

# Dental Caries and Beverage Consumption in Young Children

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**ABSTRACT.** *Objective.* Dental caries is a common, chronic disease of childhood. The impact of contemporary changes in beverage patterns, specifically decreased milk intakes and increased 100% juice and soda pop intakes, on dental caries in young children is unknown. We describe associations among caries experience and intakes of dairy foods, sugared beverages, and nutrients and overall diet quality in young children.

*Methods.* Subjects ( $n = 642$ ) are members of the Iowa Fluoride Study, a cohort followed from birth. Food and nutrient intakes were obtained from 3-day diet records analyzed at 1 ( $n = 636$ ), 2 ( $n = 525$ ), 3 ( $n = 441$ ), 4 ( $n = 410$ ), and 5 ( $n = 417$ ) years and cumulatively for 1 through 5 ( $n = 396$ ) years of age. Diet quality was defined by nutrient adequacy ratios (NARs) and calculated as the ratio of nutrient intake to Recommended Dietary Allowance/Adequate Intake. Caries were identified during dental examinations by 2 trained and calibrated dentists at 4 to 7 years of age. Examinations were visual, but a dental explorer was used to confirm questionable findings. Caries experience was assessed at both the tooth and the surface levels. Data were analyzed using SAS. The Wilcoxon rank sum test was used to compare food intakes, nutrient intakes, and NARs of subjects with and without caries experience. Logistic and Tobit regression analyses were used to identify associations among diet variables and caries experience and to develop models to predict caries experience. Not all relationships between food intakes and NARs and caries experience were linear; therefore, categorical variables were used to develop models to predict caries experience. Food and beverage intakes were categorized as none, low, and high intakes, and NARs were categorized as inadequate, low adequate, and high adequate.

*Results.* Subjects with caries had lower median intakes of milk at 2 and 3 years of age than subjects without caries. Subjects with caries had higher median intakes of regular (sugared) soda pop at 2, 3, 4, and 5 years and for 1 through 5 years; regular beverages from powder at 1, 4, and 5 years and for 1 through 5 years; and total sugared beverages at 4 and 5 years than subjects without caries.

Logistic regression models were developed for exposure variables at 1, 2, 3, 4, and 5 years and for 1 through 5 years to predict any caries experience at 4 to 7 years of age. Age at dental examination was retained in models at all ages. Children with 0 intake (vs low and high intakes) of regular beverages from powder at 1 year, regular soda pop at 2 and 3 years, and sugar-free beverages from powder at 5 years had a decreased risk of caries experience. High intakes of regular beverages from powder at 4 and 5 years and for 1 through 5 years and regular soda pop at 5 years and for 1 through 5 years were associated with significantly increased odds of caries experience relative to subjects with none or low intakes. Low (vs none or high) intakes of 100% juice at 5 years were associated with decreased caries experience. In general, inadequate intakes (vs low adequate or high adequate intakes) of nutrients (eg, riboflavin, copper, vitamin D, vitamin B<sub>12</sub>) were associated with increased caries experience and low adequate intakes (vs inadequate or high adequate intakes) of nutrients (eg, vitamin B<sub>12</sub>, vitamin C) were associated with decreased caries experience. An exception was vitamin E; either low or high adequate intakes were associated with increased caries experience at various ages. Multivariable Tobit regression models were developed for 1- through 5-year exposure variables to predict the number of tooth surfaces with caries experience at 4 to 7 years of age. Age at dental examination showed a significant positive association and fluoride exposure showed a significant negative association with the number of tooth surfaces with caries experience in the final model. Low intakes of nonmilk dairy foods (vs high intakes; all subjects had some nonmilk dairy intakes) and high adequate intakes of vitamin C (vs inadequate and low adequate intakes) were associated with fewer tooth surfaces having caries experience. High intakes of regular soda pop (vs none and low intakes) were associated with more tooth surfaces having caries experience.

*Conclusions.* Results of our study suggest that contemporary changes in beverage patterns, particularly the increase in soda pop consumption, have the potential to increase dental caries rates in children. Consumption of regular soda pop, regular powdered beverages, and, to a lesser extent, 100% juice was associated with increased caries risk. Milk had a neutral association with caries. Associations between different types of sugared beverages and caries experience were not equivalent, which could be attributable to the different sugar compositions of the beverages or different roles in the diet. Our data support contemporary dietary guidelines for children: consume 2 or more servings of dairy foods daily, limit intake of 100% juice to 4 to 6 oz daily, and restrict other sugared beverages to occasional use. Pediatricians, pediatric nurse practitioners, and dietitians are in a position to support pediatric dentists in providing preventive guidance to parents of young children. *Pediatrics* 2003;112:e184-e191.

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ABBREVIATIONS. IFS, Iowa Fluoride Study; NAR, nutrient adequacy ratio; MAR, mean adequacy ratio.

