Fluoride Ingestion Is Related to Fluid Consumption Patterns

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Abstract

Objectives: *There have been few reports regarding variations of fluoride intake by fluid consumption patterns. The purpose of this study was to estimate fluoride intake among children in the United States based on their fluid consumption patterns.* ***Methods:*** *Fluid intakes of children aged 1-10 years from plain water, beverages, and water from foods were assessed in a 24-hour recall diet survey as a part of the third National Health and Nutritional Examination Survey (NHANES III, 1988-1994). The amount of fluoride ingested from fluids in NHANES III was estimated from several assumptions about the concentration of fluoride in drinking water and beverages. Logistic regression analysis was conducted using SAS® and SUDAAN®.* ***Results:*** *Children at the 75th percentile or higher of F intake from fluids (not including water used in cooking) ingested 0.05 mg F/kg/day or more, and children at the 90th percentile or higher ingested 0.07 mg F/kg/day or more. This finding held across all age groups. There was substantial variation in the estimated amount of fluoride ingestion depending on the children's fluid consumption patterns as well as age, gender, and race/ethnicity. African-American children ingested significantly more fluoride than White children in bivariate analysis. This association remained significant after accounting for fluid consumption pattern and other confounding factors in the model.* ***Conclusion:*** *Our results raise concerns that some children are ingesting significantly more fluoride than others depending on sociodemographic factors and fluid consumption patterns. Additional research is warranted to investigate the variation in the amounts of fluoride ingestion by these factors and its impact on fluorosis prevalence in different population groups.*

Key Words: fluoride ingestion, fluid consumption pattern, children

Introduction

Several studies have indicated that the prevalence of dental fluorosis in the United States has increased during the past decades (1-4). It follows that the amount of fluoride ingested by young children is a matter of public health interest. In young children who are in a critical period of tooth development and risk for fluorosis, the amount of fluoride ingested as part of a normal diet received attention even before public water fluoridation began. McClure (5) estimated that the daily fluoride intake solely from drinking water containing 1.0 ppm F by children aged 1-12 years old ranged from 1.0 to 1.5 mgF, or an average of about 0.05-0.07 mgF/kg body weight per day. Since McClure, a number of researchers have tried to estimate fluoride intake from water, beverages, foods, and dentifrice by children (6-12). However, most of these studies were conducted with small sample sizes and specific population groups, so their results may not be generalizable. Furthermore, because of differences in methodology, results have shown a wide range of fluoride intake. From an extensive review of literature, Burt (7) suggested that the empirical range of 0.05-0.07 mg F/kg body weight/day might serve as a useful upper limit for fluoride intake in children to provide dental caries prevention with acceptable risk of dental fluorosis. More recent reports confirmed the average amount of fluoride intake among children who live in optimally fluoridated areas – approximately 0.05 mg/kg/day – but with a wider range (range: 0.02-0.10) (13,14).

Unfortunately, it is now more difficult to estimate amounts of ingested fluoride than it was in McClure's time, mainly because present-day fluoride sources are more complex than they used to be. Generally, fluid sources are more diverse, and carbonated drinks and juices have replaced a lot of water and milk consumption among children (15-18). Children's fluid consumption patterns are far from being uniform. Ershow and Cantor (19), using 1977-1978 Nationwide Food Consumption Survey data, reported significant differences in total water and tap water consumption by age, sex, and geographic region. Harnack *et al.* (15) reported a significant difference between African-American and White children in their carbonated drinks consumption in the 1994 Continuing Surveys of Food Intakes by Individuals. In our previous report using data from the third National Health and Nutrition Survey (NHANES III), we found that fluid consumption among children varied significantly by age, sex, race/ethnicity, and socioeconomic status (SES) (16,18). More recently, a brief analysis using NHANES 1999-2002 data reported large variations in water intake from foods and

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beverages in children by age, gender, and race/ethnicity (20). However, the effect on fluoride intake of diverse fluid consumption patterns related to these sociodemographic factors has not been well investigated. There are few reports of specific population groups that may be at particularly high risk due to their fluid consumption patterns.

The purpose of this analysis was to estimate the amount of fluoride ingested from drinking water and certain beverages among US children aged 1-10 years old by sociodemographic factors and fluid consumption patterns.

