Dietary Determinants of Dental Caries and Dietary Recommendations for Preschool Children

Norman Tinanoff, DDS, MS; Carol A. Palmer, EdD, RD

Abstract

Objectives: *The purpose of this review, commissioned by the Administration for Children and Families, the Health Resources and Services Administration, the Health Care Financing Administration, and the Department of Agriculture's Food and Nutrition Service, was to update the evidence of the dietary factors that affect dental caries, and subsequently formulate dietary recommendations for preschool children based on principles of cariology.* ***Methods:*** *Literature on the dental caries process, dietary factors affecting dental caries initiation and progression, and nutrition education and counseling were reviewed and synthesized. Dietary guidelines for children at various ages were then constructed based on the review.* ***Results:*** *Dental caries in preschool children is due to a combination of factors, including colonization of teeth with cariogenic bacteria, type of foods and frequency of exposure of these foods to the cariogenic bacteria, and susceptible teeth. Caries risk is greatest if sugars are consumed at high frequency and are in a form that is retained in the mouth for long periods. Sucrose is the most cariogenic sugar because it can form glucan that enables firm bacterial adhesion to teeth and limits diffusion of acid and buffers in the plaque. There is emerging interest in the effects of tooth development and its role in the future dental caries risk of the child.* ***Conclusions:*** *Nutrition education and counseling for the purposes of reducing caries in children is aimed at teaching parents the importance of reducing high frequency exposures to obvious and hidden sugars. Guidelines include: avoiding frequent consumption of juice or other sugar-containing drinks in the bottle or sippy cup, discouraging the behavior of a child sleeping with a bottle, promoting noncariogenic foods for snacks, fostering eating patterns consistent with the Food Guide Pyramid, limiting cariogenic foods to mealtimes, rapidly clearing cariogenic foods from the child's oral cavity either by toothbrushing or by consumption of protective foods, and restricting sugar-containing snacks that are slowly eaten (e.g., candy, cough drops, lollipops, suckers). Along with nutritional factors, a comprehensive approach to preventing dental caries in preschool children must include improved general dietary habits, good oral hygiene, appropriate use of fluorides, and access to preventive and restorative dental care. [J Public Health Dent 2000;60(3):197-206]*

Key Words: dental caries, preschool children, diet, recommendations, nutrition, education.

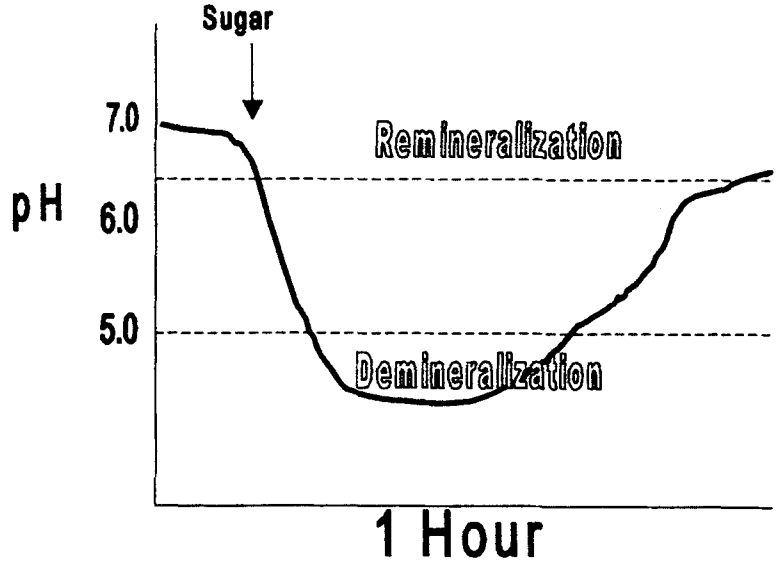
The Dental Caries Process

The assertion that diet plays a central role in the development of dental caries is unquestionable. Observations in humans, in animals, and in vitro have shown clearly that frequent and prolonged oral exposure to certain carbohydrates are fundamental to caries activity. The mechanism by which diet affects dental caries is rather simple. The bacteria attached to teeth, the so-called dental plaque, utilize mono- and disaccharides (e.g., glucose, fructose, sucrose) in their glycolytic pathways to produce energy, and acid is a byproduct of this metabolism. Consequently, the acidity of dental plaque may fall to a point where the demineralization of the tooth ensues. The rate of demineralization is dependent upon 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" value for demineralization varies among individuals, but is in the approximate range of 5.2 to 5.5 (1) (Figure 1). Conversely, the pH of the environment adjacent to the tooth may be increased by lack of substrate for bacterial metabolism, low percentage of cariogenic bacteria in the plaque, elevated secretion rate of saliva, strong buffering capacity of saliva, presence of inorganic ions in saliva, and rapid food clearance times—all resulting in less bacterial acid production, or rapid acid clearance from the plaque.

If the pH of the environment at a specific tooth location remains below the critical level for a sufficient time, enamel demineralization predominates and tooth mineral is lost. The initial stages of tooth loss occur just below the enamel surface and produce a visual whitening of the tooth, referred to as the "white spot lesion." At this stage of mineral loss, the lesion may not progress any further, or could even regain minerals (i.e., remineralize) if the cariogenic environment diminishes. Treating the tooth with fluoride, decreasing the carbohydrate source to the bacteria, reducing the levels of cariogenic bacteria, or lessening the ability of bacteria to produce acid are the preventive approaches that can remineralize the initial carious lesion. However, if disease suppression procedures are not initiated and the acidic challenge is unabated, the initial lesion will continue to lose mineral. The progressive dissolution of enamel and loss of enamel surface structure eventually give rise to a frank carious lesion (cavity). Carious lesions, even at this stage, can be successfully arrested from progression; however, such lesions often benefit from surgical and restorative proce-

Send correspondence to Dr. Tinanoff, Department of Pediatric Dentistry, 666 West Baltimore Street, Room 3 E 10, Dental School, University of Maryland, Baltimore, MD 21201. E-mail: ntinanoff@dental.umaryland.edu. Ms. Palmer is with the Department of General Dentistry, Tufts University School of Dental Medicine. Manuscript received: 3/1/00; accepted for publication: 4/3/00.

