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Comparison of the intakes of sugars by young children with and without dental caries experience

Teresa A. Marshall, PhD, RD/LD; Julie M. Eichenberger-Gilmore, PhD, RD/LD; Michelle A. Larson, PhD; John J. Warren, DDS, MS; Steven M. Levy, DDS, MPH

Historically, the role of sugars in the dental caries process has been supported by numerous epidemiologic and animal studies.¹⁻⁵ However, relationships among sugars and dental caries in contemporary society appear weak, as reviewed by Zero⁶ and Burt and Pai.⁷ Woodward and Walker² compared available sugars intakes data and decayed-missing-filled-teeth (DMFT) scores from July 1979 to June 1991 for both developed and developing countries. They reported that on a population level, sugars intakes were associated with DMFT in developing countries, but not in developed countries. The 2003 report *Diet, Nutrition and the Prevention of Chronic Diseases* by the World Health Organization and the Food and Agriculture Organization of the United Nations⁸ concluded that there is convincing evidence associating the quantity of free sugars with dental caries, noted that the frequency of sugars intake could be just as important as the amount of sugar, and stated that “no conclusion regarding the relative importance of these two variables [could] be drawn.”

Increases in the quantities and changes in the types of sugars consumed could affect the risk of dental caries. Per capita energy intakes from sugars have increased in developing countries during the

ABSTRACT

Background. Relationships among sugars and dental caries in contemporary societies are unclear. The authors describe young children's intakes of nonmilk extrinsic (NME) and intrinsic/milk sugars and relate those intakes to dental caries.

Methods. The authors conducted cross-sectional analyses of dietary data collected from the Iowa Fluoride Study using three-day diaries for subjects at ages 1, 2, 3, 4 and 5 years and for subjects aged 1 through 5 years according to dental caries experience at 4.5 to 6.9 years of age. They categorized foods and beverages as containing NME or intrinsic/milk sugars.

Results. Subjects' total, NME, food NME and intrinsic/milk sugars intakes at ages studied did not differ between subjects with and without caries experience. Beverage NME sugars intakes at age 3 years predicted caries ($P < .05$) in logistic regression models adjusted for age at dental examination and for fluoride intake.

Conclusions. Dental caries is a complex, multifactorial disease process dependent on the presence of oral bacteria, a fermentable carbohydrate substrate and host enamel. A simple NME-intrinsic/milk sugars categorization appears insufficient to capture the complex dietary component of the caries process.

Clinical Implications. Cariogenicity is more likely a function of the food and/or beverage vehicle delivering the sugar and the nature of exposure—that is, frequency and length of eating events—than of the sugar's categorization.

Key Words. Sugars; caries; diet.

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past 30 years.⁸ In the United States, per capita consumption of high-fructose corn syrup increased 10.6-fold between the 1970s and 2000, sucrose consumption decreased 33 percent between the 1960s and 2000 and total sugars consumption increased 33 percent.⁹

In 1989, the British Department of Health established a Committee on Medical Aspects of Food Policy to report on relationships among dietary sugars and both oral and systemic health.^{10,11} This committee categorized dietary sugars for oral health purposes as “nonmilk extrinsic” (NME) or “intrinsic” on the basis of the sugars’ location in terms of cellular structure and the degree to which they are processed. Nonmilk extrinsic sugars (NMES) are located outside of cells, being either released (as in juice) or added (as in confections) during processing. Intrinsic sugars occur naturally and typically reside within the cellular structure. Although lactose in milk resides extracellularly, it is considered less cariogenic than glucose, fructose, sucrose and maltose when in extrinsic form; therefore, milk sugars are not included in the NMES category. The rationale for this categorization is that foods with NMES are thought to be more cariogenic than foods with intrinsic or milk sugars.¹⁰⁻¹¹ Investigations in Great Britain using this categorization system, including reports of relationships with dental caries, have been few¹¹⁻¹³; to our knowledge, this system has not been used in the United States.

We hypothesized that children with dental caries have higher intakes of NMES, particularly from beverages, than do children without caries. In this article, we describe young children’s intakes of NME and intrinsic sugars, and we relate those intakes to dental caries experience.

