Diet and dental caries

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Dental caries prevalence is on the increase in transitional societies in the same way as chronic non-communicable diseases, having been largely controlled in developed societies. The lessons of dietary cariogenicity and preventive strategies, through dental hygiene and fluoride are still to be incorporated into the health policies and practices of many countries, and applied to at-risk populations, like immigrants, in developed nations. Preferred fluoride delivery systems are under active discussion. There is particular concern about nursing practices in early life, and, in later life, adequacy of dentition and of the problems of gingival disease need to be addressed.

Diet and dental caries

Dental caries is one of the most prevalent diseases in children[1]. It is a multifactorial disease requiring the presence of a susceptible tooth, cariogenic microflora (plaque), and a diet conducive to enamel demineralization[2]. The classic diagram of the etiology of dental caries is shown by four overlapping circles indicating the concentricity of etiological factors. To prevent or arrest dental caries it requires that only one factorial parameter be out of concentricity.

Dental caries is a disease that dates back to antiquity and occurs in populations that have never used sugar or processed foods. The prevalence of dental caries appears to increase with civilization, urbanization, and affluence. There is presently an alarming rate of increase in the prevalence of dental caries in developing countries. The introduction of sucrose into the modern diet has been associated with increased caries prevalence. However, most developed countries have seen a significant and continuing reduction in caries prevalence in the last 30 years[3].

The concept held by practicing dentists regarding the relationship between diet and dental caries is sometimes characterized by the equation:

Bacterial enzyme + Fermentable carbohydrate = Acid

Acid + Tooth = Cavity

(over time)

This concept has spurred some dentists to advocate a simplistic approach based solely on the elimination of sugar. In fact, the relationship between the numerous dietary factors and dental caries is complex[4], and may be more appropriately represented by the following hypothetical formula:

Caries expression =

$$K\left[\left(\frac{\text{Bacterial virulence}}{\text{Host resistance}}\right) \times \left(\frac{\text{Saliva Buffering capacity}}{\text{Food effects}}\right) \times \left(\frac{\text{Chemistry of tooth substance}}{\text{Oral retention of food}}\right) \times \left(\frac{\text{Stickiness}}{\text{Detersive characteristics}}\right) \times \left(\frac{\text{Food acidity}}{\text{Food texture}}\right) \times N^{n}\right]$$

Epidemiological studies

Modern diet versus primitive diet

Epidemiological studies have shown that the incidence of dental caries differs immensely among population groups. Although part of the variance can be attributed to genetic factors, the diets of different ethnic groups probably account for the major differences[5].

Skeletal remains from presucrose cultures show that dental caries incidence is much lower. For example, the caries prevalence of ancient Hawaiians was extremely low, especially throughout childhood and early adulthood. In older members (40 years and older) it usually increased due to cervical root caries complicated by concurrent periodontal disease. By contrast, the children in Hawaii today have one of the highest dental caries incidence rates in the USA[6]. The dental caries prevalence in children in French Polynesia has also been found to be relatively high.

Dental caries incidence in native populations

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(Australian Aborigines, Bantu tribes of South Africa, the New Zealand Maoris, the Eskimos) was very low prior to the introduction of the modern diet, but increased dramatically after the introduction of the North American/ European culture. The children of Tristan da Cunha were remarkably free of caries in 1937, when their diet consisted mainly of potatoes, fish, with an occasional seabird or seabird eggs, as well as beef, mutton, apples, and berries but no added sugar. They became progressively affected with severe dental caries as they grew more sophisticated in terms of life-style and the adoption of a modern diet[7]. Other factors also change, but diet appears to be the most significant.

Wartime diets

When the consumption of refined carbohydrates and sugar, was restricted during World War II, with a concurrent decrease in snacking, the dental caries rate dropped dramatically[8]. After the war, the caries rate rose as sugar restrictions were lifted. The measurable differences were most significant in England, Norway and Japan. The reduced amount of sugar consumption during the war had a most dramatic posteruptive (topical) effect on the caries incidence but no significant preeruptive (nutritional) effect. This observation was confirmed in an independent study of European children by Marthaler. This war time diet is unlikely to be acceptably introduced today.

Institutional studies

Vipeholm study

The Vipeholm dental study was a 5-year investigation of 436 adult inmates in a mental institution at the Vipeholm Hospital near Lund, Sweden in 1954[9]. The institutional diet was nutritious, contained little sugar and no between-meal snacks. The dental caries rate in the inmates was relatively low. The experimental design divided the inmates into seven groups; sugar was introduced either at mealtime (in bread and solution) or between meals (in caramels, toffee, and chocolates).