Contemporary changes have occurred in the types and quantities of beverages consumed, the manner in which they are consumed and their role in the diet. Most notable, milk intakes have decreased and 100% juice and soda pop intakes have increased during the past generation.<sup>1-3</sup> Nutrient profiles of these beverages differ, and substitution of 100% juice or soda pop for milk has important nutritional implications. Consequences of this shift in beverage consumption include decreased intakes of calcium and increased rates of childhood obesity. Less recognized, however, are the implications that changes in beverage consumption can have for dental caries.

Dental caries is the most common chronic disease of childhood.<sup>4</sup> Pain from untreated caries can affect school attendance, eating and speaking, and, subsequently, growth and development.<sup>4</sup> Oral bacteria ferment carbohydrates and produce acid, which dissolves tooth enamel during the dental caries process; thus, sweetened beverages are likely to increase risk of dental caries.

Although sweetened beverages are a source of fermentable carbohydrates, previous investigations have not consistently associated their consumption with caries experience.<sup>5-13</sup> Ismail et al<sup>5</sup> reported a strong association between caries experience and soft drink consumption during meals in 9- to 29-year-olds participating in the National Health and Nutrition Examination Survey I. Caries experience was also associated with an increased soft drink to energy ratio in 5- and 13-year-old but not 9-year-old children.<sup>6</sup> Caries presence in the upper anterior teeth of 2-year-olds was associated with increased frequency of sugary snacks, particularly sweetened beverages.<sup>7</sup> Conversely, Gibson et al<sup>8</sup> did not find an association between caries experience and soft drinks in 1.5- to 4.5-year-old children participating in the British National Diet and Nutrition Survey. Caries experience of 5- to 14-year-old school children was not associated with consumption of either soft drinks or liquids with a high content of fructose and/or sucrose.<sup>9</sup> In a study of competitive athletes, caries experience was not associated with sports drink consumption.<sup>13</sup>

Part of the discrepancy among results from previous investigations could be attributable to the grouping of sweetened beverages (eg, as soft drinks or sweetened beverages), methods used to assess beverage intake, inability to control for known confounders, and the time period of beverage intake assessment relative to the disease process. Furthermore, the manner in which beverages are consumed (snack vs meal, prolonged sipping vs quick drinking, daytime vs nocturnal feedings) likely influences the disease process but is extremely difficult to assess in a community setting.

Dairy products may contain lactose and added

sugar, but they have generally been considered protective against dental caries.<sup>14-19</sup> Erickson et al<sup>16</sup> investigated the caries-related properties of whole milk and infant formulas. Although milk supported bacterial growth, it had a high buffering capacity and required substantially more time than sucrose and some infant formulas to produce caries.<sup>16</sup> Petti et al<sup>17</sup> reported that milk was protective against caries in 6- to 11-year-old children who did not use fluoride, had poor oral hygiene, and had frequent sucrose consumption.

The impact of secular changes in beverage patterns, specifically a decrease in milk and increase in sugared beverage consumption, on caries experience in young children is unknown. We hypothesized that consumption of dairy foods as part of a high-quality diet would decrease caries risk and that replacement of milk by sugared beverages would increase caries risk. In this article, we describe associations among caries experience and intakes of dairy foods, sugared beverages, and nutrients and overall diet quality in a cohort of young children.

## METHODS

### Subjects

Subjects were participants in the Iowa Fluoride Study (IFS), a longitudinal investigation of dietary and nondietary fluoride exposures and the relationships between fluoride exposures and dental fluorosis and caries.<sup>20-25</sup> Mothers of newborn infants ( $n = 1882$ ) were recruited from 1992 to 1995 at 8 Iowa hospital postpartum units for their children's participation. Dental examinations were completed on the primary dentition of 695 children at 4 to 7 years of age. Subjects who participated in dental examinations and whose parents completed 3-day food and beverage diaries for them were the focus of this report ( $n = 642$ ). The Institutional Review Board at the University of Iowa approved all components of the IFS, and written informed consent was obtained from mothers at recruitment and again at the time of examination.

### Data Collection

Parents were mailed IFS study questionnaires and 3-day food and beverage diaries at 6 weeks; 3, 6, 9, and 12 months of age; every 4 months through 3 years of age; and every 6 months thereafter. Follow-up mailings were sent to nonrespondents at 3 and 6 weeks after each mailing. IFS questionnaires were designed to obtain information regarding the child's beverage intake, general health, and oral health behaviors.

Children underwent dental examinations in the General Clinical Research Center at The University of Iowa or in a satellite clinic. Dental examinations were conducted using a portable chair and examination light by 1 of 2 trained and calibrated examiners.<sup>26</sup> The teeth were dried, and a DenLite (Welch-Allyn Medical Products, Inc, Skaneateles Falls, NY) mirror was used for enhanced lighting. The examination was visual, but a dental explorer was used to confirm questionable findings. Transillumination with the DenLite system augmented the visual/tactile examination.