SUBJECTS, METHODS AND MATERIALS

Subjects. Subjects initially were recruited from 1992 through 1995 for the Iowa Fluoride Study (IFS), a longitudinal investigation of fluoride intakes, dental fluorosis and dental caries.¹⁴⁻²⁷ Subjects who participated in one dental examination between the ages of 4.5 and 6.9 years of age and whose parents and/or caregivers completed periodic IFS questionnaires and three-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; research assistants obtained written informed consent from mothers at recruitment and from either parent at the examination.

Data collection. Dental caries experience.

Dental examinations were conducted in the General Clinical Research Center at The University of Iowa or in one of several community locations by trained and calibrated examiners (including J.J.W.) using standardized, portable equipment.^{14,15} The examination was visual, but examiners used dental explorers to confirm questionable findings.¹⁵ Transillumination (using the DenLite system [Welch Allyn Medical Products, Skaneateles Falls, N.Y.]) augmented the visual and tactile examination.

For this study, we defined caries experience as the presence of at least one cavitated ($d_{2,3}$) or filled surface. We initially categorized lesions as noncavitated (d_1) or cavitated ($d_{2,3}$).¹⁵ Specifically, d_1 lesions manifested as distinct, chalky white enamel with no clinically visible or irreversible loss of enamel structure or break in the enamel surface. In contrast, $d_{2,3}$ lesions manifested as demonstrable loss of enamel structure. The criteria did not differentiate between cavitated enamel (d_2) and dentinal (d_3) lesions.¹⁵

Sugars intake. We mailed parents three-day food and beverage diaries when their children were 6 weeks of age; 3, 6, 9 and 12 months of age; every four months through 3 years of age; and every six months thereafter until the child was 9 years of age, though we used only the data through the age of 5 years. (The data span the years 2001 through 2004.) In these analyses, we used diaries completed when children were 1 (n = 631), 2 (n = 526), 3 (n = 447), 4 (n = 415) and 5 (n = 411) years of age (as described in Warren and colleagues^{14,15}). If the subject did not return a specific three-day food and beverage diary (for example, the 24-month diary), then we substituted the previous diary (for example, the 20-month diary). If this diary also was missing, then we substituted the subsequent diary (for example, the 28-month diary) for the yearly diary. If neither was available, we omitted the subject for that year. Inclusion in area-under-the-curve analyses (that is, a weighted average of the one-through five-year intakes) required a minimum of four diaries, including the one- and five-year diaries (n = 400). We calculated the area under the curve by using the trapezoidal rule (as described in Marshall and colleagues¹⁶ and Mar-

ABBREVIATION KEY. **DMFT:** Decayed, missing, filled teeth. **IFS:** Iowa Fluoride Study. **NMES:** Nonmilk extrinsic sugars.

shall and colleagues¹⁷).

We asked parents to record the types (including brand names) and quantities of all foods and beverages consumed by their children for one weekend day and two weekdays. Parents received written instructions on procedures, including how to measure and record quantities of foods using household measures (such as ounces or cups) or package units (such as “small serving fast-food fries,” “can of pop”). Research assistants who were registered dietitians reviewed diaries for completeness. They also coded and verified all entries from the three-day food and beverage diaries (as described in Marshall and colleagues¹⁶ and Marshall and colleagues¹⁷). We calculated weighted averages based on weekend or weekday consumption to reflect average consumption across a week (as described in Eichenberger-Gilmore and colleagues¹⁸). We used these data to create a food and beverage intake table.

We created a nutrient table from nutrient data obtained from the U.S. Department of Agriculture’s Agriculture Research Service (USDA Nutrient Database for Standard Reference, Release 12²⁸), the Minnesota Food and Nutrient Database (Nutrition Coordinating Center NDS-R, Version 4.01; University of Minnesota, Minneapolis) and data from food and beverage manufacturers (as described in Marshall and colleagues¹⁶ and Marshall and colleagues¹⁷). We used a relational database software package (Microsoft Access, Version SR-1 [Microsoft, Redmond, Wash.]) to link the food and beverage intake table and the nutrient table to calculate individual sugar and energy intakes.

We categorized foods and beverages as containing NMES if the foods were highly processed (for instance, 100 percent juice) or contained added sugars (for instance, fruit pie, ice cream, jam, breakfast cereals, juice drinks, yogurts sweetened with sugars). We subsequently categorized NMES as being contained in food or beverages. Foods and beverages were categorized as containing intrinsic/milk sugars if the foods were minimally processed (such as fresh, frozen or dried fruit) or of dairy origin (such as milk) and did not contain added sugars. For clarity, we refer to sugars as “NMES” or “intrinsic/milk” throughout this article.

