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Association of Diet with Dental Caries in Preschool Children

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This review updates the evidence supporting dietary factors that affect dental caries in preschool children and recommends dietary approaches to reduce caries risk. The carious process is strongly associated with dietary practices. Bacteria attached to teeth metabolize dietary sugars, and acid is the major byproduct of this metabolism. If the bacterial metabolism is prolonged owing to sugar consumption at a high frequency or prolonged oral retention of sugar, the acidity of dental plaque may become low enough such that tooth enamel will demineralize. Sucrose is the most cariogenic sugar because it can form glucan, which enables firm bacterial adhesion to teeth and reduces the diffusion of acid and buffers in the plaque.

Nutrition education and counseling have the following goals:

- Reducing high-frequency exposures to sugars
- Avoiding frequent consumption of juice or other sugar-containing drinks
- Discouraging the behavior of a child sleeping with a bottle
- Restricting sugar-containing snacks that are slowly eaten
- Limiting cariogenic foods to mealtimes while promoting snacking with noncariogenic foods
- Rapidly clearing cariogenic foods from the child's oral cavity by tooth brushing or by consumption of protective foods

Along with nutritional factors, a comprehensive approach to preventing dental caries in preschool children must include good oral hygiene, appropriate use of fluorides, and access to preventive and restorative dental care.

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The dental caries process

Observations in humans, animals, and in vitro have clearly shown that frequent and prolonged oral exposures to certain carbohydrates are critical to caries activity. The mechanism by which diet affects dental caries is simple. The bacteria attached to teeth use simple sugars (eg, glucose, fructose, sucrose) in their glycolytic pathways to produce energy, with acid as a byproduct of this metabolism. Consequently, the acidity of the tooth-plaque interface may fall to a point at which demineralization of the tooth ensues. The rate of demineralization is dependent on the absolute pH decrease, as well as the length of time that the pH is below a level that fosters dissolution of enamel. The critical pH for demineralization varies among individuals but is in the approximate range of 5.2 to 5.5 [1].

The initial stages of tooth loss occur just below the enamel surface to produce a visual whitening of the tooth, referred to as a "white spot" lesion. At this stage of mineral loss, the lesion may not progress any further, or may even remineralize if the cariogenic environment diminishes. Treating the tooth with fluoride, decreasing the carbohydrate source for the bacteria, reducing the levels of cariogenic bacteria, or lessening the ability of bacteria to produce acid are preventive approaches that can remineralize the initial carious lesion. If disease-suppression procedures are not initiated and the acidic challenge is not reduced, the initial lesion will continue progressive dissolution, eventually giving rise to a frank carious lesion.

Considerable evidence shows that only a limited number of the bacteria in the oral cavity have the ability to demineralize teeth. One group of these microorganisms, *Streptococcus mutans*, is most associated with the dental caries process. Classic animal experiments performed by Fitzgerald and Keyes [2] showed that rats did not develop dental caries from sugar-rich diets unless they had been infected with these oral streptococci. More recent findings have shown that preschool children with high colonization levels of *S mutans* in their oral cavity have a greater caries prevalence and a much greater risk for new lesions than do children with low levels of these bacteria [3]. *S mutans* are believed to be more caries conducive because of their ability to adhere to tooth surfaces, to produce copious amounts of acid, and to survive and continue metabolism at low pH conditions [4].

Colonization of *S mutans* in preschool children is believed to result from the transmission of these organisms from the child's primary caregiver, usually the mother [5]. The exact method of transmission is not completely understood but is suspected to be due, in part, to sharing utensils and foods. The earlier a child is colonized with *S mutans*, the greater the risk for caries [6].

Dental caries in children should be considered a transmissible and infectious bacterial disease. Children first need to become colonized with *S mutans* before they can have caries activity. When these cariogenic bacteria have an environment that favors their proliferation and metabolism

as a result of frequent exposure to carbohydrates, large quantities of acid can be generated adjacent to tooth surfaces.