### Diet Analyses

Three-day food and beverage diaries completed at 1 ( $n = 636$ ), 2 ( $n = 525$ ), 3 ( $n = 441$ ), 4 ( $n = 410$ ), and 5 ( $n = 417$ ) years of age are the focus of the present diet analysis. If the subject did not return a 3-day food and beverage diary (eg, 24 month), then the previous diary (eg, 20 month) was substituted. If this diary was also missing, then the subsequent diary (eg, 28-month) was substituted for the yearly diary. If neither was available, then the subject was omitted for that year. Inclusion in area-under-the-curve (ie, a weighted average of the 1- through 5-year intakes) analysis required a minimum of 4 diaries, including the 1- and 5-year diaries or suitable substitutions ( $n = 396$ ). The area under the curve was calculated using the trapezoidal rule. When data

were missing for a year, the trapezoidal segment covered 2 years. For instance, a subject with milk intakes of 303 g, 258 g, 183 g, and 112 g at 1, 2, 3, and 5 years, respectively, has a 1- to 5-year weighted average milk intake of  $[(303 \text{ g} + 258 \text{ g})/2 + (258 \text{ g} + 183 \text{ g})/2 + 2 \times (183 \text{ g} + 112 \text{ g})/2]/4 = 199 \text{ g}$ .

Parents were asked to record all foods and beverages consumed by their child for 1 weekend day and 2 weekdays on each diary. Detailed information regarding beverages, including brand names, types of preparation, and type of water, was requested. A relational database (Microsoft Access, version SR-1, Redmond, WA) was used to analyze food and beverage records. Nutrient data were obtained from the USDA (Nutrient Database for Standard Reference 12, Agriculture Research Service, US Department of Agriculture, Washington, DC), the Minnesota Nutrient Database, (Nutrition Coding Center NDS-R, version 4.01; Minneapolis, MN), and manufacturers' data.

The 3-day food and beverage diaries were coded and verified by registered dietitians. Weighted averages based on weekend or weekday consumption were calculated to reflect average consumption during a week. Dairy foods and all beverages were classified by food type (eg, fluid milk, cheese, 100% juice, juice drink, water). For foods having cheese or milk as an ingredient (eg, lasagna, cheeseburger), the dairy component was estimated from ingredient weights and included in the appropriate group. Nonmilk dairy intake is the sum of cheese, yogurt, and dairy desserts. Total sugared beverage intake is the sum of 100% juice, juice drinks, regular (ie, sweetened with sugar) soda pop, regular beverages from powder, and sports drinks.

Diet quality indices were created using the Dietary Reference Intakes<sup>27</sup> to define the adequacy of nutrient intakes.<sup>28,29</sup> The nutrient adequacy ratio (NAR) for a given nutrient is the ratio of an individual's mean daily intake to the age-specific Recommended Dietary Allowance or Adequate Intakes, if a recommended dietary allowance was not available. NARs were truncated at 1.0 for calculation of the mean adequacy ratio (MAR), which is the average of an individual's NARs and an index of overall diet quality.<sup>28,29</sup>

## Dental Caries

The criteria for dental caries were adapted from those of Pitts et al<sup>30,31</sup> and others<sup>32,33</sup> but did not differentiate between cavitated enamel ( $d_2$ ) and dentin ( $d_3$ ) lesions.<sup>26</sup> Instead, lesions were categorized as noncavitated ( $d_1$ ) and cavitated ( $d_{2-3}$ ) lesions. Specifically,  $d_1$  lesions presented as distinct chalky white enamel, usually adjacent or close to the soft tissue margin or adjacent to or in a pit or fissure, with no clinically visible or irreversible loss of enamel structure or break in the enamel surface. In contrast,  $d_{2-3}$  lesions presented with demonstrable loss of enamel structure. For this study, caries experience was defined as the presence of a cavitated ( $d_{2-3}$ ) or filled surface. Caries experience was assessed for each subject, including at both the tooth and the surface levels.

## Fluoride Intake

IFS questionnaires completed at the same time as the 3-day food and beverage diaries were used to estimate fluoride exposures from water consumed as a beverage and added during preparation of beverages and select foods (eg, pasta, soup, hot cereal), other beverages, fluoride supplements, and fluoride dentifrices.<sup>23</sup> Topical fluoride exposure to protect against caries was defined as the sum of fluoride from all water, other beverages, fluoride supplements, and dentifrices.

