Sugar, alternative sweeteners and meal frequency in relation to caries prevention: new perspectives

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In the last 20 years, mainly due to optimum fluoride exposure, and practice of good oral hygiene procedures, an important reduction in caries has been observed, despite the fact that sugar consumption was maintained and/or was increasing during the same lapse of time. A sugar–caries relationship cannot be established in most of the industrialized countries and the dietary factor is not as preponderant in the caries process as it used to be two decades ago. The factors which seem to contribute the most significantly to the cariogenicity of the diet are the frequency of carbohydrate ingestion and eating patterns. The relative cariogenicity of food is not correlated with the amount of carbohydrate it contains. Even if sucrose remains the most important sugar consumed in sweets, beverages and confectionery products, all fermentable-carbohydrate foods can be involved in the caries process. The use of chewing gum and other xylitol-containing products have resulted in defined reduction in caries and represent interesting alternatives for high-caries-risk populations. Caries risk and oral health assessments as well as the evaluation of oral hygiene procedures and fluoride exposure should become essential tools in dietary counselling. People who receive optimum fluoride exposure and follow regular oral hygiene measures can safely use dietary carbohydrates, preferably during meals and two to three times daily in snacks or drinks.

Sugar: Sweeteners: Meal frequency: Caries

An important decline in caries prevalence has been observed in the last 20 years in most of the industrialized countries to the extent that some countries have already reached and even exceeded the expectations of World Health Organization: a DMFT* of 3 for 12-year-olds in the year 2000 (Federation Dentaire Internationale, 1982).

This observation is made despite the fact that total sugar consumption has remained constant while sugar drinks and confectionery products have increased in most of the industrialized countries. For example, in Australia an important fall in caries prevalence has been observed with no change in diet from 1963 to 1982 and caries indices (DMFT) dropped from 8·5 to 1·5 in 12-year-old children (Burton *et al.* 1984). In the USA and in most industrialized European countries, a substantial decline in caries experience has been observed despite the continuous increase in sugar consumption in the last decade.

Whilst in developing countries the caries prevalence (Sardo-Infirri & Barmes, 1979) is still related to the increasing consumption of fermentable carbohydrates (Rugg-Gunn, 1989), it becomes more difficult to correlate the use of sugar or even sucrose in the diet with dental caries in most industrialized countries (De Paola *et al.* 1982; O'Mullane, 1989). Due to contemporary changes in oral hygiene habits, divergent degrees of fluoride exposure and the resultant variance in caries distribution, it is important to re-evaluate our approach to dietary and eating habits in relation to concepts of caries prevention.

*A caries index recording decayed, missing and filled teeth in the permanent dentition.

NEW PERSPECTIVES IN THE UNDERSTANDING OF THE CARIOUS PROCESS

Since Miller's (1890) theory, dental caries has always been considered as a multifactorial disease involving factors such as the bacteria in dental plaque, patterns of sucrose consumption, the host susceptibility, and the resultant acid dissolution of enamel tooth structure.

Although this concept is well accepted in the scientific community, it corresponds to an oversimplification of the carious process, specifically with regard to the dietary and host resistance components.

The carious process should now be considered as a dynamic process in which the specificity of the microflora and the inter-relationship between diet variables, protective mechanisms of saliva, and the acquired host resistance are of paramount importance.

The presence of microflora

Dental caries is an infectious process which requires the presence of bacteria in dental plaque.

Nevertheless, not all the dental plaques are cariogenic; the specificity and viability of microbial species present on a site are much more important factors than the quantity of dental plaque. The composition of the microflora is closely related to the pH of the oral environment which is dependent on the availability of fermentable carbohydrates.

Some bacteria such as *Streptococcus mutans* have been incriminated in the carious process, because they are able to produce a large quantity of lactic acid in aciduric conditions, and they can synthesize extracellular polysaccharides which increase the adhesion of dental plaque on the tooth surface.

Nevertheless, too much emphasis may have been placed on the responsibility of *S. mutans* in the carious process.

The microflora is very different from one to another site of the tooth and other species such as *Lactobacillus* or *Actinomyces* spp. are also able to produce caries in more-advanced lesions and in specific sites (roots) respectively. The acid production in plaque is extremely dependent on the frequency of consumption of fermentable carbohydrates favouring the multiplication of aciduric species which are in competition with the other micro-organisms.