Dietary factors in dental caries initiation and progression

Abundant epidemiologic evidence obtained from groups that have consumed low and high quantities of sugar, especially sucrose, suggest that it is the major dietary factor affecting dental caries prevalence and progression [7]. The frequency of ingestion and the form of the carbohydrate are the critical factors in the cariogenicity of sugar. Products that are sticky, retained for long periods in the mouth, or consumed with high frequency have a higher cariogenicity than foods that are eliminated quickly from the oral cavity. The frequent ingestion of products such as hard candies and throat lozenges can be extremely harmful to the teeth. A study using programmed feeding machines demonstrated that rats exposed to a high-sugar diet experienced caries according to the number of times per day the diet was presented to them. Conversely, rodents fed sugar infrequently (three times a day) experienced no smooth surface caries, suggesting that the natural defenses in the mouth can counteract the damage done by bacterial acid production from moderate sugar exposure [8]. Likewise, human pH telemetry studies show that subjects consuming three meals a day have periods of demineralization counteracted by periods of remineralization; however, if meal and snack periods are frequent, demineralization periods are increased, and there are no remineralization periods (Fig. 1).

Aside from the well-documented harm of a high-sugar intake on teeth, excessive sugar is a concern to the general health of children. High sugar–containing foods generally are low in essential nutrients and may be substituted for more nutritious foods in a child's diet. General nutrition recommendations uniformly suggest that sugar should be a small component of the diet (Fig. 2) [9].

One example of high-frequency sugar consumption is prolonged or nighttime bottle-feeding practices. Although recent evidence suggests that sleeping with a bottle is an important risk factor, that behavior is perhaps an oversimplification of the cause of the rampant caries process. Several studies report that most preschool populations take, or have taken, a bottle to bed [10,11]. Because this feeding pattern is pervasive, it follows that the parents of children with early childhood caries often respond positively to the question, "Do you put your child to bed with a bottle?" It is logical that the bottle-to-bed habit is inferred as the "cause" of early childhood caries. Reisine and Douglass [12] have reviewed the studies on infant feeding patterns and have found little support for the conclusion that the use of a nighttime bottle is a major caries risk factor. Nevertheless, despite the findings of their review, it is appropriate to discourage the bottle-to-bed

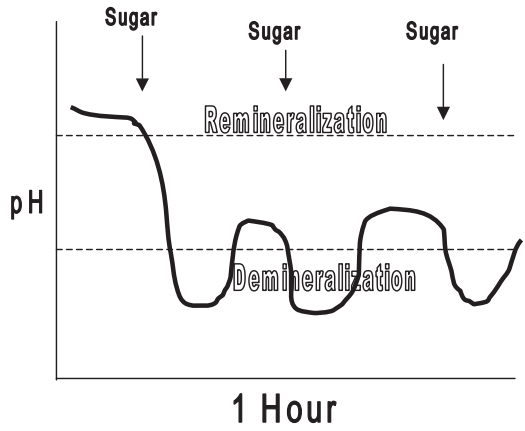

Fig. 1. Example of drops in plaque pH with high eating frequency. In such situations, there may be greater periods of demineralization and no periods of remineralization.

habit because sleeping with a bottle, especially one containing sugar, will contribute to a high-frequency contact of substrate to the bacteria.

Another controversial yet poorly documented caries risk is the potential cariogenicity of breastfeeding. Case reports have associated prolonged or

