The Roles of Meal, Snack, and Daily Total Food and Beverage Exposures on Caries Experience in Young Children

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Abstract

Objectives: *This study describes associations among caries experience and meal, snack and daily total exposures to beverages and foods in children.* ***Methods:*** *Subjects (n = 634) were members of the Iowa Fluoride Study. Beverage and food exposures were abstracted from 3-day diaries at 1, 2, 3, 4 and 5 years and calculated for 1-5 years. Eating events were defined as 30-minute intervals and categorized as meals or snacks based on time of consumption and nature of the foods. Beverage and food exposures were categorized by carbohydrate content. Dental examinations were conducted at 4.5-6.8 years; caries experience was dichotomized (any vs. none). Logistic regression models were developed to determine if caries experience differed for the fourth vs. first quartile of exposure after adjustment for age at dental exam and fluoride intake.* ***Results:*** *Higher snack (1, 2, 3, 4, 1-5 years) and daily total (2, 3, 4, 1-5 years) eating events increased caries risk ($P < 0.05$). Higher exposures to 100% juice at snacks (2 years) and soda pop at meals (2, 1-5 years), snacks (2, 3, 4, 1-5 years) and daily total (2, 3, 4, 1-5 years) increased caries risk ($P < 0.05$). Higher exposures to food sugars (3, 1-5 years) and starches (4, 5, 1-5 years) at meals decreased caries risk, while higher exposures to sugars (4, 1-5 years) at snacks increased caries risk ($P < 0.05$).* ***Conclusions:*** *Dietary methods used to investigate diet-caries relationships can influence the outcome. The cariogenicity of food, but not beverages, is associated with the timing of exposure.*

Key Words: dental caries, beverages, carbonated beverages, 100% juice, food habits, meals, snacks

Introduction

Fermentable carbohydrates of dietary origin are a necessary component of the dental caries process, but the extent of their contribution to the process remains uncertain. The classic study conducted in Vipeholm, Sweden during the late 1940's suggested that the timing of consumption and retentive nature of the carbohydrate were predictors of caries risk (1). Sugars are the preferred substrate of oral bacteria, however, Burt and Pai (2) concluded in a systematic review that the relationship between sugar consumption and dental caries in contemporary society is weak. Numerous explanations have been suggested for the limited association observed today, including the hypothesis that the protective effects of fluoride are stronger than the detrimental effects of sugar (2) and the hypothesis that total sugar consumption exceeds the threshold for an observable relationship (3). An alternative explanation is that investigation of diet is difficult and previous investigations have been limited in their methodology. For example, the grouping of sugared beverages can be problematic, collection of data using diet questionnaires limits assessment of timing of consumption and focus on diet alone limits the ability to control for confounders.

Analyses of data collected in 1992-93 using 4-day diet records by Gibson and Williams (4) did not support an association between dental caries and either the quantity or frequency of consumption of soft drinks (i.e., any sugar-sweetened beverage) among British preschool children. Conversely, Ismail *et al.* (5) reported a strong association between caries experience and 24-hour recall of soft drink consumption both during and between meals in 9 to 29-year-olds participating in the National Health and Nutrition Examination Survey I during 1971-74. Sayegh *et al.* (6) assessed regular intake of individual types of soft drinks by 4 to 5-year-old Jordanian children using a questionnaire; neither "regular" nor the time frame for reference were defined. They reported that consumption (yes/no) of squashes (i.e., fruit mashes) and teas with added sugar, but not fruit juices or carbonated beverages, were associated with dental caries. Marshall *et al.* (7) reported that higher intakes of regular soda pop assessed using three-day diet records increased the risk of both caries presence and severity in five-year-old children participating in the Iowa Fluoride Study (IFS), while 100% juice was minimally associated with caries. Although these studies were conducted during different time periods in subjects of different ages and cultures, the use of different sugars to sweeten beverages, different meal or snack consumption patterns and the presence

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of nutrients and non-nutrients in the beverages could explain the discrepant results.

Campain *et al.* (3) grouped intakes of fermentable carbohydrate-containing foods collected using 4-day diet records according to relative sugar and starch concentrations. They reported that only the quantity of low sugar/high starch foods was a significant predictor of caries increment in Australian children aged 12-13 years at baseline. Karjalainen *et al.* (8) reported that Finnish children with caries at age 6 years had higher sucrose intakes assessed using 4-day diet records, but similar frequencies of exposures to sweets assessed by questionnaire, at 3 years of age as those without caries. In a study of British pre-school children, both the quantity and frequency of sugar confection intakes, but not biscuits/cakes or chocolates, collected using 4-day diet records were associated with caries in children with limited brushing frequency (4). A similar study found that any consumption of confections and desserts, but not biscuits/cakes, assessed by questionnaire was associated with dental caries in 4 to 5-year-old Jordanian children (6). Vanobbergen *et al.* (9) reported that questionnaire-reported daily consumption of two or more between meal snacks was associated with increased caries in Flemish school-aged children. Overall, these previous studies conducted in children at different ages and from different cultures have reported somewhat inconsistent results, which could be due to differences in collecting data, defining food categories and timing of consumption and limited data that differentiated between beverage types and meal or snack eating events.

