

Practical problems in use of sugar substitutes in preventive dentistry

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Abstract

Sugar (sucrose) being most acceptable sweetening agent in use by mankind is considered as the “Arch Criminal” in dental caries initiation. Search for suitable sweetening agent which will satisfy all the characteristics of sugar along with being non-cariogenic is going on since decades. At this given point of time, there is no such substitute which will replace sugar in all aspects, but, cariogenic potential can certainly be reduced by using sugar substitutes. Recently, few sugar substitutes are even considered to have antimicrobial property against caries producing microbes in oral cavity. Although sweetening agents and sugar substitutes are available in market in various forms, how acceptable are they?, what are the public perceptions regarding their use?, and their use in caries prevention are few areas still very much unclear

Key words: *Artificial sweeteners, dental caries, sugar, xylitol*

INTRODUCTION

The importance of diet in the development of caries was suspected in antiquity and established in modern times. The process has been shown to be multifactorial in nature, but it has been generally accepted that sugar in the diet are a major contributor to the disease.^[1]

Since the earliest period of recorded history, man has suspected that the process of the dental decay is related to the type of food he consumes. In the fourth century B.C., Aristotle expressed the view that dental caries was caused by consumption of sweet figs that struck to the teeth. More than 23 centuries have elapsed, and yet we still lack any really definitive information concerning the relative cariogenicity of specific food composing the human diet.

However, in view of the human taste preference for sweetness, it is unlikely that many patients will voluntarily restrict their sucrose consumption permanently in order to reduce dental caries. A more realistic approach may be to provide sucrose substitutes in the diet that lack harmful dental side effects. In order to be successfully used in a wide variety of foods, such substances should not only be sweet but also in many instances they need to provide calories and bulk. Unfortunately, no one can estimate accurately the extent to which sucrose or other dietary sugar must be reduced in human foods in order to produce significant caries reduction.^[2,3] This lack of information is largely because of the many variables affecting human caries, including the oral retention times of food, the frequency of consumption, and the possible presence of buffers or other “protective factors” in food.^[4]

The dental professionals have the opportunity to provide advice regarding the importance of diet and role of sugars in caries formation. It is important that the dentist must be familiarized with the alternatives to sugars and the types of food products that are available with substitute sweetening agents. The identification of new safe, palatable, heat stable, non-low caloric sweetener substitutes for the more cariogenic sugars

Access this article online	
Quick Response Code:	Website: www.jispcd.org
	PMID: ***
	DOI: 10.4103/2231-0762.86373

such as sucrose, glucose, fructose and maltose continue to be actively sought for use in the food industry.^[1] Reviews on relationship between sugar and dental caries are summarized by several researchers^[5] [Table 1].

CONCEPT OF SUGAR SUBSTITUTES

The association between the frequency of sugar consumption and dental caries has been well documented.^[6] So, the dental profession shares an interest in the search for safe, palatable sugar substitutes.

The major factors that prompted for the search of suitable sugar substitutes related to dental health are as follows.

1. The attempt to persuade the patients to adopt special dietary programs to limit the frequency with which sugar-containing food are ingested could not be practically achieved for the prevention of caries on a public health scale. It is indeed difficult to change dietary habits, especially if the change

requires the elimination of palatable, conveniently available food.

2. Animal experimentation clarified many aspects of cariogenicity of sucrose relative to other dietary components and led to the discovery that in most instances dental decay is a sucrose-dependent infection involving *Streptococcus mutans*. The observations in the human have associated *S. mutans* with human dental decay and generally support the sucrose/*S. mutans* interactions observed in the animal models. As the emergence of *S. mutans* appears to be sucrose dependent, then tactics which reduce sucrose bioavailability in the plaque ecosystem should constitute effective preventive and/or therapeutic measures in caries control. Interferences with between meal sucrose bioavailability can be most easily achieved by the use of sugar substitutes, and this provides the rationale for prevention through their use.
3. The Turku xylitol chewing gum study. The clinical trials conducted in Turku showed that xylitol was non-cariogenic and quite possibly anti-cariogenic

Table 1: Review articles on the relationship between sugar (diet) and dental caries