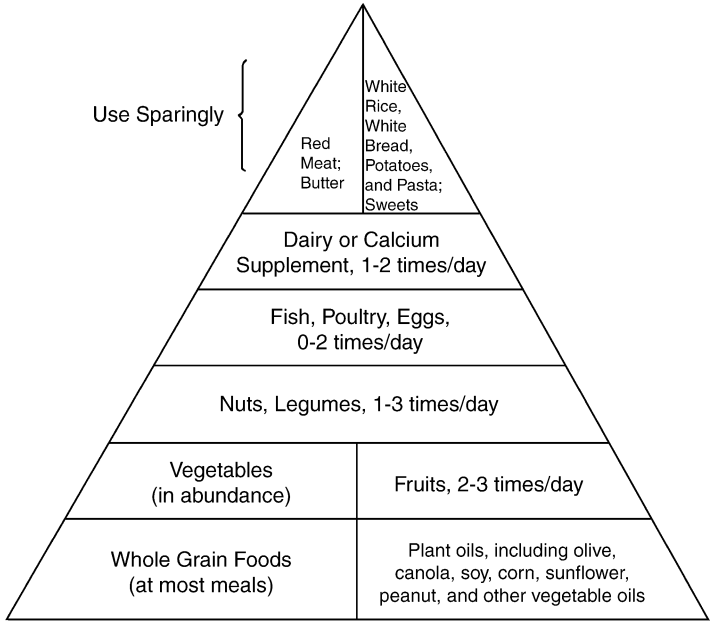

Fig. 2. Healthy eating pyramid for general nutrition shows that sweets, as well as white carbohydrates and food with high cholesterol, should be eaten sparingly. (*Modified from* Willett WC. Eat, drink, and be healthy. New York: Simon & Shuster; 2001. p. 17; with permission.)

nighttime breastfeeding with early childhood caries [13–16]. Nevertheless, one cannot dismiss a possible association between the rampant caries in these cases and other cariogenic dietary practices. Further study is required to determine the prevalence of early childhood caries in exclusively breastfed children and whether child-rearing practices, such as a lack of restriction in getting snacks [17], could contribute to caries in breastfed children as well as in bottle-fed children.

Although it is likely that early childhood caries is caused by high-frequency sugar exposure from drinks in a baby bottle or "sippy cup" (cup with spouts) and oral colonization with *S mutans*, other causes of caries, such as hypoplasia of primary teeth and high-frequency sugar consumption in solid foods, may contribute to the prevalence of this condition.

Types of food products

As mentioned previously, sugars found in the human diet support bacterial acid production and the colonization of teeth by *S mutans*. The differences in the ability of bacteria to metabolize common sugars (sucrose, glucose, and fructose) are minimal. Nevertheless, sucrose seems to be the most cariogenic sugar not only because it produces acid but also because *S mutans* can use this sugar to produce glucan, a water-insoluble polysaccharide. This polymer enables *S mutans* to adhere firmly to teeth and also inhibits the diffusion properties of plaque. The inhibition of diffusion reduces the ability of buffering components of saliva to reach the sites of carious attack and inhibits the transport of acids away from teeth. Furthermore, glucan makes the dental plaque less susceptible to mechanical disruption [18].

Fruit juice and fruit-flavored drinks have a great cariogenic potential because of their high sugar content (Table 1) and the way they are consumed. They are offered frequently to children because of their high acceptance, low cost, and the belief of parents that they are nutritious. Unfortunately, bottles and sippy cups filled with these fruit drinks are frequently given to children as continuous snacks, and children also are put to bed with them. Besides the caries implication of frequent consumption of fruit juice/drinks, there are reports of general health concerns with their excessive consumption [19]. Their high-frequency consumption should be considered as highly cariogenic and generally unhealthy for preschoolers.

The food most frequently consumed by preschool children is milk and milk-based formula. The sugar found in milk, lactose, is not fermented to the same degree as other sugars. Additionally, it may be less cariogenic because the phosphoproteins in milk inhibit enamel dissolution [20,21], and the antibacterial factors in milk may interfere with the oral microbial flora [22]. In caries experiments in rats, bovine milk was repeatedly demonstrated to be noncariogenic and even reduced the cariogenicity of sucrose-containing diets [23,24]. Human breast milk also has been shown to not

Table 1
Market basket survey of sugar content in juices or juice drinks found in a grocery store

Company	Label	Fruit juice (%)	Sugar (%)	Added sugar
Libby	Juicy Juice, Grape	100	13	No
Motts	100% Apple Juice	100	10	No
White House	Apple Juice	100	11	No
General Mills	Squeezit	1	13	Yes
Johanna Foods	Ssips	10	12	Yes
Tropicanna	Twister Light	10	3	Yes
P & G	Sunny Delight	5	13	Yes
Super G	Lemon-Lime Drink	10	13	Yes
Heinz	100% Apple	100	11	No
Gerber	100% Apple	100	13	No
Gerber	Graduate Berry Punch	100	12	No

cause enamel decalcification in laboratory experiments [25]. Additionally, milk remineralizes artificially demineralized enamel in vitro [26]. Although the lack of cariogenicity of milk is clear, it may be the vehicle for more cariogenic substances. Parents are known to combine milk or milk formulas with other food products or sugar [27]. Additionally, infant formulas that contain sucrose may be more cariogenic than lactose-based formulas.