FIGURE 1
Plaque pH Levels Showing Remineralization Periods and Demineralization Periods Due to Sugar Exposure



dures to replace the damaged dental tissue.

Abundant evidence shows the predominate role in the carious process of only a few of the many bacteria that inhabit the oral cavity. One group of these microorganisms, the mutans streptococci (ms), is most associated with the dental caries process. Classic animal experiments 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 mutans streptococci in their oral cavity have a much greater caries prevalence, as well as a much greater risk for new lesions than those children with low levels of mutans streptococci (3). Mutans streptococci are believed to be more caries conducive because of their ability to adhere to tooth surfaces, produce copious amounts of acid, and survive and continue metabolism at low pH conditions (for review, see reference 4).

The colonization of a child's oral cavity with mutans streptococci can occur only after the eruption of teeth because mutans streptococci require a nonshedding surface for attachment (5). Mutans streptococci colonization of the oral cavity, starting as early as 10 months of age (6), is generally the result of transmission of these organisms from the child's primary care giver, usually the mother (7). The exact method of transmission is not known, but is suspected to be due, in part, to sharing utensils and foods. It has been shown that the earlier a child is colonized with mutans streptococci, the greater the risk for caries (8).

In contrast to the strong associations of mutans streptococci with caries, the concept that lactobacilli are central to caries causation generally has fallen into disfavor. Because lactobacilli cannot adhere to smooth surface enamel, it is not possible for this organism to initiate a carious lesion; yet, lactobacilli often are isolated from deep dentinal carious lesions and are believed to play a role in the progression of lesions once initiated (9). Lactobacilli levels in saliva also increase in individuals at high caries risk; however, this increase appears to reflect an increase of total carbohydrate consumption (10).

Dental caries in children thus should be understood as a transmissible and infectious bacterial disease. Children first need to become colonized with mutans streptococci before they are capable of 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. With frequent and repeated acid attacks, tooth demineralization will result in a white spot lesion that, if not reversed, will become a cavitated enamel lesion. If no treatment is rendered and the carious environment continues, the decay will progress into the dentin and eventually invade the tooth's pulp.

Dietary Factors in Dental Caries Initiation and Progression

Abundant epidemiologic evidence from groups who have consumed low quantities of sugar as well as from those who have consumed high quantities shows that sugar—especially sucrose—is the major dietary factor affecting dental caries prevalence and progression (for review, see reference 11). One example of low consumption is from a study of the Hopewood House in Australia, conducted between 1947–52. Children residing in this closely supervised environment consumed diets that were virtually free of sugar and white flour products. Data collected from these children revealed an extremely low dental caries prevalence (mean decayed teeth= 0.88), compared to children attending other Australian schools (mean decayed teeth=8.66) (12). The effects of high sugar consumption are best revealed from the classic Vipeholm report (13). This study was performed on 633 individuals living in a Swedish mental institution between 1945–52. It examined the effects of the frequency of sugar consumption, the timing of sugar ingestion and the consistency (retentiveness) of the sugar on dental caries rates in this population. The results showed that the addition of sugar to the diet caused increased caries activity, but the degree was very dependent on the consistency of the sugar. Sugar increased caries most if consumed between meals, and in a form that was retained for a long time in the mouth, such as toffee. The conclusions from this study, conducted a half century ago, are still well regarded today: (1) only a small increase in caries is noted if sugar is taken with meals, (2) sugar consumed as snacks between meals is associated with a marked increase in caries increment, (3) caries activity is greatest if consumed in the form of sticky sugar-containing candies, (4) caries activity may vary greatly among individuals, and (5) caries activity will decline with the withdrawal of sugar-rich foods.

Frequency of Sugar Consumption

Only a weak correlation between the total intake of sugar and the incidence of dental caries exists (14). However, as noted in the Vipeholm study, the frequency of ingestion and the form of the carbohydrate are the critical factors in the cariogenicity of foodstuffs. 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. Therefore, frequent ingestion of foods such as hard candies and throat lozenges that contain fermentable carbohydrates can be extremely harmful to the teeth. A study using programmed feeding machines clearly demonstrated that rats exposed to a high sugar diet will experience caries according to the number of times per day a high sugar diet is presented to them. Conversely, rodents fed sugar infrequently (three times a day) experience 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 (15). 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 (Figure 2). Aside from the well-documented harm of high sugar intake on teeth, excessive sugar intake is also a concern to the general health of children. High sugar-containing foods generally are low in essential nutrients and should not be substituted for more nutritious foods in a child's diet. The US Department of Agriculture's Food Guide Pyramid (16) clearly shows that sugar should be a very small component of the diet (Figure 3).

One example of high-frequency sugar consumption is prolonged or nighttime bottle feeding. Yet recent evidence suggests that, while sleeping with a bottle is an important risk factor, it is perhaps an oversimplification of the cause of the rampant caries process. Several studies have reported that the majority of the US preschool populations take, or have taken, a bottle to bed (17,18). In one study with US Head Start children, 86 percent of children with caries of the maxillary anterior incisors were reported to have taken a bottle to bed; but surprisingly, 69 percent of those who did not have maxillary anterior caries also reportedly took a bottle to bed (19). In another study, 90 percent of children in a population with and without caries were bottle fed between 12 and 18 months of age, yet the prevalence of

FIGURE 2
Example of Plaque pH Drops with High Eating Frequency. (In such situations there may be greater periods of demineralization and no periods of remineralization.)