The main conclusions of the study were as follows:

1. An increase in carbohydrate (mostly sugar) increased the caries activity. However, the frequency of intake was much more significant than the amount of carbohydrate ingested.
2. The risk of caries was greater if the sugar was consumed in a form that stayed on the surfaces of teeth.
3. The risk of sugar increasing caries activity was greatest if the sugar was consumed between meals in a form that tended to be retained on the surfaces of the teeth.
4. The increase in caries activity varied widely between individuals.
5. Upon withdrawal of the sugar-rich foods, the increased caries activity rapidly disappeared.
6. Caries lesions could continue to appear despite the avoidance of refined sugar and maximum restrictions of natural sugars and dietary carbohydrate.
7. A high concentration of sugar in solution and its prolonged retention on tooth surfaces lead to increased caries activity.
8. The clearance time of the sugar correlated closely with caries activity.

The Vipeholm[9,10] study clearly showed that the physical form of carbohydrates (stickiness, oral clearance time, frequency of intake) was much more important in cariogenicity than was the total amount of sugar ingested.

Hopewood House children

The dental status of children between 3 and 14 years of age residing at Hopewood House, Bowral, New South Wales, Australia, was studied longitudinally for 10 years[11,12]. Almost all had lived from infancy at Hopewood House. All lived on a nutritionally adequate lacto-vegetarian diet. The absence of meat and rigid restriction of refined carbohydrates were the principal features of the Hopewood House diet. Except on weekends between-meal snacks were limited to milk, fruit, and raw vegetables.

The dental caries prevalence in young children in Hopewood House was almost negligible in primary dentition. It was approximately one tenth of the average Australian child's permanent teeth even though oral hygiene in these children was extremely poor. A total of 25 of 82 children remained caries free over the 5-year study period.

Australian children have exhibited approximately a 10 fold reduction in caries incidence over the past 30 years, due largely to the effects of fluoridation of water and the use of fluoride toothpaste.

Seventh Day Adventist children

Seventh Day Adventist dietary counsels advise limits on the use of sugar, sticky desserts, highly refined starches, and between-meal snacking. Several studies have shown that the caries prevalence in Adventist children tends to be lower than that in non-Adventist children in the same geographic location and socioeconomic stratum[13].

Turku sugar studies

In a 2-year dietary study, 125 young adults were divided into three experimental groups: sucrose, fructose, and xylitol. They consumed their entire dietary sugar intake using these sugars exclusively. There was a dramatic reduction in the incidence of dental caries after two years of xylitol consumption. Fructose was found to be as cariogenic as sucrose for the first 12 months but became less so at the end of 24 months[14].

Subsequently, a l-year chewing gum study was conducted on 102 subjects who consumed xylitol or sucrose chewing gum but otherwise pursued their usual dietary and oral hygiene habits. A similar reduction in caries increment was accomplished in the xylitol chewing gum subjects as had occurred in the subjects in the 2-year dietary study. Sucrose chewing gum was found to be cariogenic. Frequent between-meal chewing of xylitol gum produced an anticariogenic effect. The benefits of caries reduction was attributable to the use of xylitol and to the increased production of saliva[15].

Nursing bottle caries

Nursing bottle caries, is characterized by extensive and rapid carious destruction of the maxillary incisors and primary first molars, by fluids that stagnate over these teeth while the infant sleeps. Although initially the lower teeth are protected by the tongue and submandibular salivary gland secretions, in advanced cases the entire dentition may be affected. Lactose in milk might be responsible for the cariogenic conditions. However, it seems more likely that milk with added sugar, a sugary beverage, or a sugar-

dipped pacifier at bedtime is responsible for this condition[16,17].

At-will breast-feeding can also cause severe or rampant caries of the primary dentition in infants. One case study documents the variations in patterns of caries as a result of at-will breast-feeding. Since human milk is 7.2% lactose by weight (compared to 4.5% for bovine milk), nighttime feeding at the breast, with stagnation of milk, may lead to nursing caries[18].

Survey of dietary habits of children

Zita et al[19] found virtually no relationship between the total amount of sugar consumed and the incidence of dental caries. However, there was a highly significant positive correlation between the total number of sugary snacks and DMFS. Similarly, Weiss and Trihart[20] found a significant linear correlation of dental caries prevalence with the number of between-meal snacks based on a 1-day diet history of 786 children between 4 and 5 years of age.