We previously reported that caries risk was associated with consumption of individual sugared beverages (7), and speculated that differences could be due to timing of consumption. In this study, we hypothesized that sugar-containing beverages consumed at meals would not be associated with caries, while those consumed at snacks would increase caries risk, and that foods containing primarily sugars and/or highly processed starches, but not unprocessed starches, would increase caries risk. In this article, we describe the associations among caries experience and meal, snack and daily total exposures to beverages and foods in a cohort of young children.

Methods

Subjects. Subjects were participants in the IFS, a longitudinal investigation of dietary and non-dietary fluoride exposures and the relationships between fluoride exposures and dental fluorosis and caries (7, 10-16). Mothers of newborn infants were recruited from 1992 to 1995 for their children's participation. Dental examinations were completed on the primary dentition of 690 children at 4.5-6.8 years of age (12, 13). Subjects who participated in dental examinations and whose parents completed 3-day food and beverage diaries are the focus of this report (N = 634). The Institutional Review Board at the University of Iowa approved all components of the IFS; written informed consent was obtained from mothers at recruitment and at the examination.

Data collection. Parents were mailed IFS questionnaires and 3-day food and beverage diaries when their children were 6 weeks of age, 3, 6, 9 and 12 months of age, every 4 months through 3 years of age and every 6 months thereafter. IFS questionnaires were designed to obtain information regarding the children's beverage intakes, general health and oral health behaviors.

Dental caries. Dental examinations were conducted in the General Clinical Research Center at The University of Iowa or in one of several community locations (12, 13). The examination procedures and criteria for dental caries have been extensively described elsewhere. (12, 13) For this study, caries experience was defined as the presence of a cavitated (d_{2-3}) or filled surface. Caries experience was assessed at the tooth surface level and then collapsed into a dichotomous subject-level outcome (any caries vs. none).

Diet Abstraction. Three-day food and beverage diaries targeted for completion at 1, 2, 3, 4, and 5 years of age were used in these analyses. As previously described (7), if a subject did not return a diary (i.e., 24 month), then the previous diary (e.g., 20 months) was substituted. If this diary was also missing, then the subsequent diary (e.g., 28 months) was substituted for the yearly diary. If neither was available, then the subject was omitted from analyses for that year. Inclusion in area-under-the-curve analyses (i.e., a weighted average of the 1- through 5-year intakes) required a minimum of 4 diaries, including the 1 and 5 -year diaries (n = 398). The area-under-the-curve was calculated using the trapezoidal method.

Parents and caregivers were asked to record on 3-day food and beverage diaries both the times of consumption and quantities consumed for one weekend day and two weekdays. Each diary was individually reviewed and exposure data were abstracted by a registered dietitian or diet technician, and subsequently verified by a second dietitian or technician. Weighted averages based on weekend and weekday exposure were calculated to reflect average daily exposures over a week.

Food and beverage exposures were abstracted from diaries based on the carbohydrate composition of the exposure and nature of consumption. Eating events were defined as all foods and beverages consumed within a 30- minute interval. The first eating event began at the time the first food or beverage was recorded and was defined to include all foods and beverages recorded during the subsequent 30 minutes. The second eating event began at the time the next food or beverage was recorded and included the subsequent 30 minutes. All eating events throughout the day were captured in this fashion.

Each eating event was categorized as a meal or snack based on the time of consumption and nature of foods or beverages consumed. The number of meals per day was limited to three; the number of snacks was unlimited. No more than one meal could occur

during the morning, middle of the day or evening hours. To be categorized as a meal, foods consumed during the eating event had to be typical of a child's meal, and generally included multiple foods (i.e., meat, vegetable, bread and beverage) or single entrees (i.e., peanut butter sandwich or pizza). For example, a peanut butter sandwich and milk at 1 p.m. would be considered a meal. However, following an 11:30 a.m. meal of chicken nuggets, carrots, bread with butter and juice, the same peanut butter sandwich and milk consumed at 3 p.m. would be coded as a snack. Selected items (i.e., chips and Kool-Aid®; single beverages) were always coded as a snack.