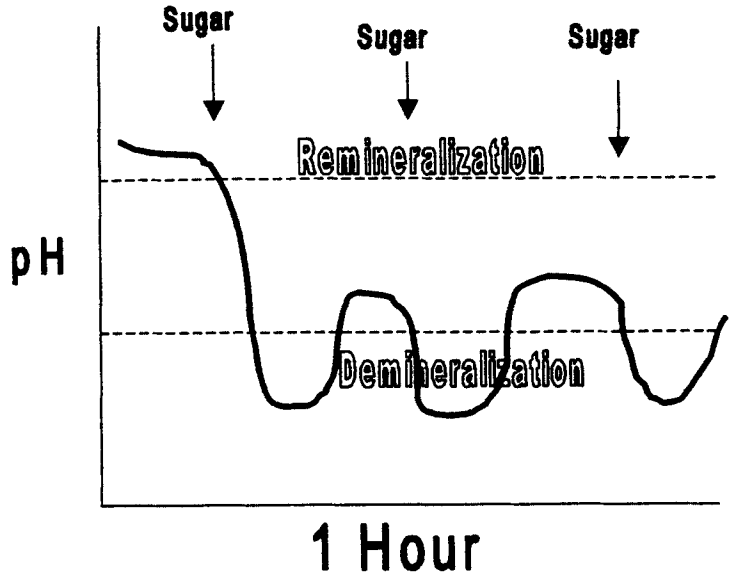
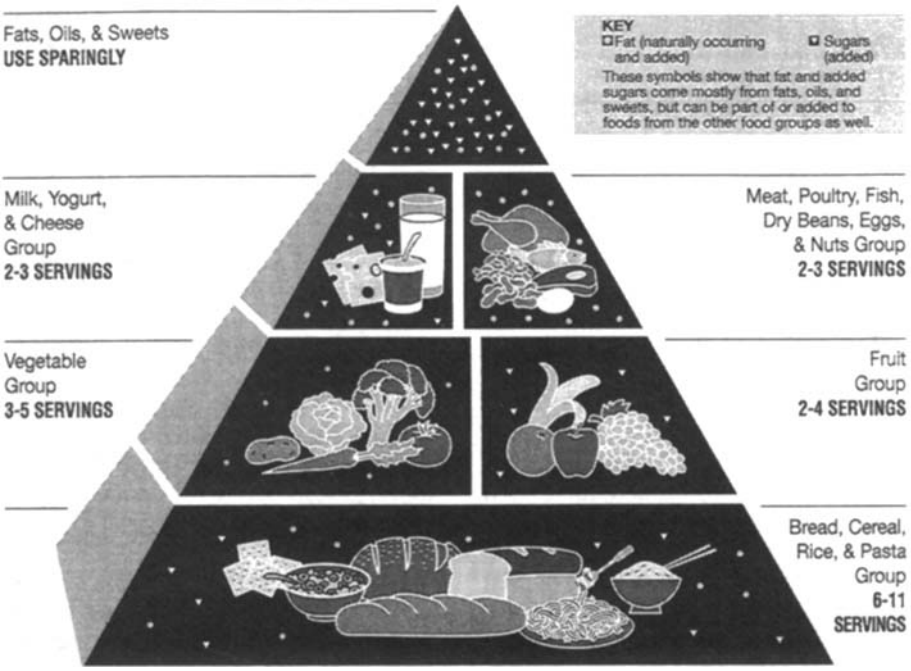


FIGURE 3
Food Guide Pyramid [Source: US Department of Agriculture and the Department of Health and Human Services] (Foods predominately composed of fats and sweets [top of pyramid] should be consumed in limited quantities.)



"nursing caries" was only 20 percent (20). Because this feeding pattern is pervasive, it follows that parents of children with early childhood caries often respond affirmatively to the question, "Do you put your child to bed with a bottle?" Thus, it is logical that the bottle-to-bed habit is inferred as the "cause" of early childhood caries. Reisine and Douglass (21) recently reviewed the studies on infant feeding patterns and found little support for the conclusion that use of a nighttime bottle is a major caries risk factor. However, despite the findings of Reisine and Douglass, it is still appropriate to discourage the bottle-to-bed habit because sleeping with a bottle, especially those containing sugar, will certainly contribute to high-frequency contact of substrate to the bacteria.

Another controversial yet poorly documented caries risk is the potential cariogenicity of prolonged or nighttime breast feeding. There are case reports associating prolonged or nighttime breast feeding and early childhood caries (22-25). However, one cannot dismiss a possible association between reported rampant caries in these cases and other cariogenic dietary practices. Further study is required to determine the prevalence of early childhood caries in exclusively breast-fed children, and whether child-rearing practices, such as lack of restriction in getting snacks (26), could contribute to caries in breast-fed children as well as in bottle-fed children.

Although it is likely that early childhood caries is due, at least in part, to high-frequency sugar exposure from drinks in a baby bottle or sippy cup (cup with drinking spout) and oral colonization with mutans streptococci, other causes of caries affecting the anterior teeth should be considered. Children who are 4 and 5 years old, an age by which bottle use generally has been discontinued, have been shown to develop caries in the maxillary anterior teeth (27). Data from developing countries also suggest that caries on anterior primary teeth cannot, in all cases, be attributed to inappropriate bottle use (28). For example, in Beijing, China, where the prevalence of caries in maxillary anterior teeth has been reported to be 45 percent in 4-year-old children (29), baby bottles generally are not available. Other etiologic factors, such as hypoplasia of primary teeth and high-frequency sugar consumption in solid foods, may contribute to the prevalence of this condition.

TABLE 1
Market Basket Survey of Sugar Content in Juices or Juice Drinks Found in a Baltimore 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	Grauate Berry Punch	100	12	no

Types of Food Products

As previously mentioned various mono- and disaccharides found in the human diet support bacterial acid production and the colonization of teeth by mutans streptococci. The difference in ability of bacteria to utilize glucose, fructose, and sucrose in metabolism and consequently produce acid is minimal. Sucrose, however, appears to be the most cariogenic sugar, not only because its metabolism produces acid, but mutans streptococci can utilize this sugar to produce glucan, a water-insoluble polysaccharide. This extracellular "glue" enables mutans streptococci to adhere firmly to teeth and also inhibits the diffusion properties of plaque. 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 (30).