Fluoride intake. We used IFS questionnaires completed for children aged from 6 weeks through 5 years to estimate fluoride intakes from water consumed as a beverage and water added during

preparation of beverages and selected foods (such as pasta, soup, hot cereal), other beverages, dietary fluoride supplements and fluoride dentifrices.¹⁹⁻²¹ We analyzed the fluoride content of the nonmunicipal water in homes and child-care locations, of filtered municipal water and of beverages available for purchase by the subjects in our study.²²⁻²⁵ These values were used to calculate subject-specific water, beverage and select food (that prepared using home water) fluoride concentrations. We defined fluoride intakes as the sum of fluoride from water, other beverages, select foods, fluoride supplements and dentifrices. We estimated cumulative fluoride intakes (in milligrams per day) from fluoride intakes in children aged from 6 weeks through 5 years using the trapezoidal method (that is, summation of trapezoidal areas under the line connecting sequential time points).

Statistical analyses. We conducted analyses using SAS (Version 9, SAS Institute, Cary, N.C.). We categorized subject characteristics, which are presented as percentages. We used the Cochran-Mantel-Haenszel test to identify demographic differences among subject groups. Daily sugars intakes are presented as medians (25th, 75th percentiles). To compare sugars intakes between subjects with and without caries, we used the Mann-Whitney *U* test. Logistic regression models helped us predict caries experience from sugars intakes while adjusting for age at dental examination and fluoride intake. We used the sign test to identify significant changes in sequential yearly trends in intakes of sugars. We considered a *P* value of less than .05 to be statistically significant.

RESULTS

Demographic characteristics of subjects (*n* = 634) and their parents at enrollment have been reported in detail elsewhere.¹⁷⁻¹⁹ Subjects were 51.9 percent female (*n* = 329) and 42.7 percent firstborn (*n* = 271). At the time of recruitment (1992 through 1995), 27 percent of household incomes were less than \$30,000, 39 percent were between \$30,000 and \$49,999, 31 percent were \$50,000 or greater, and 3 percent were unknown. Seventeen percent of mothers were aged between 16 and 24 years, 32 percent between 25 and 29 years, 31 percent between 30 and 34 years and 20 percent older than 35 years. Seven percent of fathers were aged between 16 and 24 years, 27 percent between 25 and 29 years, 33 percent between 30 and 34 years, 28 percent older than

TABLE 1

Median (25th, 75th percentiles) daily intakes of nonmilk extrinsic and intrinsic/milk sugars,* by caries experience.			
INTAKE OF SUGARS (GRAMS)	CARIES		P VALUE†
	None	Present	
Year One	n = 470	n = 161	
Nonmilk extrinsic (NME)	24 (12, 37)	22 (14, 37)	.896
Beverage	8 (2, 16)	9 (2, 16)	.706
Food	12 (6, 21)	13 (5, 20)	.717
Intrinsic/Milk	45 (35, 57)	49 (37, 60)	.146
TOTAL	71 (60, 85)	74 (62, 86)	.176
Year Two	n = 406	n = 120	
NME	55 (40, 78)	56 (40, 74)	.737
Beverage	26 (14, 42)	30 (18, 42)	.232
Food	28 (17, 39)	25 (13, 35)	.133
Intrinsic/Milk	34 (24, 43)	31 (22, 42)	.068
TOTAL	91 (74, 113)	88 (70, 107)	.114
Year Three	n = 341	n = 106	
NME	64 (47, 83)	65 (52, 81)	.453
Beverage	27 (16, 40)	34 (19, 48)	.035
Food	34 (22, 47)	31 (19, 46)	.483
Intrinsic/Milk	32 (23, 42)	29 (22, 43)	.396
TOTAL	95 (78, 121)	96 (79, 123)	.733
Year Four	n = 321	n = 94	
NME	67 (50, 89)	74 (52, 90)	.165
Beverage	28 (16, 42)	33 (19, 47)	.210
Food	37 (25, 49)	39 (25, 57)	.517
Intrinsic/Milk	32 (23, 40)	29 (22, 39)	.454
TOTAL	104 (84, 122)	106 (82, 128)	.514
Year Five	n = 312	n = 99	
NME	72 (53, 93)	73 (54, 99)	.345
Beverage	26 (15, 42)	35 (18, 46)	.129
Food	40 (28, 55)	40 (27, 58)	.957
Intrinsic/Milk	30 (22, 40)	32 (19, 42)	.835
TOTAL	104 (84, 126)	106 (84, 130)	.406
Years One-Five	n = 306	n = 94	
NME	60 (48, 75)	63 (51, 76)	.584
Beverage	26 (18, 38)	30 (20, 42)	.121
Food	32 (25, 42)	32 (22, 38)	.437
Intrinsic/Milk	34 (28, 40)	33 (26, 41)	.319
TOTAL	95 (83, 111)	96 (78, 112)	.785

