An Investigation of Bottled Water Use and Caries in the Mixed Dentition

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Abstract

Objectives: *Bottled water consumption in the United States has greatly increased in the past decade. Because the majority of commercial bottled water is low in fluoride, there is the potential for an increase in dental caries. In these secondary data analyses, associations between bottled water use and dental caries were explored.* ***Methods:*** *Subjects (*n *= 413) are in the Iowa Fluoride Study, which included dental examinations of the primary (approximately aged 5) and early erupting permanent (approximately aged 9) dentitions by trained dentist examiners. Permanent tooth caries and primary second molar increments were related to bottled water use using logistic and negative binomial regression models. All models were adjusted for age and the frequency of toothbrushing.* ***Results:*** *Bottled water use in this cohort was fairly limited (~10 percent). While bottled water users had significantly lower fluoride intakes, especially fluoride from water, there were no significant differences found in either permanent tooth caries (*P *= 0.20 and 0.91 for prevalence and $D_{2+}FS$, respectively) or primary second molar caries (*P *= 0.94 and 0.74 for incidence and $d_{2+}fs$ increment, respectively). Results for smooth surfaces differed somewhat from those for pit and fissure surfaces, but neither showed significant differences related to bottled water use.* ***Conclusion:*** *While bottled water users had significantly lower fluoride intakes, this study found no conclusive evidence of an association with increased caries. Further study is warranted, preferably using studies designed specifically to address this research question.*

Key Words: fluoride, dental caries, mixed dentition, bottled water

Introduction

Dental caries rates declined substantially overall among children and young adults in the United States during the final decades of the 20th century (1), and more recently have shown additional decline in permanent teeth of children and adolescents, but a leveling off of caries rates in the primary teeth (2). The widespread availability of and access to the caries-preventive benefits of fluoride in many forms is the major factor in the decline (3). Probably the two most important forms of fluoride on a public health level are community water fluoridation and fluoride dentifrice. These two modalities have been recommended by the US Centers for Disease Control and Prevention (CDC) as desirable for all individuals in the United States, while other fluoride exposures (e.g., dietary fluoride supplements, mouth rinses, gels/foams/varnishes) are recommended only for those at elevated caries risk (3).

The benefits of adjusted water fluoridation have consistently been reaffirmed, and the CDC and numerous other scientific, professional, and government agencies support water fluoridation (4-6). Water fluoridation was recognized by the CDC as one of the 10 most important overall public health achievements of the 20th century (7). While water fluoridation provides substantial caries-preventive benefit to all those drinking the water, those removing fluoride from their drinking water with reverse osmosis or distillation water filters and those drinking low-fluoride water from other sources do not receive the caries-preventive benefits of water fluoridation (8).

Armfield and Spencer (9) assessed the associations between dental caries and the use of nonpublic water, defined as including both bottled water and rainwater stored in tanks, in South Australian children. Using cross-sectional caries experience data from 1991 to 1995, they reported a significant positive association between primary tooth caries experience (ages 4 to 9) and consumption of nonpublic water among those with 100 percent lifetime access to fluoridated water, but not among those with less than 100 percent lifetime access to fluoridated water. There were no significant associations of nonpublic water use with permanent tooth caries experience among children aged 10-15 years.

Bottled water consumption has recently increased, with per capita US consumption rising substantially

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from 16.2 gallons in 2000 to 26.1 gallons in 2005 (10). Because bottled water has become an important source of drinking water, several studies (8,11,12) have documented the fluoride levels in bottled waters, with the majority of such products found to be low in fluoride. For example, a 1995 study (8) showed that about 83 percent of the 78 products available for purchase in Iowa City, IA had < 0.3 ppm fluoride, with an additional 7 percent having 0.3 to 0.7 ppm. Only 10 percent had or exceeded the recommended optimal range of 0.7 to 1.2 ppm fluoride. More recent analyses of bottled water samples [unpublished Iowa Fluoride Study (IFS) data from 2000 to 2004] show that 91 percent of the 103 samples assayed had fluoride levels under 0.3 ppm, 3 percent with 0.3 to 0.7 ppm, 5 percent at optimal fluoridation levels (0.7 to 1.2 ppm), and 1 percent beyond optimal (1.33 ppm).