Author(s)	Main conclusions
Marthaler (1967)	Foodstuffs containing simple sugars are far more cariogenic than common starchy foods.
Newbrun (1969)	Called for the specific elimination of sucrose or sucrose-containing foods rather than restricting total carbohydrate consumption
Bibby (1975)	Snack foods share importance with sucrose in caries causation
Sreebny (1982a)	Total consumption and frequency of intake contribute to dental caries; lacking evidence about the precise definition of the relationship
Newbrun (1982a)	Compelling evidence that the proportion of sucrose in a food is one important determinant of its cariogenicity
Sheiham (1983)	Sugar is the principal cause of caries in industrialized countries; recommended that sugar consumption be reduced to 15 kg/person/year or below
Shaw (1983)	Studies in animals consistent with the clinical evidence on the relationship between sugar and caries
Rugg-Gunn (1986)	Cariogenicity of staple starchy foods is low; the addition of sucrose to cooked starch is comparable to similar quantities of sucrose; fresh frits appear to have low cariogenicity
Bowen and Birkhed (1986)	Frequency of eating sugars is of greater importance than total sugar consumption
Walker and Cleaton-Jones (1989)	Degree of incrimination of sugar as a cause of caries is grossly exaggerated; questioned predictions of reductions in caries from decreases in sugar and snack intakes
Marthaler (1990)	In spite of dramatic reductions in caries due primarily to widespread use of fluoride, sugars continue to be the main threat to dental health
Rugg-Gunn (1990)	Dietary modification involving restriction on the frequency and amount of extrinsic sugars can be more effective than other control measures
Konig and Navia (1995)	Acknowledged the relationship between frequency and sugar intake and caries; recommended removing the focus away from elimination of sugar and towards improved oral hygiene and use of fluoride toothpaste
Ruxton <i>et al</i> (1999)	Evidence strongly supports formulation of advice on frequency of consumption, not amount
Konig (2000)	Dental health problems do not require any dietary recommendations other than those required for maintenance of general health
Van Loveren (2000)	If good oral hygiene is maintained and fluoride is supplied frequently, teeth will remain intact even if carbohydrate-containing food is frequently eaten
Sheiham (2001)	Sugars, particularly sucrose, are the most important dietary cause of caries; the intake of extrinsic sugars greater than 4 times a day increases caries risk; sugar consumption should not exceed 60 g/day for teenagers and adults and proportionally less for younger children

when substituted for sucrose either in foods or in chewing gums. The xylitol food study was a 2-year clinical trial in which young adults volunteers consumed food sweetened with sucrose, or fructose, or xylitol. The xylitol group exhibited at the end of the study about an 85-90% reduction in caries score compared to the sucrose group.^[7]

4. Cariogenicity of *S. mutans* is based upon it having a pH optimum at the critical pH for enamel demineralization. So, one can simultaneously discriminate against *S. mutans* and promote enamel remineralization by procedures which prevent or minimize acid production in the plaque. In this regard the use of sucrose substitutes becomes an extremely attractive tactic for the control and/or prevention of dental caries. The potential of this approach was first realized by the remarkable 80% reduction of caries relative to a sucrose control observed with a xylitol chewing gum in the Turku study.^[2,4,8]

Sugar alcohols mainly xylitol and sorbitol have been extensively researched since they also provide bulk and calories at the same time being less cariogenic. Many researchers have concluded that xylitol as antimicrobial properties also.^[9-17] Proposed actions of xylitol are summarized by previous research^[9] [Table 2].

A further effect of sugar substitution affecting the acidogenicity of plaque indirectly is the possibility of changing the plaque flora away from the highly acidogenic species dominating cariogenic plaque toward a relatively benign selection of organisms whose acid production potential is reduced. Substantial evidence of this effect is obtained with total substitution of sucrose. Whether or not selective substitution can have similar action is a question about which more information is needed.^[11,18-21]

Table 2: Proposed actions of xylitol

Plaque	Non-fermentability by plaque organisms Reduction in plaque quantity Selective reduction of mutans streptococci Induction of mutans streptococcus strains with reduced virulence Increased concentration of ammonia in plaque Accumulation of xylitol-5-phosphate in some plaque streptococci Participation in a futile metabolic cycle in some plaque organisms Reduced adhesion of plaque flora Reduced transmission of mutans streptococci
Saliva	Changes in quantity and quality of saliva
Enamel	Aids remineralization