* Extrinsic sugars are located outside of the cellular wall and either released (as in 100 percent juice) or added (as in confections) during processing. Intrinsic/milk sugars occur naturally and reside within the cellular structure (as in fresh fruit) or are of milk origin.
 † Mann-Whitney U test.

education and had lower incomes than did those without caries (data not shown, $P < .05$). Similarly, subjects in the IFS cohort who did not participate in dental examinations or provide regular dietary records had younger parents with lower levels of income and less education than did active participants (data not shown, $P < .05$).

Table 1 shows median (25th, 75th percentiles) daily intakes of NME and intrinsic/milk sugars at ages 1, 2, 3, 4 and 5 years and for 1 through 5 years of age according to caries experience at about 5 years of age (at some point between 4.5 and 6.9 years of age). Subjects with caries had total, NME, food NME and intrinsic/milk sugars intakes similar to those of subjects without caries at all ages. Subjects with caries had higher beverage NME sugars intakes at year three than did subjects without caries. Although not statistically significant at other ages, this trend was observable at all time points, most notably at age 5 years and at ages 1 through 5 years.

We evaluated median (25th, 75th percentiles) daily intakes of sucrose, fructose, glucose and lactose at years one, two, three, four and five and for

35 years and 5 percent unknown. Nineteen percent and 25 percent, respectively, of mothers and fathers had an educational level of high school equivalent or less; 35 percent and 28 percent, respectively, had attended some college; and 46 percent and 40 percent, respectively, had a college degree or higher education. Approximately seven percent of fathers' educational status was unknown.

Subjects with caries experience had mothers and fathers who were younger, had lower levels of

subjects aged 1 through 5 years according to caries experience at about 5 years of age (at some point between 4.5 and 6.9 years of age) (Table 2). Subjects with caries had sucrose, glucose and lactose intakes similar to those of subjects without caries at all ages. Although not statistically significant, the results suggest that subjects with caries had higher fructose intakes at ages 3 and 5 years than did subjects without caries.

We developed logistic regression models for NME and intrinsic/milk sugars at ages 1, 2, 3, 4

and 5 and for subjects aged 1 through 5 years to predict any caries while adjusting for age at dental examination and fluoride intakes at ages 1 through 5 years. The models showed that beverage NMES intakes predicted caries at age 3 years ($P < .05$), and results suggested trends at age 5 years and for ages 1 through 5 years ($P < .10$).

We calculated median (25th, 75th percentiles) percentage of total energy intakes from sugars (data not shown). The percentage of energy from total sugars ranged from 30 percent (26, 35) at age 1 year to 27 percent (24, 31) at age 5 years for subjects without caries and from 32 percent (27, 36) at age 1 year to 27 percent (23, 31) at age 5 years for subjects with caries. The percentage of energy from NMES ranged from 10 percent (6, 15) at age 1 year to 19 percent (14, 23) at age 4 years for subjects without caries and from 9 percent (6, 14) at age 1 year to 21 percent (14, 25) at age 4 years for subjects with caries. Subjects with caries had percentages of energies from total, NME, food NME and intrinsic/milk sugars intakes similar to those of subjects without caries at all ages; the percentage of energy from beverage NMES was higher in subjects with caries (20 percent [15, 25]) than in subjects without caries (19 percent [14, 23]) at age 3 years.