## Statistical Analysis

Caries data were entered using SPSS Data Entry software and converted to a SAS (SAS, version 8, Cary, NC) data set for data analysis. Subject characteristics were categorized and are presented as percentages. Food and nutrient intakes and NARs are presented as medians (25th, 75th percentiles). The Wilcoxon rank sum test was used to compare food intakes, nutrient intakes, and NARs of subjects with and without caries experience.  $P < .05$  was considered statistically significant.

Not all relationships between food intakes and NARs and caries experience were linear; therefore, categorical variables were used to develop models to predict caries experience. Food and beverage intakes were categorized into 3 levels: none (nonconsumers), low, and high. Low and high intakes were defined by the

median intake of consumers. NARs were also categorized into 3 levels: inadequate ( $<1$ ), low adequate, and high adequate. Low adequate and high adequate NARs were defined by the median NAR of subjects with NARs  $\geq 1$ . Each 3-category variable was represented by 2 indicator variables in caries experience prediction models using the LOGIST procedure in SAS. Simple logistic regression models were used to identify associations between dietary variables and caries experience that were moderately significant ( $P < .10$ ) using a joint test of the significance of the 2 indicator variables. The multiple logistic regression models that were developed to predict caries experience included age at dental examination, sex, fluoride exposure, and the 2 indicator variables representing each moderately significant dietary variable from the univariate analysis. Backward elimination was used to reduce the number of variables in the models. Final models included only variables that were significant at  $P < .05$ . When an indicator variable did not differ significantly from the reference group, it was combined with the reference group, leaving a single indicator variable.

Because they had no caries, a large proportion of the subjects (76%) had a value of 0 for the variable "number of tooth surfaces with caries." To accommodate an investigation of the association between dietary variables and the number of tooth surfaces with caries, these 0 values were considered to be left-censored. A simple model for the analysis of censored data is the Tobit model or the censored regression model.<sup>34</sup> Following the same strategy as outlined above for the logistic analysis, univariate and multivariate associations (including univariate associations significant at  $P < .05$ ) were investigated by fitting Tobit models using the LIFEREG procedure in SAS.

## RESULTS

Characteristics at enrollment in the IFS of the 642 subjects and their parents are presented in Table 1. Parents were well educated, and most were economically secure. Mothers were primarily white (97.2%), which is similar to the racial distribution of Iowa. Enrollment characteristics did not differ by caries experience (data not shown). Children who did not meet criteria for inclusion in area-under-the-curve analysis had younger mothers at enrollment than children who met the criteria ( $P < .05$ ). Children in the IFS cohort who did not participate in the dental examinations and/or did not provide dietary records had younger mothers and fathers and lower levels of mother's education, father's education, and income than study participants (data not shown;  $P < .001$ ).

Median (25th, 75th percentiles) 1- through 5-year average daily intakes of dairy foods, sugared beverages, and sugar-free beverages according to caries experience at 4 to 7 years of age are presented in Table 2. Subjects with caries experience had significantly greater intakes of regular soda pop ( $P < .001$ ) and regular beverages from powder ( $P < .01$ ) than subjects without caries experience. In addition, differences between median daily intakes of dairy foods, sugared beverages, and sugar-free beverages at 1, 2, 3, 4, and 5 years of age and caries experience at 4 to 7 years of age were investigated. Median milk intakes at 2 ( $P < .05$ ) and 3 ( $P < .05$ ) years were lower in subjects with caries experience (data not shown). Subjects with caries experience had higher median intakes of regular soda pop at 2 ( $P < .01$ ), 3 ( $P < .001$ ), 4 ( $P < .05$ ), and 5 ( $P < .01$ ) years; regular beverages from powder at 1 ( $P < .01$ ), 4 ( $P < .001$ ), and 5 ( $P < .05$ ) years; sports drinks at 4 ( $P < .05$ ) years; all sugared beverages at 4 ( $P < .05$ ) and 5 ( $P < .01$ ) years; and sugar-free beverages from powder at 5 ( $P < .01$ ) years (data not shown).

**TABLE 1.** Demographic Characteristics of Subjects and Their Families at Enrollment (%)\*

Sex	
Male	48.7
Female	51.3
Birth order	
First child	42.7
Other	57.3
Household income	
≤\$9999	4.7
\$10 000–\$19 999	8.3
\$20 000–\$29 999	14.8
\$30 000–\$39 999	20.9
\$40 000–\$49 999	16.7
\$50 000–\$59 999	12.5
≥\$60000	19.0
Unknown	3.3
Mother's age	
16–24	17.1
25–29	31.9
30–34	31.3
35+	19.6
Unknown	
Father's age	
16–24	6.5
25–29	27.1
30–34	32.9
35+	27.0
Unknown	6.5
Mother's education	
<12 y	2.3
High school/GED	17.0
Some college	19.0
2 y college	15.4
4 y college	29.1
Grad/professional	17.1
Unknown	
Father's education	
<12 y	2.2
High school/GED	23.5
Some college	15.4
2 y college	12.5
4 y college	25.6
Grad/professional	15.7
Unknown	5.1

\* *N* = 642 subjects.