Since bottled water is predominantly supoptimal in fluoride content, the purpose of this paper is to directly assess the association between dental caries in the mixed dentition and use of commercially bottled water.

Methods

This study is a secondary analysis of data collected for the IFS. While the original study was designed to analyze the complicated relationships among fluoride exposures and intake, dental fluorosis, and caries, it was not specifically designed to study the effect of bottled water on caries. However, the previously collected data do offer an opportunity to begin to explore the association of patterns of bottled water use with caries.

Subjects in the study were participants in the IFS, a cohort recruited at birth from eight Iowa hospitals and followed longitudinally until the present. Parents of newborns were recruited in 1992 to 1995 following Institutional Review Board (IRB)-approved procedures. Parents filled out questionnaires at regular intervals thereafter concerning the amounts and sources of water that their child consumed. The questionnaires also requested information on other beverages and foods, fluoride supplements, oral hygiene habits, and dental visits. Informed consent was obtained from parents and assent from children, according to procedures approved by the Institutional Review Board (IRB) at the University of Iowa.

Relevant to these analyses, questionnaires were sent to parents at 6-month intervals, and information was gathered from age 6 until the time of the mixed dentition exam (ages vary). The parents completed the questionnaires, which obtained information about total amount of water consumed during the previous week and whether their children consumed "mostly" tap or bottled water.

For each given questionnaire, respondents who used "mostly tap" water at home were classified as nonbottled water users, respondents using "mostly bottled" were classified as bottled water users, and respondents using "about equal amounts" were classified as half users. Subjects who reported using bottled water from a noncommercial source (e.g., water from grandparents' home that was transported in bottles) were reclassified as nonbottled water users. For these analyses, subjects then received an overall area-under-the-curve (AUC) "bottled water user" classification if they were estimated to have used 25 percent or more bottled water over the interval from age 6 until their mixed dentition caries exam. AUC estimates represent weighted daily averages, with weights corresponding to the length of time between questionnaire returns, and they use information collected on all questionnaires between age 6 and the time of the mixed dentition exam. Although most brands of bottled water were assayed for fluoride levels, the specific results were not used to calculate actual water fluoride levels in the present study, because our goal was to assess association (if any) of dental caries with bottled water use, not with varying water fluoride levels.

Daily fluoride intake (mg F) was estimated from reported intake of water, other beverages and selected foods, dentifrice ingestion, and fluoride supplements on each returned questionnaire (13). Fluoride levels of water sources, dentifrice, and supplements were ascertained on a subject-specific basis, with individual assays of water when sources were nonpublic. The fluoride level in water sources was a weighted average of water from home, child-care, school, and bottled water, with weights depending on the amount consumed from each water source. Dentifrice ingestion was estimated by considering the fluoride level of the reported brand of dentifrice, amount of dentifrice used per brushing, frequency of toothbrushing, and estimated proportion swallowed by the child (14). Daily toothbrushing frequency was assigned a numeric value corresponding to the response category (i.e., never = 0, less than once = 0.5, once = 1, twice = 2, three times = 3, and more than three = 3.5). Estimated daily fluoride ingestion and toothbrushing frequency were averaged using the AUC trapezoidal method. If the 6-year response was missing, an interpolated estimate was used. Low socioeconomic status (SES) was assessed only at recruitment and represents that portion of the sample with both low family income (<$30,000/year) and mothers not having 4-year college degrees.

Children were examined by two trained and calibrated examiners in the primary dentition at about age 5, and again in the mixed dentition at about age 9. Exams were conducted using portable equipment, including adjustable dental chairs, halogen exam lights, and lighted mirrors. The examinations were primarily visual, with compressed air used to dry the teeth, but dental explorers were used to confirm questionable lesions. Criteria for assessing both smooth surface and pit and fissure lesions were based on those of the World Health Organization (15), as well as those of Pitts (16) and Ismail (17), for both the primary (dfs) and permanent (DFS) teeth, and included both noncavitated (d_1/D_1) and cavitated (d_{2+}/D_{2+}) lesions. Specifically, the cavitated (d_{2+}/D_{2+}) lesions required, at minimum, either demonstrable loss of tooth structure or softness of the lesion if probed with a dental explorer (18). For these analyses, the definition of caries cases included only children who had cavitated or filled surfaces ($d_{2+}fs/D_{2+}FS$), while noncases included children with only sound teeth or noncavitated (d_1/D_1) surfaces. Each subject in this report was required to have all eight permanent incisors, four permanent first molars, and four primary second molars at the time of the mixed dentition exam. Each subject had four primary second molars at the time of the primary tooth exam as well. In order to assess interexaminer reliability, a subsample of children had exams by both examiners, approximately 9 percent at age 5 and 3 percent at age 9.