We investigated yearly changes in median daily intakes of sugars by individual type (Figure 1) and classified the types as NME or intrinsic/milk (Figure 2). Sucrose and total sugars intakes increased each year from ages 1 to 4 years for subjects with and without caries (all $P < .05$) and then remained steady. Total NMES intakes increased each year from ages 1 to 4 years for subjects with caries, and from ages 1 year to 2 years for subjects without caries (all $P < .05$). Beverage NMES intakes increased from age 1 year to age 2 years for subjects with and without caries ($P < .05$). Intakes of solid NMES

increased each year from ages 1 to 3 years for subjects with caries, and from ages 1 to 4 years for subjects without caries (all $P < .05$). Intrinsic/milk sugars intakes declined between ages 1 and 2 years for both groups and then remained steady.

DISCUSSION

Our results provide limited support for our hypotheses that children with dental caries consume more NMES than do children without dental caries. Neither individual nor total sugars intakes differed between subjects with and without caries. These data are consistent with the conclusion of Burt and Pai,⁷ who conducted a systematic review of sugars consumption and caries risk and stated, “The relationship between sugars consumption and caries is much weaker in the

TABLE 2

SUGARS (GRAMS)	CARIES		P VALUE*
	None	Present	
Year One	n = 470	n = 161	
Sucrose	15 (10, 23)	15 (9, 22)	.560
Fructose	10 (6, 15)	10 (6, 15)	.992
Glucose	9 (5, 14)	9 (6, 13)	.798
Lactose	33 (22, 43)	36 (24, 47)	.066
Year Two	n = 406	n = 120	
Sucrose	28 (20, 37)	26 (19, 35)	.285
Fructose	19 (13, 28)	20 (12, 27)	.624
Glucose	19 (13, 25)	19 (12, 25)	.554
Lactose	21 (15, 28)	20 (13, 28)	.196
Year Three	n = 341	n = 106	
Sucrose	33 (23, 44)	32 (23, 42)	.972
Fructose	19 (13, 26)	20 (16, 31)	.089
Glucose	19 (14, 25)	19 (15, 28)	.300
Lactose	21 (15, 28)	(12, 27)	.157
Year Four	n = 321	n = 94	
Sucrose	35 (26, 46)	39 (29, 51)	.137
Fructose	20 (14, 26)	21 (14, 27)	.793
Glucose	20 (15, 25)	20 (14, 28)	.606
Lactose	22 (16, 28)	22 (14, 28)	.576
Year Five	n = 312	n = 99	
Sucrose	37 (27, 52)	35 (27, 51)	.768
Fructose	20 (13, 26)	23 (15, 29)	.094
Glucose	20 (14, 27)	22 (15, 28)	.083
Lactose	21 (16, 28)	23 (15, 29)	.959
Years One-Five	n = 306	n = 94	
Sucrose	31 (25, 39)	31 (27, 37)	.985
Fructose	19 (15, 24)	19 (15, 24)	.823
Glucose	19 (15, 23)	18 (15, 23)	.976
Lactose	23 (18, 28)	23 (17, 27)	.427

* Mann-Whitney U test.

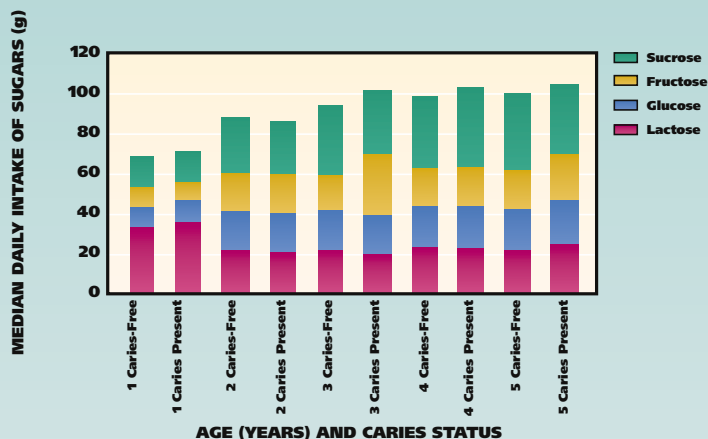


Figure 1. Median daily intakes of sugars at ages 1, 2, 3, 4 and 5 years for subjects without and with caries. g: Grams.