Starch is often regarded as a relatively low cariogenic carbohydrate. Human and animal experiments have generally found that starchy foods such as rice, potatoes, pasta, and bread have low cariogenicity; however, if starch is finely ground, heat treated, and eaten frequently, it can cause caries, although probably less than simpler sugars. Additionally, starch that is retained on the teeth long enough to be hydrolyzed by salivary amylase can be broken down to simple sugars and consequently metabolized by bacteria. Starchy foods containing substantial amounts of sucrose seem to be as cariogenic as a similar amount of sucrose [7].

Certain foods besides milk may be protective against caries. Aged cheese has been shown to be protective because it stimulates salivary flow and raises the calcium, phosphorus, and protein content of plaque. The sugar alcohols (eg, sorbitol, mannitol, and xylitol) are sweeteners that are metabolized by bacteria at a much slower rate than glucose or sucrose, or not at all. Clinical studies have shown that xylitol chewing gum even can reverse initial white spot lesions on teeth [28]. The use of alternate sweeteners may work well in certain foods, such as drinks and chewing gums; however, it is difficult to replace sucrose in many foods because of its excellent properties of enhancing flavor, providing bulk, and improving texture.

Nutrition education and counseling

Nutrition education for the purpose of reducing the caries incidence in children is aimed at teaching parents the importance of reducing dietary

exposures to sweet foods and hidden sugars. Education is necessary but not sufficient to change eating behaviors. Dietary counseling aims to help parents change their and their childrens' eating behaviors so that they choose diets with low cariogenic or noncariogenic snacks, limit sweet foods to mealtimes, and perform tooth brushing after sugar exposures. Dietary recommendations must be realistic and based on the dietary behaviors of the family. It is pointless to prescribe changes that cannot or will not be implemented. Additionally, modifications to the diet can only be made over time, aided by repetition and reinforcement. The goal must be to help caregivers develop lifelong dietary habits that promote general and oral health for themselves and for those whom they influence.

The data are limited regarding whether preventive dietary counseling can reduce the incidence of caries. Two Swedish studies have tested the effect of preventive education programs for new mothers on the subsequent caries experience of their children. One study provided diet and oral hygiene counseling to the test group at 6, 12, and 24 months of age, as well as fluoride supplements. A 65% lower caries experience was observed in the 4-year-old children of mothers who received counseling in a comparison with the control group [29]. Another study with a similar program found a 42% decrease in caries prevalence after 4 years [30]. Some evidence suggests that dietary counseling alone can be effective for people who have a high-caries risk. Two studies conducted on caries-active individuals showed that dietary counseling and reinforcement reduced the caries increment 85% [31] and 60% [32].

Although the results of these studies are encouraging, it is not clear why there have not been more studies to explore the potential of dietary counseling in reducing dental caries, especially for preschool children. Clearly, there needs to be more information regarding the benefits of dietary counseling. Because of the limited data that are available, diet counseling should be recommended at least for those individuals who are at high caries risk.

Dietary guidelines for children at various ages or with special needs

The prenatal period

There is emerging interest in the effect of the prenatal period on tooth development and future dental caries risk in children. The primary teeth undergo significant formation before birth, with mineralization beginning at around 3 to 4 months of pregnancy. At birth, the primary incisor crowns are almost completely formed, and the primary canines and primary first molars are one-third to one-half formed. Crown completion of the second primary molars occurs approximately 1 year after birth. During the early phase of tooth development, irreversible damage to the teeth may occur from poor nutrition of the mother.

Evidence from underdeveloped countries with poor nutrition shows that enamel hypoplasia in primary teeth is common [33,34]. Besides the high prevalence of enamel hypoplasia, possibly owing to poor prenatal nutrition, enamel hypoplasia and subsequent dental caries in primary teeth also are found in children who are born prematurely [35]. Children with enamel hypoplasia reportedly have a 2.5 times greater risk for dental caries than children who do not have such defects [33].

