Research Article

Consumption of baked nuts or seeds reduces dental plaque acidogenicity after sucrose challenge

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ABSTRACT: Purpose: To assess the acidogenic potential of eight different types of baked nuts or seeds eaten alone and after a sucrose challenge using in-dwelling electrode telemetry. **Methods:** Six participants wearing a mandibular partial prosthesis incorporated with a miniature glass pH electrode were enrolled. The plaque pH was measured after 5 or 6 days of plaque accumulation. To establish a control, the subjects were instructed to rinse with sucrose, without any subsequent treatment, at the first visit. At each subsequent test visit, the subjects were asked to chew sugar free xylitol gum or consume 10 g of baked (180°C, 5 minutes) peanuts, walnuts, pistachios, cashews, almonds, sunflower seeds, pumpkin seeds, or watermelon seeds alone and 10 minutes after a sucrose rinse. The minimum plaque pH value and area of plaque pH curve under 5.7 ($AUC_{5.7}$) during and after nut/seed consumption or gum chewing alone, the plaque pH value at 10 minutes after the sucrose rinse, the time required for the pH to return to >5.7 and $AUC_{5.7}$ after the sucrose rinse with or without nut/seed consumption or gum chewing were calculated from the telemetric curves. **Results:** The sucrose rinse induced a rapid decrease in the plaque pH to 4.32 ± 0.17 at 10 minutes; this value remained below 5.7 for the measurement period. The $AUC_{5.7}$ values were 34.58 ± 7.27 and 63.55 ± 15.17 for 40 and 60 minutes after the sucrose challenge, respectively. With the exception of cashews and pumpkin seeds (minimum pH, 5.42 and 5.63 respectively), the nuts or seeds did not decrease the plaque pH to below 5.7 when consumed alone, with the $AUC_{5.7}$ values during and after consumption (total 40 minutes) ranging from 0.24 to 2.5 (8.44 for cashews), which were significantly lower than those after the sucrose challenge. Furthermore, nut/seed consumption or gum chewing after the sucrose challenge significantly reversed the sucrose-induced decrease in the plaque pH, and the time required for the pH to return to >5.7 and the $AUC_{5.7}$ values for 60 minutes after the sucrose challenge were much less than that of the sucrose challenge without subsequent interference. (*Am J Dent* 2016; 29:145-148).

CLINICAL SIGNIFICANCE: Baked nuts or seeds did not enhance plaque acidogenicity when consumed without additional sugar and may help prevent caries when consumed after the intake of meals or sugar-containing snacks or beverages.

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Introduction

Dental caries is a diet-associated disease.[1] The most important dietary factor involved in caries development is fermentable carbohydrates.[2,3] When carbohydrates are consumed, dental plaque bacteria use them to produce acids, which induce a rapid pH drop in the plaque biofilm to a level that can cause demineralization of the dental enamel. This low pH persists for some time and returns to the original value after 30-60 minutes through acid clearance or buffering by saliva or alkali generated from salivary substrates such as arginine and urea. This pH reversal allows for the remineralization of dental enamel.[4-6] The pH of dental plaque generally fluctuates during the day, because of the periodic ingestion of foods and/or beverages. The integrity of the enamel depends on the balance between demineralization and remineralization, with dental caries occurring when the amount of demineralization exceeds that of remineralization over a prolonged period.[7,8] Therefore, frequent consumption of sugar-containing snacks or beverages between meals is an important risk factor for the development of dental caries through the promotion of acid production and demineralization.[9-12] Studies[13] suggest that the intake of snacks between meals has doubled in children and adults over recent decades. Therefore, it is important, as a dietary control strategy for caries prevention, to limit the consumption of sugar-containing snacks or promote healthy snacking patterns.