Caries increment in the primary second molars was adjusted for reversals (19), and then rounded to the nearest integer. Permanent tooth caries assessment for this report has been limited to that of the permanent incisors and first molars, as those teeth were consistently erupted in nearly all subjects. Total caries increments were subdivided into those found on smooth surfaces and those found on pit and fissure surfaces.

Prevalence and incidence rates are reported by surface type (smooth/pit and fissure) and tooth type (primary/permanent). Caries rates for bottled water users versus nonusers were compared using Fisher's exact test. Logistic regression was used to assess effects on caries prevalence and incidence. Generalized linear models were used to fit permanent tooth $D_{2+}FS$ and pri-mary second molar $d_{2+}fs$ increments. Models using Poisson, zero-inflated Poisson, negative binomial, and zero-inflated negative binomial distributions were compared, and Akaike's information criterion (AIC) was used to choose the model with the best fit. The data were analyzed with SAS (20).

All regression models were adjusted for the child's age, overall brushing frequency, and use of commercially bottled water. With only 42 subjects designated as "bottled water users," it was important to limit the number of variables included in the models to avoid overfitting. Nevertheless, we wanted to explore the impact of total fluoride intake (0.13 to 2.05 mg/day), water fluoride level (<0.70 versus ≥0.70), and low SES (based on income and mother's educational level). Therefore, each of these additional variables was added singly to the regression equations to determine their effect.

Results

A total of 413 children had both primary and mixed dentition exams, as well as sufficient information on water sources. All subjects had eight permanent incisors and four permanent first molars at the time of the mixed dentition exam, as well as all four primary second molars at both the primary and mixed dentition exams. Those subjects and those teeth are the basis of this report. The children's mothers were predominantly White (98 percent) and of relatively high SES, with 48 percent of mothers having a 4-year college degree at the time of the child's birth. The subjects ranged in age from 4.5 to 7.0 years (mean age 5.1) at the primary dentition exam, with 25 percent caries ($d_{2+}f$) prevalence. At the time of the mixed dentition exam, the subjects ranged in age from 7.7 to 12.0 years (mean 9.2) and had 36 percent primary second molar caries prevalence, 0.2 percent (n = 1) permanent incisor caries prevalence ($D_{2+}F$), and 21 percent permanent first molar caries prevalence. Interexaminer agreement for person-level $d_{2+}f$ on the primary molars was 95.4 percent (kappa = 0.86) at the age-5 exam and 100 percent (kappa = 1.00) at the age-9 exam. Interexaminer agreement for person-level $D_{2+}F$ on the permanent incisors and first molars (age-9 exam) was 88.2 percent (kappa = 0.60).

Using the "bottled water user" classification scheme described earlier (25 percent bottled water use AUC from age 6 until the mixed dentition exam), 10 percent (n = 42) of subjects were classified as commercial bottled water users versus 90 percent classified as nonbottled water users. Table 1 shows that the bottled water users and the nonusers were similar with respect to gender, proportion of low-SES families, number of questionnaires returned, soda pop consumption, toothbrushing frequency, home tap water fluoride level, visits to the dentist, age at the time of the mixed dentition exam, and number of sealants. The AUC estimates were based on as few as three questionnaires and up to a maximum of 11 questionnaires, with a median of six questionnaires per subject.

Total AUC fluoride intake estimates (mg/day) were significantly lower among subjects using commercially bottled water (Table 2). Fluoride intakes from diet (other than water), ingested dentifrice, and fluoride supplements did not differ significantly between bottled water users and tap users. Fluoride ingested from water was the only component of total fluoride intake that differed significantly between the two groups ($P < 0.001$). Figure 1 provides a snapshot of the fluoride levels of bottled water and tap water linked to the 6-year-old questionnaires in the IFS. It can be seen that the bottled waters in our study generally had substantially lower fluoride levels than home tap water, which had a bimodal distribution involving both fluoridated and nonfluoridated sources.