Protective properties of saliva

Saliva plays a vital role in protection against caries; it is involved in the re-mineralization process; the concentration of Ca and phosphate in saliva may inhibit the demineralization phase at the outer surface of the teeth.

The enzymic properties and buffer capacities of saliva help to neutralize plaque acid and enhance re-mineralization.

Some foods, such as chewing-gum, may stimulate the saliva flow and consequently improve the buffering capacity of saliva because of its higher bicarbonate concentration.

Conversely, in xerostomic conditions or even during sleeping periods, the much reduced saliva flow will slow the oral clearance of plaque acids and available substrate.

It is recommended, therefore, that eating be avoided before bedtime. Mothers must avoid giving their infant milk or juice bottles as a pacifier before or during sleeping times.

Finally, saliva constitutes an excellent reservoir of F^-, allowing a slow release and topical action on dental plaque and dental tissues.

Role of diet, fermentable carbohydrates and sucrose in the carious process

Sucrose has been considered to be the main causative dietary factor in caries development. Throughout the world in various populations and geographic regions, even if the presence of caries had been observed before the introduction of sugar-containing confectionery foods, the increased availability of sugar was always associated with an increased incidence of caries. The introduction of refined sugar in the diet of native populations (Polynesia, Eskimos), but also the sudden modification of their dietary habits (soft cooked foods), have certainly largely been responsible for the dramatic increase in the incidence of caries. On the other hand, sugar restriction such as observed during the Second World War (Sognaes, 1948) or in total substitution of sugar by xylitol (Scheinin *et al.* 1975) have indicated an important reduction in dental caries.

But in the last 20 years, and mainly due to fluoride exposure in its systemic and mainly topical use, an important reduction in caries has been observed, despite the fact that sugar consumption was maintained and/or was increasing during the same lapse of time. Once again, too much emphasis has been placed on the specific role of sucrose instead of assessing the cariogenic potential of foods and its inter-relationship with the individual protective mechanisms of saliva and the host resistance.

EFFECT OF DIET AND ESPECIALLY CARBOHYDRATE ON DENTAL CARIES

Carbohydrates, an essential source of energy for the body, are generally classified into two different groups: sugars and starches. 'Fermentable carbohydrates' refers to any type of sugars or cooked starches that are digested by the oral bacteria to produce acids and constitute the most important substrate for oral microbial metabolism. Sugar, which is used very imprecisely, should include not only sucrose but also the other mono- and disaccharides such as fructose, glucose, lactose, maltose and invert sugar which are found in many food products and can be fermented by oral micro-organisms to produce acid in the dental plaque.

CARIOGENICITY OF FOOD

Ideally, the cariogenic potential of a food should be established from well-controlled clinical studies in human subjects. Mainly because human experimental use of cariogenic diets cannot be conducted for ethical reasons (Rugg-Gunn & Edgar, 1984), indirect cariological tests were developed to estimate the degree to which certain foods influence the carious process.

Two main types of tests were used: one type compares the amount of acid produced following consumption of various foods (Imfeld, 1977) or the degree of retention of food (Edgar *et al.* 1975); the other type compares the extent to which different foods lead to caries in rats (Mundorff *et al.* 1990). Although neither method alone is sufficient to give individual cariogenic ranking for specific foods, both methods are sufficient to demonstrate a basic principle: to some degree, all fermentable carbohydrate foods can be involved in the caries process. Sucrose remains the most important sugar consumed in sweets, beverages and confectionery products and has been considered as the 'arch criminal' of dental caries (Newbrun & Frostell, 1978) but other foods, such as bread, rice, fruits and honey, also present caries-inducing properties, as demonstrated by the two types of tests; even starch can support low levels of caries activity in both experimental animals (Shaw, 1973; Bowen *et al.* 1980) and human subjects (Sreebny, 1983). French-fried potatoes, bread, cup cakes, bananas, as well as sucrose and confectionery, can all contribute to the decay process.

The relative cariogenicity of food is not correlated with the amount of carbohydrate it contains, and there is limited evidence that caries prevalence increases in proportion to increased concentrations of sugar in food products (King *et al.* 1955). It is not in fact possible to estimate the minimal cariogenic concentration of sucrose in foods because this threshold level varies with the retention characteristics and the oral sugar clearance rate, the frequency of ingestion of each specific item, the cariostatic component content on the one hand, and oral hygiene, saliva characteristics, dietary habits and fluoride exposure of the consumer, on the other hand.