DIFFICULTIES IN THE SUBSTITUTION OF SUCROSE

There may be weighty reasons for the replacement of sucrose by other sweeteners, but such substitution is not at all simple. The sweetness of the sweeteners varies widely. If the sweetness of sucrose is 1, then that of lactose is 0.2, whereas the sweetness of saccharin is 300. If the product is to taste as sweet as the conventional sucrose product, but it is sweetened with alternative sweeteners, then the change of sweetener also causes other changes in the recipe.

If the dry matter of sucrose is replaced fully by the dry matter of the new sweetener, the new product differs from the sucrose product not only in sweetness, but often in many other properties. Sweeteners differ from each other both in their physical and chemical properties. Sucrose is an unusually versatile sweetener, useful in many different types of products. If sucrose has to be replaced for health or price policy reasons by a “new sugar” it is possible that a single sweetener is not able to fulfill all the roles of sucrose in the different products. Instead, different types of foods have to be sweetened by the sweetener that can best imitate the role of sucrose in the product in question.

It is advantageous to use fructose in cold, slightly acid drinks where the sweetness of fructose is enhanced. In baking, fructose, like other reducing sugars, browns more strongly than sucrose, therefore lower baking temperature or shorter baking times are necessary.

Sugar alcohols, xylitol and sorbitol, replace sucrose well in most of the products. For yeast leavened baking they are unsuitable, however. Also for the sweetening of products in which fermentation has a decisive part (e.g. Yoghurt), xylitol and sorbitol must not be added before fermentation.

The sweetening powers of glucose, lactose, and maltose syrup are insufficient to sweeten food products. Saccharin and Cyclamate leave some bitter aftertaste, and although both are non-caloric sweeteners the energy content of food products, other than beverages, cannot be reduced using these sweeteners, because good, non-caloric baking agents, as alternatives to sucrose do not exist.^[3,22] Non-sweet uses of sugar (sucrose) are enumerated by Mackay Donald AM^[23] [Table 3].

ACCEPTANCE OF SUGAR AND SUGAR SUBSTITUTES BY THE PUBLIC

Since the public cannot accept what is not offered to it and food processors will not offer what they think not

Table 3: Non-sweet uses of sugar**Non-sweet use of sugar and functional applications**

Fermentation substrate	CO ₂ producer for bread
Fermentation substrate	Alcohol producer for beer, wines, etc.
Texturizer	Crumb texture in cakes, some meat products
Antistaling agent	Delays staling in cookies, cakes
Preservative	Jams, jellies
Colligative properties	Affects water balance and activity in pickles, fabricated foods, etc.
Humectant	Chewing gum, dog food
Browning agent	Maillard reaction, cakes, bread, barbecue sauce
Glazing agent	Cakes, candies
Sets like plaster	Icing sugar
Various specialty candy uses	Creams, toffees, caramels, fondants, etc
Caramel source	
Liquid centre candies	
Softener for chewing gum base	
'Snap' for chocolate bars	
Mouth feel, bodying agent	Canned fruits, tables syrups
Saliva stimulant (apart from taste)	
Diluent for drugs, enzymes	
Diluent for APM and saccharin	Tabletop sweeteners
Stimulant of residual pancreatic action	
First aid for diabetics (prevent insulin shock)	
Glass former (as in hard of cotton candy), plate glass for stuntmen.	
Flavor fixative	
Rapid energy source	Snack bars, IV drip
Forms syrups by acid catalysis	
Epilator	
Liquefies to syrup with little water	
Promotes fat difestibility (as in chocolate)	
Pharmaceutical necessity for cough syrups, i.e. demulcent	
Use in treatment of severe burns	
Wound healer	
Source of acid (as result of bacterial action)	
Gelling promoter (as in gelatin desserts)	
Dusting powder for handling chewing gum, other sticky foods	
Emergency antifreeze	
Bait for anti-traps	
Prevents freezer burn in frozen foods	
Foam stabilizer	
Source chemical for rigid polyurethane foams	
Source chemical for sucrose esters (fat substitutes) and emulsifiers	
Hardener for asphalt	
Set-retarder for pre-mixed concrete	
Perchlorate explosives, chlorate percussion caps, primers and smoke signals	
Making fly paper	
Wetting and dispersing agent – cocoa	
Sabotage of enemy vehicles	
Income producer for dentists	
Helps stabilize red color in processed meats	
Prevents shrinkage in smoked and cooked meats	
Improves bread texture; delays starch gelation and protein coagulation	
Prevents protein los and denaturation in comminuted fish products (Sirimi)	

