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Cariogenic potential of presweetened breakfast cereals

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Abstract

Twelve presweetened breakfast cereals were evaluated for cariogenic potential by in vitro methods. The parameters evaluated were the levels of acid produced by a cariogenic strain of Streptococcus mutans *as influenced by each cereal, the percentage of sugar content, and the salivary retention time of glucose after ingestion of each cereal with or without milk.*

Cariogenicity was found to be related to sugar content and most cereals exhibited an increased salivary retention time when consumed without milk.

Those cereals with a low cariogenic potential were Cheerios,® Rice Krispies,® Grape-nuts,® and Cocoa Puffs.® Cereals associated with high cariogenic potential were Cookie Crisp®, Sugar Corn Pops®, Cocoa Krispies,® Frosted Mini-wheats,® and Powdered Donutz.®

Thus, two factors should influence the discriminate selection of presweetened breakfast cereals: the quantity of sugar present and the use of the product with or without milk. Each of these factors may alter the cariogenicity of breakfast cereals.

There has been a growing concern within the dental profession about the cariogenic potential of various foods. Ideally, assessment of food cariogenicity involves several factors which encompass the host, the diet, and those microorganisms contained in plaque which ferment carbohydrates and produce acids that ultimately cause dental decay through the demineralization process.[1] In addition to the presence of sucrose, other factors such as the frequency or sequence of consumption, salivary retention time, amount of acid formed during fermentation by microbes and the condition under which the food is ingested may affect the cariogenic potential of a food product.[2-6]

Because of the increased use of processed snack and convenience foods by consumers,[7] investigations of the cariogenic potential of these foods are necessary to identify products that may be potentially detrimental to teeth. This will enable the clinician and patient to recognize and select foods which are less caries conducive. Several methods have been documented for measuring and comparing the cariogenic potential of foodstuffs. Some of these methods include plaque pH measurements, enamel solubility studies, in vivo plaque and acid formation, dietary monitoring, and animal caries studies.

Imfeld et al.[8] have conducted research on plaque pH measurements through the use of indwelling electrodes during consumption of various foods. Weiss and Bibby[9] demonstrated that milk and its casein constituents offered the enamel protection from dissolution in acids. Similarly, Bibby et al.[10] showed that the presence of milk in a fermentable food reduced enamel solubility. Enamel solubility can be reduced by more than 20% when using cows' milk, regardless of its being raw or pasteurized, whole or skim.[9] Further studies on enamel demineralization by Bibby and Mundorff[11] indicated that fermentation of snack foods was influenced by flavoring agents and other components.

Newbrun et al.[12] compared the dietary habits and dental health of 17 persons with hereditary fructose intolerance, a disorder requiring a lifetime sucrose-restricted diet, to those of a control group and concluded that a direct causal relationship exists between sugar ingestion and caries. Berry and Martin[4] conducted in vitro acid production and enamel demineralization studies on machine-vended and health-food snacks to determine their relative caries-promoting ability. Wilson[7] measured the effect of ready-to-eat cereals on dental caries in 145 adolescent males.

Animal studies also have been used to measure cariogenic potential. Stookey[13] assessed diet consistency of presweetened cereals in rats. Grenby and

Bull[14] studied the effects of breakfast cereals on dental caries in rats as well as caries control using a calcium glycerophosphate additive. Egelberg[15] determined the importance of diet consistency in bacterial plaque formation and gingivitis in dogs by studying the effects of dietary frequency and oral bypass.

Interest in determining the cariogenic potential of sucrose-containing foods not only has been stimulated by the increased consumption of processed foods containing sucrose,[7] but also by the advertising of these foods. Presweetened cereals were chosen for this study because presweetened cereals often are eaten as between meal snacks without milk.[16] Also, children, the primary consumers of presweetened cereals, are the main target of advertising of those cereals having a higher sugar content.[16-18] If presweetened cereals are consumed as snacks without milk then the protective effect of casein in milk is absent. Additionally, cereals consumed dry are more likely to stick to teeth, thus increasing the retention of fermentable carbohydrates in the mouth.[3]

The present study included 3 methods to measure the in vitro ability of a cariogenic strain of *Streptococcus mutans* to produce acid from fermentable carbohydrates found in each cereal and a method to determine salivary retention time of glucose after the consumption of each cereal either with or without milk.

Methods and Materials

Twelve presweetened breakfast cereals were chosen for evaluation of their cariogenic potential: Cookie Crisp,[a] Cocoa Krispies,[b] Fruit Loops,[b] Sugar Corn Pops,[b] Frosted Mini-wheats,[b] Rice Krispies,[b] Sugar Frosted Flakes,[b] Cocoa Puffs,[c] Powdered Donutz,[c] Cheerios,[c] Cap'n Crunch,[d] and Grape-nuts.[e] These cereals were selected by a preadolescent consumer and purchased from a local grocery store. All cereals are available at most supermarkets since they are advertised and distributed nationally. Prior to analysis each cereal was crushed with a mortar and pestle to an equivalent consistency, and then sterilized using ethylene oxide gas to avoid the possibility of contamination from microorganisms within the cereal or from the environment.