Each individual food and beverage exposure was categorized according to fermentable carbohydrate type and coded as consumed during a meal or snack. Each eating event during which the food or beverage was consumed was coded as an exposure. If grape juice was recorded twice during one eating event, then one 100% juice exposure was recorded. However, if both grape juice and apple juice were recorded during one eating event, then two 100% juice exposures were recorded.

Beverages abstracted included milk-based beverages: milk and infant formula; and beverages with sugar: 100% juice, juice drinks, regular soda pop, reconstituted beverages with sugar, sports drinks, flavored water and other sugared beverages. The relationships between beverage exposures and dental caries were evaluated, and beverages were then collapsed for subsequent analyses. Since traditionally milk and infant formula serve the same purpose in the diet, they were combined to form a milk/formula group. All beverages with sugar were combined to form a "sugared beverages" category, while all beverages with sugar except 100% juice were combined to form an "added sugared beverages" category.

Foods abstracted included high sugar foods: candy, sugar-based desserts (i.e., ice cream, pudding, gelatin), sugar condiments (i.e., table sugar, molasses, syrup); and high starch (with or without sugar) foods: baked starch with sugar (i.e., brownies, cake, donuts), presweetened cereals (i.e., frosted flakes), unsweetened cereals (i.e., bran flakes), processed snacks (i.e., potato chips, tortilla chips, flavored crackers) and unprocessed starches (i.e., rice, pasta, sandwich bread). The relationships between food categories and dental caries were evaluated, and food categories were then collapsed for subsequent analyses. High sugar foods were combined to form a "sugars" category; high starch foods were combined to form a "starches" category; and both sugars and starches were combined to form a "sugars and starches" category.

Fluoride intake. IFS questionnaires completed from 6 weeks through 5 years of age were used to estimate fluoride intakes from water consumed as a beverage and added during preparation of beverages and selected foods (e.g., pasta, soup, hot cereal), other beverages, dietary fluoride supplements and fluoride dentifrices (10, 15). Fluoride intakes were defined as the sum of fluoride from all water, other beverages, select foods, fluoride supplements and dentifrices. Cumulative fluoride intakes (mg/day) were estimated from fluoride intakes from 6 weeks through 5 years of age using the trapezoidal method.

Statistical analyses. Analyses were conducted using SAS (SAS, version 8.0; Cary, NC). Subject characteristics were categorized and are presented as percentages. Daily food and beverage exposures are presented as medians (25^{th}, 75^{th} percentiles). Logistic regression models were developed to determine if caries risk differed between subjects in the fourth vs. first quartile (reference group) of food and beverage exposures. All models were adjusted for age at dental exam and cumulative fluoride intakes. A P-value of < 0.05 was considered statistically significant.

Results

Demographic characteristics of the 634 subjects and their parents at enrollment in the IFS are presented in Table 1. Children in the IFS cohort who did not participate in the dental exams and/or did not provide regular dietary records had younger mothers and fathers and lower levels of mother's education, father's education and income than did study participants (data not shown; $p < 0.001$).

Subjects were 4.5-6.8 years of age (median = 5.1) at the time of the dental exam. The percentage of subjects with caries experience in the primary dentition was 25.7%. Median (25^{th}, 75^{th} percentiles) cumulative fluoride intakes of subjects with and without caries were 0.55 (0.46, 0.72) and 0.63 (0.49, 0.80) mg/day, respectively.

Median (25^{th}, 75^{th} percentiles) average daily exposures to beverage and food categories by meal and snack events for 1- through 5-years of age are presented in Table 2. Median milk/formula and soda-pop exposures were higher at meals than at snacks. One hundred percent juice

TABLE 1
Demographic characteristics of subjects and their families at enrollment (%)

Gender		
Male	47.9	
Female	52.1	
Birth Order		
First child	42.4	
Other	57.6	
Household Income		
≤ $9,999	4.7	
$10,000-19,999	8.4	
$20,000-29,999	14.8	
$30,000-39,999	20.7	
$40,000-49,999	16.7	
$50,000-59,999	12.6	
≥$60,000	18.8	
Unknown	3.3	
Age	Mother	Father
16-24	17.0	6.8
25-29	31.9	26.8
30-34	31.4	33.1
35+	19.7	28.2
Unknown		5.1
Education	Mother	Father
<12 y	2.2	2.2
High school/GED	17.0	23.8
Some college	19.1	15.3
2 y college	15.5	12.5
4 y college	29.2	25.2
Grad/professional	17.0	16.1
Unknown		4.9

N = 634

TABLE 2
Median (25th, 75th percentiles) average daily exposures to beverage and food categories by meal, snack and daily total events for 1 through 5 years* of age (N = 398).