Permanent incisor/first molar caries prevalence ($D_{2+}F$) and primary second molar caries incidence ($d_{2+}f$) rates by surface type are listed in Table 3. Although bottled water users had somewhat higher caries prevalence and incidence on the pit and fissure surfaces, they had slightly lower rates for smooth surfaces. None of the differences were statistically significant (all $P \geq 0.24$). Similar results were found for

Table 1
Descriptive Means and Percentages for Bottled Water Users and Nonusers

	Bottled water users* (n = 42)	Nonusers (n = 371)	P-value
Baseline			
Gender			
Boys	48%	50%	0.88†
Girls	52%	50%	
Low socioeconomic status (SES)‡	17%	19%	0.84†
Number of questionnaires returned from age 6 until the mixed dentition exam	6.5	6.4	0.66¶
AUC age 6 to dental exam			
Soda pop intake (oz./day)	3.21	3.15	0.87¶
Daily toothbrushing frequency	1.6	1.5	0.31¶
Home tap water fluoride level (ppm)	0.75	0.80	0.48¶
Percentage of questionnaires reporting a visit to the dentist within previous 6 months§	74%	75%	0.88¶
Dental exam			
Age at mixed dentition exam	9.3	9.2	0.49¶
Sealed surfaces on primary second molars	1.6	1.3	0.25¶
Sealed surfaces on permanent first molars	3.0	2.7	0.42¶

* Bottled water users defined as subjects estimated as using 25% or more commercially bottled water between age 6 years and the time of the mixed dentition exam.
† P-values from Fisher's exact test.
‡ Low-SES families defined as those having both low family income (<$30,000/year) and mothers not having 4-year college degrees.
¶ P-value from t-test.
§ Percentage of questionnaires reporting dental visits for each subject ranged from 0 to 100%, with a median of 83%.

Table 2
Fluoride Intake (mg/day) by Commercial Bottled Water Use and Source

Fluoride source	Bottled water user*	n	Mean	Standard deviation	Median	25th percentile	75th percentile	Wilcoxon P-value
Water	Yes	35	0.21	0.16	0.17	0.09	0.27	<0.001
	No	341	0.39	0.27	0.32	0.19	0.51	
Other beverages and food	Yes	35	0.22	0.13	0.17	0.11	0.31	0.11
	No	341	0.18	0.10	0.16	0.11	0.22	
Ingested dentifrice	Yes	35	0.12	0.17	0.06	0.00	0.23	0.29
	No	341	0.13	0.18	0.08	0.03	0.16	
Fluoride supplements	Yes	35	0.02	0.08	0.00	0.00	0.00	0.84
	No	341	0.01	0.07	0.00	0.00	0.00	
Total fluoride	Yes	35	0.57	0.26	0.52	0.37	0.78	0.04
	No	341	0.71	0.36	0.63	0.44	0.89	

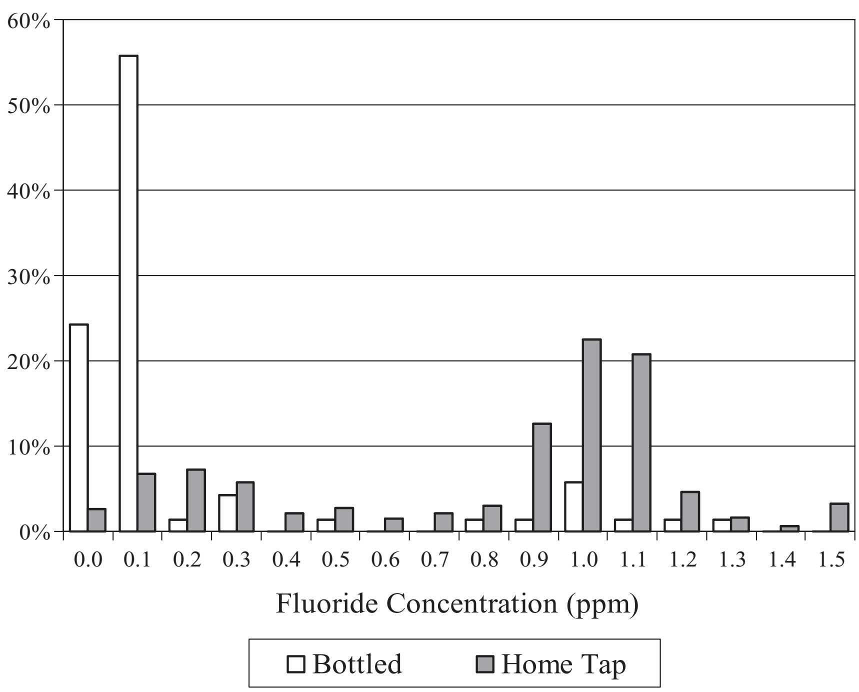
* Bottled water users are defined as subjects estimated as using 25% or more commercially bottled water between age 6 years and the time of the mixed dentition exam.