Fresh fruits contain various sugars and may be capable of causing caries under some conditions. However, fruit juice and fruit-flavored drinks have a much greater cariogenic potential because of their high sugar content (Table 1) and the way they are often consumed. They are offered frequently to children because of their high acceptance by children, low cost, and the belief by parents that they are nutritious. Unfortunately, bottles and sippy cups filled with these fruit drinks frequently are 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 or fruit drinks, there are reports of general health concerns about their excessive consumption (31). Their high-frequency consumption, therefore, should be considered as highly cariogenic, as well as generally unhealthy for preschool children.

The most frequently consumed food in preschool children is milk and milk-based formula. The sugar found in milk, lactose, is not fermented to the same degree as other sugars. It may be less cariogenic because the phosphoproteins in milk inhibit enamel dissolution (32,33) and the antibacterial factors in milk may interfere with the oral microbial flora (34). In rat caries experiments, bovine milk repeatedly has been demonstrated to be noncariogenic and even reduces the cariogenicity of sucrose-containing diets (35,36). Human breast milk also has been shown to not cause enamel decalcification in laboratory experiments (37). Additionally, milk remineralizes artificially demineralized enamel in vitro (38). While the lack of cariogenicity of milk is clear, it may be the vehicle for more cariogenic substances. Parents are known to frequently combine milk or milk formulas with other food products or sugar (39). Furthermore, infant formulas that contain sucrose may not be as noncariogenic as lactose-based

formulas. More research is needed to determine the dental implications of using infant formula that contain sugars other than lactose.

Starch often is regarded as a relatively low cariogenic carbohydrate. Human and animal experiments generally have found that starchy foods such as rice, potatoes, pasta, and bread have very low cariogenicity. However, if starch is finely ground, heat-treated, and eaten frequently, it can cause caries, albeit less than sucrose. Additionally, starch that is retained on the teeth long enough to be hydrolyzed by salivary amylase also can be broken down to mono- and disaccharides and consequently metabolized by bacteria. Starchy foods containing substantial amounts of sucrose appear to be as cariogenic as a similar amount of sucrose (for review, see reference 11).

Evidence exists that 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 (e.g., 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 (40). 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 sucrose's excellent properties of enhancing flavor, providing bulk, and improving texture.

Nutrition Education and Counseling

Nutrition education for the purposes of reducing 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. Diet counseling aims to help parents change their and their children's dietary behaviors so that they choose diets with low or noncariogenic snacks, limit sweet foods to mealtimes, and perform toothbrushing after sugar exposures. Dietary recommendations must be realistic and always based on current dietary behaviors of the family. It is pointless to prescribe changes that a patient cannot or will not implement. 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, which promote general and oral health for themselves and for those whom they influence.

TABLE 2
Calcification, Crown Completion, and Eruption Times of Primary Teeth*

Tooth	1st Evidence of Calcification (months in utero)	Crown Completed (months)	Eruption (months)
Primary dentition: upper			
Central incisor	3–4	4	7.5
Lateral incisor	4.5	5	8
Canine	5.5	9	16–20
First molar	5	6	12–16
Second molar	6	10–12	20–30
Primary dentition: lower			
Central incisor	4.5	4	6.5
Lateral incisor	4.5	4.25	7
Canine	5	9	16–20
First molar	5	6	12–16
Second molar	6	10–12	20–30

*Adapted from Logan WAG, Cronfield R. J Am Dent Assoc 1933;20:420.

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. This study observed a 65 percent lower caries experience in the 4-year-old children of mothers who received counseling as compared to the control group (41). Another study with a similar program found a 42 percent decrease in caries prevalence after 4 years (42). There also is limited evidence that preventive diet counseling can be effective for people who have serious caries problems. Two studies conducted with caries-active individuals show that dietary counseling and reinforcement reduced caries increment 85 percent (43) and 60 percent (44).

Although the results of these few 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 in preschool children. Clearly, more information is needed regarding counseling procedures, the magnitude of their effect, and their costs before dietary counseling can be recommended as a routine caries-preventive procedure. With the current information regarding the effect of diet counseling on caries incidence, the emphasis should be on using counseling 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 the future dental caries risk of the child. The child's primary teeth have their significant formation before birth, with mineralization beginning around the third or fourth month of pregnancy. At birth, the primary tooth 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 one year after birth (Table 2). During the early phase of tooth growth, irreversible damage to dental tissues can occur from insults such as inadequate nutrition. For example, hypoplastic enamel can result from use of drugs such as tetracycline, from infections, or from maternal osteo-

malacia (vitamin D deficiency) (45).

Evidence from underdeveloped countries with poor nutrition shows that developmental defects (enamel hypoplasia) of the primary teeth are common (46,47). A comprehensive review found a strong association between enamel hypoplasia and dental caries in developing countries. For instance in Pulapuka, an isolated atoll in the Pacific, developmental defects of the primary teeth are reported to be between 51–86 percent, with 58–61 percent of these teeth developing dental caries (48). Surprisingly, a high prevalence (14 percent) of enamel hypoplasia also has been found in inner-city US populations (Douglass J, personal communication, 1999). Besides the high prevalence of enamel hypoplasia possibly due to poor prenatal nutrition, frequent enamel hypoplastic areas and subsequent dental caries in primary teeth also are found in children who are born prematurely (49). Children with enamel hypoplasia reportedly have a 2.5 times greater risk of developing dental caries than children who do not have such defects (28).

In addition to the possible effect of poor prenatal nutrition on increased enamel defects in their offspring, mothers with active caries are more likely to transmit cariogenic bacteria to their offspring (50). Conversely, reducing mutans streptococci in mothers by means of antimicrobial agents (e.g., chlorhexidine) has been shown to reduce both the maternal transfer of these bacteria and dental caries in the offspring (51,52).

Fluoride is an important nutrient that increases the resistance of teeth. However, fluoride supplementation for pregnant women is not recommended because there is little evidence that systemic fluoride (e.g., oral fluoride supplements) provided to the mother during pregnancy reduces caries prevalence in their offspring (53).

