-intensity sweeteners. Polyols such as sorbitol, maltitol, mannitol, and xylitol show a little or no fermentability in dental plaque. Sugar alcohols that have been identified and developed are generally considered safe for teeth and make an important contribution to the prevention of dental caries (4-8). For many years, all polyols have been studied for their effects on oral health, and these studies have led to the consensus that all polyols are non-cariogenic because they do not decrease pH below 5.7 (9). Therefore polyols are widely used as sweetening agents in chewing gum and various candy formulations. Among polyols, xylitol gum has been investigated most intensively. However, the technical characteristics of xylitol make it suitable for some applications but not all and therefore, the use of other polyols is required (2,10).

Maltitol has 95% of the sweetness of sucrose and almost identical properties except for browning (11). Its high sweetness allows it to be used without being mixed with other sweeteners, and it exhibits a negligible cooling effect in comparison with other sugar alcohols, and is very similar to the subtle cooling effect of sucrose (12). It is not metabolized by oral bacteria, so it does not promote tooth decay (13,14). Maltitol's good taste, reduced caloric value, versatility, and its high level of sweetness in comparison with most of other polyols facilitate its use in a wide variety of products. With increasing demand for products reduced in calories and simple sugars, the use of maltitol is expected to increase. Fewer studies on the anti-cariogenic effects of maltitol have been made in the dental research area.

The purpose of this study was to evaluate the anti-cariogenic effects of maltitol compared with xylitol in sugar-free gum by investigating the changes of oral flora and remineralizing enamel subsurface lesions in a human *in situ* model.

Materials and Methods

Subjects This study followed a protocol reviewed and approved by the institutional review board of Seoul National University Dental Hospital IRB #1-Dental Clinical Research (IRB Identification No. CRI06011). The subjects of this study were 24 healthy adults (17 males, 7 females) aged 26 on the average (male: 26±2.0, female: 26±1.0) who were in good general and oral health and provided a written informed consent and medical history information. Criteria for exclusion were the use of antibiotics or other antibacterial medicaments that could affect plaque growth during the last 3 months, fewer than 20 teeth available for evaluation, fixed or removable orthodontics appliances, partial dentures, known allergies against test agents, and pregnancy.

Study design The clinical study consisted of 8 weeks' randomized, double blind, controlled, cross-over clinical trials (Table 1). After exact examination, all the subjects received professional prophylaxis, fluoride toothpaste (LG Household & Health Care Ltd., Seoul, Korea), and a

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Table 1. Study design and schedule

		Test cycle 1		Test cycle 2		Test cycle 3		Test cycle 4	
Investigational events	Day 0	1 - 7	8 - 14	15 - 21	22 - 28	29 - 35	36 - 42	43 - 49	50 - 56
Dental status	×								
Personal data	×								
Medical history	×								
Professional toothcleaning	×								
Chewing gum[1)]									
Group I		GB		M		X		S	
Group II		M		X		S		GB	
Group III		X		S		GB		M	
Group IV		S		GB		M		X	
Washout			×		×		×		×
Microhardness	×	×	×	×	×	×	×	×	×
SEM	×		×		×		×		×

[1)]GB, gum base; M, maltitol chewing gum; X, xylitol chewing gum; S, sugar chewing gum.

toothbrush (Burtler, Sunstar Americas, Chicago, IL, USA), which they were obliged to use during the 1-week hygiene phase before the experiment period and during the washout period. At the beginning of each test week (day 1, 15, 29, and 43), the subjects had further professional tooth cleaning and were supplied with the test products in a randomized 4×4 latin square design. Every subject in the maltitol, xylitol, sugar, and gum base control groups was instructed to chew the allocated 2 gum pellets containing 1.2±0.1 g/piece of maltitol, xylitol, or sugar 7 times a day (at 9, 11 am, 1, 3, 5, 7, and 9 p.m. at 2-hr intervals) for 5 min (a total of 14 gum pellets/day) between the regular meals. After each test week, there was a week washout period to stabilize the oral conditions.

Chewing gum All the gum pellets were manufactured similarly in size, consistency, colors, and sweetness by Societe Roquette Frères, Shanghai, China and marked A, B, C, and D until all results were evaluated. The gum pellets contained approximately 56% of only one kind of carbohydrate (maltitol 56%, xylitol 57%, or sugar 55% each) without coating.

Preparation of bovine enamel specimens Extracted bovine incisors were stored in 0.1% thymol solution for 30 days at 4°C before embedding. Bovine enamel discs with a diameter of 5 mm were prepared from upper jaw incisors by first excising a cylinder perpendicular to the labial surface of the teeth with a diamond-coated corer under the constant flow of cooling water. The labial surface of a bovine enamel surface was polished with a polishing machine (The LaboSystem, Struers, Ballerup, Denmark) up to 2,000 grit silicon carbide papers sequentially and polishing paper No. 4,000 and 6,000 grit to expose a flat enamel surface. Before being used in the experiment, all prepared specimens were stored in constant relative humidity of 100%.