Methods

Study Population. Data for this study came from NHANES III, 1988-1994. The data were acquired from two series of public release CD-ROMs (21,22) released by the National Center for Health Statistics (NCHS). A detailed description of design specifications and the sample design and weighting and estimation procedures for NHANES III can be found elsewhere (23).

The sample for our analyses comprised children aged 1-10 years who completed the 24-hour dietary interview (or proxy interview for the younger children) at a Mobile Examination Center (MEC) in NHANES III. Dietary interview data included information about the completeness of the survey as determined by the interviewer. As recommended by NCHS, only those with a final dietary recall status classified as complete were included in this analysis. All breast-fed children, as determined by the interviewer, were excluded from this analysis because the amount of breast milk consumed cannot be determined with sufficient precision (21). As a result, among 8,613 children aged 1-10 years who completed the 24-hour diet recall survey, 1,070 (12.4 percent) were excluded due to incomplete data, leaving 7,543 eligible for this analysis.

Sociodemographic Information. Children were stratified by their age: 1-2 years (Toddlers), 3-5 years (Pre-schoolers), and 6-10 years (School children). Race and ethnicity classifications were non-Hispanic Whites, non-Hispanic African-Americans, Mexican-Americans, and Others. The Others category included all Hispanics, regardless of race, who did not self-identify as Mexican-American, and also included all non-Hispanics from racial groups other than Whites or African-Americans. SES was categorized on the basis of the poverty income ratio (PIR), which is the ratio of reported annual family income to the federal poverty threshold. The categories of SES in this analysis were: low SES (0.000-1.300 PIR), middle SES (1.301-3.500 PIR), and high SES (3.501 and above PIR). Body weight was measured as a part of the MEC physical examination.

Fluid Consumption Data. There are two measurements of fluid consumption provided in the NHANES III data. These are: a) the amount of plain water ingested (including tap and spring water) and b) the amount of fluid ingested from food and beverages other than plain water (21). The total amount of fluid intake for a child was calculated by adding these two measurements. The amounts of fluid from various items of food and beverages were differentiated based on the Individual Food File in the NHANES III dataset (22). We defined major fluid sources as "plain drinking water" (tap and spring water), "milk" (and milk drinks), "juice" (100 percent fruit and vegetable juices and other noncarbonated juice drinks), and "carbonated drinks." Fluid intake from sources other than these major sources, such as soup, baby formula, homemade water-based beverages, and water used for cooking, was all grouped into "other foods and beverages." Further details of definitions and groupings of fluid sources and the methodology for analyzing fluid consumption data was previously published (16,18).

The children's fluid consumption patterns were identified by cluster analysis based on the above mentioned groupings of major fluid sources using the FASTCLUS procedure in the Statistical Analysis System (SAS) Software (24). We conducted the cluster analysis based on the *proportions* of total fluid intake represented by each of the four primary sources defined previously, rather than the *absolute amount* of fluid intake. The resulting four clusters were: a) High Carbonated Drinks; b) High Milk; c), High Juice; and d) High Plain Water. Detailed descriptions of the cluster analysis can be found elsewhere (18).

Estimation of Fluoride Ingestion. Fluoride ingestion cannot be estimated directly because NHANES III did not collect fluoride concentrations of individual water sources. Therefore, we used several assumptions about concentration of fluoride in drinking water and beverages. Fluoride concentrations in drinking water were assumed to be 1.0 ppm if fluoridated and less than 0.3 ppm if not fluoridated. Fluoride concentration in beverages was assumed to be 0.8 ppm if prepared with fluoridated water or less than 0.3 ppm otherwise, based on published reports (10,25,26). The amount of fluoride ingested was also estimated in cases where children took fluoride supplements, using the 1994 revision of ADA recommendation for F supplement dosage: For drinking water less than 0.3 ppm F, the amount of fluoride from supplements was 0.25 mg F/day for children under 3 years, 0.5 mg F/day for children under 6 years, and 1.0 mg F/day for children 6 years and older (27).

With these assumptions, we calculated the amount of fluoride intake (absolute amount as well as amount per kg body weight; from here on referred to as F-intake) from drinking water, carbonated drinks, and juice separately or altogether as a sum. Milk was excluded from this analysis because it contains only a negligible amount of fluoride (28). Coffee and tea were also excluded, despite their reportedly high fluoride contents, because in our previous analysis only a small percentage of children of this age consumed these beverages (16). Other sources of fluid intake (i.e., all water grouped in "other foods and beverages") such as water used in reconstitution or cooking, for example, soup, baby foods, and other home-made juice were also excluded due to difficulties with assuming fluoride concentration of each food item. Therefore, the results of this analysis are most likely an underestimation of actual fluid and F-intake.