Nuts and seeds contain relatively low fermentable carbohydrates[14] and are popular snack foods in many regions of the world. Nuts and seeds are also rich in important nutrients, including proteins, fibers, unsaturated fatty acids, minerals, and vitamins. Moreover, recent epidemiologic and clinical studies have provided consistent evidence of the cardioprotective effects of nuts and seeds.[15,16] A questionnaire-based investigation[17] also revealed that the average weekly intake of nuts is associated with less caries experience. The low acidogenic potential of peanuts was shown decades ago,[18] and these nuts are now recommended as a putative cariostatic food.[19] Therefore, one can presume that other nuts and seeds can also serve as healthy snack foods with regard to dental health. However, the acidogenic potential of the nuts and seeds commonly consumed in most parts of the world remains to be fully assessed.

In addition, the order in which different foods are consumed during a meal also affects dental plaque acidogenicity. This means that the cariogenic potential of sugars can be modified by the ingestion of noncariogenic foods or a change in the order of consumption of sugary foods relative to other foods during a meal.[20-22] Although the acidogenicity and demineralization potential of many foods have been well assessed,[11,23] the acidogenicity of popular nuts and seeds and the benefits of their consumption after a sugar challenge remain to be explored in terms of caries prevention.

In the present study, the acidogenic potential of eight different types of baked nuts or seeds (baked peanuts, walnuts, pistachios, cashews, almonds, sunflower seeds, pumpkin seeds,

and watermelon seeds) was examined when consumed alone or after a sucrose challenge using in-dwelling electrode telemetry.

Material and Methods

Subjects - Six healthy subjects aged 56 to 72 years (four males and two females) were recruited from the Department of Prosthodontics, Peking University School and Hospital of Stomatology. Subjects with two or three missing teeth in the premolar and molar regions of the mandible were included. None of them exhibited active caries lesions, unfilled cavities, periodontal disease, or other oral diseases. The stimulated salivary secretion rate was ≥ 0.6 ml/minute for all subjects, and the mean saliva pH was 7.48. Ethical approval (Approval no. PKUSSIRB-201311100) was obtained from the Ethical Committee of Peking University Health Science Center. Informed consent for participation was obtained from each subject.

In-dwelling electrode telemetry - The in-dwelling electrode telemetry system was established and performed as previously described.[24-26] Briefly, a mandibular partial prosthesis incorporated with a miniature glass pH electrode[a] was fabricated for each subject. The tip of the electrode faced the interdental surface of the subject's adjacent abutment teeth below the proximal contact point. The pH was continuously recorded (μR1000[b]) and the original pH curve was scanned (intuos3[c]) and analyzed by computer software (TelDat,[d] Version 1.5). The electrode was calibrated with a standard buffer pH of 7.00 before each test session.

Plaque accumulation - Plaque accumulation on the tip of the electrode was encouraged as previously described.[24-26] Briefly, the subjects were instructed to wear the prosthesis with clean electrodes in place and were not permitted to remove it or alter their eating habits. They were asked to refrain from all oral hygiene measures for the entire experimental period, except for rinsing with water and brushing their teeth with toothpaste. pH measurements were obtained early in the morning on the test day. The subjects were not permitted to consume anything but water for 14 hours before the test.

Experimental procedures - The tested items included the following: peanuts, walnuts, pistachios, cashews, almonds, sunflower seeds, pumpkin seeds, and watermelon seeds. All nuts or seeds purchased from the local market were baked 180°C (356°F) for 5 minutes without the addition of sugar or salt or any other food additives to avoid any additional effects on plaque pH. At the first visit, the subjects were instructed to rinse with 15 ml of 10% sucrose for 2 minutes, and the pH was measured for 60 minutes after the sucrose rinse. On subsequent visits, each subject chewed xylitol-containing gum (sugar free) or consumed a 10 g serving of one of the nuts or seeds. A 1-week interval was maintained between each visit.