Rugg-Gunn *et al.* (1984) conducted a longitudinal 2-year study on English adolescent schoolchildren and demonstrated that the group who developed no caries ate daily a very similar quantity of total sugars and confectionery in comparison with the group which experienced most caries.

Woodward *et al.* (1994) examined the data on dental caries amongst 12-year-old children and the sugar consumption of the total population for ninety countries. For the whole data set, the dental caries scores (DMFT) tend to rise with sugar consumption but a sugar–caries relationship could not be established from data recorded in the twenty-nine industrialized countries.

RETENTIVENESS AND FOOD CLEARANCE

Retentiveness

The composition and retentive properties of foods are key factors because they strongly influence the speed of a food's oral clearance and consequently have a direct impact on its potential cariogenicity. Prolonged oral retention of foods leads to extended periods of acid formation. Thus, fermentable carbohydrate dietary items which are slowly eliminated from the tooth surface are more cariogenic. Consequently, physical characteristics of food such as adhesiveness, solubility, texture, and hardness are essential as they may affect the sugar oral clearance and saliva flow. Studies on oral sugar clearance (Lanke 1957; Edgar *et al.* 1975; Linke *et al.* 1989; Mundorff *et al.* 1990; Kaskhet *et al.* 1991) demonstrate:
(a) that the rate of elimination of sugar is individual, highly related to the fluidity and flow of saliva;
(b) that the stickiness of food is not as important as the amount of carbohydrate remaining in plaque and saliva because high initial retention can be followed by rapid oral clearance; consequently, the level of cariogenicity of food should be mainly related to its rate of clearance (Mundorff *et al.* 1990);
(c) that white bread and raisins are retained a longer time than chocolate milk or some sweets (Edgar *et al.* 1975; Kaskhet *et al.* 1991) and could produce a higher sugar concentration, particularly when consumed between meals (Lanke, 1957).

ROLE OF MEALS AND MEAL FREQUENCY

The factors which seem to contribute the most significantly to the cariogenicity of the diet are the frequency of consumption and eating patterns. The Vipeholm study (Gustafsson *et al.* 1954), a pioneering major 5-year clinical study was designed to assess the effect of eating pattern and frequency of carbohydrate ingestion and demonstrated that:
frequent sugar intake between meals can increase the incidence of caries in individuals with poor oral hygiene;
if sweets are to be consumed they should be eaten during rather than between meals;
the caries incidence increases if the sugar is retained on tooth surfaces.

This study provided strong evidence that the frequency and form of sugar intake are more important than the absolute amount of sugar consumed.

Several studies have confirmed the results of the Vipeholm study (Gustafsson *et al.* 1954). King *et al.* (1955) conducted a 2-year survey in the UK of the effect of supplementing the diet of children with additional sugar in relation to the incidence of caries. The findings indicated, as in the Gustafsson *et al.* (1954) study, that even doubling the daily sugar intake in children, but only during the meals, did not result in an important increase in caries increment.

Other studies have demonstrated the importance of consumption frequency in animals (König *et al.* 1968; Firestone *et al.* 1982; Bowen *et al.* 1983) and in human subjects (Weiss & Trithart, 1960; Von Der Fehr *et al.* 1970; Martinsson, 1972).

Weiss & Trithart (1960) reported a direct and consistent relationship between caries experience and the frequency of eating items of high sugar content or high degree of adhesiveness between meals, by examining the dietary habits of 783 pre-schoolers in West Tennessee. A frequency of three exposures to refined carbohydrate each day was considered to be constant. The average frequency of eating a high-sugar item between meals was 1·75 items daily. The children who reported eating no items of this nature between meals exhibited a def (caries indices for primary dentition) of 3·3 teeth per child; in contrast those who reported eating four or more such items between meals exhibited a def of 9·8 teeth per child.

Most eating and drinking occasions contain some carbohydrate; the more often foods and drinks are consumed, the greater the potential risk to teeth. It is difficult to determine exactly how often each day it is 'safe' to eat, since a number of inter-related factors are involved:

the amount of time the food stays in the mouth as well as intervals between eating and drinking occasions;

whether or not the teeth are cleaned and exposed to fluoride regularly.