A positive correlation has been found between the frequency of eating snacks and severity of dental caries among children[21]. In a post-fluoride environment, a typical diet of 5-7 meals or snacks per day for children appears to be "safe" provided the teeth are cleaned with fluoride toothpaste twice or more daily. The type of food or drink does not seem to be important.

Hereditary fructose intolerance

Hereditary fructose intolerance (HFI) is caused by remarkably reduced levels of hepatic fructose-l-phosphate aldolase, which splits fructose-1-phosphate into two 3-carbon fragments for further metabolism. Persons affected with this rare metabolic disorder have learned to avoid any food that contains fructose or sucrose, because the ingestion of these foods can cause nausea, vomiting, malaise, tremor, excessive sweating, and coma due to fructosemia. Most of the symptoms are due to a secondary hypoglycaemia. These persons live quite comfortably on other foods (glucose, galactose, and lactose-containing foods like milk, bread, dairy products, rice, and noodles). Although there have been only a limited number of cases reported in the literature, the dental caries prevalence in these subjects has been extremely low[22].

Cariogenicity of foods

Sucrose and other sugars

Sucrose has been labelled the arch criminal of dental caries and blamed as the primary culprit in the pathogenesis of dental caries, probably because of its prevalence in the diet[23].

Unfortunately, the singular focus on the potential cariogenicity of sucrose led to an erroneous belief that other sweeteners (fructose, high-fructose corn syrup, so-called naturally occurring sugars) are either noncariogenic or significantly less cariogenic than sucrose. In fact, studies done on primates and other animal models have shown that mixtures of glucose and fructose are as cariogenic as sucrose. The studies have raised questions about whether any benefits are derived by substituting fructose for sucrose. These data pose further complications in the light of practical dietary counseling practices, because it is not commonly recognized that many fruits and vegetables contain substantial amounts of naturally occurring sugars. For example, unsweetened pineapple juice may contain as much as 13% sugar, exceeding the sugar levels of most carbonated beverages[24].

Sugars like fructose, glucose, corn syrup, and other "naturally occurring" sugars were once considered to be much less cariogenic than sucrose. However, this is not true. Honey, sugar cane, figs, and dried fruits are highly cariogenic in spite of their "natural" status[25].

Cariogenicity tests of foods

Despite many years of research on the cariogenicity of foods, at present no single test will determine conclusively the cariogenicity of one food versus another.

With the exception of clinical trials, nearly all tests deal with one dimension of cariogenicity. For example, a test may measure oral retention of food or the enamel dissolved by a drop in plaque pH. Of all the tests generated so far, the intraoral plaque pH telemetry method has received the greatest acceptance. In Switzerland, products that have been tested in vivo and found not to lower the plaque pH below 5.7 for 30 minutes after ingestion have been allowed to proclaim themselves "safe for teeth"[26]. Swiss confectioners are permitted to advertise their products as safe for teeth if convincing pH-telemetric data are accepted as evidence by the Swiss Office of Health. Labelling a product as noncariogenic (nicht kariogen) is allowed only when the data are derived from a clinical study of caries incidence. The basic assumption is that nonacidogenic or hypoacidogenic (pH 5.7) foods are probably either noncariogenic or only slightly cariogenic. For example, confectionery sweetened exclusively with xylitol can be advertised as "noncariogenic" because xylitol is nonacidogenic in telemetric pH tests and was shown to be noncariogenic in the Turku sugar studies. Scores of confectioneries have been tested by the Swiss Bioelectronic Unit at the Zurich Dental University Institute. However, the pattern and sequence of food intake are important variables influencing plaque pH. They found that cereal eaten between orange juice and toast with jam tended to increase the pH-lowering effect of these two foods. Furthermore, eating peanuts stimulated sufficient salivation to significantly raise the plaque pH[27,28,29]. Another criticism of the intraoral plaque telemetry test is that it can be used only on a small number of persons. In order to determine the cariogenicity of all foodstuffs, given their sequence and frequency of intake, would be nearly impossible.

Caries-inhibiting foods and food components

Phosphates

Nearly 200 animal studies using various forms of phosphate supplements have shown that phosphates in the diet of experimental animals (mostly rodents) result in significant caries reduction[30]. Sodium metaphosphate appears to be most effective. Although the precise mechanisms of action are not known, it is generally believed that phosphates exert their cariostatic effects via local rather than systemic routes.

Unrefined grain, such as oat hulls, that contain a relatively high phytate (organic phosphate) content have some inhibiting effects on caries as do milk and cheese by virtue of their phosphate content[31].