During each session, the subjects first chewed paraffin for 3 minutes to normalize the plaque pH. After an initial period of 20 minutes for establishment of the baseline plaque pH, the subjects were instructed to eat 10 g of one of the test nuts or seeds for 10 minutes and rest for 30 minutes. Then, the pH was adjusted to the baseline by asking them to rinse with water for 2 minutes, chew paraffin for 3 minutes, and rest for 4 minutes. The subjects were then instructed to rinse with 15 ml of 10% sucrose for 2 minutes. Ten minutes after expectoration, they consumed the same amount of the same nuts or seeds for 10 minutes, and the pH was recorded for 40 minutes after consumption. The nuts or seeds were randomly chosen for each subject at each visit. Each subject underwent 10 test sessions, and a total of 60 (6 × 10) telemetric curves were recorded.

Table 1. Minimum plaque pH (mean ± SD) and $AUC_{5.7}$ (mean ± SD) values during and after the consumption of eight different types of nuts or seeds (n= 6).

Groups	Minimum pH	$AUC_{5.7}$ (arbitrary unit)
Peanuts	6.04 ± 0.40	0.50 ± 0.89*
Sunflower seeds	5.94 ± 0.31	2.50 ± 4.00*
Almonds	5.88 ± 0.53	1.11 ± 0.64*
Walnuts	5.85 ± 0.32	0.62 ± 0.37*
Watermelon seeds	5.78 ± 0.25	0.24 ± 0.27*
Pistachios	5.77 ± 0.40	1.96 ± 3.69*
Pumpkin seeds	5.63 ± 0.28	2.14 ± 2.61*
Cashews	5.42 ± 0.43	8.44 ± 7.95*
Xylitol gum	6.68 ± 0.35	0*
Sucrose rinse (40 minutes)	4.32 ± 0.17	34.58 ± 7.27

*P< 0.05 versus the sucrose rinse group.

In all experiments, the minimum plaque pH value and area of plaque pH curve under 5.7 ($AUC_{5.7}$) during and after nut/seed consumption or gum chewing alone, the plaque pH value at 10 minutes after the sucrose rinse, the time required for the pH to return to >5.7 and $AUC_{5.7}$ after the sucrose rinse with or without nut/seed consumption or gum chewing were calculated from the telemetric curves. $AUC_{5.7}$ is a parameter for the severity and duration of acidogenicity and is derived from a pH × time integration by computer software (TelDat, Version 1.5). A larger $AUC_{5.7}$ value represents higher acidogenic potential. In the present study, a pH of 5.7 was automatically set as the critical pH for the analysis of pH curves by the software (TelDat, Version 1.5), which was developed on the basis of the Swiss Food Ordinance that states the following: "Products may be labeled 'safe for teeth' with regard to dental caries only if they have been proved in intraoral plaque telemetric tests not to depress the pH of interdental plaque below 5.7 by bacterial fermentation either during consumption or up to 30 minutes later".[24]

Statistical analysis was performed using SPSS 15.0[e] for Windows. Differences in $AUC_{5.7}$ values and the time required for the pH to return to > 5.7 between the sucrose challenge group and the chewing gum or nut/seed groups and between the chewing gum and nut/seed consumption groups were examined using two-way ANOVA. All data were presented as means ± standard deviation (SD). A P-value of < 0.05 was considered statistically significant.

Results

The sucrose rinse resulted in a significant and prolonged decrease in the plaque pH.

Rinsing with 10% sucrose for 2 minutes resulted in a rapid decrease in the plaque pH to 4.32 ± 0.17 at 10 minutes; this value remained below the critical value of 5.7 until the end of measurement. The $AUC_{5.7}$ values for 40 and 60 minutes after the sucrose challenge were 34.58 ± 7.27 and 63.55 ± 15.17, respectively.

The plaque pH mostly remained > 5.7 after nut/seed consumption alone.

As shown in Table 1, the minimum plaque pH did not decrease to < 5.7 during the 10-minute eating phase and the following 30 minutes for all nuts/seeds except cashews and

Table 2. Minimum plaque pH (mean ± SD) values at 10 minutes after the sucrose challenge, time (mean ± SD) required for the plaque pH to return to 5.7, and $AUC_{5.7}$ (mean ± SD) values for eight different types of nuts or seeds (n = 6) consumed after the sucrose challenge.

