Dental Caries and Dental Fluorosis at Varying Water Fluoride Concentrations

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Abstract

Objectives: *The purpose of this study was to investigate the relationships between caries experience and dental fluorosis at different fluoride concentrations in drinking water. The impact of other fluoride products also was assessed.* ***Methods:*** *This study used data from the 1986–87 National Survey of US Schoolchildren. Fluoride levels of school water were used as an indicator of the children's water fluoride exposure. The use of fluoride drops, tablets, professional fluoride treatments, and school fluoride rinses were ascertained from caregiver questionnaires. Only children with a single continuous residence (n=18,755) were included in this analysis.* ***Results:*** *The sharpest declines in dfs and DMFS were associated with increases in water fluoride levels between 0 and 0.7 ppm F, with little additional decline between 0.7 and 1.2 ppm F. Fluorosis prevalence was 13.5 percent, 21.7 percent, 29.9 percent, and 41.4 percent for children who consumed <0.3, 0.3 to <0.7, 0.7 to 1.2, and >1.2 ppm F water. In addition to fluoridated water, the use of fluoride supplements was associated with both lower caries and increased fluorosis.* ***Conclusions:*** *A suitable trade-off between caries and fluorosis appears to occur around 0.7 ppm F. Data from this study suggest that a reconsideration of the policies concerning the most appropriate concentrations for water fluoridation might be appropriate for the United States. [J Public Health Dent 1997;57(3):136-43]*

Key Words: dental caries, caries prevention, dental fluorosis, epidemiology, fluoride, water fluoridation.

Fifty years ago, when fluoride was first added to public water supplies for the purpose of controlling dental decay, fluoride-containing drinking water was the only significant source of fluoride exposure. Today, about 56 percent of the US population consumes fluoridated water (1) and there is widespread use of fluoride drops, tablets, gels, mouthrinses, and toothpastes. Furthermore, processed beverages and foods, which are distributed widely in fluoridated and nonfluoridated communities, now can contain substantial amounts of fluoride due to the use of fluoridated water in their production (2,3).

Numerous local and national studies have demonstrated a substantial decline in caries prevalence in the United States over the past several decades (4-8). Fluoride is considered to have played a major role in these reductions. At the same time, the prevalence of dental fluorosis, which is caused by excess fluoride intake during the period of preeruptive tooth formation, also has increased over the decades since the start of water fluoridation (9-12).

Public policy on the most appropriate concentrations for water fluoridation depends upon the trade-off between caries control and the undesirable side effect of dental fluorosis. The data on which current policy is based were collected 40–60 years ago. Because fluoride exposure in the United States has changed so much since then, the data are now of limited use. The purpose of this project was to analyze national data to further investigate the trade-offs between caries experience and fluorosis from the use of water fluoridation and other fluoride products.

Methods

This study uses data from the 1986–87 National Survey of Oral Health of US Schoolchildren conducted by the National Institute of Dental Research (NIDR). This survey is unique in that it is the only national oral health survey in the United States to collect detailed information on fluoride exposures and dental fluorosis. Data were obtained from a public use data tape provided by the NIDR.

The design and conduct of this survey have been described previously (6,7,13). Briefly, oral examinations were completed for 40,693 children aged 4–22 years, which is 78 percent of all sampled students. These examinations included a visual and tactile assessment of dental caries and restorations using the diagnostic criteria of Radike (14). No radiographs were taken. Children in grade 2 and higher were examined for dental fluorosis. A classification system based on Dean's Fluorosis Index (15) was used to evaluate all erupted permanent teeth. Artificial light was used and the teeth were not air-dried before scoring. Fourteen field examiners were used in this survey. Repeated interrater comparisons during the survey found that the level of disagreement on diagnosing caries was extremely small. For exact fluorosis diagnosis agreement between examiners, paired *T*-test *P*-values of .05 or less were found for seven of 28 sets of replicate exams. When the criterion for agreement was relaxed to within one point on the fluorosis scale, no *P*-values less than .05 were found. To reduce any effects of examiner bias, at least five examiners were used in each of the 14 sampling strata, with two strata per geographic region (6).

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TABLE 1
Distribution and Mean of dfs Scores by Water Fluoride Status*

			dfs (%)					
	n†	*N*%‡	0	1–5	6–10	11–20	>20	Mean (SE)
<0.3 ppm F	4,122	38.9	46.5	25.7	12.6	11.1	3.9	4.49 (0.28)
0.3– <0.7 ppm F	1,035	8.3	45.4	29.3	12.1	10.1	3.1	4.18 (0.27)
0.7–1.2 ppm F	4,205	49.8	51.1	27.9	11.1	7.6	2.3	3.35 (0.23)
>1.2 ppm F	415	3.0	50.4	28.6	11.5	7.9	1.7	3.42 (0.39)
All	9,777	100	48.9	27.1	11.8	9.2	3.0	3.87 (0.17)

*Scores are standardized to the age and sex distribution of US schoolchildren aged 5–10 years who had a history of a single residence.
†Sample size.
‡Weighted population percentage.