Statistical Analysis

SAS® software (24) was used for data management and descriptive analysis. Since NHANES III is based on a complex, multi-stage cluster sample design, SUDAAN® (Research Triangle Institute, Release 7.5) was used to estimate variance adjusted for this complex sample design (29). All analyses incorporated sampling weights to adjust for unequal sampling probabilities and nonresponse bias (23).

After descriptive analyses were conducted, logistic regression modeling was used to evaluate factors associated with the outcome of F-intake beyond the level of 0.05 mgF/kg/day. In our analysis, we used 0.05 mgF/kg/day as the threshold level instead of 0.07 mgF/kg/day, because overall estimation of projected F-intake in our analysis was likely to be at least about 25 percent underestimation since we limited our fluid sources only to drinking water and beverages excluding waters used in reconstitution and cooking as described above. Furthermore, this analysis did not include fluoride ingestion from solid food and other potential sources such as fluoridated toothpaste. We report here both crude associations and adjusted associations after controlling for confounding. Statistical significance of association was determined at the 5 percent error level (i.e., $\alpha = 0.05$).

Results

Fluoride Intake from Fluoridated Drinking Water and Beverages. Table 1 presents means and percentiles of the estimated F-intake per kg body weight from drinking water (assumed to be 1.0 ppm F) and some selected beverages (assumed to be 0.8 ppm F) along with the mean amount of fluid consumption from these sources per day. While the absolute amount of F-intake (mg F/day) increased with age (data now shown), the amount of F-intake per kg/body weight (mg F/kg/day) was relatively stable among children aged 1-5 years old and then slightly decreased among children older than 5 years of age. The percentile distribution shows substantial variability of F-intake among children, a reflection of variability in fluid intake.

From Table 1, children at the upper 75th percentile showed F-intake greater than 0.05 mg/kg/day, but not greater than 0.07 mg/kg/day, when consuming drinking water and beverages together across all age groups. For children at the 90th percentile (especially younger children), the amount of F-intake can easily exceed 0.07 mg/kg/day.

Table 2 shows the result of cluster grouping, percentage of children in each cluster, and the amount of estimated mean F-intake per kg/body weight from each fluid source in each cluster of fluid intake patterns. About 11 percent of the 1-10 year-old children were grouped to the High Carbo cluster, whereas the High Water cluster included the largest percentage of children (38.6 percent). The amount of estimated mean F-intake

Table 1
Estimated Fluoride Ingestion per Body Weight (mg F/kg body wt/day) Based on Fluid Intake (per Body Weight) Percentiles, Assuming Water with 1.0 ppm F and Beverages with 0.8 ppm F Were Being Consumed

	Fluid intake (ml/day)	Fluoride intake (mg F/kg/day)					
Fluid source	Mean	Mean	10th	25th	50th	75th	90th
Age 1-2 (*n* = 2,285)							
Drinking water only	330.7	0.027	0.004	0.011	0.021	0.040	0.070
Carbonated drink only	45.9	0.003	0	0	0	0.004	0.011
Juice only	233.6	0.015	0	0.002	0.011	0.021	0.033
Sum*	610.2	0.045	0.015	0.025	0.040	0.062	0.090
Age 3-5 (*n* = 2,790)							
Drinking water only	503.6	0.029	0.006	0.140	0.026	0.046	0.072
Carbonated drink only	102.5	0.005	0	0	0	0.008	0.014
Juice only	247.2	0.011	0	0.003	0.009	0.017	0.025
Sum*	853.3	0.045	0.018	0.028	0.042	0.063	0.091
Age 6-10 (*n* = 2,468)							
Drinking water only	768.4	0.026	0.006	0.011	0.022	0.037	0.058
Carbonated drink only	192.8	0.005	0	0	0	0.008	0.013
Juice only	208.5	0.006	0	0	0.005	0.010	0.016
Sum*	1,169.7	0.037	0.013	0.021	0.033	0.050	0.071

NOTE: Drinking water (tap and spring water); Carbonated drinks (carbonated soft drinks, soda pop); Juice (100% fruit and vegetable juices and other noncarbonated juice drinks, excluding home-reconstituted juice).
* Sum = Drinking water (assuming 1.0 ppm F) + carbonated drinks (assuming 0.8 ppm F) + juice (assuming 0.8 ppm F). Other sources of fluid intake such as water used in reconstitution or cooking, for example, soup, baby foods, and other water-based beverages were excluded.