Dietary variable	Meal events	Snack events	Total events
All foods and beverages	3.0 (2.9, 3.0)	3.1 (2.4, 3.8)	6.1 (5.4, 6.8)
Beverages			
100% Juice	0.4 (0.2, 0.8)	0.4 (0.2, 0.8)	1.0 (0.5, 1.4)
Soda-pop	0.1 (0.0, 0.3)	0.0 (0.0, 0.1)	0.2 (0.1, 0.4)
Milk/formula	1.7 (1.3, 2.1)	0.7 (0.4, 1.1)	2.5 (2.0, 3.1)
Sugared beverages†	1.0 (0.7, 1.3)	0.8 (0.5, 1.3)	1.9 (1.3, 2.5)
Added sugar beverages‡	0.4 (0.2, 0.7)	0.3 (0.1, 0.6)	0.8 (0.4, 1.3)
Foods			
Candy	0.0 (0.0, 0.1)	0.2 (0.0, 0.3)	0.2 (0.0, 0.4)
Sugar-based desserts	0.2 (0.0, 0.3)	0.2 (0.1, 0.3)	0.4 (0.3, 0.6)
Sugar condiments	0.3 (0.1, 0.4)	0.0 (0.0, 0.1)	0.3 (0.1, 0.5)
Sugars§	0.5 (0.3,0.8)	0.5 (0.3,0.7)	1.0 (0.7,1.4)
Baked starch with sugar	0.3 (0.2, 0.5)	0.6 (0.4, 0.8)	0.9 (0.7, 1.2)
Presweetened cereals	0.3 (0.1, 0.5)	0.0 (0.0, 0.1)	0.3 (0.2, 0.5)
Unsweetened cereals	0.1 (0.0, 0.3)	0.0 (0.0, 0.1)	0.2 (0.1, 0.3)
Processed snacks	0.3 (0.1, 0.4)	0.3 (0.1, 0.4)	0.6 (0.4, 0.8)
Unprocessed starches	2.5 (2.1, 2.7)	0.2 (0.1, 0.3)	2.7 (2.3, 3.0)
Starches¶	3.5 (3.2, 3.9)	1.2 (0.8, 1.5)	4.8 (4.3, 5.3)
All sugars and starches	4.0 (3.5, 4.6)	1.7 (1.3, 2.1)	5.8 (5.2, 6.5)

* Weighted average of 1- through 5-year intakes.
† Sugared beverages include 100% juice and beverages prepared with added sugars (i.e., juice drinks, soda-pop, sports drinks, teas, flavored milks and reconstituted drinks).
‡ Added sugar beverages include beverages prepared with added sugars.
§ Sugars include candy, sugar-based desserts and sugar condiment exposures.
¶ Starches include baked starch with sugar, presweetened cereals, unsweetened cereals, processed snacks and unprocessed starches.

TABLE 3
Odds ratios (95th % CI) of caries risk at 4.5-6.8 years of age for 4th quartile (i.e., high exposure) compared to 1st quartile (i.e., low exposure) of the number of meal, snack and daily total eating events at 1, 2, 3, 4, 5 and 1 through 5 Years of Age.*

Year	Eating Events		
	Meal	Snack	Total
1	1.13	2.31	2.03
(N = 616)	(0.49, 2.60)	(1.08, 4.94)†	(0.95, 4.31)
2	0.58	2.58	2.69
(N = 527)	(0.29, 1.19)	(1.23, 5.42)†	(1.30, 5.58)‡
3	1.06	2.39	2.61
(N = 441)	(0.44, 2.56)	(1.13, 5.06)†	(1.23, 5.54)†
4	1.38	4.26	4.62
(N = 411)	(0.55, 3.50)	(1.58, 11.48)‡	(1.72, 12.39)‡
5	0.90	1.78	1.38
(N = 413)	(0.40, 2.00)	(0.81, 3.91)	(0.66, 2.90)
1-5	0.97	2.24	2.26
(N = 398)	(0.51, 1.85)	(1.03, 4.86)†	(1.06, 4.82)†

*Adjusted for age at dental exam and total fluoride intake
† $P < 0.05$
‡ $P < 0.01$

exposures were similar at meals and snacks. Candy and baked starch with sugar exposures were higher at snacks than at meals. Sugar condiments, cereals and unprocessed starch exposures were higher at meals than at snacks.