standardized caries rates, which were stratified by age or toothbrushing frequency (data not shown).

Logistic regression odds ratios, confidence intervals, and P-values for permanent incisor/first molar caries prevalence and primary second molar caries incidence are presented in Table 4. Two subjects were excluded from the analyses because of insufficient data on toothbrushing frequency. Because only one subject had caries on the smooth surfaces of the permanent incisors/first molars, only a single regression model for total caries in those permanent teeth is presented. All models (A to D) show that toothbrushing frequency is negatively associated with caries experience (all $P \le 0.04$), but that differences in age (A, P = 0.71), years between exams (B to D, all P ≥ 0.12), and bottled water use (all $P \ge 0.20$) were not significantly associated with caries experience. Caries incidence rates for smooth surfaces in the primary second molars were slightly lower among bottled water users, but caries rates for pit and fissure surfaces were slightly higher, with neither statistically significant. All two-way interaction effects were analyzed and, except for one, they were not significant and did not result in any significant effects for bottled water use. Using the Hosmer and Lemeshow goodness-of-fit test (21, p. 177), the pit and fissure primary second molar incidence model with a significant interaction effect (bottled water use by years between exams) showed a poorer fit than the model without the interaction. Hence, we have not presented any logistic models involving interactions.

Separate analyses that added total fluoride intake, water fluoride level, and low SES to the models generally did not make any substantive improvements to the models (based on the AIC) and had nonsignificant *P*-values. The exception was for total fluoride intake on the smooth surface caries incidence model, where total fluoride intake showed a significant (P = 0.01) preventive effect. However, none of the additional models resulted in significant effects for bottled water use (all $P > 0.19$).

Figure 1
Home tap water and bottled water fluoride levels (%): 6-year questionnaire



In order to analyze caries severity, generalized linear models were used to compare $D_{2+}FS$ among the permanent incisors/first molars and $d_{2+}fs$ increment among the primary second molars. Several types of distributions were compared using Akaike's information criterion to determine the best fit. For permanent incisor/first molar $D_{2+}FS$ models, AIC values were 753, 656, 650, and 658 for the Poisson, zero-inflated Poisson, negative binomial, and zero-inflated negative binomial models, respectively (a lower value corresponds to a better fit). For primary second molar $d_{2+}fs$ increment models, the AIC values were 1,379, 1,040, 1,009, and 1,029 for the Poisson, zero-inflated Poisson, negative binomial, and zero-inflated negative binomial models, respectively.

While all models resulted in similar nonsignificant results for bottled water use, Table 5 presents only the results for the best-fitting negative binomial distribution models. Caries counts for permanent incisor/first molar smooth surfaces were again insufficient for modeling purposes, so only a single total caries model is presented for those permanent teeth (Table 5, model A). Bottled water users had slightly higher caries counts (nonsignificant) after adjusting for other factors in the model. Caries increment counts on primary second molar smooth surfaces were slightly lower for bottled water users than for nonusers after adjusting for age and brushing frequency (model C). For primary second molar pit and

Table 3
Caries Prevalence and Incidence in the Mixed Dentition

	Permanent incisor/first molar caries prevalence*			Primary second molar incidence†		
Surface type	Nonbottled water user prevalence (%) (n = 371)	Bottled water user prevalence (%) (n = 42)	Fisher's exact test *P*-value	Nonbottled water user incidence (%) (n = 371)	Bottled water user incidence (%) (n = 42)	Fisher's exact test *P*-value
All surfaces	20	29	0.24	32	31	1.00
Smooth	2	0	1.00	22	19	0.85
Pit and fissure	20	29	0.24	27	29	0.86

* Percentage of children with D_{2+} caries and/or fillings on the permanent incisors and/or first molars at approximately age 9.
† Percentage of children showing a net increase in $d_{2+}fs$ on the primary second molars (ages 5 to 9).