Table 2
Estimated Mean Fluoride Ingestion (mg F/kg/day) from Some Fluid Sources by Fluid Consumption Pattern (Cluster), Assuming Water with 1.0 ppm F and Beverages with 0.8 ppm F Were Being Consumed

	Cluster			
Fluid source	High Carbo. (*n* = 745; 10.8%)	High Juice (*n* = 1,444; 21.2%)	High Milk (*n* = 2,045; 29.5%)	High Water (*n* = 3,309; 38.6%)
Age 1-2				
Drinking water only	0.013	0.013	0.015	0.052
Carbonated drink only	0.014	0.002	0.002	0.002
Juice only	0.007	0.035	0.010	0.012
Sum*	0.034	0.050	0.027	0.066
Age 3-5				
Drinking water only	0.015	0.013	0.015	0.051
Carbonated drink only	0.019	0.002	0.003	0.004
Juice only	0.005	0.025	0.006	0.008
Sum*	0.039	0.041	0.024	0.063
Age 6-10				
Drinking water only	0.012	0.015	0.012	0.042
Carbonated drink only	0.015	0.002	0.003	0.004
Juice only	0.003	0.015	0.004	0.004
Sum*	0.030	0.032	0.019	0.050

NOTE: Drinking water (tap and spring water); Carbonated drinks (carbonated soft drinks, soda pop); Juice (100% fruit and vegetable juices and other noncarbonated juice drinks, excluding home-reconstituted juice).
* Sum = Drinking water (assuming 1.0 ppm F) + carbonated drinks (assuming 0.8 ppm F) + juice (assuming 0.8 ppm F). Other sources of fluid intake such as water used in reconstitution or cooking, for example, soup, baby foods, and other water-based beverages were excluded.

was lowest among children in the High Milk cluster, whereas it was highest among children in the High Water cluster across all age groups. In the High Water cluster, estimated mean F-intake from the drinking water and beverage consumption (drinking water by itself among younger children) easily reached or exceeded 0.05 mg/kg/day. However, the estimated mean amount of fluoride intake did not exceed the level of 0.07 mg/kg/day. Juice could be a significant source of fluoride, especially for children in the High Juice cluster, when juice was assumed to be prepared with fluoridated water. Although the same concentration of fluoride was assumed (0.8 ppm F), quantities of carbonated drinks by themselves do not seem to be a significant source of F-intake even in the High Carbonated Drinks cluster, probably because the amount carbonated drinks consumption relative to other fluid sources is generally low among most children under 10 years of age.

Table 3 presents the amount of estimated mean F-intake per kg/body weight from drinking water

Table 3
Estimation of Mean Fluoride Intake* per Body Weight (mg F/kg/day) by Sociodemographic Factors and Fluid Consumption Patterns, Assuming Drinking Water with 1.0 ppm F and Beverages with 0.8 ppm F Were Being Consumed

	Age group			All
	1-2 years	3-5 years	6-10 years	1-10 years
Cluster				
HC	0.034	0.039	0.030	0.033
HJ	0.050	0.041	0.032	0.039
HM	0.027	0.024	0.019	0.023
HW	0.066	0.063	0.050	0.056
Sex				
M	0.045	0.046	0.039	0.042
F	0.045	0.044	0.035	0.039
Race/Ethnicity				
White	0.042	0.041	0.036	0.039
African-American	0.057	0.058	0.042	0.050
Mexican-American	0.046	0.049	0.036	0.042
Other	0.040	0.043	0.033	0.038
SES				
Low	0.050	0.051	0.039	0.045
Middle	0.043	0.043	0.036	0.040
High	0.039	0.035	0.035	0.036
Total	0.045	0.045	0.037	0.041

* From drinking water (assuming 1.0 ppm F) + carbonated drinks (assuming 0.8 ppm F) + juice (assuming 0.8 ppm F).
HC: High Carbonated Drinks cluster, HM: High Milk cluster, HJ: High Juice cluster, HW: High Water cluster.