Median (25th, 75th percentiles) 1- through 5-year average daily nutrient intakes and NARs according to caries experience are presented in Table 3. There were no significant differences between median nutrient intakes or indices of diet quality according to caries experience at 4 to 7 years. However, associations between median nutrient intakes and NARs at 2 and 3 years and caries experience at 4 to 7 years were observed (data not shown). Calcium intake and NAR ( $P < .05$ ) and magnesium intake and NAR ( $P < .05$ ) at 2 years and vitamin D intake and NAR ( $P < .05$ ) at 3 years were lower in subjects with caries experience.

Logistic regression models were developed for exposure variables at 1, 2, 3, 4, and 5 years and for 1 through 5 years to predict any caries experience at 4 to 7 years of age (Table 4). Initial models included age at dental examination, sex, fluoride exposure, and dietary variables that were significant ( $P < .10$ ) from univariate analysis. Age at dental examination was retained in models at all ages. Children with 0 intake (vs low and high intakes) of regular beverages from powder at 1 year, regular soda pop at 2 and 3 years, and sugar-free beverages from powder at 5

**TABLE 2.** Median (25th, 75th Percentiles) 1- Through 5-Year Average\* Daily Intakes of Dairy Foods, Sugared Beverages, and Sugar-Free Beverages by Caries Experience

Variable	Caries-Free† ( <i>n</i> = 301)	Caries Present† ( <i>n</i> = 95)
Dairy		
Milk (g)	364 (275, 460)	360 (245, 437)
Milk from powder (g)	0 (0, 0)	0 (0, 0)
Cheese (g)	18 (11, 25)	16 (9, 25)
Yogurt (g)	0 (0, 10)	0 (0, 8)
Dairy Desserts (g)	17 (7, 32)	19 (7, 33)
Total dairy (g)	45 (29, 67)	44 (28, 67)
Sugared beverages		
100% Juice (g)	114 (56, 188)	107 (62, 166)
Juice drinks (g)	33 (12, 79)	33 (8, 77)
Regular soda pop (g)	28 (4, 62)	46 (16, 86)§
Regular beverages from powder (g)	0 (0, 23)	12 (0, 62)‡
Sports drinks (g)	0 (0, 0)	0 (0, 0)
Total sugared beverages (g)	232 (155, 319)	260 (170, 363)
Sugar-free beverages		
Sugar-free soda pop (g)	0 (0, 6)	0 (0, 8)
Sugar-free beverages from powder (g)	0 (0, 0)	0 (0, 0)
Water (g)	101 (51, 167)	97 (41, 168)
Total sugar-free beverages (g)	108 (60, 182)	111 (52, 190)

\* Inclusion required a minimum of 4 diaries, including years 1 and 5 or suitable substitutions.

† Median (25th, 75th percentiles)

‡  $P < .01$ .

§  $P < .001$ .

years had a decreased risk of caries experience. High intakes of regular beverages from powder at 4 and 5 years and for 1 through 5 years and regular soda pop at 5 years and for 1 through 5 years were associated with significantly increased odds of caries experience relative to subjects with none or low intakes. Low (vs none or high) intakes of 100% juice at 5 years were associated with reduced caries experience at 4 to 7 years. In general, inadequate intakes (vs low adequate or high adequate intakes) of nutrients (eg, riboflavin, copper, vitamin D, vitamin B<sub>12</sub>) were associated with increased caries experience, and low adequate intakes (vs inadequate or high adequate intakes) of nutrients (eg, vitamin B<sub>12</sub>, vitamin C) were associated with decreased caries experience. An exception was vitamin E; either low or high adequate intakes were associated with increased caries experience at various ages.

Associations between dairy foods, sugared beverages, sugar-free beverages, and NARs for 1 through 5 years and the number of tooth surfaces with any caries experience at 4 to 7 years were also investigated using Tobit regressions (data not shown). Low intakes of nonmilk dairy foods, compared with high intakes ( $P < .05$ ), were associated with fewer tooth surfaces having caries experience; all subjects consumed some nonmilk dairy foods. Lack of 100% juice consumption, compared with both low ( $P < .01$ ) and high ( $P < .05$ ) intakes, was associated with fewer tooth surfaces having caries experience. Lack of regular soda pop consumption, compared with both low ( $P < .05$ ) and high ( $P < .001$ ) intakes, was also associated with fewer tooth surfaces having caries experience. Low intakes of sugar-free soda pop, compared with no intake ( $P < .025$ ), were associated with

**TABLE 3.** Median (25th, 75th Percentiles) 1- Through 5-Year Average\* Daily Nutrient Intakes and NARs by Caries Experience