Results of clinical trials of phosphate supplements have been much less successful. Several studies have

documented significant caries reductions when dicalcium phosphate dihydrate was added to chewing gum, and when calcium sucrose phosphate was added to hard candy, flour and bakery products. Unfortunately, there is not a good understanding of present levels of phosphate in food. Various government agencies hold conflicting views on optimal levels.

Other inhibiting substances

Pyridoxine, fat, tannic acid, zanthines and constituents of cocoa and chocolate are believed to have caries protective factors[31,32].

It has been suggested that fibrous and detersive foods may also prevent caries. There is, however, inadequate clinical evidence to document such statements. The relationship is indirect at best. Foods like peanuts, fruits and vegetables which require vigorous mastication stimulate salivation. This raises plaque pH, and saliva promotes remineralization to "heal" the incipient lesions[29,33].

Snacking patterns in children

Pediatric nutritionists believe children should not have only three square meals a day but should have smaller and more frequent intakes of food. It would be ideal to suggest that only noncariogenic snacks be eaten, however, it is more realistic and practical to recommend a "low cariogenic" snacking pattern that allows sufficient clearance time between meals and snacks for saliva and fluoride to remineralize early incipient lesions. Morgan and Leveille[34] surveyed the snacking patterns of US children, aged 5 to 12 years, and concluded that children snacked 45.8% of the possible time and on the average each child consumed 1.37 snacks per day. They also observed that some children did not snack at all but that others consistently consumed at least three snacks per day. The most frequently eaten snacks were sweetened baked products, which comprised 35% of all snacks. Sweetened beverages (noncarbonated and soft drinks) were drunk in 24% of snacks, and in 20% of snacks milk was consumed. Other beverages (fruit juices and sweetened drinks) were found in 8% of snack composition. Salted products (potato chips, pretzels, popcorn) comprised 20% of reported snacks and ice cream and related products were found in 16%. Between-meal snacks made a positive nutrient contribution in the 5-to-12 year-old children, because snacks accounted for 15 % or more of the average total daily intake of the following nutrients: ascorbic acid, riboflavin, vitamin D, calcium, phosphorus, potassium, magnesium, and copper. At least 10% of the average daily intake of fiber, thiamin, niacin, folic acid, iron, zinc, and vitamins A, B-6, and B-12. No attempt was made to determine the cariogenicity or the dental health status of these children.

The ideal snack

Many of the physical and chemical attributes of an ideal snack from a dental health viewpoint are already known[35].

1. Its physical form should stimulate salivation.
2. It should produce a minimal amount of intra-oral retention.
3. Its chemical composition should include: a relatively high protein and low fat content; minimal fermentable carbohydrates; a moderate mineral content (particularly calcium, phosphate, and fluoride); an inherent pH above 5.5 so as not to increase oral acidity; a large inherent acid-buffer capacity during mastication; and a low sodium content. With present-day food technology these attributes should not pose an insurmountable problem.

Although the proclivity for sweet taste has been shown to be an innate biological preference of neonates[36], it is subject to postnatal conditioning (cultural practices, family food habits) and other factors. The ingestion of nutritious and noncariogenic foods in early life should greatly help the development of sound dietary practices.

Fluoride

The relationship between the optimal intake of fluoride and improved dental health is now well established. Fluoridation of drinking water has had a major anticariogenic effect. The beneficial effect is both systemic, pre-eruptively on developing teeth, and also topical, on erupted teeth.

Although fluoride occurs naturally in almost all drinking water, most contains less than the optimal amount. Therefore it is desirable to ensure that all children receive the benefit of optimally fluoridated water[37].

Prenatal fluoride

In spite of claims that prenatal fluoride supplements impart immunity against dental caries in the dentition of the offspring, there is insufficient conclusive evidence to indicate a significant caries preventive effect on the primary and permanent teeth from the use of prenatal fluoride supplements[38].

Postnatal fluoride supplements

Numerous clinical trials have shown that post-natally administered fluoride supplements are effective cariostatic agents in communities that are fluoride deficient. If fluoride supplements are used continuously for a number of years, dental caries reduction similar to that derived from water fluoridation may be achieved. Preparations containing fluoride and vitamins are as effective as fluoride alone. Combined fluoride/ vitamin preparations are generally more readily accepted by parents and are more likely to be used conscientiously than separate fluoride and vitamin preparations[39]. Because of recent concerns of excessive fluoride intake leading to very mild enamel fluorosis, the dosage for fluoride supplements has been decreased[40].