In addition, average daily exposures by meal and snack events at 1, 2, 3, 4, and 5 years were reviewed (data not shown). Median meal eating events remained the same (i.e., 3) throughout the 5 years, while snack eating events decreased from 3.7 at 1 year to 2.7 at 5 years. Median juice exposures at meals were consistent throughout the 5 years, while snack exposures peaked at 0.7 at 2 years. Median soda-pop exposures were 0 at meals and snacks throughout the 5 years; the 75th percentile of exposures increased with age for both meal and snack exposures. Median sugar exposures at meals increased from 0.3 at 1 year to 0.5 at 5 years, while sugar exposures at snacks increased from 0.0 at 1 year to 0.7 at 5 years. Median starch exposures at meals increased from 3.0 at 1 year to 3.7 at 3 years and remained stable, while starch exposures at snacks increased from 0.7 at 1 year to 1.3 at 2 years and remained stable thereafter.

Logistic regression models were developed to predict caries experience at 4.5-6.8 years of age from the number of meal and snack eating events (Table 3). Children in the highest quartile of eating events were compared to those in the lowest quartile; models were adjusted for age at dental exam and fluoride intake. Children in the highest quartile of snack eating events at 1, 2, 3, 4, and 1 through 5-years had an increased risk of caries experience relative to children in the lowest quartile. Similarly, children in the highest quartile of daily total eating events at 2, 3, 4 and 1 through 5-years had an increased risk of caries relative to children in the lowest quartile.

Logistic regression models developed to predict caries experience at 4.5-6.8 years of age from beverage exposures at meals and snacks are presented in Table 4. Although children in the highest quartile of 100% juice

TABLE 4
Odds ratios (95th % CI) of caries risk at 4.5-6.8 years of age for 4th quartile (i.e., high exposure) compared to 1st quartile (i.e., low exposure) of beverage exposures at meal, snack and daily total events at 1, 2, 3, 4, 5 and 1 through 5-years of age.*

100% Juice			
Year	Meal	Snack	Total
1	1.20	1.01	1.13
(N = 616)	(0.65, 2.20)	(0.56, 1.84)	(0.59, 2.19)
2	1.23	2.18	1.32
(N = 527)	(0.59, 2.56)	(1.10, 4.33)†	(0.64, 2.73)
3	1.42	1.38	0.80
(N = 441)	(0.64, 3.19)	(0.72, 2.65)	(0.38, 1.66)
4	0.87	1.10	0.83
(N = 411)	(0.45,1.69)	(0.58, 2.09)	(0.39, 1.76)
5	0.56	0.79	0.63
(N = 413)	(0.28, 1.12)	(0.32, 1.94)	(0.31, 1.29)
1-5	0.94	1.03	0.90
(N = 398)	(0.46, 1.96)	(0.48, 2.25)	(0.44, 1.85)
Soda-Pop			
Year	Meal	Snack	Total
1	1.30	0.61	1.35
(N = 616)	(0.53, 3.23)	(0.13,2.83)	(0.60, 3.03)
2	2.68	2.50	3.27
(N=527)	(1.29, 5.55)‡	(1.42,4.42)‡	(1.78, 6.00)§
3	1.27	2.96	2.28
(N = 441)	(0.63, 2.59)	(1.69,5.18)§	(1.23, 4.22)‡
4	1.68	2.88	2.35
(N = 411)	(0.88, 3.22)	(1.24,6.69)†	(1.13, 4.88)†
5	1.54	1.57	1.80
(N = 413)	(0.81, 2.93)	(0.71,3.47)	(0.86, 3.76)
1-5	3.23	2.50	3.76
(N = 398)	(1.46, 7.14)‡	(1.21,5.14)†	(1.66, 8.50)‡
Milk/Formula			
Year	Meal	Snack	Total
1	0.34	2.18	1.42
(N = 616)	(0.17, 0.70)‡	(1.08, 4.42)†	(0.69, 2.89)
2	0.54	0.77	0.88
(N=527)	(0.24, 1.21)	(0.40, 1.47)	(0.41, 1.87)
3	0.46	1.09	0.54
(N=441)	(0.20, 1.07)	(0.53, 2.21)	(0.24, 1.21)
4	0.67	1.04	1.01
(N=411)	(0.28, 1.60)	(0.53, 2.05)	(0.45, 2.31)
5	1.08	1.47	1.08
(N=413)	(0.45, 2.60)	(0.76, 2.83)	(0.49, 2.37)
1-5	0.55	0.87	0.54
(N=398)	(0.26, 1.18)	(0.41, 1.84)	(0.25, 1.14)
Sugared Beverages¶			
Year	Meal	Snack	Total
1	1.48	1.20	1.66
	(0.74, 2.97)	(0.58, 2.48)	(0.78, 3.54)
2	1.93	3.11	2.57
	(0.80, 4.68)	(1.27, 7.61)†	(1.19, 5.53)†
3	1.95	2.08	1.71
	(0.90, 4.28)	(0.82, 5.26)	(0.79, 3.69)
4	1.56	1.37	2.43
	(0.70, 3.44)	(0.57, 3.33)	(0.94, 6.29)
5	0.98	1.24	1.02
	(0.43, 2.21)	(0.53, 2.93)	(0.46, 2.29)
1-5	1.37	1.74	2.06
	(0.65, 2.86)	(0.79, 3.82)	(0.95, 4.46)