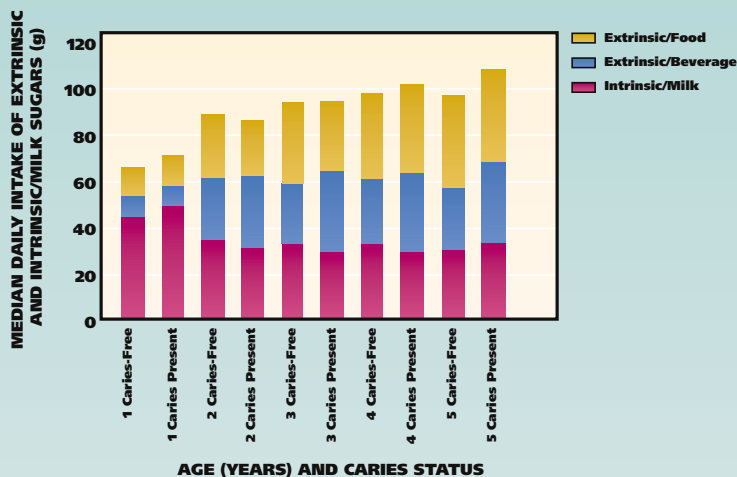


Figure 2. Median daily intakes of sugars classified as extrinsic or intrinsic/milk at ages 1, 2, 3, 4 and 5 years for subjects with and without caries. g: Grams.

modern age of fluoride intake than it used to be.” Similarly, Zero⁶ argued that, though a causal relationship between sugars and dental caries is well-established, the relationship is modified by frequency of sugars exposure, fluoride intake and oral hygiene practices.⁶

NME and intrinsic/milk sugars intakes were similar at all ages for the subjects with and without caries, suggesting that dietary factors beyond the sugars source and extent of processing could be significant contributors to caries risk.

Although we did not consider timing of consumption in our study, we previously showed that in the same study population, the cariogenicity of sugars- and starch-containing foods was higher when consumed more frequently (as with snacks) than when included with meals.¹⁹ Consumption of mixed foods containing fats, proteins and calcium at meals, perhaps through stimulation of saliva, could limit the cariogenicity of NMES.²⁹⁻³¹

Our results support the observations of other investigators who concluded that factors other than NMES intakes were more important determinants of caries. Gibson and Williams¹² analyzed data for children aged 1.5 to 4.5 years from the British National Diet and Nutrition Survey. They observed an association between the percentage of energy intake from NMES and dental caries only in children who brushed their teeth less than twice a day, suggesting that oral hygiene was more important than sugars consumption. Habibian and colleagues¹³ evaluated associations between dietary behaviors, oral hygiene and mutans streptococci in British children at 12 and 18 months of age. They found that early tooth-brushing and the number of eating and drinking events were more closely associated with mutans streptococci than were sugars intakes.

However, in support of our hypothesis, after adjusting for age at dental examination and for fluoride intakes, we found that beverage NMES intakes at age 3 years predicted caries. Although this relationship was significant only at age 3 years, we observed similar trends at all ages. Previous reports by our group¹⁷ and Sohn and colleagues³² have shown that soda (that is, carbonated beverages) is more cariogenic than 100 percent juice; we combined data regarding sugars from both of these beverages in our analyses, which potentially dilutes the effect of the greater cariogenicity of soda. After further investigation, we found that the frequency of soda consumption at snacks or meals was associated with caries to a greater extent than was the frequency of consumption of 100 percent juice.¹⁹ The cariogenicity of sugars found in soda could be enhanced by oligosaccharides present in the high-fructose corn syrup used to sweeten the beverage.^{33,34} Another explanation is that the cariogenicity of sugars found in 100 percent juice could be limited by the nonnutrient compounds (for example, phytochemicals) that that juice contains.

After 1 year of age, the percentage of energy from NMES in subjects in our study is higher

than the 10 percent recommended by the World Health Organization.⁸ NMES intakes of subjects in our study are consistent with the added sugars intakes of preschool children in the United States (71 grams/day calculated for 18 percent total energy) reported by Kranz and colleagues,³⁵ while our total sugars intakes are consistent with those (75-93 g/day) reported by Skinner and colleagues.³⁶ The trends we observed in sugars intakes are consistent with changes in dietary patterns in early childhood. Decreases in lactose and intrinsic/milk sugars intakes between years one and two are consistent with a decreased consumption of infant formula and milk products as children make the transition to solid food. Similarly, the increased fructose intakes by the subjects in our study after 1 year of age are consistent with greater consumption of 100 percent juices in early childhood. Higher intakes of sucrose and food extrinsic sugars during the first three years of life are consistent with increased food acceptance and consumption of more confections.

