Are sugar-free confections really beneficial for dental health?

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RESEARCH

IN BRIEF

- Sugar-free does not mean calorie-free. Some sugar-free products generate nearly 50% of calories produced by table sugar.
- In general, sugar-free products may help prevent dental caries. However, if they contain acidic additives, it may increase the probability of demineralising enamel, thus causing dental erosion.
- Avoiding acid-containing, usually fruit-flavoured sugar-free products may be beneficial.

Background Various sugar substitutes have been introduced and are widely used in confections and beverages to avoid tooth decay from sugar and other fermentable carbohydrates. One group of sugar substitutes are sugar alcohols or polyols. They have been specifically used in foods for diabetic patients because polyols are not readily absorbed in the intestine and blood stream, preventing post-prandial elevation of glucose level. Additionally they may lower caloric intake. **Methods** We searched PubMed, Cochrane Controlled Trials Registry, Cochrane Oral Health Review, Centre for Reviews and Dissemination in the UK, National Library for Public Health and a Centre for Evidence Based Dentistry website up to the end of October 2010, using the search terms 'sugar alcohol' or 'sugar-free' or 'polyols' and combined with a search with terms 'dental caries' or 'dental erosion'. **Results** Xylitol, a polyol, has been approved by the US Food and Drug Administration for its non-cariogenic properties that actually reduce the risk of dental decay and recently, the European Union also officially approved a health claim about xylitol as a 'tooth friendly' component in chewing gums. Although the presence of acidic flavourings and preservatives in sugar-free products has received less attention, these additives may have adverse dental health effects, such as dental erosion. Furthermore, the term sugar-free may generate false security because people may automatically believe that sugar-free products are safe on teeth. **Conclusion** We concluded that polyol-based sugar-free products may decrease dental caries incidence but they may bring another dental health risk, dental erosion, if they contain acidic flavouring. There is a need for properly conducted clinical studies in this area.

INTRODUCTION

Dental caries is one of the most prevalent health issues affecting a large proportion of the world population and is considered to be the most common form of chronic disease among schoolchildren. In adults, untreated tooth decay is seen in 28% of people aged 35-44 and 18% of people aged 65 years and older.[1] Caries dates back over a million years and caries is still widely observed in developing countries.[2]

Sugars and other fermentable dietary carbohydrates are substrates to microorganisms that ferment carbohydrates and generate acids. The acidity causes demineralisation of the tooth enamel which is the initial step in dental caries lesions. Hence, blocking any of the aetiological factors will decrease caries activity. These include suppressing acidogenic bacteria in the mouth by maintaining good oral hygiene and limiting consumption of fermentable carbohydrates. In addition, use of fluoride, which reduces enamel liability to acid dissolution, leads to less dental caries.[3]

Sugar substitutes have been introduced and widely investigated in limiting the dietary source of caries hazards.[4] Of these, the sugar alcohol polyols are most popular today in many foods and beverages. Most notably, they have been used in chewing gums and candies as well as in soft drinks and sports drinks. Furthermore, polyols are less likely to exacerbate diabetes because these molecules are not readily absorbed into the blood stream.[5]

Sugar alcohols produce less acid from fermentation of carbohydrate by oral microbiota.[6] Any acidity surrounding the tooth, especially a pH below the critical value of approximately pH 5.5 of dental enamel, may induce chemical dissolution or erosion.[7,8] Dental erosion is a slowly progressing condition described as the irreversible loss of dental hard tissue due to a chemical process without involvement of microorganisms.[9]

Acids are frequently added as flavouring and preservative agents in confections and beverages but their role in dental health has not been thoroughly studied.[10] Depending on whether the acidic compound is in liquid or solid form, the location of dental defects may differ. Acidic liquids preferentially seem to cause erosion of the anterior maxillary and mandibular teeth. Erosion from solid acids such as in candies manifests mainly on posterior teeth with smooth, silky-glazed

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appearance of enamel and cupping of the occlusal surfaces of posterior teeth.[10]