exposures at snacks at 2 years of age had an increased risk of caries experience relative to children in the lowest quartile, inconsistent associations with caries at meals or snacks at other ages were observed. At multiple ages, children in the highest quartile of soda-pop exposures at meals, snacks, and daily total had an increased risk of caries experience relative to children in the lowest quartile. At 1 year of age only, higher exposures to milk and/or formula at meals were associated with a decreased risk of caries, while higher exposures at snacks were associated with an increased risk. Children in the highest quartile of daily total exposures to all sugared beverages had an increased risk of caries relative to children in the lowest quartile at 2 years. Higher exposures to added sugared beverages at meals, snacks and daily total were associated with an increased risk of caries at multiple ages.

Logistic regression models developed to predict caries experience from sugar-and starch- containing foods at meals and snacks are presented in Table 5. Children in the highest quartile of sugar exposures at meals at 3 years and 1 through 5 years had a decreased risk of caries relative to children in the lowest quartile, while children in the highest quartile at snacks at 4 years and 1 through 5 years had an increased risk of caries. More exposures to starches at meals were associated with a decreased risk of caries at 4, 5 and 1 through 5 years; snack and daily total exposures were not associated with caries. Similarly, children in the highest quartile of all sugar and starch exposures at meals at 4, 5 and 1 through 5 years had a decreased risk of caries relative to children in the lowest quartile, while children in the highest quartile of snack exposures at 2 years had an increased risk of caries. Daily total exposures to all sugars and starches were associated with caries experience at age 5 only.

Additional logistic regression models were developed to predict caries experience from individual types of sugar- and starch-containing foods (data not shown). Children in the

Table 4 - Continued

Added Sugar Beverages[#]			
Year	Meal	Snack	Total
1	1.40	0.98	1.33
	(0.79, 2.50)	(0.51, 1.87)	(0.80, 2.21)
2	2.14	1.85	2.41
	(1.10, 4.18)[†]	(1.02, 3.35)[†]	(1.14, 5.08)[†]
3	1.67	1.81	2.42
	(0.76, 3.65)	(0.94, 3.47)	(1.13, 5.17)[†]
4	2.02	2.50	1.89
	(0.94, 4.34)	(1.28, 4.90)[‡]	(0.84, 4.25)
5	1.86	1.35	1.52
	(0.84, 4.12)	(0.68, 2.65)	(0.73, 3.14)
1-5	2.31	3.59	2.64
	(0.99, 5.37)	(1.47, 8.74)[‡]	(1.18, 5.93)[†]

* Adjusted for age at dental exam and total fluoride intake
[†] $P < 0.05$
[‡] $P < 0.01$
[§] $P < 0.001$
[¶] Sugared beverages include 100% juice and beverages prepared with added sugars (i.e., juice drinks, soda-pop, sports drinks, teas, flavored milks and reconstituted drinks).
[#] Added sugar beverages include beverages prepared with added sugars.

highest quartile of sugar-based dessert exposures at meals had a decreased risk of caries (1 through 5 years; $P < 0.05$), while children in the highest quartile at snacks had an increased risk of caries (1 through 5 years; $P < 0.05$); total daily exposures to sugar-based desserts were not associated with caries. Similarly, children in the highest quartile of unprocessed starch exposures at meals had a decreased risk of caries (1 through 5 years; $P < 0.05$), while children in the highest quartile at snacks had an increased risk of caries (1 through 5 years; $P < 0.01$); total daily exposures to unprocessed starches were not associated with caries. Associations among processed starch exposures and caries showed similar trends, but did not achieve statistical significance.

Discussion

Results reported herein suggest that the methods employed to investigate relationships between diet and dental caries can and do affect the outcome. Traditionally, dietary studies of caries have combined beverages and foods according to sugar content. Such combinations minimize the contributions of specific beverages or foods—beverages and foods are more than the sum of their nutrients. Caries protective or enabling effects of packaging the sugar with starch, fat and protein; interactions between bacteria and other nutrients; and protective non-nutritive substances are ignored with simple combinations. In addition, total daily exposures are typically assessed; however, it is reasonable to expect that the caries risk attributed to a food or beverage differs based on the timing and presence of other foods during consumption.