In addition to poor prenatal nutrition increasing the risk for enamel defects in offspring, mothers with active caries also are more likely to the transmit cariogenic bacteria to their children [36]. Conversely, reducing *S mutans* in mothers by means of antimicrobial agents (eg, chlorhexidine) has been shown to reduce the maternal transfer of these bacteria and dental caries in offspring [37,38].

Pregnancy is a critical time to focus on preventive oral care approaches. Nevertheless, a survey of expectant parents demonstrated that they were generally uninformed about dental practices, despite their high level of concern about the dental health of their offspring [39]. In addition to a lack of knowledge on dental care for children, the pregnant woman's eating habits and cravings may lead to frequent snacking on candy or other decay-promoting foods, increasing her risk of caries [40].

Pregnant women should be instructed on the importance of a healthy diet during pregnancy for them and for their unborn children. Emphasis on the healthy eating pyramid, obtaining the majority of calories from nutrient-rich foods, and consuming sufficient calcium are essential. Sweets and other low-nutrient foods should be minimized.

Birth to 1 year

Nutrition in the first year of life is met primarily by breast milk or infant formula. Adequate nutrition is vitally important during this period of significant tooth development. Even brief occurrences of malnutrition during the first year of life may result in enamel hypoplasia and, consequently, an increased risk of caries [41]. Breastfeeding should be encouraged because of its general health benefits and the little likelihood that this means of nutrition fosters caries. There also is evidence suggesting that supplementing infant diets with vitamins reduces the prevalence of enamel hypoplasia [42].

Breast milk is relatively low in fluoride [43]. Infants who receive all or some of their feedings from dry powder or concentrated infant formulas may receive enough fluoride if the local water supply is fluoridated [44]. Systemic fluoride supplements may be recommended for children over 6 months of age who reside in communities that are known to be nonfluoridated. Supplementing a child without first determining the fluoride content of the drinking water is not recommended because of the risk for fluorosis.

Children make the transition from the exclusive milk diet of infancy to a variety of foods in the first year; therefore, this is an important time to exert a positive influence over eating habits. Although children are inclined to like sweet and salty foods and to avoid sour or bitter foods, repeated experience and parental influence shape their preferences for the majority of foods. Infants who are given sugars early in life favor products with higher sugar levels when they are toddlers [45,46]. The rate of dental caries in 3-year-old children having a high exposure to sugar during infancy is significantly greater than that in children who have less exposure to sugar [47].

Infants, especially those living in poverty, are at high risk for early childhood caries [48]. Most implicated in this rampant disease process is the prolonged use of baby bottles and sippy cups containing fermentable sugars (eg, fruit juice, soda, and other sweetened drinks); pacifiers dipped in sugar, honey, or syrups; or other high-frequency sugar exposures. One traditional way to reduce this risk is to encourage mothers to wean the infant to a cup by 1 year; however, frequent exposure to sweet liquids even in a cup may also increase the caries risk. Drinks (other than milk or water) given in a bottle or a cup should be limited and provided mainly at main mealtimes.

Guidelines for promoting good nutrition and decreasing the caries risk in infants include the following:

- Discourage the behavior of placing a child to bed with a bottle
- Prohibit dipping pacifiers in sugar, honey, or syrup
- Discourage the child from continuous drinking from a bottle or sippy cup
- Introduce the cup to begin weaning from the bottle
- Reduce the use of beverages other than breast milk, infant formula, or water
- Follow infant feeding guidelines to ensure optimal nutrition

1 to 2 years

Between the age of 12 and 24 months, most of the remaining primary teeth erupt. As the toddler is introduced to a variety of new foods, healthful meal and snack patterns should be instilled. Variety, moderation, and attention to careful selection of between-meal snacks will benefit oral and general health. Nutritious "finger foods" such as cheese and fruit should be offered as snacks. Frequent cariogenic snacks or continual sipping of cariogenic liquids place the toddler at high risk for caries development.

