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Review Article

Sugar substitutes and dental health

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ABSTRACT

Sugar is one of the most widely consumed sweetening agents. Unfortunately, its use has been linked to various disease states, such as obesity, diabetes mellitus (DM) and dental caries. Dental caries is a chronic disease which can affect us at any age. The role of sugar (and other fermentable carbohydrates such as highly refined flour) as a risk factor in the initiation and progression of dental caries is increasing day by day. Sugar substitutes are food additives that provide a sweet taste more or less similar to that of sugar and plays important role in control of dental caries.

Keywords: Dentistry, Health, Sugar, Sugar substitute

INTRODUCTION

The etymology of the word "sugar" has been traced to the Chinese term shache, literally, "sand-sugar plant", then to the Sanskrit, sharkera, meaning sand or gravel, and more directly from the Arabic, sukkar.[1]

Search for suitable sweetening agent which will satisfy all the characteristics of sugar is going on through years, since then 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.[2]

Sucrose (table sugar) is considered as sugar by most of the people. The term sugars include all the monosaccharides and disaccharides, the most common of which are glucose, fructose, sucrose, maltose and lactose.

Sucrose is an unusually versatile sweetener, useful in many different types of products, so difficulties in the substitution of sucrose arise as sweeteners differ from each other both in their physical and chemical properties. Replacement of sucrose by other sweeteners is not at all simple because they differ from each other both in their physical and chemical properties. As single sweetener is not able to fulfil all the roles of sucrose in the different products, sweetener that can best imitate the role of sucrose in the product in question should be added.[1]

Chewing gum was suggested as a practical vehicle for caries prevention, because it allows xylitol to stay in the mouth long enough and requires only a low dose. It is also considered as practical vehicle for nicotine in smoking cessation programs or different medicines.[3,4]

The sugar substitutes, which may also be called alternative, artificial, high-intensity, or non-nutritive sweeteners, can replace the sweetness of sugar while providing few or no calories. In addition to the calorie savings, these sugar substitutes have the advantage of not promoting tooth decay, and they are useful in dietary planning for people who are coping with obesity or diabetes.[3]

The dental professionals have the opportunity to provide advice regarding the importance of diet and role of sugars in caries formation. It is unlikely that many patients will voluntarily restrict their sucrose consumption permanently in order to reduce dental caries keeping in view of the human taste preference for sweetness. So, 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.

REVIEW OF LITERATURE

Many theories have evolved through years in explaining the etiology of dental caries, which is interplay between oral bacteria, local carbohydrates and tooth surface that may be shown schematically as follows:

Bacteria + Sugars + Teeth -÷ Organic acids Dental caries

But according to current concepts, dental caries is a multi-factorial disease where 'time' factor is also considered. However, it is also known that these four criteria are not always enough to cause the disease and a sheltered environment promoting development of a cariogenic biofilm is required. The caries process does not have an inevitable outcome, and different individuals will be susceptible to different degrees depending on the shape of their teeth, oral hygiene habits, and the buffering capacity of their saliva.

Dental caries can occur on any surface of a tooth that is exposed to the oral cavity, but not the structures that are retained within the bone.

Table 1: Classic evidence from humans supporting the role of sugar in dental caries.

Study	Reference(s)	Main conclusions
Vipehlom study	Gustafsson et al	The more frequently sugar is consumed the greater the risk; sugar consumed between meals has much greater caries potential than when consumed during a meal
Turku sugar	Scheinin et al	When sugars are almost completely replaced by non-fermentable sugar substitutes, caries increment is dramatically reduced; fructose is less cariogenic than sucrose
World War II	Toverud Takeuchi	Caries decreased and increased with sugar consumption during and after the war respectively
Hopewood house	Harris	Modern diet more cariogenic than vegetarian low sugar diet
Tristan da Cunha	Hollowat et al Fisher	Introduction of a modern diet including sugar and refined carbohydrate to this remote island greatly increased caries prevalence
Hereditary Fructose Intolerance	Marthaler Newbrun et al	Less caries in individuals that must avoid sucrose and fructose, but not other sugars and complex carbohydrate
Experimental Caries in Man	von der Fehr et al Geddes at al	Incipient caries can be rapidly induced by frequent rinsing with high concentration sucrose solutions in the absence of oral hygiene
Stephan plaque pH response	Stephan	Demonstrated the relationship between sugar exposure resulting in the acidification of dental plaque and caries experience