be accepted, the key elements of acceptance are those used by food technologists and market researchers in the design of new products. Similarity to sucrose taste is only one of several factors. The important ones are legality, price, stability, utility in product classes (e.g. low-calorie foods), ease of advertising the advantage of the product to the consumer, and the ability to induce a purchase motivation through advertising, and education of the consumer, who usually has little or no understanding of terms like sugar substitute or artificial sweetener.

Saccharin can substitute for the taste of sugar; lactose or sorbitol or water for the weight or bulk of sugar; xylitol for both taste and bulk. But, of these, only lactose can substitute for the browning function of sucrose, and none of them can substitute for sucrose in all of its 40 or 50 uses. While many of these uses are trivial, many are vital to the function of sucrose in foods, and it is wrong to think that sugar in foods can be simply substituted by replacing it with artificial sweeteners like saccharin and cyclamate.

The term “artificial sweetener” is a poor one and fails to distinguish nutritive from non-nutritive sweeteners or even natural from synthetic ones. However, it is used because it is commonly employed and because it is sometimes useful to have a term sufficiently imprecise to cover both intensive sweeteners and bulk sugar substitutes that may not even be sweet.

In the beverage field it is clear that artificial sweeteners created new products which were additional to the sugar-sweetened products, and not competitive with them. Similarly introduction of “sugar less” chewing gum increased the total chewing gum market size without decreasing the consumption of sugar gum. The point remains that per capita consumption of sugar has been stable for decades, in spite of the use of saccharin, cyclamate, and now aspartame.^[23]

Although it is reasonable to link sweetness liking to eating habits, and eating habits to caries experience, it may be less so to equate sweetness acceptance directly with dental harm. A three-way study on sugar acceptance, frequency, and amount of sugar inputs, and caries prevalence would be of interest.

FACTORS INFLUENCING DESIGN OF SWEET-TASTING FOODS

Sweetness alone is an insufficient description of that quality of sugar and sugar substitutes providing hedonic satisfaction. Many hundreds of compounds are naturally

sweet in their own right but their descriptive terms are usually based on approximating the sweet taste of sucrose.

Cooling

May be beneficial in acceptance, but not always. The cooling of dextrose is an insufficient hedonic extra to compensate for the lack of sweetness of dextrose vis-à-vis sucrose, but the cooling effect of xylitol which is as sweet as sucrose, can be a definite product advantage in certain food types.

Bitterness

If perceived in a sweetener, is generally considered a negative attribute leading to decreased acceptance, but in an appropriate product form may lead to increased acceptance. Saccharin can give more distinct fruit flavors, or can be hidden in bitter products.

Licorice taste

Simply perceived as a long-lasting, back-of-the-throat licorice-like sweetness, is invariably regarded as a product deficiency, as in glycyrrhizin products. Thus greatly limits the utility of the dehydrochalcones, and many other extremely intense sweetening agents.

Water content and size of sample

The water content of foods is augmented on eating by salivation so that sweetness perception is actually a series of unconscious tasting of sweetness dilutions.

Sugar substitutes stated sweetness intensity has to be specified as a ratio at a given concentration of sucrose, and is frequently quite different over the useful range of sucrose concentrations. A sweetener may match sucrose in a beverage, but be a bad mismatch in a food format. Tasting foods dry means saliva is needed for solution, so that poorly soluble sugars like lactose are perceived as gritty as well as insufficiently sweet.

In a situation where acceptance is so complex, one-for-one exchange of any sweetener for another is very hazardous and major products with established franchises are loath to depart from formulae established over many years. However, it has been shown that when a new sugar substitute becomes available, it usually is not used to replace sugar but to create a new brand or new category of beverage.