Table 4
Logistic Regression Models for Permanent Incisor/First Molar Caries Prevalence and Primary Second Molar Caries Incidence (n = 411)

Permanent tooth caries prevalence ($D_{2+}F$): incisors and first molars	AIC	Exam age Odds ratio (95% C.I.)	P	Brushing frequency Odds ratio (95% C.I.)	P	Bottled water use Odds ratio (95% C.I.)	P
A. All surfaces	429	1.07 (0.76, 1.49)	0.71	0.60 (0.37, 0.98)	0.04	1.61 (0.78, 3.31)	0.20
Primary tooth caries incidence ($d_{2+}f$): second molars	**AIC**	**Years between exams Odds ratio (95% C.I.)**	**P**	**Brushing frequency Odds ratio (95% C.I.)**	**P**	**Bottled water use Odds ratio (95% C.I.)**	**P**
B. All surfaces	506	1.22 (0.91, 1.62)	0.18	0.45 (0.29, 0.70)	<0.001	1.03 (0.51, 2.08)	0.94
C. Smooth surfaces	421	1.30 (0.94, 1.80)	0.12	0.42 (0.26, 0.69)	<0.001	0.91 (0.40, 2.07)	0.82
D. Pit and fissure	476	1.24 (0.92, 1.67)	0.17	0.50 (0.32, 0.78)	0.003	1.16 (0.56, 2.38)	0.69

AIC, Akaike's information criterion; C.I., confidence intervals.

Table 5
Generalized Linear Models* for Permanent Incisor/First Molar $D_{2+}FS$ and Primary Second Molar $d_{2+}fs$ Increment (n = 411)

Permanent $D_{2+}FS$: incisors and first molars	AIC	Exam age Coefficient (95% C.I.)	P	Brushing frequency Coefficient (95% C.I.)	P	Bottled water use Coefficient (95% C.I.)	P
A. All Surfaces	650	0.11 (−0.24, 0.45)	0.55	−0.61 (−1.09, −0.13)	0.02	0.10 (−0.69, 0.90)	0.91
Primary $d_{2+}fs$ increment: second molars	**AIC**	**Years between exams Coefficient (95% C.I.)**	**P**	**Brushing frequency Coefficient (95% C.I.)**	**P**	**Bottled water use Coefficient (95% C.I.)**	**P**
B. All surfaces	1,009	0.14 (−0.16, 0.44)	0.37	−0.82 (−1.27, −0.38)	<0.001	0.12 (−0.59, 0.83)	0.74
C. Smooth surfaces	678	0.18 (−0.16, 0.52)	0.29	−0.87 (−1.37, −0.37)	<0.001	−0.20 (−1.05, 0.64)	0.64
D. Pit and fissure	761	0.10 (−0.19, 0.39)	0.49	−0.76 (−1.19, −0.34)	<0.001	0.36 (−0.29, 1.02)	0.28

* Models used a negative binomial distribution with log link.
AIC, Akaike's information criterion; C.I., confidence intervals.

fissure caries increments (model D), bottled water users had slightly higher caries counts after adjusting for other factors.

We explored all two-way interaction effects for the variables in the four main-effects models in Table 5. All were nonsignificant ($P > 0.05$) and did not change the nonsignificance of the bottled water main effect, except for the age by toothbrushing frequency interaction of the permanent incisor/first molar $D_{2+}FS$ model (model A). The interaction model had a slightly better overall fit (AIC = 647), but showed that children examined before age 8.3 years had a positive effect for toothbrushing frequency (more $D_{2+}FS$ with increased brushing). However, even with this two-way interaction effect in place, the main effect for bottled water use was still not significant (P = 0.73). Only the main-effects models are presented in Table 5, without interactions.