In comparison to what is known about the fermentation of sucrose and other fermentable sugars, data regarding oral health consequences of polyols are sparse. The present review is mainly based on a PubMed literature search up to the end of October 2010 resulting in the collection of 471 references with the keywords 'sugar alcohol' or 'sugar free' or 'polyols' and combined with a search using the terms 'dental caries' or 'dental erosion'. We also searched Cochrane Controlled Trials Registry, Cochrane Oral Health Review, Centre for Reviews and Dissemination in the UK, American Dental Association Library and National Library for Public Health, and a Centre for Evidence Based Dentistry (CEBD) website, but did not find any additional literature. The lack of well-conducted studies or randomised trials on the topic prohibited us from conducting a meta-analysis and quantifying dental erosion. The review is thus mainly descriptive.

POLYOLS

Polyols are naturally found in fruits and vegetables but are also manufactured from inorganic sources.[5] Polyols are hydrogenated forms of carbohydrates whose carbonyl group has been reduced to primary or secondary hydroxyl group with structural similarities to sugars and/or alcohols. Polyols are typically used in conjunction with other artificial sweeteners because they tend to have lower sweetness than natural sugars. Some of the common sugar alcohols include xylitol (5-carbon sugar alcohol), sorbitol (6-carbon sugar alcohol), maltitol (12-carbon sugar alcohol), mannitol (6-carbon sugar alcohol), and isomalt (12-carbon sugar alcohol).

The primary indication for polyols has been in the production of foods for people suffering from diabetes because unlike sugars, polyols are not readily absorbed in the intestine. This prevents post-prandial fluctuation of the blood glucose levels and helps in achieving lower caloric intake. However, polyols are not calorie-free, as shown in Table 1. Sorbitol generates nearly 65% of the calories from the same amount of sucrose, and the lowest calories are generated by lactitol and isomalt, with 50% of the calories that sucrose generates. Therefore, high levels of polyol intake may still have deleterious effects on the blood sugar level although to a lesser extent than other caloric sweeteners. In addition, because polyols are not well-absorbed in the intestine, accumulation of unabsorbed polyols may cause gastro-intestinal disturbance and osmotic diarrhoea, which is not within the scope of this review.

Polyols and oral health

There have been particularly many studies analysing the effects of xylitol in chewing gum.[11–13] Xylitol has been approved by the U.S. Food and Drug Administration (FDA) for its non-cariogenic properties that actually reduce the risk of dental decay.[14] Recently, the European Commission also approved a health claim of xylitol on 'tooth friendliness' when used in chewing gum.[15]

Oral bacteria are unable to ferment xylitol. Studies have also shown that xylitol chewing gum can increase salivary flow leading to improved buffering effects of the saliva.[16] Furthermore, xylitol has the ability to reduce the growth of oral bacteria by inhibiting glycolysis. When xylitol is taken up by oral bacteria, it is incorporated as xylitol 5-phosphate which inhibits the enzymes involved in metabolism.[17] Sugar alcohols have been termed as non-fermentable sugars in the literature, yet some oral bacteria can metabolise certain sugar alcohols.[18] For example, maltitol and sorbitol appear to have variable fermentability depending on the species of bacteria involved. Among polyols, scientific evidence indicates that xylitol demonstrates the strongest caries prevention effect.[19,20]

The oral microorganism that displays strong acidogenicity is *Streptococcus mutans*.[21] Unlike other species of the viridans streptococci family, *S. mutans* is capable of fermenting mannitol and sorbitol.[22] Lyon showed the various types of carbohydrates that can be metabolised by *S. mutans* and other strains of microorganisms.[11] He also showed that *S. mutans* ferments mannitol but not xylitol. Thus, xylitol shows superior anticariogenic properties in this regard.[11]

There are three notable properties of xylitol that have made it an important sugar alcohol in the dental perspective: 1) xylitol is not readily fermented by oral bacteria, especially by streptococci; 2) it has been shown to reduce the numbers of *S. mutans* in the oral cavity by limiting the source of fermentable substrates for their survival; and 3) xylitol can induce the production of salivary enzymes which lead to the growth inhibition of bacteria in plaque.[13] Together, these mechanisms are important in reducing dental caries incidence in patients. The effective dose of xylitol appears to be between 6.44 g and 10.32 g xylitol per day. Furthermore, lower doses of xylitol have also been shown to be efficient in caries prevention.[23,24]