Our results did not support our earlier hypothesis that different caries risks associated with individual sugared beverages (7) were due to timing of consumption. Rather, the results suggest that the caries risks associated with consumption of 100% juice and soda pop are fundamentally different, with soda pop increasing caries risk more than 100% juice; while the timing of consumption (i.e., meal or snack) has minimal impact on risk. The strength of the caries risk associated with "sugared" beverages, which includes 100% juice and beverages prepared with added sugars, was generally less than that associated with "added sugar" beverages, suggesting that grouping 100% juice with beverages prepared with added sugar reduces the estimate of the adverse effects of added sugar. Efforts by other investigators and our earlier work support our results that consumption of 100% juice is not associated with caries (6, 7); whereas, consumption of soda-pop (7, 15, 17) and other beverages prepared with added sugars (6, 7) are associated with caries; and that consumption of combined sugared beverages may or may not be associated with caries (4, 5, 18). The reason for the discrepancy between 100% juice and beverages prepared with added sugars is unclear. The sugar substrates in 100% juice are primarily fructose and glucose, whereas the added sugar substrate in purchased liquid beverages in the United States is primarily high fructose corn syrup, while sucrose is the primary sugar in reconstituted powdered beverages.

Carbohydrate-containing foods were categorized based on the presence or absence of sugar and starch, and the degree of processing of the starch. The rationale for this categorization was our hypothesis that foods composed of sugars, cooked sugar and starch combinations, highly processed starches (i.e., short glucose chains) and relatively unprocessed starches (i.e., long glucose chains) would have different caries risks. In general, caries risk in our subjects was associated with exposure to both sugar- and starch-containing foods; however, the risks associated with timing of exposures were more notable than the risks associated with sugar-starch categories. Exposure to sugar- and starch-containing foods at meals appeared to decrease caries risk, while exposure at snacks increased caries risk. Total daily exposures to sugar- and starch-containing foods reflect the balance of lower meal and higher snack risks, and were not consistently associated with caries. Interestingly, the decreased meal and increased snack risks associated with milk/formula exposures at 1 year were similar to those for sugar- and starch-containing foods. Our results are consistent with those observed during the longitudinal Vipeholm study conducted in institutionalized adults (1). Provision of sugar-based

TABLE 5
Odds ratios of caries risk at 4.5-6.8 years of age for 4th quartile (i.e., high exposure) compared to 1st quartile (i.e., low exposure) of sugar- and starch-containing foods at meal, snack and daily total events at 1, 2, 3, 4, 5 and 1 through 5 Years of Age

Sugars¶			
Year	Meal	Snack	Total
1	1.13	1.48	1.30
(N = 616)	(0.58, 2.21)	(0.71, 3.09)	(0.70, 2.42)
2	0.63	1.56	1.02
(N = 527)	(0.33, 1.23)	(0.79, 3.11)	(0.43, 2.39)
3	0.39	1.56	0.80
(N = 441)	(0.17, 0.94)†	(0.67, 3.64)	(0.39, 1.66)
4	0.47	2.65	1.19
(N = 411)	(0.20, 1.11)	(1.14, 6.16)†	(0.53, 2.66)
5	0.63	1.45	1.07
(N = 413)	(0.26, 1.55)	(0.66, 3.18)	(0.47, 2.41)
1-5	0.36	2.82	0.75
(N = 398)	(0.16, 0.81)†	(1.19, 6.72)†	(0.34, 1.63)
Starches#			
Year	Meal	Snack	Total
1	0.64	0.95	0.55
	(0.30, 1.37)	(0.46,1.94)	(0.27, 1.11)
2	0.63	1.50	0.94
	(0.27, 1.44)	(0.65,3.48)	(0.41, 2.18)
3	0.58	0.86	0.74
	(0.24, 1.40)	(0.39,1.90)	(0.35, 1.55)
4	0.37	2.20	0.74
	(0.14, 1.00)†	(0.82,5.85)	(0.33, 1.67)
5	0.26	1.61	0.84
	(0.10, 0.65)‡	(0.71,3.62)	(0.39, 1.81)
1-5	0.45	1.35	0.90
	(0.21, 0.97)†	(0.62,2.94)	(0.42, 1.94)
All Sugars and Starches			
Year	Meal	Snack	Total
1	0.77	0.87	0.83
	(0.39, 1.50)	(0.43, 1.78)	(0.42, 1.65)
2	0.52	2.59	0.82
	(0.25, 1.06)	(1.05, 6.36)†	(0.39, 1.72)
3	0.47	1.24	0.79
	(0.22, 1.02)	(0.61, 2.51)	(0.39, 1.61)
4	0.36	2.09	0.74
	(0.15, 0.87)†	(0.90, 4.82)	(0.33, 1.66)
5	0.31	1.70	0.43
	(0.13, 0.73)‡	(0.83, 3.51)	(0.21, 0.89)†
1-5	0.22	1.72	0.73
	(0.10, 0.50)§	(0.77, 3.84)	(0.35, 1.52)