At each fermentable-carbohydrate challenge the teeth are exposed to an increased acidity of the oral environment and possible demineralization can be initiated at the outer enamel surfaces. In addition, frequent acidic conditions in the oral environment do not allow the mineralization process to take place because resting periods are too short to permit the buffering capacities of saliva to neutralize plaque acid.

Eating between meals should be safe for most people, assuming their oral hygiene is good. However, constant nibbling or sipping of sugared drinks throughout the entire day is very harmful.

ALTERNATIVE SWEETENERS

The use of alternative sweeteners has allowed some sweet foods to be made without sugars. These sweeteners are either of the intensive type, for example saccharine or aspartame, or are bulk sweeteners such as sorbitol, xylitol or maltitol. These alternative sweeteners, and particularly sugar alcohols (polyols) such as xylitol, sorbitol or mannitol, are not readily fermented by the oral bacteria (Edwardsson *et al.* 1977; Mühlemann *et al.* 1977) and are useful for those who find it difficult to achieve a low-enough frequency of intake of traditional carbohydrate-containing foods and drinks.

Xylitol has been particularly attractive because it is a natural carbohydrate derivative sugar substitute produced during normal metabolism and found in small amounts in fruits and vegetables.

During the past 20 years extensive research has been done on xylitol in animals and in human clinical surveys and several review articles (Mäkinen & Scheinin, 1982; Linke, 1986; Bär, 1988; Mäkinen, 1992; Birkhed, 1994; Tanzer, 1995; Trahan, 1995) have demonstrated that this sweetener possesses non-cariogenic and probably even anticariogenic properties.

Xylitol's use, particularly in chewing-gum, has been evaluated in numerous clinical longitudinal surveys (Scheinin *et al.* 1975, 1985; Isokangas *et al.* 1988; Kandelman *et al.* 1988, 1990; Mäkinen *et al.* 1995) which clearly indicated a caries inhibitory effect mainly attributed to:

its role in the re-mineralization process;

its capacity to reduce the quantity of dental plaque;

its ability to reduce the number of *mutans streptococci* colonies;

its influence on the pH of dental plaque and the buffer capacity of saliva.

The use of xylitol-containing products has resulted in definite reduction of caries and represents an interesting alternative for high-caries-risk populations.

When it is not possible to brush and floss, especially after a fermentable-carbohydrate challenge, chewing of xylitol-containing gum may reduce dental plaque and dental caries. Its use can help to neutralize acid levels in dental plaque and clear from tooth surfaces the fermentable-carbohydrate deposits contained in food.

IMPACT OF ORAL HYGIENE AND FLUORIDE EXPOSURE ON CARIES DISTRIBUTION AND ON THE IMPORTANCE OF DIETARY FACTORS

As indicated previously, the important decline in caries observed in a large number of industrialized countries has occurred without a concomitant reduction in sugar consumption and can be explained only by the increased availability of fluoride, particularly from toothpastes, and the promotion and application of good oral hygiene procedures.

The large increase in caries-free children in North America and in Europe has been achieved mainly by optimum fluoride administration in comparison with the relatively moderate benefit of a drastic reduction in sugar supply as observed during the Second World War (König, 1990).

People who receive appropriate systemic and topical fluoride supplements and follow regular oral hygiene measures can safely use dietary carbohydrates preferably during meals and two to three times daily in snacks or drinks.

When oral hygiene is poor, or when fluoride is not available (a situation which prevails in most developing countries), the frequency of consumption of fermentable carbohydrates, particularly between meals, becomes an important caries-related factor (Burt *et al.* 1988; Sundin *et al.* 1992) and should be restricted.

NEED FOR FURTHER RESEARCH AND RECOMMENDATIONS

Due to the increased resistance of teeth, mainly attributed to wider exposure to fluoride, and improvement in oral hygiene, the dietary factor is not as preponderant in the caries process as it was 20 years ago.

More research is needed to determine the influence of the frequency of meals in relation to:

caries-free *v.* caries-risk populations;

fermentable carbohydrates *v.* sucrose snacks;

type of foods in meals *v.* in snacks.

Taking into account these new epidemiological components, caries risk and oral health assessments, as well as the evaluation of oral hygiene procedures and fluoride exposure, should become essential tools in dietary counselling at the individual and collective levels.

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