Pregnancy, thus, is a critical time to focus on preventive oral care approaches. However, 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. Parents believed oral hygiene practices should start "early," but they were unsure at what age they should begin. Further, they were not familiar with proper oral cleaning and toothbrushing techniques (54). In addition to lack of knowledge of dental care for their children, the eating habits and cravings of pregnant women may lead to frequent snacking on candy or other decay-promoting foods, thereby increasing their risk of caries (55).

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

Birth to 1 Year of Age. Nutritional needs in the first year of infancy are met primarily by breast milk and/or infant formula, followed by sequential introduction of baby foods starting with fortified cereals at approximately 6 months of age. 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 increased risk of caries (56). Breast feeding should be encouraged because of its general health benefits and the little likelihood that this means of nutrition fosters caries. Evidence also suggests supplementing infants' diets with vitamins because they can reduce the prevalence of enamel hypoplasia (57).

Breast milk is relatively low in fluoride (58); however, 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 (59).

TABLE 3
Systemic Fluoride Recommendations Based on Fluoride Content of Water and Child's Age

	Fluoride Content of Water (mgF)		
Age	<0.3 ppm	0.3–0.6 ppm	>0.6 ppm
6 mos–3 yrs	0.25	0	0
3–6 yrs	0.50	0.25	0
6–16 yrs	1.00	0.50	0

Systemic fluoride supplements for those children older than age 6 months who reside in communities known to be nonfluoridated may be recommended (Table 3). Prescribing fluoride supplements for infants younger than 6 months of age, or supplementing a child without first determining the fluoride content of the drinking water, is not recommended because of the risk of fluorosis. Fluorosis of the teeth is generally not harmful, but can produce a visual problem (white lines) on the front teeth. Currently, it is believed that the major causes of excessive fluoride intake and subsequent fluorosis are inappropriate use of fluoridated supplements and/or unsupervised consumption of toothpastes by the child. Parents need to make sure that only a pea-sized or smaller amount of fluoridated toothpaste is used to brush a child's teeth (60). In general, systemic fluoride supplementation should not be the cornerstone of a caries prevention program because the greatest benefit of fluoride is considered to be due to its topical effect, compliance with correct dosages of fluoride is low, and a prescription is needed to obtain the supplement, posing a barrier to their use.

Children make the transition from the exclusive milk diet of infancy to a variety of foods in the first year, so this is an important time to exert positive influence on eating habits. At around the age of 6 months, when infants start the transition from bottle to cup, it is important that they not be allowed to use a sippy cup for long periods of time because this behavior will promote caries.

Children can be introduced to sucrose-containing food and drinks at around the time of the eruption of the first tooth. While children are inclined to like sweet and salty foods and avoid sour or bitter foods, repeated experience and parental influence shape their preferences for the majority of foods. The predispositions that shape food acceptance patterns also include the fear of new foods, and the tendency to learn to prefer and accept new foods when they are offered repeatedly. Thus, the caretaker's feeding practices play a fundamental role in the development of the child's choice of food types. Infants given sugars early in life favor products with higher sugar levels when they are toddlers (61,62). In addition, dental caries in

3-year-old children having high exposure to various sugars during infancy is significantly greater than that of children who had less exposure to sugar (for review, see reference 63).

Infants, especially those living in poverty, are at high risk for developing early childhood caries (64). Most implicated in this rampant disease process is prolonged use of baby bottles, during the day or night, containing highly fermentable sugars (e.g., fruit juice, soda, and other sweetened drinks), pacifiers dipped in sweet agents such as sugar, honey, or syrups, or other high-frequency sugar exposures. Therefore, health care providers must be aware of these harmful feeding practices and discourage them before they start. One traditional way to reduce this risk is to encourage mothers to wean the infant to a cup by 1 year of age. However, frequent exposure to sweet liquids even in a cup may also increase caries risk. Therefore, drinks (other than milk or water) either in a bottle or a cup should be limited and given mainly at main mealtimes.

Guidelines for promoting good nutrition and decreasing 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 a child from carrying and continuously drinking from a bottle or sippy cup,
- introduce the cup to begin weaning from the bottle,
- reduce use of beverages, other than breast milk, infant formula, or water, and
- follow infant feeding guidelines to ensure optimal nutrition.

1–2 Years of Age. Between the age of 12 and 24 months, most of the remaining primary teeth erupt, and by the third birthday, all of the 20 primary teeth have erupted. 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.

Feeding behavior changes throughout the toddler years. Oral and neuromuscular development improves eating ability, increased refinement of hand and finger movement occurs, and the eruption of the primary teeth leads toddlers to self-feeding. Severe lack of weight gain or "failure to thrive" may be an indicator of dental problems and these cases should be referred to a physician and dentist for diagnosis and treatment.