POSSIBLE EFFECT OF SALIVATION ON ACCEPTANCE

Salivation experiments are surprisingly difficult to

carry out even with chewing gum. The consciousness of producing saliva for measurement greatly affects the output. As common experience illustrates, sugar is initially released very rapidly in the first minute of either real or stimulated chewing, with a gradual tapering off in sugar release for the next 3-5 min. What is less obvious, however, based on actual saliva collection measurements, is that *in vivo* saliva production seems roughly to correspond to the rate of sugar release from the gum base; and that except for the very early and late collections, the bulk of saliva produced was found to contain about 10% sugar.

Although this information is fragmentary, it at least suggests that gelatin desserts as eaten might also end up as 10% sucrose in saliva; and perhaps all sweet products end up near the “bliss point” on eating. If so, a sugar substitute has to match not only the desired sweetness but the functionality of sucrose, so that solution rate and/or saliva production will produce a bolus of food near the “bliss point”.

For dental reasons, we should be aware of the salivation properties of sweeteners as distinct from their sweetness properties. As long as by far the bulk of sugar substitutes are aqueous solutions of intense sweeteners, it is perhaps not a matter of prime concern. But if we wish to move sugar substitution beyond diet soft drinks into the realm of real foods-where the bulk of sugar is to be found- then perhaps sugar substitutes should be examined as much for their salivation efficacy as taste efficacy. It would be ironic to move to sugar substitute much less effective than sucrose in promoting salivation, since saliva is undoubtedly the major defense against the oral threats posed by the diet.

It should be noted that the plaque pH value has been shown to correlate with saliva flows induced by test foods; and that the plaque pH value given by a sugar-coated cereal was found to be higher than that given by the uncoated version. The reason appears to be that the saliva flow induced by the sugar coating, by virtue of increased buffer and plaque washing effects, more than compensates for the glycolytic effect of the higher sugar concentration. It seems clear, therefore, that both acceptance and potential cariogenicity have to be considered as related factors subject to the mediating effect of saliva, and that sucrose-replacement strategies must take the form and nature of the food containing the sugar (and other fermentable carbohydrates) into account before the ideal sugar substitute for that food can be determined.

AGE AND DENTURE WEARING AS POSSIBLE FACTORS IN SWEETNESS ACCEPTANCE

The studies have shown that age per se does not seem greatly to affect taste acuity, at least for men, and neither does the wearing of dentures, at least as judged by measuring sensitivity when using standard test solutions for the four salt, sour, sweet, and bitter tastes.

The lack of food recognition is said to be the most frustrating aspect of denture wearing. Food manufacturers are acutely aware of the interaction of sweetness with the other organoleptic modalities and strive to put out balanced products. But for denture wearers, this balance point will be wrong for many foods, and they may attempt to restore it by restoring to the only flavor stimulants readily available, i.e. salt and sugar. Increased salt consumption could clearly be a health concern, and increased sugar consumption might be a health concern even beyond oral hygiene for some groups (e.g. unrecognized diabetics) even if fewer susceptible teeth are at risk.

POTENTIAL PSYCHOLOGICAL STRESS FACTORS

By far the biggest use of sugar substitutes is made without concern for teeth or gums, though undoubtedly some dental benefit is obtained, in the manufacture of diet drinks or other calorie-controlled foods. A study of the motivations of those who consume them may yield important clues for those wishing to promote the use of artificial sweeteners for foods causing less dental or oral harm.

Dieters are the most highly motivated of all consumers, or the largest users of artificial sweeteners. Clearly, people who diet to lose weight and the group that depends heavily on artificial sweeteners are under stress, even if self-imposed. Applied psychologists use the term “Cognitive dissonance” to describe stressful psychological processing of data, the kind a person would prefer not to process at all.

Behavioral research for the oral-hygiene conscious user of artificial sweeteners may also be needed. Is he stressed, subject to cognitive dissonance? Would better-tasting substitutes help? Or is it possible that a taste-deficiency is needed for recognition, for triggering release of stress or guilt feelings?