Table 1 Caloric content of various sugar alcohols

Name	Caloric content (kcal/g)
Sucrose	4
Sorbitol	2.6
Mannitol	1.6
Maltitol	2.1
Lactitol	2
Xylitol	2.4
Isomalt	2

Source: Food Insight sugar alcohols factsheet. Available at http://www.foodinsight.org/Resources/Detail.aspx?topic=Sugar_Alcohols_Fact_Sheet

The most commonly used polyol in several sugar-free chewing gums in the United States, however, is sorbitol. This is mainly due to its low cost compared to xylitol.[25] Since sorbitol is fermented by mutans streptococci, thereby increasing the acid production in plaque, it should be considered low-cariogenic rather than non-cariogenic.[26] Animal studies have also shown that microorganisms can learn to metabolise sorbitol when the fermentable sugar supply is restricted.[27]

EVIDENCE OF CARIES REDUCTION

Clinical trials with xylitol

The effect of xylitol chewing gum has been extensively studied over the past 30 years.[28] Blocking the early mother-child transmission of *S. mutans* is also an important step in caries prevention since the early *S. mutans* colonisation is connected with early childhood caries. The effect of maternal use of xylitol chewing gum on caries and on mutans streptococci in children has been shown to be beneficial in caries reduction, with significantly less

S. mutans colonisation and less caries in the children.[24,29]

The use of xylitol products has also been tested on patients with high caries risk, with fixed orthodontic appliances, disabled school children and/or veterans with high root caries risk.[30–32] Xylitol appeared to have caries preventive effects in all but one of these studies. However, in a two-year double blind trial evaluating the effect of xylitol- and xylitol/fluoride-containing lozenges on proximal caries, no statistically significant differences were found in caries incidence between the experimental groups and a control group that did not receive lozenges.[33]

Milk for neonates would be a natural vehicle for administration of anticaries compounds. Hence, the taste of xylitol in milk as a first step toward measuring the effectiveness of xylitol-containing milk on caries was tested in Peruvian children.[34] The xylitol-sweetened milk appeared to be well accepted, offering a novel means for administration. However, we question the wisdom of introducing sweet taste sensation at an early age which may not be beneficial.

Clinical trials with sorbitol

Sorbitol is the most commonly used polyol in the United States because of its low cost. However, only a few clinical trials have been conducted on its caries-inhibitory action. Some trials have been conducted with xylitol, sorbitol, and mixtures of xylitol and sorbitol. According to the review by Burt, chewing sorbitol-sweetened gum no more than three times a day had low cariogenicity compared to chewing sugar-sweetened gum.[25] Although small amounts of sorbitol can be fermented by oral microorganisms, this amount does not lower the plaque pH enough to cause demineralisation of enamel.[35] In a rat model, however, an adaptation to sorbitol did take place and resulted in an enhanced drop in plaque pH following sorbitol application.[27]

Caries reduction with other polyols

Lactitol and maltitol have been tested mainly in laboratory animals. Lactitol, a lactose-based sugar alcohol, showed anti-dental caries properties similar to xylitol.[36] However, since it is made from lactose and whey, lactose-intolerant persons may experience gastric disturbance. Maltitol was not utilised by mutans streptococci, nor did it produce sufficient acid to demineralise tooth enamel. Replacement of sucrose with maltitol in the diet resulted in a trend towards caries reduction.[37] More recently, Mäkinen and co-workers compared the effects of erythritol, a tetritol (4-carbon sugar alcohol), with xylitol and D-glucitol (a 6-carbon sugar alcohol) on the risk of dental caries.[38] The use of erythritol and xylitol resulted in a statistically significant reduction in the plaque and saliva levels of *S. mutans* ($p < 0.001$ in most cases) and there was also a significant reduction in the amount of dental plaque in groups receiving erythritol and xylitol. Further studies are needed, however, to verify these results.