Artificial incipient lesion using pH-cycling Before making an artificial incipient lesion, all specimens' Vickers hardness number was measured with a surface microhardness tester (HMV-2000; Shimadzu Corp., Tokyo, Japan). These measurements were done 3 times, and the specimens' Vickers hardness number was above 100 was selected for the experiment. To make an artificial incipient lesion, each specimen was immersed in a demineralized solution (75 mM acetate buffer, pH 4.3, containing 2.0 mM calcium, and 2.0 mM phosphate) for 3 hr at 37°C followed by 21 hr of immersion in a remineralizing solution (20 mM cacodylate buffer, pH 7.4, containing 1.5 mM calcium, 0.9 mM phosphate, and 0.15 M KCl). After completing the pH-cycling procedure, the specimens were stored in constant relative humidity of 100%.

Preparation of removable appliance Dental impression was taken with alginate to make appliances with acrylic resin, and recessed 3 troughs on the lingual side of the mandibular premolar/molar regions to mount bovine enamel specimens on them. Utility wax was used to fix the bovine enamel specimens in the troughs. These appliances with bovine specimens were sterilized by the use of gamma radiation from cobalt-60. The irradiation was performed using a Gammacell 220 Excel (GC-220E; MDS Nordion, Ottowa, ON, Canada) for 14 hr and 49 min at 27°C producing a dose of 25 kGy. The irradiation time was determined taking into consideration the correction the radioactive decay of γ-ray source (Fig. 1).

Surface microhardness (SMH) analysis The degree of demineralization of the enamel slabs was measured by evaluating changes in microhardness. Microhardness was measured before and after pH-cycling, and after each test period. The laboratory staff quantitatively assessed changes in the mineral contents of enamel specimens by surface microhardness tester (HMV-2000; Shimadzu Corp.) equipped with a Vickers indenter. Using the utility wax, each enamel specimen mounted on the flat plastic block and measured. SMH determined by measuring the length of the indentations. To get more reliable results, measurements were repeated 5 times. The laboratory staff placed 5 baseline indentations spaced 100 μm apart with a Vickers diamond under 500 g load in the center of each flattened, polished sound enamel specimen. After *in vitro* demineralization, they again tested the enamel specimens for SMH by placing 5 indentations

Fig. 1. The *in situ* appliance. Showing the recessed trough areas on the fitting surface of the device, positioned just opposite to the lower first and second molars. Three enamel specimens were mounted on the base of each trough.

directly below the baseline indentations. After 7 days' intraoral exposure, the enamel specimens were removed from the removable appliance. The laboratory staff cleaned them and tested them for SMH once more by placing 5 indentations 100 μm directly above the baseline indentations.

Scanning electron microscopy (SEM) Demineralization and remineralization effects of the chewing gum were determined by measuring the roughness of the enamel specimens and observed with a SEM. SEM images were obtained by scanning electron microscope (S-4700; Hitachi Ltd., Tokyo, Japan) to evaluate the conditions of the surface, especially, enamel prism areas.

Data analysis Repeated measures analysis of variance with SPSS 12.0 for Windows 2000 with the general linear model (GLM) was used to analyze the data. Data (means and standard deviations) on the experimental group were computed, and a post hoc multiple comparison (Student-Newman-Keuls) procedure was used to determine if significant differences existed among the study groups. For all tests, the significance level was set at 0.05.

Table 2. Mean values of microhardness

	$\Delta Z^{1)}$	GLM+[2)]
	Mean±SD	*p*-value
Gum base	-13.98±25.08[a]	
Maltitol	-1.51±25.56[a]	
Xylitol	-11.11±18.43[a]	0.005
Sugar	-23.89±12.32[b]	

[1)]Difference between before and after gum mastication; Different superscripts are significantly different ($p<0.005$, post hoc analysis by Student-Newman-Keuls).
[2)]Results of repeated measures GLM.

Results and Discussion

The mean value of microhardness of 'after gum mastication' vs. 'before gum mastication' by Vickers' microhardness are shown in Table 2. All the treatment groups exhibited increased surface microhardness compared with their pre-treatment. It was statistically higher than that of the negative control group ($p<0.005$). Especially, Vickers' microhardness of experimental chewing gum containing maltitol was significantly higher than that of sugar gum ($p<0.005$).

The SEM images of the enamel surface lesion show the effects on each of gum base, maltitol, xylitol, and sugar compared with the standard (Fig. 2). The images of confocal microradiography and SEM of the enamel subsurface lesion showed a higher remineralization effect of chewing gum containing gum base, maltitol, or xylitol than sugar-containing one.