The bacteria most responsible for dental cavities are the mutans streptococci, most prominently *Streptococcus mutans* and *Streptococcuss sobrinus*, and lactobacilli. If left untreated, the disease can lead to pain, tooth loss and infection. Tooth decay disease is caused by specific types of bacteria that produce acid in the presence of fermentable carbohydrates such as sucrose, fructose, and glucose. The mineral content of teeth is sensitive to increases in acidity from the production of lactic acid. To be specific, a tooth (which is primarily mineral in content) is in a constant state of back-and-forth demineralization and remineralization between the tooth and surrounding saliva. The classic evidence supporting the role of sugar (soluble carbohydrates) in dental caries in man is well documented by some of the studies like- The Vipeholm Study, Turku Sugar Study, World War II Food Rationing, Hopewood House Study, Tristan da Cunha, Hereditary Fructose Intolerance, Experimental Caries in Man, and Stephan

Plaque pH Response. Table 1 and Table 2 describes the Classic evidence from humans supporting the role of sugar in dental caries and review articles on the relationship between sugar (diet) and dental caries respectively.[5]

Table 2: Review articles on the relationship between sugar (diet) and dental caries.

Author(s)	Main conclusion
Marthaler	Foodstuff containing simple sugars are far more cariogenic than common starchy food
Newbrun	Called for the specific elimination of sucrose or sucrose containing foods rather than restricting total carbohydrate consumption
Bibby	Snack foods share importance with sucrose in caries causation
Sreebny	Total consumption and frequency of intake contribute to dental caries; lacking evidence about the precise definition of the relationship
Newburn	Compelling evidence that the proportion of sucrose in a food is one important determinant of its cariogenicity
Sheiham	Sugar is the principal cause of caries in industrialized counteies; recommended that sugar consumption be reduced to 15kg/person/year or below
Shaw	Studies in animals consistent with the clinical evidence on the relationship between sugar and caries
Rugg-Gunn	Cariogenicity of staple starchy food is low;the addition of sucrose to cooked starch is comparable to similar quantities of sucrose; fresh fruits appear to have low cariogenicty
Bowen and Birkhed	Frequency of eating sugars is of greaer importance than total sugar consumption
Walker & Cleaton-Jones	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	In spite of dramatic reductions in caries due primarily to widespread use of fluoride, sugar continue to be the main threat to dental health

DISCUSSION

Sugar substitutes are food additives that are used to mimic the sweet taste of sugar. Sugar substitutes can either be intense or bulk sweeteners. Intense or non-nutritive sweeteners are sugar substitutes that are usually many times sweeter than sucrose.[5] Their sweetness may overcome sweetness of glucose up to 8000 times thus a much less amount of sweetener is used and only a minute fraction of the caloric content of sucrose is consumed.[4,5] Sugar substitutes are mainly categorized into natural and synthetic sugar substitutes; the latter are generally referred to as artificial sweeteners.[3,5] Natural sugar substitutes are those that are found naturally in certain fruits and vegetable, yet they may not be found in adequate amounts suitable for major extraction and consumption.[5-7]

Natural sugar substitutes

Sugar Alcohols

Sugar alcohols, also known as polyols (polyhydric alcohol, or poly alcohol)), are carbohydrates in which the carbonyl group is hydrogenated to form a hydroxyl group.[5] Sugar alcohols can be naturally found in many fruits and vegetables, but they can also be manufactured. They are not considered non-nutritive sweeteners, because they contain calories, as compare to sucrose calorie content is low.[5-7] Sugar alcohols may also be added to processed foods to protect them from browning upon heating. This is because sugar alcohols are non-reducing sugars, thus do not caramelize nor do they participate in the Maillard reaction. For this reason, they are used as food additives to protect the color of some processed foods.[4,5] Sugar alcohols have ability to produce a perceptible cooling sensation in the mouth when dissolving from the crystalline state. This cooling sensation is due to the characteristic endothermic dissolution of sugar alcohols, making them ideal sweeteners for sugar free menthol and peppermint flavored candies and chewing gums.[5,8]

Sugar alcohols may contribute some benefits to human, such as their low glycemic index. Sugar alcohols are used to replace sucrose in many sweets, chocolates, and baked goods that can be consumed by diabetics as their consumption results in a slower and smaller increase in blood sugar compared to products with sucrose. This leads to a decrease of the glycemic load of a person and a diet where sucrose is replaced by sugar alcohols presumably reduces the risk of obesity, type 2 diabetes and cardiovascular diseases.[5] Sugar alcohols have benefit that they are noncariogenic, i.e. they do not result in tooth decay. This is because oral bacteria do not ferment them as readily as sucrose. Therefore, they are extensively used in products that are intended to be kept in the mouth for a long while, such as chewing gums and breath mints, like Xylitol gums.[4,5]