EVIDENCE OF HIDDEN RISK

Acids in sugar-free candies and beverages

Addition of other ingredients such as acids to produce an enjoyable taste is another important aspect of sugar-free candies and beverages. Acids are also used in foods as preservatives. From a dental health point of view, acidic flavouring agents have the same detrimental effects on dental enamel as the microorganism-generated acids from sugar fermentation. This is evidenced by the demineralisation observed *in vitro* studies[39] and also shown following the consumption of sugar-free beverages. The effect of acids in sugar-free products has yet to be widely studied *in vivo*, and more studies are needed in this area of research. Our literature review will next expand to dental erosion by discussing the acids added to sugar-free products in this perspective.

Dental erosion

When a patient presents with dental erosion, the possibility of frequent consumption of acidic candies should be considered as a potential detrimental aetiologic factor. The risk of erosion from acidic additives in sugar-free products has been recognised as early as 1978 by Kleber and colleagues.[40] This phenomenon may be more apparent in paediatric patients due to low salivary volume.[41] Recently a few *in vivo, ex vivo* and *in vitro* studies have been published on confections, confirming their erosive capacity.[10,41–45] According to the study by Wagoner and co-workers, both original flavour and sour versions of candies were potentially erosive; generally the erosive capacity was directly proportional to the acidity of the candies investigated.[45]

In a study by Brand and co-workers, the erosive potential of several lollipops and the protective effect of saliva were investigated. Ten healthy volunteers consumed different types of lollipops and their salivary flow rate and pH was determined. The lollipops differed in their erosive potential depending on their flavours. Fruit and cola flavoured lollipops had a very low pH of 2.3-2.4 and showed a drop in the salivary pH to well below the critical value of 5.5. Strawberry yoghurt and salty liquorice lollipops had pH values of 3.8-4.7 and also resulted in a salivary pH below 5.5.[43] Hence these products appeared to be potentially detrimental to the teeth.[46]

Candies are also made in spray-form in Europe and some chewing gums are filled with acidic centers.[41,42] The seven candy sprays tested by Gambon and co-workers had an extremely low pH of 1.9-2.3. All these candy sprays had erosive potential and the effect may be even greater with children as their salivary volume is smaller than in adults.[41] Also the longer exposure time to these acids may increase the risk of erosion even more.[47] The acidic filling of a chewing gum reduced the microhardness of both primary and permanent enamel in a study by Bolan *et al.* Sour sweets have been found to be even more erosive than orange juice, which is a well-known erosive agent.[10]

Since dental erosion is an irreversible pathology and erosive lesions on teeth are difficult to treat, the addition of protective ingredients such as calcium and/or phosphate to candies has been considered. The addition of calcium has been shown to reduce the erosive tendency of potentially erosive candies.[44,48] Salivary calcium concentration of around 15 mmol/l resulted in considerable attenuation in the erosive potential of a candy compared to candies without calcium ($p < 0.001$).[44] However, one recent study did not observe any protection against erosion by adding various minerals.[49] The exact quantification of the possible protective effect of adding calcium into potentially erosive candies should be conducted in the future. The erosive potential of a foodstuff

is the result of complex interactions of many molecules where calcium chelating properties are only one parameter.[50] Table 2 presents studies where acidic products have been tested in relation to dental erosion.

SUMMARY

As the use of sorbitol and xylitol containing products increases, the public should be educated on the hidden risk of dental erosion due to acidic additives as well as the adverse effects of gastric disturbance and osmotic diarrhoea. Especially in sugar-free products, these adverse effects may be more insidious because the public has blind confidence that they are oral health friendly. Also, the exposure time to such products should be considered. Thus, hard candies or lollipops may be more harmful if they are slowly melted in the mouth than candy spray.[47]

Adding calcium and phosphate to the product is a promising approach to counteract the adverse erosive effect on teeth but more studies are needed to confirm its efficacy. At present, the reports of protective effects of fluoride against dental erosion are conflicting. Thus, we defer further discussion until a clear trend emerges.