Cariogenic potential is related with the fermentable rate of carbohydrate, oral retention time of dietary carbohydrate, the frequency of carbohydrate intake, salivary flow, buffering capacity of saliva, and the fluoride content of plaque and surface enamel (15). Cariogenic potential is at its minimum when zero-H ions are formed. Moreover, the acid production rate of maltitol, sorbitol, and xylitol is low or not detectable from the experiment (16). The main advantage

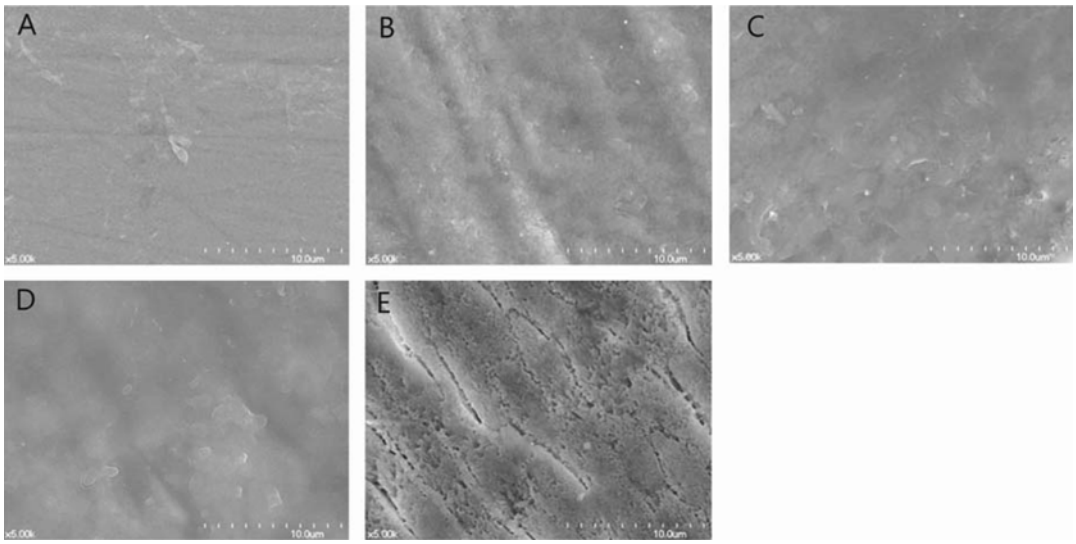

Fig. 2. Representative SEM images of enamel surface lesions showing the effect of each of gum base, maltitol, xylitol, and sugar compared with the standard. A, standard; B, after mastication of gum base; C, after mastication of maltitol gum; D, after mastication of xylitol gum; E, after mastication of sugar gum.

of polyols is reported to be their noncariogenicity and low caloric content because of their slow and incomplete adsorption in the intestine (17,18). In this experiment, anti-cariogenic effects were investigated in several ways. SEM detected significantly higher remineralization in the specimens of the sugar-free chewing gum groups than in the control. Remineralization resulting from the use of sugar alcohols has been suggested, but evidence from clinical trials is less clear (19,20). Like the study of Rugg-Gunn *et al.* (4), the result of our study showed that the use of sugar-free chewing gum after an acidogenic challenge can enhance the remineralizing potential of the mouth. As salivation increases and plaque pH rises, it is likely to be a result of increased plaque buffering by the stimulated saliva. Rapid restoration of plaque pH tends to favor remineralization. Leach *et al.* (1) demonstrated that the daily chewing of 5 sticks of chewing gum resulted in significantly higher remineralization over a 21-day experimental period than during a non-chewing control period. However, that study was different from ours in that gum was chewed immediately after the meal or snack in that study. Therefore, the effect could be mediated by the inhibition of demineralization following a cariogenic challenge rather than by enhanced remineralization during the eating phase. In our study, enamel sections containing subsurface lesions were positioned lingual to the mandibular molars by means of a removable appliance. The subjects wore the appliances for a 7-week period except during oral hygiene procedures. So, this result supports the previous study by Dodds *et al.* (21) that the frequent use of chewing gum could raise the remineralization potential of plaque by the mechanism of maintaining high resting plaque pH in response to a sugar challenge.

Unfortunately, we could not differentiate between sugar alcohols and gum base, and this work was done only for a 1-week treatment period of chewing, but if this study prolong the treatment periods and analyze the sub-surface levels of enamel, remineralization effects of each polyol may be able to differentiate exactly.

Our recent trial suggested that the effectiveness of maltitol chewing gum could be similar to that of chewing xylitol gum in remineralization. For caries-active individuals or individuals with increased susceptibility to dental caries, the regular chewing of maltitol-sweetened gum can be a useful supplement to other caries-preventive measures.

In conclusion, we found that SEM of enamel lesions showed the remineralization effect of gum containing gum base only, maltitol, xylitol compared to sugar gum. Maltitol and xylitol gum may be useful in the prevention of dental caries as sugar substitute.

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