The experimental design incorporated several test or control conditions for each cereal to examine acid production and demineralization. Each tube contained a basal broth medium which included trypticase but no added carbohydrates or buffers.[19] The test or control conditions included 10 ml of basal medium, *S. mutans* strain 6715 cells suspended in a solution of sterile phosphate buffer (0.06 M, pH 6.8), 10 mg of hydroxyapatite (HA), and 0.5 g cereal, either singly or in combination. Each test mixture was placed in an anaerobic chamber containing an atmosphere of 85% nitrogen, 10% hydrogen, and 5% carbon dioxide and allowed to incubate for 24 hr at 35°C. Three methods were used to estimate acid production of *S. mutans* — terminal pH, total titratable acidity, and calcium ion release through demineralization of HA, the main inorganic component of enamel.

Change in Terminal pH

After incubation, a pH meter[f] was used to obtain the level of acidity of each test or control mixture. By subtracting the final pH value from the initial, the change in pH due to the acids formed by *S. mutans* while metabolizing the components of each cereal was evaluated.

Total Titratable Acidity

The quantity of 0.001 M sodium hydroxide necessary to back titrate each test or control condition to the starting pH of the uninoculated control was determined using a pH meter and a buret filled with titrant.

Calcium Ion Release

Demineralization of HA was monitored by measuring the release of calcium ion. A 20-μl aliquot was removed from each test or control mixture and added to a working solution of calcium reagent.[20] The calcium level in each sample then was estimated using a fluorometer.[g] The relative intensity of fluorescence of each tube was compared to a standard curve of known calcein levels.

Oral Retention Time

Salivary retention of the reducing sugars of each cereal used in the study was analyzed by a glucose oxidase[h] method. Each of 6 volunteers was provided 6, 1-ounce servings of 2 cereals which were ingested without milk on 3 different days. Concentrations of salivary glucose in subjects were tested before ingestion of test cereals, immediately after, and at 10-min intervals during a 30-min period. An identical analysis also was performed on the same cereals moistened with milk.

[a] Ralston Purina Co: St Louis, MO.
[b] Kellogg's: Battle Creek, MI.
[c] General Mills, Inc: Minneapolis, MN.
[d] Quaker Oats Co: Chicago, IL.
[e] Post/General Foods Corp: White Plains, NY.

[f] Model 125 — Corning Instruments: Medfield, MA.
[g] Model J4-8960 Aminco Bowman Spectrophotofluorometer — American Instrument Co: Silver Spring, MD.
[h] Ames Co, Miles Laboratories, Inc: Elkhart, IN.

Statistical Analysis

The data were evaluated for correlation between the sugar content of each cereal and acid production measured by 3 methods. The Pearson's product-moment correlation coefficient (r)[21] was calculated[22] for each method.

Results

Table 1 presents the production of acid by *S. mutans*, the salivary retention time, and percentage of sugar content for each cereal. These parameters were evaluated in order to rank the cariogenic potential of the cereals (Table 2). In general, a positive correlation was found between those cereals having a high sucrose content and the production of acid. The correlation coefficient was statistically significant at the 0.01 level when relating cereal sugar content to change in pH ($r = +0.72$) and total titratable acidity ($r = +0.86$), but calcium release was not significant at $p = 0.05$ (although $r = +0.53$). Of the 6 cereals found to have the greatest change in pH, 5 had a sucrose content of 42% or greater. These same cereals, along with Frosted Mini-wheats, Cap'n Crunch, Sugar Frosted Flakes, Powdered Donutz, Cocoa Krispies, Cookie Crisp, and Sugar Corn Pops exhibited a greater release of calcium ion from the HA crystals than their counterparts with a lower sucrose content. These same cereals tended to exhibit a higher concentration of sugar in the oral cavity when no milk was consumed with the product. Consumption with milk markedly reduced salivary retention time of sugar in all cereals included in this study. Those cereals judged to be least cariogenic (having the smallest change in terminal pH, a minimum concentration of calcium ion release, and decreased salivary retention time) were Grape-nuts, Cocoa Puffs, Rice Krispies, and Cheerios.