Dietary methodology limitations of this study have been reported previously^{16,17} and are typical of self-reported data, including the possibility that reported intakes might not reflect actual intakes. Changes in dietary patterns resulting from preventive guidance provided by local health practitioners could limit our ability to identify sugars-caries relationships. Detection of caries by means of visual and tactile examinations and without the use of radiographs likely underestimated the caries experience. Defining caries as a cavitated or filled surface could overestimate caries experience if noncaries lesions were filled. Also, we defined caries as being simply present or absent; degrees of caries severity could have a different association with sugars categories. Subjects and their families are representative of a middle-to-upper socioeconomic class, and associations between sugars types and caries experience might be more pronounced in a more diverse socioeconomic group.

CONCLUSIONS

Dental caries is a complex, multifactorial disease process dependent on the presence of oral bacteria, a fermentable carbohydrate substrate and host enamel, and is influenced by dietary habits, oral hygiene practices and fluoride intakes. Thus, a simple NME-intrinsic/milk sugars categorization appears insufficient to explain the dietary

component of caries' complex biological process in this population. Cariogenicity is more likely a function of the food and/or beverage vehicle delivering the sugar and the nature of exposure—that is, frequency and length of eating events—than the sugars categorization. ■

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1. Gustafsson BE, Quensel CE, Lanke LS, 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 Odontol Scand* 1954;11(3-4):232-64.
2. Woodward M, Walker AR. Sugar consumption and dental caries: evidence from 90 countries. *Br Dent J* 1994;176(8):297-302.
3. Burt BA, Eklund SA, Morgan KJ, et al. The effects of sugars intake and frequency of ingestion on dental caries increment in a three-year longitudinal study. *J Dent Res* 1988;67(11):1422-9.
4. Arnadottir IB, Rozier RG, Saemundsson SR, Sigurjons H, Holbrook WP. Approximal caries and sugar consumption in Icelandic teenagers. *Community Dent Oral Epidemiol* 1998;26(2):115-21.
5. Peres RC, Coppi LC, Franco EM, Volpato MC, Groppo FC, Rosalen PL. Cariogenicity of different types of milk: an experimental study using animal model. *Braz Dent J* 2002;13(1):27-32.
6. Zero DT. Sugars: the arch criminal? *Caries Res* 2004;38(3):277-85.
7. Burt BA, Pai S. Sugar consumption and caries risk: a systematic review. *J Dent Educ* 2001;65(10):1017-23.
8. World Health Organization and Food and Agriculture Organization of the United Nations. Diet, nutrition and the prevention of chronic diseases: report of a joint WHO/FAO expert consultation. WHO Technical Report Series 916. Geneva: World Health Organization; 2003. Available at: "www.fao.org/documents/show_cdr.asp?url_file=/DOCREP/005/AC911E/AC911E00.HTM". Accessed Nov. 11, 2005.
9. Jensen HH, Beghin JC. US Sweetener consumption trends and dietary guidelines. *Iowa Ag Review* 2005;11:10-11.
10. Edgar WM. Extrinsic and intrinsic sugars: a review of recent UK recommendations on diet and caries. *Caries Res* 1993;27(supplement 1):64-7.
11. Gibson SA. Non-milk extrinsic sugars in the diets of pre-school children: association with intakes of micronutrients, energy, fat and NSP. *Br J Nutr* 1997;78(3):367-78.
12. Gibson S, Williams S. Dental caries in pre-school children: associations with social class, toothbrushing habit and consumption of sugars and sugar-containing foods: further analysis of data from the national diet and nutrition survey of children aged 1.5-4.5 years. *Caries Res* 1999;33(2):101-13.
13. Habibian M, Beighton D, Stevenson R, Lawson M, Roberts G. Relationships between dietary behaviours, oral hygiene and mutans streptococci in dental plaque of a group of infants in southern England. *Arch Oral Biol* 2002;47(6):491-8.
14. Warren JJ, Levy SM, Kanellis MJ. Prevalence of dental fluorosis in the primary dentition. *J Public Health Dent* 2001;61(2):87-91.
15. Warren JJ, Levy SM, Kanellis MJ. Dental caries in the primary dentition: assessing prevalence of cavitated and noncavitated lesions. *J Public Health Dent* 2002;62(2):109-14.
16. Marshall TA, Eichenberger-Gilmore JM, Broffitt B, Stumbo PJ, Levy SM. Diet quality in young children is influenced by beverage consumption. *J Am Coll Nutr* 2005;24(1):65-75.
17. Marshall TA, Levy SM, Broffitt B, et al. Dental caries and beverage consumption in young children. *Pediatrics* 2003; 112(3 pt 1):e184-91.
18. Eichenberger-Gilmore JM, Hong L, Broffitt B, Levy SM. Longitudinal patterns of vitamin and mineral supplement use in young white children. *JADA* 2005;105(5):763-72.
19. Marshall TA, Broffitt B, Eichenberger-Gilmore JM, Warren JJ, Cunningham MA, Levy SM. The roles of meal, snack, and daily total food and beverage exposures on caries experience in young children. *J Public Health Dent* 2005;65(3):166-73.