Novel sweeteners

These are the recent sugar substitutes and variable chemical structures, these novel sweeteners are extracted from varying sources and used for different purposes. Novel sweeteners such as tagatose, inulin, and fructose oligosaccharides are not completely digested by the human. This, along with their selective support of the growth of beneficial colonic bacteria, makes them

prebiotics. Prebiotic sweeteners are used in foods because their indigestibility renders them less caloric. More importantly, these novel sweeteners were proven to support the growth of bifidobacteria and lactobacilli in the intestinal tract at the expense of pathogenic clostridia, coliformand other types of bacteria.[5]

Artificial sweeteners

Artificial sweeteners are synthetic sugar substitutes that can either be completely synthesized or chemically derived from naturally occurring substances. They are considered intense sweeteners and are thus used to replace sucrose in many foods for health and dietary reasons.[5] Their sweetness often requires them to be mixed with other sweeteners to dilute their intensity, mimic the sweetness of sugar and cover any aftertaste caused by the particular intense sweetener.

The used amount of sweetener needed to produce a sweet taste is very minute compared to sucrose and they should be mixed with bulk sweeteners in order for them to be sold to consumers as tabletop sweeteners. Artificial sweeteners are also mixed with bulk sweeteners when used in baked goods and confectionaries, because they lack the bulk properties needed in these types of foods.5 Being non-cariogenic artificial sweeteners can be used in various products such as toothpastes, chewing gums and many medications, especially those intended for the pediatric population. Unlike, sucrose, artificial sweeteners are not fermented by the oral microflora. Hence, they do not produce the acidic waste responsible for the fall in oral pH - the primary cause of tooth decay.[5] Artificial sweeteners may also be of possible benefit for diabetics, as they are not metabolized in the body into glucose. Thus, they do not cause a rise in blood sugar nor do they cause reactive hypoglycemia associated with high GI foods. This allows diabetics to satisfy their sugar cravings while still managing their blood glucose.[5,6]

Various nutritive and non-nutritive sugar substitutes are listed in Table 3.[6]

Table 3: Classifications of sugar substitutes.

A. Nutritive Sweeteners	B. Non-Nutritive Sweeteners
I. Monosaccharide polyols	a. Saccharin
a. Sorbitol	b. Acesulfame - K
b. Xylitol	c. Aspartame
c. Mannitol	d. Thaumatin
d. Erythritol	e. Cyclamate
II. Disaccharide polyols	f. Dulcin
a. Isomalt (Palatinit)	g. Aldoximes
b. Maltitol	h. Neotame
c. Isomaltulose	i. Stevia
d. Trehalose	j. Sucralose
III. Polysaccharide polyols	
a. Hydrogenated glucose syrup	

Nutritive sweeteners

Nutritive sweeteners are also called as carbohydrate sweeteners (caloric). It provides a high-quality sweet taste and has an acceptable texture and shape and thus remains the most popular sweetener.[6,7]

Monosaccharide polyols

Monosaccharide alcohol is the general term for the chain – like polyalcohol obtained by reducing the carboxyl group of sugars.[6]

Sorbitol (D-glucitol)

Sorbitol occurs naturally in cherries, plums, apples, many berries, seaweeds and algae. It is moderately sweet, relatively inexpensive and has less shelf life because of hygroscopic property.[6] Sorbitol should be considered a low cariogenic sweetener rather than a non-cariogenic one because consumption of larger amount increases the acid producing microorganism in plaque.[6-8]

Xylitol

Xylitol is a pentose alcohol with sweetness similar to sucrose, found naturally in a variety of fruits, vegetables and also are available in various other processed forms such as gums, lozenges, syrups and snack foods. It is directly absorbed by the small intestine and subsequently metabolized. Xylitol is not fermented by cariogenic salivary mutans streptococcus as it replaces sucrose with xylitol and "starves" the cariogenic microorganisms. Therefore, consistent use of xylitol-sweetened gum reduces plaque accumulation. Hence, enamel demineralization is prevented, and plaque bacteria cannot undergo proliferation.[6] Xylitol sweetened gum offers more benefit in terms of reducing caries risk than does sorbitol-sweetened gum. Patients who chew gum regularly should be encouraged to chew gums sweetened with sorbitol or xylitol.[6,8,9] Various action of xylitol are as follows:

- Xylitol prevents the accumulation of plaque on the tooth surfaces.
- Plaque pH does not drop when xylitol-sweetened gum is chewed, but remineralization is enhanced.
- Chewing any gum stimulates the flow of saliva, which enhances the buffering effect.