Variable:	Nutrient Intake		NAR	
	Caries-Free† (n = 301)	Caries Present† (n = 95)	Caries Free† (n = 301)	Caries Present† (n = 95)
Energy (kj)	5411 (4878, 6160)	5369 (4833, 6185)		
Carbohydrate (g)	155 (139, 174)	153 (134, 175)		
Fat (g)	49 (41, 56)	47 (41, 59)		
Protein (g)	46 (41, 51)	45 (38, 51)	2.41 (2.16, 2.73)	2.36 (2.00, 2.69)
Thiamin (mg)	1.0 (0.9, 1.2)	1.0 (0.9, 1.2)	1.94 (1.68, 2.25)	1.89 (1.58, 2.18)
Riboflavin (mg)	1.5 (1.3, 1.7)	1.4 (1.2, 1.7)	2.69 (2.35, 3.10)	2.62 (2.24, 3.12)
Niacin (mg)	12 (10, 14)	11.9 (10.3, 14.0)	1.81 (1.53, 2.07)	1.76 (1.52, 2.06)
Folate (µg)	130 (110, 155)	135 (106, 160)	0.77 (0.65, 0.92)	0.81 (0.63, 0.95)
Pantothenic acid (mg)	2.9 (2.6, 3.3)	2.8 (2.4, 3.3)	1.21 (1.08, 1.41)	1.16 (1.00, 1.39)
Vitamin B <sub>6</sub> (mg)	1.0 (0.8, 1.1)	1.0 (0.8, 1.1)	1.78 (1.48, 2.11)	1.79 (1.39, 2.07)
Vitamin B <sub>12</sub> (µg)	2.6 (2.2, 3.1)	2.6 (2.1, 3.1)	2.59 (2.20, 3.13)	2.60 (2.09, 3.04)
Vitamin C (mg)	36 (28, 47)	38 (30, 48)	1.92 (1.49, 2.50)	1.96 (1.50, 2.51)
Vitamin A (µg RE)	377 (261, 564)	328 (237, 553)	1.12 (0.77, 1.67)	0.98 (0.70, 1.58)
Vitamin D (µg)	5.8 (4.8, 6.9)	5.6 (4.5, 6.8)	1.17 (0.96, 1.39)	1.12 (0.89, 1.36)
Vitamin E (mg TE)	4.9 (4.2, 5.8)	4.9 (4.1, 5.9)	0.77 (0.66, 0.90)	0.77 (0.65, 0.93)
Calcium (mg)	810 (668, 949)	778 (645, 914)	1.32 (1.09, 1.56)	1.27 (1.04, 1.53)
Copper (µg)	524 (445, 586)	515 (432, 605)	1.39 (1.18, 1.56)	1.36 (1.15, 1.60)
Iron (mg)	8.2 (7.0, 9.5)	7.8 (6.4, 9.9)	1.01 (0.85, 1.16)	0.95 (0.79, 1.16)
Magnesium (mg)	159 (141, 177)	152 (134, 183)	1.61 (1.43, 1.80)	1.53 (1.36, 1.85)
Phosphorous (mg)	904 (792, 1038)	872 (755, 1023)	1.90 (1.66, 2.19)	1.84 (1.59, 2.18)
Selenium (µg)	60 (54, 71)	61 (53, 70)	2.52 (2.26, 2.98)	2.55 (2.22, 2.94)
Zinc (mg)	6.4 (5.6, 7.4)	6.6 (5.3, 7.5)	1.70 (1.50, 1.96)	1.75 (1.40, 2.00)
Mean adequacy ratio			0.97 (0.94, 0.98)	0.97 (0.93, 0.98)

\* Inclusion required a minimum of 4 diaries, including years 1 and 5 or suitable substitutions.

† Median (25th, 75th percentiles).

fewer tooth surfaces having caries experience. Low adequate vitamin C intakes, compared with inadequate ( $P < .001$ ) or high adequate ( $P < .001$ ) intakes, were associated with an increased number of tooth surfaces having caries experience.

Multivariable Tobit regression models were developed for 1- through 5-year exposure variables to predict the number of tooth surfaces with caries experience at 4 to 7 years of age (Table 5). The initial model included age at dental examination, sex, fluoride exposure, and the dietary variables that were significant ( $P < .05$ ) from univariate analysis. Age at dental examination showed a significant positive association ( $P < .005$ ) and fluoride exposure showed a significant negative association ( $P < .002$ ) with the number of tooth surfaces with caries experience in the final model. Low intakes of nonmilk dairy foods (vs high intakes; all subjects had some nonmilk dairy intakes) and high adequate intakes of vitamin C (vs inadequate and low adequate intakes) were associated with fewer tooth surfaces having caries experience. High intakes of regular soda pop (vs none and low intakes) were associated with more tooth surfaces having caries experience.