There are of course other cultural and behavioral factors to be considered. The belief among Chinese of the

health benefits of sugar for the liver; the fear of cancer from saccharin, or testicular atrophy from cyclamate; the desire for “natural” foods; the drive to be young, healthy, active, attractive, and free of clogged arteries, diabetes and decayed teeth reflects knowledge inputs, both right and wrong, from a wide variety of sources capable of modifying the direct hedonic response and thus the acceptance of any sweetener.

POSSIBLE PHYSIOLOGICAL FACTORS

Physiological responses to sweetness, as well as sweeteners, cannot be neglected in acceptance considerations. The studies have shown that anticipatory responses, due to gustatory clues, can be seen not only in saliva flow but also in gastric and pancreatic secretions, the level and type of insulin release, and even in liver function.

Insulin resulting from oral stimulation by sugar affects the later gastric response of insulin to sugar, making it less acute and long lasting. Sucrose in the mouth also affects the glucose level in the liver. Saccharin works as well as sugar in the oral stimulation of insulin, and works as well as the taste of oil in modifying blood triglyceride levels produced by fatty meal. In some fashion, taste primes the digestive process and important digestive effects due specifically to sucrose (or fructose) in affecting liver function cannot be ruled out. Quite possibly, biochemical responses to a sweetener may be learned and associated with sweetener type, and its acceptance thereby affected, whether the effect is direct (as with the digestive discomfort caused by polyols) or taste mediated.

SATIETY EFFECTS ON ACCEPTANCE

Each product, even at the same optimum sweetness, has its own individual capacity to generate a specific acceptance. We can thus prognosticate the prior consumption of artificially sweetened products, no matter how well sweetened, will not affect acceptance of later sucrose-sweetened products. If so, there would not seem to be an opportunity for a preferred “displacing” role for an artificial sweetener in a dentally improved food. The research suggests that the entire range of sugar products would need to be reformulated with artificial sweeteners; or perhaps that the creation of sufficient monotony throughout all foods or confections would ensure that acceptance would not be stimulated by any one of them. Successful dresses seem in fact to be based on this principle.

DISPLACEMENT EFFECT OF SUGAR SUBSTITUTES ON SUCROSE USAGE IN FOODS

The data accumulated for many years do not support to the idea that enormous use of sugar substitutes has yet had any depressing effect upon the per capita consumption of sugar (sucrose and other nutritive sweeteners).

In the beverage field it is clear that artificial sweeteners created new products which were additional to the sugar sweetened products, and not competitive with them. Similarly, introduction of “sugar less” chewing gum increased the total chewing gum market size without decreasing the consumption of sugar gum. The point remains that percaput consumption of sugar has been stable for decades, in spite of the use of saccharin, cyclamate, and now aspartame.

However, the use of corn-based fructose syrups has threatened to replace all sucrose in regular beverages as the result of the availability of a cheaper sweetener indistinguishable in taste (and calories) for sucrose.

The substitution or displacement effect, if it exists, has yet to be seen for a non-fermentable sugar substitute. When it does occur, it will be much more likely to affect the fructose syrups being used in beverages than sucrose itself.^[23]

SUMMARY AND CONCLUSION

The evidence for casual relationship between sugars and dental caries has been established. Dental caries still remains a very costly and widespread disease that in many industrialized countries affects mainly disadvantaged individuals and is of serious concern in many developing countries. Use of sugar substitutes in preventive dentistry is gaining importance. At the same time it faces some practical problems in satisfying several favorable properties of sugar (sucrose). Availability, taste preference, physiochemical properties and most importantly their cost and public perception are few areas which influence their acceptance by public.

Replacing sugar (sucrose) with a suitable substitute to combat dental caries is an option wide open. Recent studies suggesting antimicrobial properties as well as less cariogenicity of some sugar substitutes such as xylitol is encouraging. But, will any substitute be able to functionally satisfy vast number of properties of sugar? Should we emphasize on other preventive modalities

for dental caries rather than substituting sugar? Future research in this aspect is essential for definitive answer.

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How to cite this article: Roshan NM, Sakeenabi B. Practical problems in use of sugar substitutes in preventive dentistry. *J Int Soc Prevent Communit Dent* 2011;1:1-8.

Source of Support: Nil, **Conflict of Interest:** None declared.

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