FIGURE 4
Contributing Factors to Dental Caries in Children Living in Poverty

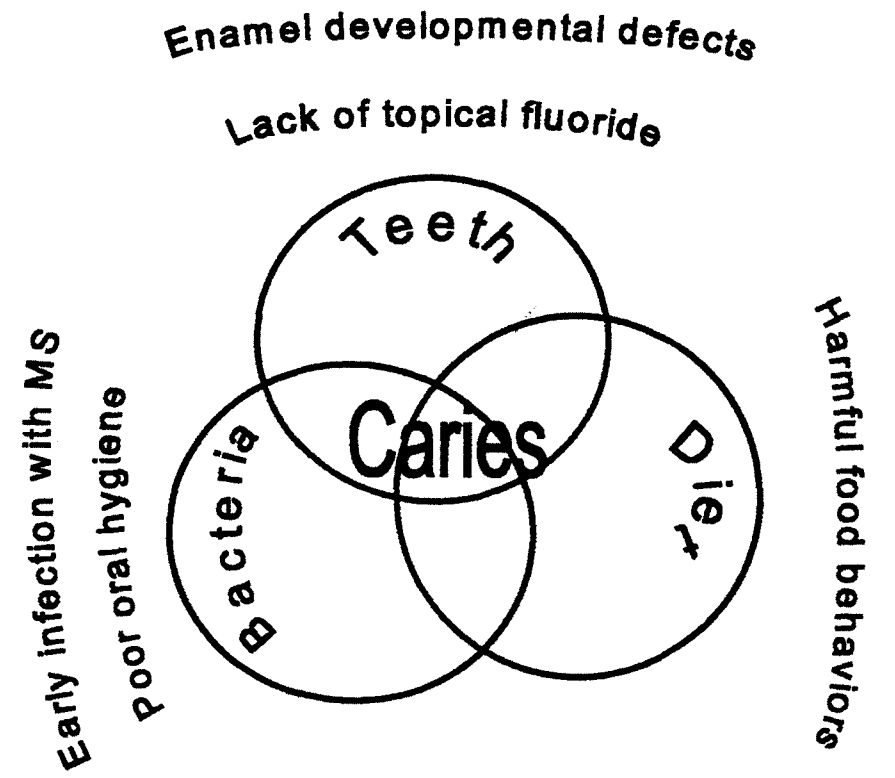


Figure 3 shows the Food Guide Pyramid recently published by the US Department of Agriculture (16). According to a USDA survey of children's food intake, only 2 percent of children consume the recommended number of servings of foods in the Food Guide Pyramid, and 11 percent do not meet any of the recommendations (65). High sugar intake is also of concern to 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 (16). An example of this problem is the large consumption of juices by toddlers. Juice consumption has increased from 3.2 to 5.5 fl oz/day, and 11 percent of preschoolers consumed more than 12 fluid ounces of juice daily. This high juice consumption, especially those high in sorbitol and fructose, can cause "toddlers' diarrhea" (31).

The eating patterns of most toddlers are characterized by reduction in intake relative to size. This normal reduction in intake results from decreased growth velocity. Children tend to reject new foods up to five to ten times before they are accepted. Thus, rejected foods should be reintroduced several times by making them available and accessible (66). Caregivers should provide children with healthy foods, but let children decide for themselves when and how much to eat. This feeding strategy fosters children's reactions to internal hunger and satiety cues. However, coercive strategies to encourage young children to consume high sugar foods as "rewards" should be avoided. Additionally, cariogenic foods should be limited to mealtimes and followed by quick oral clearance, either by toothbrushing or by consumption of protective foods (67).

Guidelines for promoting good nutrition and decreasing 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 a child from carrying and continuously 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, and
- stimulate a child's appetite at mealtimes by reducing between-meal snacking.

2–5 Years of Age. At these ages, caregivers and health care workers need to ensure that good dietary habits, including regular meal patterns, are instilled in the child. Repeated positive experiences associated with high-sucrose or high-calorie foods tend to increase children's preferences for them. In a study of 3–5-year-olds, children with a conditioned preference for high-calorie foods were fatter and had higher fat diets than their peers (68).

As children approach the 4–5-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. Noncariogenic snacks should be provided at home and in lunch boxes (Table 4). Sugar-containing snacks that are eaten slowly (e.g., candy, cough drops, lollipops, suckers) should be discouraged strongly.

Additional guidelines for preschoolers include the following:

- promote nutritious, noncariogenic foods for meals, as well as for snacks;
- strongly discourage the consumption of slowly eaten, sugar-containing foods; and
- encourage that the majority of food consumption be at regular mealtimes.

Children with Special Health Care Needs. Children with special needs may have greatly increased caries risk

TABLE 4
Cariogenic Potential of Children's Foods and Snacks

Noncariogenic	Low Cariogenic	Highly Cariogenic
Cheeses	Fruits (except dried)	Candy†
Nuts*	Chocolate milk	Cookies
Dried meat sticks	While grain products	Cake
Plain milk		Sweetened beverages (including fruit juices)
Vegetables		Fruit roll-ups, dried fruit
Popcorn*		Breakfast bars
Flavored club soda		
Diet sodas		

*Not appropriate for infants and toddlers due to potential choking problems.
†Sticky and/or slowly eaten candy is extremely cariogenic.

TABLE 5
Oral Health Dietary Guidelines for Expectant Mothers and Preschool Children

Dental Period	Fluoride	Nutrition
Pregnant women	• Fluoride supplementation not indicated • Use of fluoridated toothpaste	• Follow the Food Guide Pyramid, taking into account increased needs for pregnancy • Take prenatal vitamin/mineral supplement as prescribed • Limit intake of cariogenic foods, especially as between-meal snacks
Birth to 1 year	• Oral supplementation recommended after 6 months, if appropriate • Use of fluoridated water if available • With eruption of teeth, start tooth cleaning	• Avoid allowing the infant to sleep or nap with bottle • Avoid excessive consumption of juice • Eliminate dipping pacifiers in sweetened foods
1–2 years	• Oral supplementation recommended, if appropriate • Use of fluoridated water if available • Toothbrushing with fluoride-containing toothpaste.	• 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 Food Guide Pyramid
2–5 years	• Oral supplementation recommended, if appropriate • Use fluoridated water if available • Toothbrushing with fluoride-containing toothpaste	• Discourage slowly eaten sugar-containing foods • Promote noncariogenic foods for snacks • Encourage eating at meals and Food Guide Pyramid

due to feeding difficulties, frequent snacking on sweets, poor oral clearance of foods, xerostomia, or chronic use of sugar-based medications. For example, children with Down syndrome, cerebral palsy, and muscular dystrophy may have decreased muscle tone, often producing difficulties with sucking and/or swallowing. Such problems may prolong feeding time and food clearance, exposing the teeth to cariogenic foods for longer periods (69). Any one of these factors may greatly increase dental caries incidence in children who also present challenges in performing preventive and restorative dental care. Therefore, exceptional measures must be taken to prevent caries and other oral health problems in children with special needs. Preventive nutritional counseling that can reduce the development of oral disease in these children is essential (70).

Conclusions

Children, especially those living in low socioeconomic situations, are susceptible to dental caries perhaps due to poorer nutrition, less emphasis on following health behaviors, and insufficient access to dental care (Figure 4). Appropriate nutrition early in life represents a major determinant of the child's dental, as well as general health. Caregivers need information and guidance to help foster positive dietary and dental health behaviors that enable an early start in preventing dental caries in their children. Strategies should begin with the mother before birth and continue through infancy and childhood (Table 5). These nutrition and oral care guidelines should have a meaningful impact on the child's caries experience.