## DISCUSSION

Our results suggest that secular dietary changes, particularly the increase in soda pop consumption, have the potential to increase dental caries rates in children. Although our data support the hypothesis that sugared beverages increase caries risk, associations between different types of sugared beverages and caries experience were not equivalent in our study, which could explain some of the discrepancies among the findings of other investigators.<sup>5-13</sup> An improved understanding of the relationships be-

tween types of sugared beverages and caries experience is important for continued refinement of preventive dietary guidelines for oral health.

Beginning as early as 2 years of age, regular soda pop was associated with an increased presence of caries at 4 to 7 years of age. In addition, the combined 1- through 5-year intake of regular soda pop was the strongest predictor of the extent of caries. Associations between regular beverages reconstituted from powder and the presence of caries were observed beginning at 1 year of age, but regular beverages from powder were not associated with the extent of caries. Low intakes of 100% juice were associated with a reduced presence of caries. Any intake of 100% juice was associated with an increased extent of caries; however, juice consumption was not included in the final model. Juice drinks were not associated with the presence or extent of caries. Our results suggest that regular soda pop and regular beverages from powder are more strongly associated with caries risk than 100% juice or juice drinks.

The reason for this discrepancy between different types of sugared beverages is not clear. The sugar substrates in 100% juice are primarily fructose and glucose, whereas the substrate in regular soda pop and regular beverages from powder is sucrose and/or high-fructose corn syrup (ie, fructose and glucose). Juice drinks are sweetened with high-fructose corn syrup or a blend of sucrose and high-fructose corn syrup. Glucosyltransferase from *Streptococcus mutans* uses sucrose but not fructose or glucose to form extracellular glycans that facilitate dental plaque adherence to the enamel surface.<sup>35</sup> Linkages between glycans are rigid and increase the porosity of the plaque, which could facilitate diffusion of sugars and acid within the plaque and in-

**TABLE 4.** Results of Logistic Regression Models\* to Predict Caries Experience at 4 to 7 Years of Age for 1-, 2-, 3-, 4-, and 5-Year and Combined 1- Through 5-Year Exposure Variables

Exposure Variables	Odds Ratio (95% CI)
Year 1 (n = 636)	
Age at dental examination (y)	1.7 (1.1, 2.7)†
Regular beverages from powder  , nonuser	0.37 (0.17, 0.81)†
Riboflavin, inadequate intake	4.6 (1.1, 19.1)†
Copper, inadequate intake	1.6 (1.1, 2.5)†
Vitamin B <sub>12</sub> , low adequate intake	0.50 (0.34, 0.73)§
Vitamin C, low adequate intake	0.65 (0.44, 0.95)†
Vitamin E, high adequate intake	2.4 (1.3, 4.1)‡
Year 2 (n = 525)	
Age at dental examination (y)	2.33 (1.4, 3.7)‡
Regular soda pop, nonuser	0.48 (0.32, 0.72)§
Year 3 (n = 421)	
Age at dental examination (y)	2.61 (1.4, 4.6)‡
Fluoride exposure (mg)	0.54 (0.30, 0.96)†
Vitamin D, inadequate intake	1.6 (1.01, 2.6)†
Regular soda pop, nonuser	0.50 (0.31, 0.81)‡
Vitamin E, low adequate intake	2.0 (1.03, 3.74)†
Year 4 (n = 410)	
Age at dental examination (y)	2.34 (1.2, 4.3)†
Regular beverages from powder, high intake	2.5 (1.3, 4.7)‡
Year 5 (n = 417)	
Age at dental examination (y)	2.9 (1.5, 5.7)‡
100% juice, low intake	0.57 (0.34, 0.97)†
Regular soda pop, high intake	2.0 (1.2, 3.3)‡
Regular beverages from powder, high intake	2.0 (1.0, 3.9)†
Sugar-free beverages from powder, nonuser	0.14 (0.02, 0.87)†
Vitamin B <sub>12</sub> , inadequate intake	3.7 (1.1, 11.9)†
Vitamin E, high adequate intake	2.0 (1.1, 3.7)†
Years 1-5 (n = 396)	
Age at dental examination (y)	3.2 (1.6, 6.1)§
Regular soda pop, high intake	2.2 (1.4, 3.6)†
Regular beverages from powder, high intake	2.0 (1.2, 3.4)†

CI indicates confidence interval.

\* Preliminary models include age at dental examination, sex, fluoride exposure, and dietary variables significant at  $P < .10$  in univariate analysis. Dietary categories included nonuser, low intake, and high intake. The category stated in the model is compared with both of the other categories. Nutrient categories included inadequate, low adequate, and high adequate intakes. The category stated in the model is compared with both of the other categories.

†  $P < .05$ .

‡  $P < .01$ .

§  $P < .001$ .

|| Sugar-containing powdered beverages reconstituted with water.