Groups	10 min after sucrose challenge	Time required for the pH to return to 5.7 (min)	$AUC_{5.7}$ values after the sucrose challenge (arbitrary unit)
Almonds	4.39 ± 0.04	18.20 ± 5.91*	17.60 ± 6.53*
Pistachios	4.50 ± 0.13	21.40 ± 8.39*	18.32 ± 8.53*
Walnuts	4.34 ± 0.11	27.00 ± 4.36*	18.57 ± 16.47*
Peanuts	4.45 ± 0.08	19.40 ± 4.79*	21.61 ± 9.86*
Sunflower seeds	4.31 ± 0.15	23.00 ± 4.26*	23.01 ± 6.57*
Watermelon seeds	4.36 ± 0.15	27.38 ± 6.60*	27.96 ± 10.01*
Pumpkin seeds	4.33 ± 0.33	30.88 ± 8.23*#	31.48 ± 7.29*#
Cashews	4.41 ± 0.31	31.50 ± 4.69*#	39.20 ± 10.80*#
Xylitol gum	4.52 ± 0.21	17.75 ± 2.22*	15.10 ± 6.94*
Sucrose rinse (60 min)	4.32 ± 0.17	57.50 ± 1.22	63.55 ± 15.17

*P< 0.05 versus the sucrose rinse group.
#P< 0.05 versus the xylitol gum group.
min = minutes.

pumpkin seeds, which decreased the pH to 5.42 ± 0.43 and 5.63 ± 0.28, respectively. The $AUC_{5.7}$ values for 40 minutes after consumption ranged from 0.24 to 2.5 (8.44 for cashews), which were significantly lower than that after the sucrose challenge. However, the minimum plaque pH of xylitol gum chewing was 6.68 ± 0.35 and the $AUC_{5.7}$ value was zero during same period of time (Table 1).

The sucrose-induced decrease in the plaque pH was significantly reversed by nut/seed consumption or gum chewing.

The sucrose rinse resulted in a rapid decrease in the plaque pH to 4.31-4.50 at 10 minutes after expectoration (Table 2). However, nut/seed consumption after the sucrose challenge increased the pH to 5.7 and maintained it around this value during the measurement period. All the nuts and seeds and the xylitol-containing gum significantly decreased the mean $AUC_{5.7}$ values (Table 2) after the sucrose challenge. With the exception of cashews and pumpkin seeds, the $AUC_{5.7}$ values were similar between the gum and the nut/seed groups (P> 0.05; Table 2). Similar results were obtained for the time required for the plaque pH to return to > 5.7 for the gum and the nut/seed groups (P> 0.05; Table 2). However, the time required for the pH to return to > 5.7 for the gum and the nut/seed groups for 60 minutes after the sucrose challenge were much less than those calculated after the sucrose challenge alone.

Discussion

In the present clinical study, in-dwelling electrode telemetry was used to demonstrate that the consumption of plainly baked peanuts, walnuts, pistachios, cashews, almonds, sunflower seeds, pumpkin seeds, and watermelon seeds rarely decreases the pH of dental plaque below the critical pH of 5.7, at which enamel demineralization occurs. These findings suggest that these baked nuts or seeds have low cariogenic potential. Moreover, the consumption of these baked nuts or seeds significantly reversed a sucrose-induced decrease in the plaque pH, implying that the consumption of these baked nuts or seeds after the intake of sugary foods may inhibit demineralization and help caries prevention.