A high-sugar intake at this age is a concern for general as well as dental health because high sugar–containing foods generally are low in essential nutrients and may substitute for foods that are more nutritious. An example of this is the large consumption of juices by toddlers, with 11% of preschoolers consuming more than 12 fluid ounces of juice daily [19].

Toddlers may reject new foods before they are accepted, but the rejected foods should be reintroduced several times by making them available [49].

Caregivers should provide children with healthy foods and let children decide for themselves when and how much to eat. This feeding strategy fosters children's reactions to internal hunger and satiety cues. Coercive strategies to encourage young children to consume high-sugar foods as "rewards" must be avoided. Additionally, cariogenic foods should be limited to mealtimes and followed by quick oral clearance by tooth brushing or by consumption of protective foods [50].

Guidelines for promoting good nutrition and decreasing the caries risk in toddlers include the following:

- Discourage the behavior of placing a child to bed with a bottle
- Complete the weaning of infants from the bottle
- Discourage the child from continuous drinking from a bottle or sippy cup
- Limit juice or sugar-containing drink intake to 4 oz per day and only in a cup
- Restrict cariogenic foods to mealtimes
- Establish routine meals with family members eating together
- Stimulate the child's appetite at mealtimes by reducing between-meal snacking

2 to 5 years

At this age, caregivers need to ensure that good dietary habits, including regular meal patterns, are instilled in the child. Repeated experiences associated with high sucrose/calorie foods tend to increase the child's preferences for them. In a study of 3- to 5-year-olds, children with a conditioned preference for high-calorie foods were fatter and had higher fat diets than their peers [51].

As children approach the 4- to 5-year age range, they generally have fewer feeding and nutritional problems; however, because they are more independent, food intake between meals tends to increase. Sound eating practices learned earlier should help with appropriate snack choices.

Table 2
Cariogenic potential of children's foods and snacks

Noncariogenic	Low cariogenic	High cariogenic
Cheeses	Fruits (except dried)	Candy[b]
Nuts[a]	Chocolate milk	Cookies
Dried meat sticks	Whole grain products	Cake
Plain milk		Sweetened beverages (including fruit juices)
Vegetables		Fruit roll-ups, dried fruit
Popcorn[a]		Breakfast bars
Flavored club soda		
Diet sodas		

[a] Not appropriate for infants and toddlers owing to potential choking problems.
[b] Sticky or slowly eaten candy is extremely cariogenic.

Table 3
Oral health dietary guidelines for expectant mothers and preschool children

Dental period	Nutrition
Pregnant women	Follow the healthy eating pyramid, taking into account increased needs for pregnancy
	Take prenatal vitamin/mineral supplements as prescribed
	Limit intake of cariogenic foods, especially as between-meal snacks
Birth to 1 year	Avoid allowing the infant to sleep or nap with bottle
	Avoid excessive consumption of juice
	Eliminate dipping pacifiers in sweetened foods
1 to 2 years	Avoid frequent consumption of juice or other sugar-containing drinks in bottle or sippy cup
	Encourage weaning
	Continue avoidance of the bottle to bed
	Promote noncariogenic foods for snacks
	Foster routine eating pattern and healthy eating pyramid
2 to 5 years	Discourage slowly eaten, sugar-containing foods
	Promote noncariogenic foods for snacks
	Encourage eating at meals and healthy eating pyramid

Noncariogenic snacks should be provided at home and in lunchboxes (Table 2). Sugar-containing snacks that are slowly eaten (eg, candy, cough drops, lollipops, suckers) should be strongly discouraged.

Additional guidelines for preschoolers include the following:

- Promote nutritious noncariogenic foods for meals and snacks
- Strongly discourage the consumption of slowly eaten, sugar-containing foods
- Encourage the majority of food consumption at regular mealtimes

Summary

Preschool children, especially those living in low socioeconomic situations, are susceptible to dental caries, perhaps owing to poorer nutrition, less emphasis on health behaviors, and insufficient access to dental care. Appropriate nutrition in early life represents a major determinant of the child's dental and general health. Caregivers need information and guidance to help foster positive dietary and dental health behaviors. Strategies should begin with the mother before birth and should continue through infancy and childhood (Table 3).

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