**TABLE 5.** Results of a Tobit Life Regression Model\* to Predict Number of Tooth Surfaces With Caries Experience at 4 to 7 Years of Age for Combined 1- Through 5-Year Exposure Variables

Exposure Variables Years 1-5 (n = 317)	Parameter Estimate	P Value
Age at dental examination (y)	0.541	.005
Fluoride exposure (mg)	-0.818	.002
Nonmilk dairy, low intake†	-0.552	.001
Regular soda pop, high intake	0.767	<.001
Vitamin C, high adequate intake	-0.504	.002
Intercept	-0.593	.585

\* The preliminary model included age at dental exam, sex, fluoride exposure, and dietary variables significant at  $P < .05$  in univariate analysis. Dietary categories included nonuser, low intake, and high intake. The category stated in the model is compared with both of the other categories, unless otherwise noted. Nutrient categories included inadequate, low adequate, and high adequate intakes. The category stated in the model is compared with both of the other categories.

† Versus high intake; all subjects consumed some nonmilk dairy foods.

crease caries risk.<sup>36</sup> In the laboratory, sucrose seems to promote *Streptococcus mutans* selection; however, these results are not always supported by epidemiologic studies.<sup>37</sup> Our data support the hypothesis

that beverages that contain sucrose could be more detrimental to oral health than beverages that are sweetened with other sugars.

Alternatively, the differences in caries risk associated with different types of sugared beverages could be a reflection of their role in the diet and timing of ingestion (eg, 100% juice with meals; regular soda pop between meals). However, we did not assess timing of beverage consumption or whether beverages were consumed alone or with other foods, both of which might influence caries risk. Vanobbergen et al<sup>12</sup> did not distinguish between types of sugared beverages but did report that between-meal consumption of sugared beverages increased both risk of and extent of caries in 7-year-old children.

In vitro studies suggest that compounds within dairy foods (eg, calcium, phosphorous, casein, fat) protect against caries formation by promoting remineralization, buffering acids and limiting demineralization. Milk intakes at 2 and 3 years of age were lower in subjects with caries; however, milk was neutral with respect to caries risk. Milk intake was stable and relatively homogeneous in this sample (unpublished data), which could have precluded the

observation of caries' protective effects. In contrast to milk, high intakes of nonmilk dairy foods were associated with an increased extent of caries. Yogurt and dairy desserts are made with added sugar (eg, sucrose and/or high-fructose corn syrup), which is a substrate for oral bacteria.

Sugared beverages are typically high in energy and low in nutrients. Both excessive energy and marginal nutrient intakes are associated with diminished immune function. This, in turn, could influence caries susceptibility. In this study, inadequate intakes of several nutrients were associated with an increased caries presence, and low adequate intakes of other nutrients were associated with a reduced caries presence. High nutrient intakes might be associated with a fermentable carbohydrate food not included in our analyses. Additional research is needed to determine whether these nutrients have a direct role in the caries process or reflect a dietary habit not investigated in our study.

Fluoride exposure was not consistently associated with caries prevalence in our subjects but was associated with reduced extent of caries. These findings suggest a complex interaction between adverse dietary effects and protective fluoride effects. Furthermore, they underscore the need for preventive fluoride guidance in patients who present with caries.

Our study has several limitations that must be acknowledged. Although dietary data were collected longitudinally, the oral examination occurred at 1 time point, which limited our ability to track dietary intake and caries experience simultaneously. Changes in dietary patterns resulting from preventive guidance provided by local physicians, dentists, or other health care providers could have limited our ability to identify associations between dietary factors and caries experience. With the large number of exposure variables and 2 outcome variables, one would expect chance associations to be observed. Therefore, inconsistent or 1-time associations must be viewed with caution. Dietary data were reported by the parent or the caregiver (eg, babysitter) and do not necessarily reflect actual consumption. Dental examinations were visual, and tactile examination was used to confirm findings. Examinations did not include radiographs. Thus, caries lesions, particularly interproximal lesions, could have been underdiagnosed. 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<sup>4</sup>; thus, associations observed between sugared beverages and dental caries experience could be more pronounced in a more diverse socioeconomic group.

## CONCLUSIONS

The results of our study support our hypothesis that contemporary changes in beverage patterns have the potential to affect oral health. Consumption of regular soda pop, regular powdered beverages, and, to a lesser extent, 100% juice in early childhood was associated with increased caries risk. Milk had a neutral association with caries. Our data support

contemporary dietary guidelines for children: consume 2 or more servings of dairy foods daily, limit intake of 100% juice to 4 to 6 oz daily, and restrict other sugared beverages to occasional use. Pediatricians, pediatric nurse practitioners, and dietitians are in a position to support pediatric dentists in providing preventive guidance to parents of young children.

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