Discussion

It is well known that foods high in sucrose which are consumed frequently tend to be cariogenic.[23] The ability of a food to contribute to the carious process has been related directly to sucrose content.[2, 6] Although sucrose content and frequency of intake are important in determining cariogenic potential of foods, other factors such as salivary retention time, amount of acid formed on fermentation in bacteria, and the conditions under which foods are consumed also should be considered. As sucrose content increases, acidity of microbial origin also increases, thus increasing enamel demineralization and potential caries formation. It is possible that some cereals contain intrinsic acid which could provide another source of acid than that produced by the microorganism. Flavoring agents and the presence of phosphate additives have been shown to affect the fermentation of salivary bacteria.[24]

Consistency, or the physical form of the cereals, also affects oral retention time. For example, Frosted Mini-wheats and Sugar Corn Pops, which possess a high sucrose content produced sugar retention times comparable to the cereals of low sugar content when consumed with milk. However, when consumed without milk the retention time was higher, both immediately following and 10 min after ingestion. This suggests that unless consumed with milk, these cereals tend to have longer retention times, thus enhancing enamel demineralization through bacterial acid production. Because children tend to consume these cereals as snacks without milk,[16] the cariogenic po-

Table 1. Acid production of *Streptococcus mutans*, salivary glucose retention times, and percentage of sugar content of 12 presweetened breakfast cereals

	Acid Production			Salivary Retention Time (mg % Glucose after 10 min)		% Sugar
	ΔpH	TTA	Ca^{++} Release	With milk	Without milk	Content ****
Cookie Crisp	2.3*	6.4**	42***	0	0	45.9
Cocoa Krispies	2.4	5.6	71	0	45	45.9
Froot Loops	2.3	5.5	38	0	25	45.9
Sugar Corn Pops	2.4	4.6	74	0	130	45.9
Sugar Frosted Flakes	2.5	4.5	39	0	0	45.9
Cap'n Crunch	2.0	5.3	72	0	25	42.3
Cocoa Puffs	1.9	4.7	10	0	0	38.8
Powdered Donutz	2.5	5.4	92	0	45	35.3
Frosted Mini-wheats	2.5	4.6	95	25	25	26.0
Grape-nuts	1.9	3.5	15	0	0	7.0
Rice Krispies	1.7	2.3	2	0	25	7.0
Cheerios	0.4	0.3	5	0	0	3.0

* Initial minus terminal pH; ** ml of 0.001 M NaOH for back titration to initial pH; *** μg/ml released through demineralization of HA; **** Sucrose and other sugars.

Table 2. Ranking of Presweetened Breakfast Cereals.

Cheerios (1)*
Rice Krispies (1.06)
Grape-nuts (1.2)
Cocoa Puffs (1.3)
Sugar Frosted Flakes (1.6)
Froot Loops (1.8)
Cap'n Crunch (1.9)
Cookie Crisp (2.2)
Sugar Corn Pops (2.3)
Cocoa Krispies (2.7)
Frosted Mini-wheats (2.7)
Powdered Donutz (3.2)

* Numerical order based on the sum of the composite rank of each cereal divided by the value of the least cariogenic cereal (Cheerios).

tential of these foods becomes greater. Without the protective effect that milk has on enamel solubility the tooth becomes more susceptible to acid demineralization and may be exposed to fermentable carbohydrate for longer periods.

Further, the presence of chocolate may act to decrease pH in presweetened cereals. Cariostatic properties of cocoa extracts have been shown to exist.[25] Results of this study indicate that Cocoa Puffs, while almost 40% sucrose, exhibited a minimal pH change when compared to cereals of lower sucrose content. Total titratable acidity and the release of calcium from HA crystals was lower, denoting a possible relationship between the presence of chocolate and decreased caries potential.

Summary and Conclusions

Cariogenic potential was found to be related directly to the sugar content of each cereal. In addition, those cereals possessing high cariogenic potential tended to exhibit increased salivary retention time when consumed without milk, thereby increasing exposure time of the cereal to the oral cavity. Increased exposure time allows for utilization of the carbohydrates present, thus increasing acid production. Those cereals ranked as highly cariogenic tended to release greater amounts of calcium when exposed to the acid-producing microorganism, *S. mutans*. This demonstrates the potentially damaging effects these cereals can have on human enamel, especially when a fluid medium such as milk, is not present to allow the dilution of carbohydrates. Although milk has been found to have a "protective" effect on enamel by reducing its demineralization,[10] it has been demonstrated that the use of water in the dilution of acid after intake of carbohydrates has only minimal effects on pH decrease.[26]

This study draws a definite correlation among the presence of sucrose, oral retention time, acid demineralization, and the cariogenic potential of presweetened breakfast cereals. The ingestion of milk influenced the cariogenic potential of presweetened breakfast cereals by reducing the length of time that fermentable carbohydrates were retained in the mouth. Dental professionals can utilize this information to enhance public awareness of the potential dangers that some presweetened cereals can pose to child's oral health, especially when consumed frequently as a between-meal snack without milk.

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