References

1. Larsen MJ, Bruun C. Enamel/saliva—inorganic chemical reaction. In: Thylstrup A, Fejerskov O. Textbook of cariology. Copenhagen: Munksgaard, 1986:181-98.
2. Fitzgerald RJ, Keyes PH. Demonstration of the etiologic role of streptococci in experimental caries in the hamster. J Am Dent Assoc 1960;61:23-33.
3. Thibodeau EA, O'Sullivan DM. Salivary mutans streptococci and dental caries patterns in preschool children. Community Dent Oral Epidemiol 1966;24:164-8.
4. Loesche WJ. Role of *Streptococcus mutans* in human dental decay. Microbiol Rev 1986;50:353-80.
5. Berkowitz RJ, Jordan HV, White G. The early establishment of *Streptococcus mutans* in the mouths of infants. Arch Oral Biol 1975;20:171-4.
6. Karn T, O'Sullivan DA, Tinanoff N. Mutans streptococci levels in 8-15-month-old children. J Public Health Dent 1999; 58:248-9.
7. Berkowitz RJ, Turner J, Green P. Primary oral infection of infants with *Streptococcus mutans*. Arch Oral Biol 1980;25:221-4.
8. Kohler B, Andreen I, Jonsson B. The earlier the colonization by mutans streptococci, the higher the caries prevalence at 4 years of age. Oral Microbiol Immunol 1988;3:14-17.
9. Edwardsson S. Microorganisms associated with dental caries. In: Thylstrup A, Fejerskov O. Textbook of cariology. Copenhagen: Munksgaard, 1986:107-14.
10. Tanzer JM. Microbiology of dental caries, In: Slots J, Taubman MA. Contemporary oral microbiology and immunology. St. Louis, MO: Mosby Year Book, 1992:377-424.
11. Rugg-Gunn AJ. Diet and dental caries. In: Murray JJ. Prevention of oral disease. Oxford: Oxford University Press, 1996:3-31.
12. Marthaler TM. Epidemiological and clinical dental findings in relation to intake of carbohydrates. Caries Res 1967; 1:222-38.
13. Gustafsson BE, Quensel CE, Swenander-Lanke L, et al. The Vipeholm dental caries study. The effect of different levels of carbohydrate intake on caries activity in 436 individuals observed for five years. Acta Odont Scand 1954;11:232-6.
14. Burt BA, Eklund SA, Morgan KJ, et al. The effects of sugar intake and frequency of ingestion of dental caries increment in a three-year longitudinal study J Dent Res 1988;67:1422-9.
15. Bowen WH, Amsbough SM, Monell-Torrens S, Brunelle J, Kuzmiak-Jones H, Cole MR. A method to assess cariogenic potential of foods. J Am Dent Assoc 1980; 100:677-81.
16. United States Department of Agriculture, Center for Nutrition, Policy and Promotion, 1999. http//:www.usda.gov/ cnpp/.
17. Kaste LM, Gift HC. Inappropriate infant bottle feeding. Status of the Healthy People 2000 Objectives. Arch Pediatr 1995; 149:786-91.
18. Powell D. Milk ... is it related to rampant caries of the eary primary dentition? J Calif Dent Assoc 1976;4:58-63.
19. O'Sullivan DM, Tinanoff N. Social and biological factors contributing to caries of the maxillary anterior teeth. Pediatr Dent 1993;15:41-4.
20. Swerint JR, Mungo R, Negrete VF, Duggan AK, Korsch BM. Child-rearing practices and nursing caries. Pediatr 1993; 92:233-7.
21. Reisine S, Douglass JM. Psychosocial and behavioral issues in early childhood caries. Community Dent Oral Epidemiol 1998;26(Suppl 1):32-44.
22. Curzon MEJ, Drummond BK. Case report—rampant caries in an infant related to prolonged on-demand breast feeding and a lacto-vegetarian diet. J Pediatr Dent 1987;3:25-28.
23. Dilley GJ, Dilley DH, Machen JB. Prolonged nursing habit: a profile of patients and their families. J Dent Child 1980;47: 102-8.
24. Gardner DE, Norwood JR, Eisenson JE. At-will breast feeding and dental caries: four case reports. J Dent Child 1977;44: 186-91.
25. Kotlow LA. Breast feeding: a cause of dental caries in children. J Dent Child 1977;25:192-3.
26. Johnsen DC. Characteristics and backgrounds of children with "nursing caries." Pediatr Dent 1982;4:218-24.
27. Tinanoff N, O'Sullivan DM. Early childhood caries: overview and recent finding. Pediatr Dent 1987;19:12-16.
28. Davies GN. Early childhood caries—a synopsis. Community Dent Oral Epidemiol 1998;26(Suppl 1):106-16.
29. Douglass JM, Wei Y, Zhang BX, Tinanoff N. Caries prevalence and pattern in 3- to 6-year-old Beijing children. Community Dent Oral Epidemiol 1995;23:340-3.
30. Schachetele CF. Dental caries: prevention and control. In: Stallard RE, ed. A textbook of preventive dentistry. 2nd ed. Philadelphia: W. B. Saunders, 1982:241-53.
31. Dennison BA. Fruit juice consumption by infants and children: a review. J Am Coll Nutr 1996;15:4S-11S.
32. Reynolds EC, Riley PF, Storey E. Phosphoprotein inhibition of hydroxyapatite dissolution. Calcif Tiss Int 1982;34:S52-6.
33. Weiss ME, Bibby BG. Effects of milk on enamel solubility. Arch Oral Biol 1966; 11:49-57.
34. Kosikowski F. Cheese and fermented milk food. Ann Arbor, MI: Edwards Brother, 1970:330.
35. Reynolds EC, Johnson IH. Effect of milk on caries incidence and bacterial composition of dental plaque in the rat. Arch Oral Biol 1981;26:445-51.
36. Bowen WH, Pearson SK. Effect of milk on cariogenesis. Caries Res 1993;27:461-6.
37. Erickson PR, Mazhari E. Investigation of the role of human breast milk in caries development. Pediatr Dent 1999;21:86-90.
38. McDougall WA. Effect of milk on enamel demineralization and remineralization in vitro. Caries Res 1977;11:166-72.
39. Mohan A, Morse D, O'Sullivan DM, Tinanoff N. The relationship between bottle usage/content, age, and number of teeth with salivary mutans streptococci levels in 6- to 24-month old children. Community Dent Oral Epidemiol 1998; 26:12-20.
40. Scheinin A, Makinen KK, Ylitalo K. Turku sugar studies V. Final report on the effect of sucrose, fructose, and xylitol diets on the caries incidence in man. Acta Odontol Scand 1976;34:179-216.
41. Holst K, Kohler L. Preventing dental caries in children: report of a Swedish program. Devel Med Child Neur 1975;17: 602-4.
42. Holm AK, Blomquist HK, Grossner GG, Grahnen H, Samuelson G. A comparative study of oral health as related to general health, food habits, and socioeconomic condition of 4-year-old Swedish children. Community Dent Oral Epidemiol 1975;3:34-9.
43. Becks H. Rampant dental caries: prevention and prognosis. A five-year clinical study. J Am Dent Assoc 1944;31:1189-200.