The acidogenicity of baked nuts or seeds is low. Although the consumption of cashews or pumpkin seeds resulted in a minimum plaque pH that was only slightly below the critical pH of 5.7, and according to the ToothFriendly International criteria, these may not be tooth-friendly foods, the minimum plaque pH after the consumption of the other nuts or seeds remained > 5.7 during the 40-minute measurement. Therefore, the overall acidogenicity of the assessed plainly baked nuts or seeds was low, suggesting that there would be no or minimal demineralization of the teeth during and after their consumption. The low acidogenicity of the nuts or seeds may be primarily related to their relatively low content of carbohydrates or total soluble sugars.[14,27-29] For example, Venkatachalam[14] reported that the total soluble sugars content in cashews was 3.96% (grams per 100 g of the edible portion, the highest), whereas that in peanuts, pistachios, walnuts, and almonds was 0.55%-2.11%. Therefore, among the nuts and seeds examined, cashews appeared to be slightly more acidogenic compared with the others, which was also evidenced by the $AUC_{5.7}$ values. Nevertheless, the possible demineralization effects of cashews were not significant, because the corresponding $AUC_{5.7}$ value was still much smaller than that of sucrose challenge alone. Collectively, these findings suggest that nuts and seeds, including the most commonly consumed worldwide – peanuts – have low or negligible cariogenic potential.

The consumption of nuts or seeds may help in reversing the demineralization effects of the sugar present in snacks or beverages. In the present study, the consumption of baked nuts or seeds after a sucrose challenge reversed the sugar-induced decrease in the plaque pH, increasing it from 4.32-4.52 to approximately 5.7. The time required for the plaque pH to return to > 5.7 was significantly reduced, and the sugar-induced $AUC_{5.7}$ value was also decreased by approximately one third, and thus may decrease the opportunity for tooth demineralization. It is well known that the carbohydrate content and acidogenicity of foods play an important role in caries development. In addition, the sequence in which the foods are consumed is also an important dietary factor affecting the acidogenicity of foods. For instance, the consumption of dairy products can increase the plaque pH and decrease the cariogenicity of previously eaten sugary foods.[20,22] The present results also showed that the consumption of baked nuts or seeds after a sucrose challenge mitigated the acidogenicity of sucrose. Moreover, the results for peanut consumption after a sucrose challenge were consistent with the pioneering findings of Imfeld.[18]

The effects of nut/seed consumption (except cashews and pumpkin seeds, which showed higher $AUC_{5.7}$ values compared to sugar free gum) after a sucrose challenge were similar to those of xylitol-containing chewing gum (sugar free), which has been shown to help reduce caries.[30] Therefore, the consumption of baked nuts or seeds after exposure to sugar or fermentable carbohydrates may also help caries prevention.

The mechanism underlying the pH-reversing effects of baked nuts or seeds after a sucrose challenge can be primarily attributed to saliva stimulation. This can be supported by the present findings that xylitol-containing chewing gum (sugar free) could also effectively reverse the sucrose-induced decrease in the plaque pH. However, the pH-reversing effects of the food item depends on whether it is a sialagogue, its sugar content, and other buffering factors.[21] For instance, Imfeld[18]

previously showed that the consumption of apples had no significant beneficial effects on plaque acidified by the prior consumption of sugar; the increased buffering capacity of saliva stimulated by apple chewing was clearly offset by the low pH of the apples (dietary acid) and their sugar content. The nuts and seeds used in the present study also contained some level of fermentable carbohydrates that should compromise the buffering capacity of saliva to some extent; however, the pH-reversing effects of the nuts or seeds (except for cashews and pumpkin seeds) were similar to those of the xylitol-containing chewing gum. Therefore, we speculate that the nuts or seeds also contain other beneficial factors that counteract the decrease in the plaque pH. One of these can be arginine-rich proteins,[27,31] which can be used as substrates by the arginine deiminase system to produce alkali to neutralize the acids generated by sucrose fermentation.[32] Although the xylitol-containing gum and the nuts or seeds had similar effects on the plaque pH, the underlying mechanism may be slightly different. In addition, when the nuts or seeds themselves contain relatively high levels of fermentable carbohydrates, as demonstrated for cashews, the additional plaque pH-decreasing effects were obvious, while the pH-reversing effects were significantly decreased.

In conclusion, nuts or seeds are low acidogenic foods and consumption of baked nuts or seeds can reduce the plaque acidogenicity after a sucrose challenge.

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