Hence, if a child lives in a non-fluoridated community, then the use of a fluoride supplement starting at 6 months of age and continued at least 12 years, would give caries protection for both the primary and permanent teeth.

Fluoride toothpaste

Fluoride toothpaste contributes significantly to the reduction of dental decay in both fluoridated and non-fluoridated communities. It is the single most effective means of reducing caries in non-fluoridated communities because of its extensive availability. The maximum fluoride concentration in toothpaste in America is 0.1%, this is equivalent to 1,000 ppm F. However, in Europe, toothpaste may contain 1200 ppm F or more[41].

Concern has been expressed about the ingestion of fluoride toothpaste by infants and young children who may like to eat toothpaste. It has been estimated that the average

fluoride ingestion after a single brushing with a fluoride toothpaste is between 0.12 to 0.30 mg. Therefore, only a smear of fluoride toothpaste should be used by infants and toddlers. Alternatively, a reduced fluoride children's toothpaste may be used by toddlers before the age of two years[42].

Topical fluoride applications and fluoride rinses

When a child visits a dentist for a checkup, the teeth should be cleaned professionally by the dentist or a dental hygienist. A topical fluoride solution or gel containing 1.23% acidulated sodium fluoride should be applied to the teeth to increase their resistance to dental decay. Those children who have multiple cavities may require additional fluoride gel to be applied at home on a daily basis[43]. Furthermore, children who are receiving orthodontic treatment should use a fluoride mouth rinse containing either 0.2% NaF weekly or 0.05% NaF daily[44]. Because brushing of teeth is made more difficult by the presence of orthodontic braces, the use of fluoride mouthrinse should help to counter-balance the increased susceptibility to decay during orthodontic treatment.

Conclusion and recommendations

It is now clear that sucrose is not the only dietary contributor to dental decay. Many other sugars, whether refined in the form of sweets and confection or occurring naturally in fruits and juices are equally cariogenic. Recent research has confirmed that it is not the amount of sugar consumed, but the frequency and pattern of intake that is important. Furthermore, starches are potentially as caries-promoting as simple sugars. In fact, some starchy foods are retained in the mouth for much longer periods of time than simple sugars. This prolonged retention may be more harmful than sugars which are cleared by saliva very readily. Contrary to popular belief, some foods commonly perceived as sticky and retentive such as caramel, actually clear faster than foods not generally considered sticky, including potato chips, bread and dried fruit.

Foods that require vigorous mastication or are tasty will stimulate greater salivary flow. Saliva has a most important role in the buffering capacity of acids produced by bacteria as well as promoting remineralization of early incipient enamel lesions and inhibiting the amount of demineralization.

Most significantly, is the protective effect of fluoride, whether present in water, foods, beverages or toothpaste, in the reduction of dental caries. The improvement in oral health awareness and dental hygiene practice in developed countries have resulted in precipitous falls in the dental caries prevalence in most developed countries. It is indeed possible to have a caries free generation with the availability of water fluoridation and the judicious use of foods and proper dietary habits.

Simple, practical dietary advice by dental and medical practitioners for the public should include:

1. Practicing effective oral hygiene by brushing teeth with fluoride toothpaste at least twice per day.
2. Allowing saliva to neutralize acids and remineralize tooth enamel by limiting the frequency of eating or drinking to not more than 6-7 meals or snacks per day.
3. Avoiding habits of prolonged sucking on a nursing bottle or constant eating and drinking of foods and beverages containing carbohydrates.
4. Having regular check ups and cleanings with a dentist.

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摘要：

龋齿是儿童最常见的疾病之一，而膳食与龋齿密切有关。蔗糖不是造成龋齿的唯一膳食因素，其他糖类都具有同样的致龋性。甚至淀粉类食物，由于其在口腔的滞留时间比某些单糖还要长，因此对牙齿的危害更大。某些通常认为是“粘性”和易滞留的实物（如硬糖）实际上比认为是“非粘性”的实物（如薯条、面包）清除的更快。需要剧烈咀嚼的和味浓的实物刺激唾液形成，唾液在中和细菌产酸中发挥重要作用，同时对幼儿牙釉损伤的重新矿化和抑制矿物质溶出也有重要促进作用。无论是饮水或是食物、饮料、牙膏中的氟都有预防龋齿的作用。在发达国家，由于对口腔卫生认识的提高，并付诸实践，龋齿发生率已出现下降趋势。提供加氟的饮水、选择适当的食物、保持适当的饮食习惯，就可使我们的后代免受龋齿之忧。

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