44. Krasse B. Approaches to prevention. In: Stiles HM, Loesche WJ, O'Brein TC, eds. Proceedings of "microbial aspects of dental caries" [Abstract]. Microbiol 1976; 3(Spec Suppl):867-76.
45. DePaola DP, Faine MP, Palmer CA. Nutrition in relation to dental medicine. In: Shils ME, Olson JA, Shike M, Ross AC, eds. Modern nutrition in health and disease. 9th ed. Baltimore, MD: Williams and Wilkins, 1999:1099-124.
46. Davies GN. A comparative epidemiological study of the diet and dental caries in three isolated communities. Ala Dent Rev 1958;4:19-28.
47. Sweeny EA, Guzman M. Oral conditions in children from three highland villages in Guatemala. Arch Oral Biol 1966;11: 687-98.
48. Seow WK. Biological mechanisms of early childhood caries. Community Dent Oral Epidemiol 1998;26(Suppl 1):8-27.
49. Johnsen D, Krejci C, Hack M, Fanaroff A. Distribution of enamel defects and the association with respiratory distress in very low birth weight infants. J Dent Res 1984;63:59-64.
50. Kohler B, Bratthall D. Intra-familial levels of *Streptococcus mutans* and some aspects of the bacterial transmission. Scand J Dent Res 1978;86:35-42.
51. Kohler B, Andreen I, Jonsson B. The effect of caries-preventive measures in mothers on dental caries and the oral presence of the bacteria *Streptococcus mutans* and lactobacilli in their children Arch Oral Biol 1984;29:879-83.
52. Kohler B, Bratthall D, Krasse B. Preventive measures in mothers influence the establishment of the bacterium *Streptococcus mutans* in their infants. Arch Oral Biol 1983;28:225-31.
55. Leverett DH, Adair SM, Vaughan BW, Proskin HM, Moss ME. Randomized clinical trial of the effect of prenatal fluoride supplements in preventing dental caries. Caries Res 1997;31:174-9.
54. Tsamtsouris A, Stack A, Padamesee M. Dental education of expectant parents. J Pedodont 1986;10:309-21.
55. Chiodo BT, Rosenstein DL. Dental treatment during pregnancy: a preventive approach. J Am Dent Assoc 1985;110:309-21.
56. Alvarez JO. Nutrition, tooth development, and dental caries. Am J Clin Nutr 1995;61:410S-16S.
57. May RL, Goodman AH, Meindl RS. Response of bone and enamel formation to nutritional supplementation and morbidity among malnourished Guatemalan children. Am J Phys Anthropol 1993;92: 37-51.
58. Burt BA. The changing patterns of systemic fluoride intake. J Dent Res 1992; 71:1228-37.
59. Levy SM, Kiritsy MC, Warren JJ. Sources of fluoride intake in children. J Public Health Dent 1995;55:39-52.
60. Croll TP, Tinanoff N. The dentifrice deception revisited. Quintessence Int 1992; 23:77-8.
61. Jamel HA, Sheiham A, Watt RG, Cowell CR. Sweet preferences, consumption of sweet tea and dental caries: studies in urban and rural Iraqi populations. Int Dent J 1997;47:213-17.
62. Rossow I, Kjaernes U, Holst D. Patterns of sugar consumption in early childhood. Community Dent Oral Epidemiol 1990; 18:12-16.
63. Ismail AI. The role of early dietary habits in dental caries development. Spec Care Dent 1998;18:40-5.
64. Tang J, Altman DS, Robertson D, O'Sullivan DM, Douglass JM, Tinanoff N. Dental caries prevalence and treatment levels in Arizona preschool children. Public Health Rep 1997;112:319-29.
65. Munoz KA, Krebs-Smith SM, Ballard-Barbash R, et al. Food intakes of US children and adolescents compared with recommendations. Pediatrics 1998;101:952-3.
66. Sullivan SA, Birch LL. Infant dietary experience and acceptance of solid foods. Pediatrics 1994:93:271-7.
67. Kashket S, Zhang J, Van Houte J. Accumulation of fermentable sugars and metabolic acids in food particles that become entrapped on the dentition. J Dent Res 1996;75:1885-91.
68. Fisher JO, Birch LL. Fat preferences and fat consumption of 3- to 5-year-old children are related to parental adiposity. J Am Diet Assoc 1995;95:759-64.
69. McKinney LS, Palmer CA, Dwyer JT, Garcia R. Common dentally related nutrition concerns of children with special needs. Part 1. Topics Clin Nutr 1991;6:70-5.
70. Tesini DA, Fenton SJ. Oral health needs of persons with physical or mental disabilities. Dent Clin N Am 1994;38:483-98.