Mannitol

Mannitol is a polyol made by hydrogenation of fructose. It was first isolated from the sap of a flowering ash tree found in Southern Europe and Asia. It does not absorb moisture into products (non-hygroscopic) and is therefore often used as a dusting powder for chewing gum to prevent the gum from sticking to manufacturing equipment and wrappers. It is also included in chocolate-flavoured coating agents for ice cream and sweets due to its high melting point and does

not discolour at high temperatures, which makes it ideal for use in pharmaceuticals and nutritional tablets.[6,9]

Erythritol

Erythritol exists widely in nature, including in lichens, mushrooms, fruits, fermented foods and body fluids of mammals. It is also obtained from the fermentation of glucose by yeast. The sweetness of erythritol is 70-80% that of sucrose. Erythritol is predominantly absorbed from the small intestine and most of the absorbed sugar are excreted in urine without being metabolised therefore it does not cause diarrhea.[6]

Disaccharide polyols

Disaccharide polyols are those sugar substitutes which contain more than one hydroxyl groups. Various forms of disaccharides polyols are described as follows:

Isomalt (Palatinit)

Palatinit is obtained by the dehydrogenation of palatinose. The sweetness of palatinit is 45% that of sucrose. The majority of ingested palatinit reaches large intestine, where it is fermented to organic acid by enterobacteria and subsequently absorbed.[6]

Maltitol

Maltitol, also termed as reducing maltose, is a disaccharide alcohol of glucose and sorbitol. The sweetness of maltitol is 75-80% that of sucrose and its quality of taste resembles that of sucrose.[6]

Isomaltulose (Palatinose)

Palatinose is a disaccharide of glucose and fructose. It is obtained from sucrose using a transferase produced by Protamino bacterrubrum. The sweetness of palatinose is 42% that of sucrose.It does not induce diarrhoea. For this reason, it is considered as an excellent sweetener for infants, children and diabetic patients.[6]

Polysaccharide polyols

Polysaccharide are sugar substitutes which contains more than one hydroxyl group and are described as below:

Hydrogenated glucose syrup (Lycasin)

Most commonly used type being Lycasin (8055) containing 6-8% sorbitol, 50-55% maltitol, 20-25% maltotritol and 10-20% polysaccharide alcohols.[6] Various studies found that human plaque pH measurement rank Lycasin as hypoacidogenic. Mixed cultures of oral microorganisms incubated with Lycasin produced less polysaccharide and acid with less demineralizing action on dental enamel and hydroxyapatite than the sugar incubated controls. Overall Lycasin (8055) has a very low cariogenic potential but no active cariostatic properties.[6]

Non-nutritive sweeteners

Low-calorie sweeteners (referred to as non-nutritive sweeteners, artificial sweeteners or sugar calories) are ingredients added to foods, yogurt, medicinal preparation, dentifrices, mouthwash and beverages to provide sweetness without adding a calorie. The non-caloric sweeteners are generally much sweeter than sucrose and can, therefore, be used in small amounts.[6]

Saccharin

Saccharin was first developed in 1878; oldest approved artificial sweetener. It is 300 times as sweet as sucrose by weight, non-cariogenic and non-caloric but can have a slightly bitter or metallic taste.6 Saccharin, when used as a supplement to a cariogenic diet significantly, reduced both fissure and smooth surface caries in rats, apparently interfering with the growth of Streptococcus mutans.[6]

Acesulfame - K

Hoechst (1967), found that compounds with the dihydro - oxthiazinone dioxide ring system had a sweet taste. In terms of sweetness, Acesulfame - K is about 130 times as sweet as sucrose. It is stable in high temperature, low pH and storage range that is likely to be encountered in foods and beverages.[6] It is not cariogenic, but no active cariostatic properties have been reported aside from a positive synergistic effect on inhibition of acid production by oral microorganisms when combined with cyclamate and saccharine.[6]

Aspartame

Aspartame was accidentally discovered in 1965 by Searle Research Laboratories to have a pronounced sweet taste, being about 180 times sweeter than sucrose in aqueous solution, known under the brand name "NutraSweet". It is an odourless white crystalline powder with a refreshing sweet taste, but it is extremely unstable at extreme pH range. It is used in noncarbonated fruit juices, fruit drinks, frozen stick type confections, breath mints and sweetening agents in drug products.[6]