(assuming 1 ppm F) and beverages (assuming 0.8 ppm F) by selected sociodemographic factors. Boys were ingesting slightly higher amounts of fluoride than girls except for the youngest age group. Across all age groups, African-American children were ingesting higher amounts of fluoride than other race/ethnicity groups, followed by Mexican-Americans. There was a clear inverse relationship between SES and F-intake. Children from lower SES groups may be ingesting higher amounts of fluoride than those from higher SES levels across age groups. However, the differences between race/ethnicity groups and SES levels substantially decreased among children aged 6-10, as overall F-intake per kg/body weight decreased.

Table 4 presents the logistic regression analyses for estimated F-intakes of more than 0.05 mg F/kg/day from water and beverages, when use of fluoridated drinking water (1 ppm F) and beverages (0.8 ppm F) were assumed. As expected from results in Table 3, factors such as age, sex, race/ethnicity, and SES showed a significant crude association with fluoride intake of 0.05 mgF/kg/day or greater. Older children are at a lower risk of ingesting more fluoride than younger children because they consume less fluid relative to body weight. African-American children ingested significantly higher amounts of F than White children. There was a significant difference in the estimated F-intake between children of low SES and high SES in a bivariate comparison, but the difference became insignificant in the multivariable model after accounting for confounding. The effect of fluid consumption patterns (clusters) on F-intake was clear: children in the High Water cluster were about 20 times more likely to ingest 0.05 mgF/kg/day or greater than those in the High Milk cluster. Children in the High Carbonated drinks and the High Juice clusters were also about 3-6 times more likely to ingest more F (0.05 mgF/kg/day or greater) compared with children in the High Milk cluster.

Table 4 also presents results from a multiple logistic model ("adjusted" columns). The fluid consumption cluster remained the most prominent explanatory variable for higher F-intake among children after controlling for other variables in the model. Age, sex, and being African-American, remained significant explanatory variables but with less strength (lower odds ratios) after controlling for confounding. From these variables, 22 percent of the variability in F-intake was explained (Pseudo R-square = 0.22).

Fluoride Intake from Water Fluoridation and Supplements Use. Table 5 presents estimated F-intake from different hypothetical situations, e.g., whether the area is

Table 4
Logistic Regression Models to Predict High Fluoride Intake (0.05 mg/kg/day or higher) from Drinking Water and Beverages, Assuming Water with 1.0 ppm F and Beverages with 0.8 ppm F Were Being Consumed

	Fluoride intake (0.05 mg F/kg/day or higher)			
	Crude		Adjusted	
	OR	(Group *P*-value) 95% C.I.	OR	(Group *P*-value) 95% C.I.
Age group		(<0.001)		(<0.001)
1-2	1		1	
3-5	0.97	0.81-1.17	0.73	0.59-0.90
6-10	0.58	0.48-0.72	0.34	0.28-0.43
Cluster		(<0.001)		(<0.001)
HC	3.77	2.40-5.92	5.17	3.32-8.06
HJ	6.51	4.55-9.29	7.91	5.26-11.89
HM	1		1	
HW	21.88	15.88-30.15	29.77	21.00-42.21
Sex		(<0.001)		(<0.001)
M	1.49	1.23-1.82	1.79	1.36-2.36
F	1		1	
Race/Ethnicity		(<0.001)		(0.17)
White	1		1	
African-American	1.92	1.57-2.35	1.32	1.01-1.73
Mexican-American	1.27	1.00-1.60	1.25	0.93-1.68
Other	1.03	0.69-1.53	1.04	0.68-1.61
SES		(0.006)		(0.63)
Low	1.67	1.22-2.30	1.20	0.81-1.78
Middle	1.30	0.97-1.74	1.17	0.82-1.66
High	1		1	
				Pseudo R-square = 0.22

HC: High Carbonated Drinks cluster, HM: High Milk cluster, HJ: High Juice cluster, HW: High Water cluster.