The addition of total fluoride intake, water fluoride level, and low SES, in general, did not make any substantive improvements to the models (based on the AIC) and had nonsignificant P-values. The exception was for total fluoride intake on the smooth surface and total caries incidence models, where total fluoride intake showed significant (P = 0.01 and P = 0.02, respectively) preventive effects. However, none of the additional models resulted in significant effects for bottled water use (all $P > 0.27$).

Discussion

This study found that children who were defined as bottled water users (estimated to use at least 25 percent bottled water from age 6 until the mixed dentition exam) had reduced fluoride intakes from water and also reduced total fluoride intakes. This confirms the logical reasoning that if individuals consume bottled waters, which are typically low in fluoride, the overall result will be lower fluoride intakes. Presumably, such reduced exposure to fluoride would result in increased caries occurrence. However, the present study did not find any significant differences in caries prevalence or incidence between bottled water users and those who did not use much bottled water.

However, with only 42 subjects designated as bottled water users (~10 percent), our analyses lacked sufficient statistical power to detect significant caries effects from bottled water use. For example, based on the permanent incisor/first molar prevalence of pit and fissure caries reported in Table 3, a large-sample, one-tailed test for a difference in proportions has less than 16 percent power ($\alpha = 0.05$). The relatively low use of bottled water by study participants may reflect the fact that data from this ongoing longitudinal study were collected several years ago when bottled water use was less common. Moreover, as an observational study, there were not defined groups of exclusive bottled water users, and the minimum needed to be classified as a bottled water user was 25 percent of their total water intake. Thus, many of those classified as "users" consumed considerable proportions of their total water intake from fluoridated tap water, which would have diluted possible differences. However, the low prevalence of substantial bottled water use precluded a more stringent definition of bottled water use that might be associated with more dramatic effects.

Our future analyses of bottled water use will be able to incorporate the actual amounts of bottled water and tap water consumed, but the early questionnaires used for this study (up to age 8.5) were not designed with that level of detail. An optimally designed study would compare subjects consuming only bottled water with subjects consuming only fluoridated tap water, but that type of comparison is not possible within the IFS cohort.

The public health implications of this study's results are limited, but it is clear that the use of relatively small amounts of bottled water by a small portion of the population has little impact on caries. However, this finding does not preclude a substantial impact in populations where bottled water use is prevalent and large amounts are consumed relative to other beverages, particularly fluoridated tap water. Indeed, concerning the IFS, as bottled water use increases over time and as the children get older (approximately 7 percent usage at age 6 versus 14 percent at age 11 in the present study), bottled water's effects on caries may become statistically significant.

The study also allowed us to consider different approaches in fitting caries regression models using Poisson, zero-inflated Poisson, negative binomial, and zero-inflated negative binomial distributions. Previous research has confirmed that negative binomial models fit cross-sectional caries and longitudinal incidence models well (22). Their study showed that zero-inflated negative binomial models were better fitting than zero-inflated Poisson models. While our analyses included the zero-inflated models, our data were adequately fit by the standard negative binomial model. Poisson models are designed for outcome measures that are based on counts, but negative binomial models also represent count data well because they represent a mixture of Poisson distributions with individual Poisson intensity parameters that follow a gamma distribution (21, p. 559-60). Because individuals vary in susceptibility to caries experience, the negative binomial model should be an improvement over the Poisson model for caries count data. The adjustment for zero-inflation, though, may be more or less necessary, depending on the properties of the population under study.

The finding that increased brushing frequency was associated with reduced caries prevalence and incidence was intriguing and suggests the need for continued analyses of our data. To that end, we plan to study how various sources of topical fluoride exposures (dentifrice, mouth rinse, water) are related to caries prevalence and incidence in this age group, as well as in the entire permanent dentition at age 13 among cohort children (we are currently conducting those examinations). In addition, we plan to assess how longitudinal (nonfluoride) dietary patterns, along with fluoride and demographic factors, relate to caries prevalence and incidence in these children.

In conclusion, the results of the study suggest that children consuming at least some bottled water have significantly lower levels of fluoride intake, but that these differences in fluoride ingestion did not translate into statistically significant differences in caries prevalence or incidence. However, because of the low prevalence of any bottled water use and many subjects' concurrent use of (primarily fluoridated) tap water by study participants, the association between caries and bottled water should be studied further in larger studies and ones better designed to address this research question.

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