In general, sugar-free products appear to be beneficial as far as dental caries is concerned. However, the unrecognised risk of acidic flavouring in sugar-free candies and beverages on dental health calls for more studies and public awareness. Based on research results by Kleber and Wagoner, acidic additives lower the pH of saliva well below the critical level of 5.5, regardless of acid type (Fig. 1). Some researchers advocate future randomized, cross-over trials. However, it may be unethical to expose study subjects to irreversible harm from dental erosion. Thus, future studies should include *in vivo* assessment of pH change with the consumption of sugar-free confections with and without acidic flavouring and *ex vivo* assessment of erosion at such respective pH levels.

CONCLUSIONS

Although some disagreement exists, results from numerous studies have shown that substitution of table sugar with sugar-free sweeteners is a healthier choice for dental caries prevention. However, the acid flavouring and preservatives used in the sugar-free confections and beverages cause the salivary pH to drop below the critical value and thus may cause dental erosion. Therefore, properly conducted randomised controlled trials using sugar-free products with or without acidic additives are needed.

Table 2 Studies testing sugar-free products with acids

Type of study	Test subject/object	Main result	Comments	Reference
In vitro, acidulants	Bovine incisors	Fumaric acid, tartaric acid and citric acid showed highest demineralisation. There was less erosion when these acids were given in sorbitol candy.	Enamel dissolution was correlated with the potential of the acids to chelate calcium.	Kleber *et al.*[40]
Ex vivo and *in vitro*, beverages	Five healthy women	Citric acid was the most detrimental to enamel.	All drinks had a pH of below 5.5.	Meurman *et al.*[46]
Ex vivo, beverages	Bovine tooth enamel	Most erosion with cola, orange beverage, sports drink, orange juice, diet cola. Fluoride did not influence erosive depth.	Carbonated mineral water, beer, coffee, yoghurt and buttermilk did not cause surface erosion. Lowest pH below 4.5.	Rytömaa *et al.*[39]
In vivo and *in vitro*, acidic candies	20 healthy volunteers	Modified candy reduced the erosive potential of acidic candies	Critical pH may not fully reflect when dental erosion is expected to occur.	Jensdottir *et al.*[44]
In vitro, sour candies	28 different sour candies	pH for all below 4.0, some to 1.6 and 1.8	Primary teeth are more prone to erosion, soft tissue irritation was possible.	Robyn *et al.*[50]
In vitro, acidic centre-filled chewing gum	80 enamel blocks	The acidic filling of gum reduced the microhardness of enamel	Both primary and permanent enamel were affected	Bolan *et al.*[42]
In vitro, lollipops	10 healthy volunteers	Lollipops differ in erosive potential	Fruit and cola flavoured lollipops have the greatest erosive effect.	Brand *et al.* 2009[51]
In vivo and *in vitro*, candy sprays	Seven different candy sprays on adult volunteers	Candy sprays have a very low pH of 1.9-2.3	Effect on children may be greater as their salivary volumes are smaller than adults´	Gambon *et al.* 2009[41]

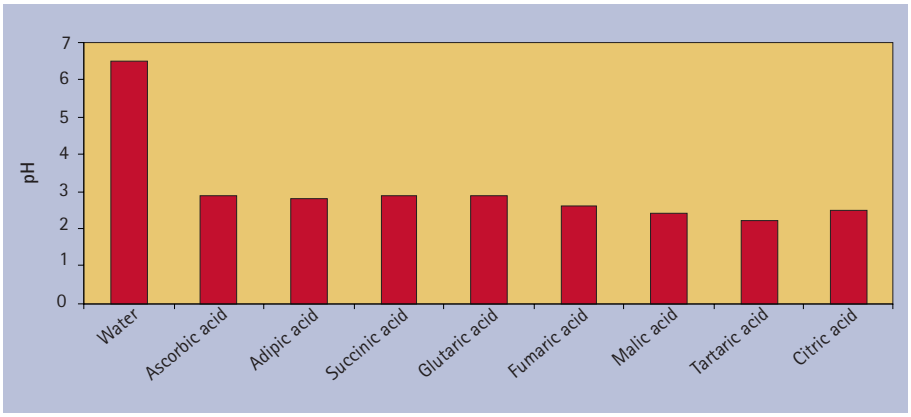

Fig. 1 pH change with various acidic additives in sugar-free confections

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