20. Levy SM, Warren JJ, Davis CS, Kirchner HL, Kanellis MJ, Wefel JS. Patterns of fluoride intake from birth to 36 months. *J Public Health Dent* 2001;61(2):70-7.
21. Levy SM, Warren JJ, Broffitt B. Patterns of fluoride intake from 36 to 72 months of age. *J Public Health Dent* 2003;63(4):211-20.
22. Van Winkle S, Levy SM, Kiritsy MC, Heilman JR, Wefel JS, Marshall T. Water and formula fluoride concentrations: significance for infants fed formula. *Pediatr Dent* 1995;17(4):305-10.
23. Kiritsy MC, Levy SM, Warren JJ, Guha-Chowdhury N, Heilman JR, Marshall T. Assessing fluoride concentrations of juices and juice-flavored drinks. *JADA* 1996;127(7):895-902.
24. Heilman JR, Kiritsy MC, Levy SM, Wefel JS. Fluoride concentrations of infant foods. *JADA* 1997;128(7):857-63.
25. Heilman JR, Kiritsy MC, Levy SM, Wefel JS. Assessing fluoride levels of carbonated soft drinks. *JADA* 1999;130(11):1593-9.
26. Levy SM, Warren JJ, Broffitt B, Hillis SL, Kanellis MJ. Fluoride, beverages and dental caries in the primary dentition. *Caries Res* 2003;37(3):157-65.
27. Marshall TA, Levy SM, Warren JJ, Broffitt B, Eichenberger-Gilmore JM, Stumbo PJ. Associations between intakes of fluoride from beverages during infancy and dental fluorosis of primary teeth. *J Am Coll Nutr* 2004;23(2):108-16.
28. U.S. Department of Agriculture, Agricultural Research Service. USDA nutrient database for standard reference, release 12 (database online). Washington: U.S. Department of Agriculture, Agricultural Research Service; 1998. Available at: "www.nal.usda.gov/fnic/foodcomp". Accessed Nov. 22, 2006.
29. Sheiham A. Dietary effects on dental diseases. *Public Health Nutr* 2001;4(2B):569-91.
30. Levine RS. Milk, flavoured milk products and caries. *Br Dent J* 2001;191(1):20.
31. Mundorff-Shrestha SA, Featherstone JD, Eisenberg AD, et al. Cariogenic potential of foods, II: relationship of food composition, plaque microbial counts, and salivary parameters to caries in the rat model. *Caries Res* 1994;28(2):106-15.
32. Sohn W, Burt BA, Sowers MR. Carbonated soft drinks and dental caries in the primary dentition. *J Dent Res* 2006;85(3):262-6.
33. Moynihan PJ. Update on the nomenclature of carbohydrates and their dental effects. *J Dent* 1998;26(3):209-18.
34. Al-Khatib GR, Duggal MS, Toumba KJ. An evaluation of the acidogenic potential of maltodextrins in vivo. *J Dent* 2001;29(6):409-14.
35. Kranz S, Smiciklas-Wright H, Siega-Riz AM, Mitchell D. Adverse effect of high added sugar consumption on dietary intake in American preschoolers. *J Pediatr* 2005;146(1):105-11.
36. Skinner JD, Carruth BR, Moran J 3rd, Houck K, Coletta F. Fruit juice intake is not related to children's growth. *Pediatrics* 1999;103(1):58-64.