*Adjusted for age at dental exam and total fluoride exposure
† $P < 0.05$
‡ $P < 0.01$
§ $P < 0.001$
¶ Sugars include candy, sugar desserts and sugar exposures.
# Starches include baked starch with sugar, presweetened cereals, unsweetened cereals, processed snacks and unprocessed starches.

foods (toffee, caramels and chocolate) both at and between meals was associated with an increased caries risk, while provision of caramels and chocolates only at meals was not associated with increased caries risk (1). Provision of sweetened breads was not associated with caries when provided once a day, but was associated with a slight increase in caries risk when provided 4 times daily (1). The reason for the discrepancy between meal and snack exposures is unknown, but could reflect more controlled exposures at meals or that other foods consumed as part of meals serve to clear the carbohydrates from the mouth and/or limit the drop in oral pH associated with more solitary exposures at snacks.

Our results could partially explain the inconsistent observations from studies concerning consumption of sugar- and starch-containing foods and dental caries. Although sugars are known to be cariogenic, investigators have not consistently documented an increased risk of caries with increased sugar consumption in contemporary society (3, 4, 8, 18). Campain *et al.* (3) explored interactions between starch and sugar intakes and concluded that "starch was a significant modifier of the relationship between dental caries and foods with low sugar levels." They also hypothesized that between meal exposures and frequency of consumption of starch foods affected the carbohydrate-caries relationship (3). Indeed, between meal and snack exposures have been reported as cariogenic (6, 9), while total intakes have been inconsistently reported as cariogenic (3, 4, 18, 19). Our results suggest that the timing of exposure to sugar- and starch-containing foods is a critical determinant of caries risk.

Although the results of our studies have implications for the methodology employed in future investigations of the diet-caries relationship, the results have clinical implications as well. Our results suggest that exposure to beverages prepared with added sugars is detrimental to oral health, regardless of timing of consumption, while exposure to sugar- and starch-containing foods is safer at meals than at snacks. Our results suggest that 100% juice is less detrimental to oral health than beverages containing added sugars; however, excessive consumption of 100% juice has been associated with growth failure (20) and the American Academy of Pediatrics has established guidelines for consumption (21).

Our study has several limitations that should be acknowledged. Dietary

data were reported by the parent and/or caregiver and do not necessarily reflect actual consumption. Food categories were selected to emphasize sugar and starch combinations, and didn't completely account for other nutrients. For example, sugar-based desserts included ice creams and gelatins. Although the primary bacterial substrate in both is sucrose, ice cream contains milk and gelatin does not. Although dietary data were collected longitudinally, the oral examination occurred at one time point, which limited our ability to track dietary intake and caries experience simultaneously (7). Changes in dietary patterns resulting from preventive guidance provided by local care providers could have limited our ability to identify associations between dietary factors and caries experience (7). Parents who provide young children with soda pop and added sugared beverages could encourage other less healthy behaviors, including an overall lower quality diet (22). With a large number of exposure variables and one outcome variable, one would expect chance associations to be observed. Therefore, inconsistent or 1-time associations must be viewed with caution (7). Dental examinations were primarily visual with tactile confirmation, and did not include radiographs, so that some children with caries may not have been diagnosed. (13). Finally, subjects and their families are generally from high-income, well-educated families and are not representative of children throughout the United States. Socioeconomic status is associated with oral health behaviors and oral disease (23); thus, associations could be more pronounced in a more diverse socioeconomic group (7).

Conclusions

Two separate themes repeatedly surfaced during analyses of these data. First, the methodology employed in investigation of diet-caries relationships can influence the outcome. We abstracted very detailed data (i.e., individual beverages, exposure events) from 3-day diet records and subsequently collapsed variables with similar attributes. In doing so, we were able to identify differences between beverages, exposure events and dental caries that were not expected or initially obvious. Second, our data provide evidence to refine and support dietary recommendations for caries prevention. These guidelines include limiting beverages containing added sugar to occasional use, and providing sugar- and starch-containing foods at meal events.

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