Table 5
Hypothetical* Estimation of Mean Fluoride Intake† per Body Weight by Sociodemographic Factors and Fluid Consumption Patterns (mg F/kg/day)

		Nonfluoridated water			
		Fluoridated beverage*		Nonfluoridated beverage*	
	Fluoridated water and beverage*		With daily F-supplements		With daily F-supplements
Age group					
1-2	0.045	0.026	0.047	0.015	0.036
3-5	0.045	0.025	0.054	0.015	0.044
6-10	0.037	0.019	0.054	0.012	0.047
Cluster					
HC	0.033	0.024	0.054	0.011	0.042
HJ	0.039	0.029	0.060	0.013	0.045
HM	0.023	0.013	0.043	0.008	0.037
HW	0.056	0.024	0.054	0.018	0.048
Sex					
M	0.042	0.023	0.053	0.014	0.044
F	0.039	0.021	0.052	0.013	0.044
Race/Ethnicity					
White	0.039	0.022	0.052	0.013	0.044
African-American	0.050	0.025	0.055	0.016	0.046
Mexican-American	0.042	0.022	0.052	0.014	0.044
Other	0.038	0.021	0.051	0.013	0.043
SES					
Low	0.045	0.023	0.054	0.015	0.045
Middle	0.040	0.022	0.052	0.013	0.044
High	0.036	0.021	0.051	0.012	0.042
TOTAL	0.041	0.022	0.053	0.013	0.044

* Fluoridated water: 1.0 ppm F. Nonfluoridated water: less than 0.3 ppm F. Fluoridated beverages: 0.8 ppm F. Nonfluoridated beverages: less than 0.3 ppm F. Fluoride supplements: ADA recommendation daily dose.
† Fluoride intake from plain water + carbonated drinks + juice.
HC: High Carbonated Drinks cluster, HM: High Milk cluster, HJ: High Juice cluster, HW: High Water cluster.

fluoridated or not, or if it is a nonfluoridated area whether beverages are fluoridated and/or supplements are assumed to be used. Total estimated mean F-intake was 0.041 mg/kg/day when both fluoridated plain drinking water and fluoridated beverages were consumed. This amount was 0.022 mg/kg/day or 0.013 mg/kg/day among children consuming nonfluoridated water, depending on the fluoride concentration in their beverages. However, when fluoride supplements were used, the F-intake could exceed that of children in fluoridated areas. The projected average F-intake relative to body weight from supplements by itself did not exceed 0.05 mg/kg/day across any ages (data not shown). However, when fluoridated beverage consumption (assumed 0.8 ppm F) and supplement use were combined, the average estimated amount of F-intake exceeded 0.05 mg/kg/day (but not 0.07 mg/kg/day), even when children were assumed to live in nonfluoridated area (assumed 0.3 ppm F in water). While the average may not exceed the threshold levels, it can be speculated that, from the distribution of Table 1, children on the upper percentile in the fluid consumption distribution are still prone to intake of a higher level of fluoride than 0.05-0.07 mg/kg/day.

When a nonfluoridated area was assumed, differences in estimated mean F-intake by sociodemographic factors and fluid consumption cluster were less prominent than those in a fluoridated area, due to generally reduced amounts of estimated fluoride intake. It is noticeable that children in the High Juice cluster ingested the highest amount of fluoride if fluoridated beverages were consumed in a nonfluoridated area, especially when supplements use was assumed.

Discussion

The results of this analysis confirm that there is considerable variation in the amount of fluoride ingestion among children (30,31). The result also indicates that some groups of children could potentially ingest excessive amounts of fluoride depending on fluid consumption pattern and sociodemographic characteristics.

In this analysis, our estimates of F-intake from drinking water and beverages were based on actual fluid consumption data collected during NHANES III. Since NHANES III adopted a cross-sectional design and a 24-hour recall food survey method, our analysis inherited both the limitations and the strengths of NHANES. Detailed discussions of these issues have been presented elsewhere (16,18). Briefly, a 24-hour recall diet survey is considered to provide a fairly stable estimate for a group mean value. However, since NHANES III did not collect information on fluoride concentration in drinking water, we used several assumptions to estimate these values. The water fluoride levels were hypothetical estimations and not actual measurements. Given the difficulties in obtaining precise measurements of individual water or beverages F-intake, however, we think this population-based estimate is the best available for future research and establishment of public policy.