Thaumatin

In West Africa the inhabitants used an extract "thaumatin" derived from fruits of a shrub, Thaumatoccus daniellii to sweeten foods such as bread and palm wine. It is 100,000 times sweeter than sucrose on molar basis and 3,000 times sweeter on weight basis.[6]

Cyclamate

Cyclamate are 30 times sweeter than sucrose and is freely soluble in water. It is not fermented by oral

microorganisms, consequently non – acidogenic in plaque pH measurements in vivo and thus possesses no cariogenicity.Cyclamates as 1% dietary levels produce a minimal laxative effect and are tumour promoters rather than true carcinogens.[6]

Neotame

Neotame is a derivative of aspartic acid and phenylalanine. It is approximately 7,000 - 8,000 times sweeter than sugar, although some report a sweetening power of up to 13,000 times that of sugar. Neotame was approved by FDI in July 2002 as a general-purpose sweetener. Because of extraordinary sweetness, neotame is consumed in small amounts and produces reduced level of phenylalanine in bloodstream which is clinically insignificant. It is not fermentable by oral microbiota and possesses a crisp and sweet taste.[6]

Stevia

Stevia is calorie free, non-cariogenic and intensely sweet naturally occurring compound found in the leaves of a small shrub, Stevia rebaudiana Bertoni, also called Yerbaa Dulce, which grows wild in Paraguay. It is 300 times sweeter than sucrose and heat stable with little or no metallic taste. In 2008, FDA responded favourably to chemically refined derivative of stevia, the extract Rebaudioside A, to be used as a general purpose sweetener. Stevia has been shown to be safe for diabetic patient and has no mutagenic property.[6]

Sucralose

Sucralose is a non-nutritive, non-caloric trichlorinated derivative of sucrose. It is 600 times sweeter than sucrose but is not metabolized by the body. It is heat stable thus widely used in carbonated and non-carbonated beverages, tea and coffee sweetener, baked goods, chewing gums and frozen desserts.[6]

Using sucrose substitutes to promote oral health

Keeping in mind that the quantity of sugar substitutes used in preserved foods other than sweets is rather high in some communities.[10-12] Instead, authors need to consider how to use sugar substitutes or non-cariogenic sweets to promote oral health. Each of the sugar substitutes has particular characteristics that should be utilised so that the requirements of specific individuals are met. The prevalence of dental caries in children is declining, but children at high risk of developing dental caries are still an important public health concern.[7]

Most of the sugar substitutes mentioned are considered non-cariogenic.[10,12] The use of sugar substitutes in sweets is believed to have contributed in part to the decline in the prevalence of dental caries in industrialised countries. Their anticariogenic effects include:[10]

- Inhibition of insoluble glucan synthesis from sucrose by mutans streptococci.
- Decrease in mutans streptococci numbers in whole saliva and plaque.
- Increase in the buffering capacity and pH of dental plaque.
- Interference with enamel demineralisation and an increase in enamel remineralisation.

Possible health hazards of sugar substitutes

Despite of beneficial effects in reducing caries and various other systemic diseases Sugar substitutes have various side effects on human body. Sugar alcohols are widely known to produce various undesirable gastrointestinal side effects, including diarrhea, bloating, and flatulence due to their incomplete digestion and some, such as sorbitol, are medically used as hyperosmotic laxatives.[5]

CONCLUSION

The various sucrose substitutes have different characteristics and have some sort of advantage in preventing dental caries. For example, adding aspartame or stevioside to maltitol and xylitol has been recommended, as has using a combination of palatinose and xylitol. However, adding xylitol to fermentable sugars, such as sucrose, should be avoided. Using sucrose substitutes in all sweets would be an effective public health measure, but this is not a realistic option: Instead, we need to consider how to use sucrose substitutes or non-cariogenic sweets to promote oral health. Each of the sucrose substitutes has particular characteristics that should be utilized so that the requirements of specific individuals are met. The prevalence of dental caries in children is declining, but children at high risk of developing dental caries are still an important public health concern.

The use of non-cariogenic sweets can be recommended by professionals in these clinical settings as an important adjunct to reducing dental caries risk in individuals. Trusted information about different sugar substitutes should be collected from authorized sites and press releases by government organizations. This can avoid misconception about the various food additives such as sugar substitutes.

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