In estimating F-intake in this analysis, we only considered major fluid sources; that is, drinking water, carbonated drinks, and juice and juice drinks, excluding various minor sources of fluid intake such as soup, baby food, water-based drinks, water used for reconstitution, and water used for cooking. Consequently, the calculated amount of F-intake was likely to be underestimated. Fluids from these minor sources that were not considered in this analysis comprised, on average, about 25 percent of total fluid consumption among children (18). Swallowed fluoride toothpaste is a potential major source of F-intake among children (4,31,32). With sizable variation depending on amount of toothpaste and frequency of brushing, it has been reported that young children may ingest, on average, 0.02-0.04 mgF/kg/day from fluoride toothpaste (6,11,12,30,33). Swallowed toothpaste was not included in our analysis, since the subject of this paper is F-intake from various fluid consumption patterns. However, when F-intake from toothpaste (0.02-0.04 mgF/kg/day) is considered in addition to fluid sources, it can be projected that the amount of fluoride ingested by children who are at the 50th percentile or higher of the fluid consumption distribution can exceed 0.05 mgF/kg/day or even 0.07 mgF/kg/day.

Diffusion of fluoride from fluoridated areas to nonfluoridated areas through consumption of fluoridated beverages has been reported (10,26,34). Accordingly, the recommended dose of fluoride supplements was adjusted downward in 1994 (27). Our results showed that, in nonfluoridated areas, some children's total F-intake may exceed the recommended amount when fluoride supplements are used, especially in cases where children consume substantial amount of fluoridated beverages. This finding reaffirms the recommendation that supplements should be prescribed only to high caries-risk children whose exposure to fluoride is low (13), after checking the background fluoride level of drinking water and other potential sources (35,36) as well as caries risk of children (37) to minimize the risk of dental fluorosis.

We used F-intake of 0.05 mg/kg body weight as a threshold level in the logistic regression model to offset underestimation of F-intake in our analysis. While this has been suggested as a good empirical upper level (7), and many studies have reported typical F-intake being within this range, it should be recognized that the precise threshold has not been established. An elevated risk of dental fluorosis has been reported from children who ingested 0.04 mgF/kg body weight (38,39). Again, considering the fact that our analysis included only some major fluid sources in estimating the amount of fluoride intake – therefore likely resulting in substantial underestimation – it seemed reasonable to use the lower end (0.05 mgF/kg body weight) as a cut-off point in the logistic regression model.

Our results show that there is substantial variation in children's fluid consumption patterns that could potentially lead to wide variation in the amount of F-intake via fluid consumption among these children. Depending on the major fluid source (e.g., whether it is milk, juice, carbonated drinks, or drinking water), which determined their consumption patterns (clusters), the amount of F-intake differs significantly. This result implies that even in the same fluoridated area, some children may be ingesting significantly more fluoride than others.

Fluoride intake also varies by sociodemographic characteristics. While several researchers suggested that there might be an influence of race/ethnicity and SES on the fluid consumption and F-intake (20,26,40) investigation of this issue has received little attention. Our previous reports showed that African-American children and children from low SES have a tendency toward higher consumption of plain drinking water and lower consumption of milk compared with their White or more affluent counterparts (18,41). The findings of this analysis showed that African-American children may still be ingesting significantly more fluoride per kg body weight than White children, although the difference has substantially narrowed, after accounting for their fluid consumption (cluster) patterns. The differences by SES groups became insignificant after accounting for other variables in the model.

The national water fluoridation recommendation, set in 1962 by the US Public Health Service, considered ambient temperature to account for differing amounts of total fluid consumption by climate zone, but neither various fluid sources and consumption patterns nor sociodemographic characteristics were considered (42). Adjusted fluoridation of public water is still effective and one of the most cost-effective preventive measures against dental caries for individuals of all ages (43). However, with the changes in modern lifestyle, social, and environmental changes as well as changes in disease patterns, water fluoridation should be refined and readjusted.

Our results raise concerns that African-American children, and/or children of lower SES, are ingesting significantly more fluoride than children who are higher on the social scale. They may be therefore at higher risk for fluorosis. On the other hand, these groups of children are, in general, also at higher risk for dental caries, so a greater exposure to fluoride is likely to impart more protection against dental caries. The fluoride exposure that achieves the best balance between fluorosis risk on the one hand and protection against dental caries on the other has been a frontline question since Dean's pioneering work in the 1930s, and is still not fully resolved. What has been learned since then is that the subject is more complex than simply measuring the fluoride concentration in drinking water. Defining this balance will require additional research on how fluorosis relates to caries in light of psychological, behavioral, and social effects among affected children and their parents. This line of research was called for by the National Research Council report on fluoride in drinking water (14).

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