TABLE 2
Distribution and Mean of DMFS Scores by Water Fluoride Status*

			DMFS (%)					
	n†	*N*%‡	0	1–5	6–10	11–20	>20	Mean (SE)
<0.3 ppm F	7,584	36.3	53.2	25.8	12.5	6.6	1.9	3.08 (0.15)
0.3– <0.7 ppm F	2,183	10.1	57.1	23.9	12.2	5.4	1.3	2.71 (0.12)
0.7–1.2 ppm F	8,097	50.4	55.2	27.1	11.8	5.0	0.8	2.53 (0.11)
>1.2 ppm F	891	3.2	52.5	29.0	9.8	8.1	0.6	2.80 (0.39)
All	18,755	100	54.6	26.3	12.1	5.7	1.3	2.75 (0.09)

*Scores are standardized to the age and sex distribution of US schoolchildren aged 5–17 years who had a history of a single residence.
†Sample size.
‡Weighted population percentage.

Parents or guardians of the children completed a written questionnaire that included questions regarding their children's residence history and use of fluoride drops, fluoride tablets, professional topical fluoride treatments, and school fluoride rinses. For these analyses, fluoride product use was considered positive if the product was used at any time in the child's life.

A 500 ml water sample was obtained from each surveyed school and was analyzed in the laboratory for fluoride content. This fluoride level was used as a measure of the children's water fluoride exposure status. About one-half of the children, however, had resided at more than one address at some point of their lives, which clearly rendered the school water fluoride level measurement an unreliable indicator of the fluoride level of the water consumed by the child throughout life. To improve the validity of the water fluoride determinations, only children with a history of a single continuous residence were included in the analyses. This restriction meant that 18,755 children aged 5 to 17 years were included in the caries analysis, and 15,532 children aged 7 to 17 were included in the fluorosis analysis.

The Statistical Analysis System (SAS) Version 6.10 (16) was used for data management and for descriptive statistical procedures. The SUDAAN (SUrvey DAta ANalysis) Release 6.40 statistical program (17) was used for statistical tests because of the need to adjust variances for the complex sample design of the NIDR survey. Sample weighting to represent the population of US schoolchildren was used for all analyses.

Results

Dental Caries. Based on the level of fluoride in the school water sample, we categorized children in four levels of water fluoride (F) exposure: <0.3 ppm F, 0.3 to <0.7 ppm F, 0.7 to 1.2 ppm F, and >1.2 ppm F. The distribution and means of the number of primary decayed or filled surfaces (dfs) for children aged 5 to 10 years, and permanent decayed, missing, or filled surfaces (DMFS) for children aged 5 to 17 years are presented in Tables 1 and 2. For dfs, these figures were standardized to the age and sex distribution of US children aged 5 to 10 years who reported a single residence. For DMFS, standardization was to children aged 5 to 17 years who reported a single residence. Tables 1 and 2 show that approximately one-half of the children showed no decay in either the primary or permanent dentitions. Of the children with some caries history, approximately one-half had five or fewer involved tooth surfaces.

Tables 1 and 2 also demonstrate that mean dfs and DMFS scores decreased with increasing water fluoride levels from <0.3 ppm F to 0.7–1.2 ppm F, and then increased at >1.2 ppm F. Note, however, the sparsity of data at >1.2 ppm F. The mean dfs score of 3.35 for the 0.7–1.2 ppm F group was 25.4 percent less than the dfs score of 4.49 for the <0.3 ppm F group (*T*-test, *P*=.004). Significant differences also were seen between the 0.3 to <0.7 and 0.7–1.2 ppm F groups (*T*-test, *P*=.045) and the <0.3 and >1.2 ppm F groups (*T*-test, *P*=.031). For the permanent teeth, the mean DMFS of 2.53 in the 0.7–1.2 ppm F group was 17.9 percent lower than that of the <0.3 ppm F group, where the mean DMFS was 3.08 (*T*-test, *P*=.003). Other comparisons of mean dfs and DMFS scores were not significant at *P*<.05.

To provide a more detailed description of the association between water fluoride level and caries, age- and sex-standardized mean dfs and DMFS scores were calculated for water fluoride levels from 0 to 1.6 ppm F or more, and are shown in Figure 1. For the primary dentition, dfs declined sharply from 0 ppm F (categorized as 0 to <0.1 ppm F) to 0.6 ppm F, was fairly flat between 0.6 to 1.2 ppm F, and generally declined further with higher fluoride concentrations. In the permanent dentition, a gradual decline in DMFS occurred from 0 ppm F to 0.7 ppm F, and plateaued to 1.2 ppm. A similar graph limited to children who also reported no history of fluoride drop or tablet use (not shown) was almost identical to that in Figure 1.

Multiple regression procedures were used to model the association between caries levels (dfs or DMFS) and demographic and fluoride exposure variables. Urban/rural status, and race/ethnicity variables were not significantly associated with caries levels and were not included in the final models. Region-of-residence variables were significant, but contained no explanatory power beyond that contained in the water fluoride exposure variables. The region-of-residence variables therefore were eliminated from the models to minimize error due to multicollinearity. Table 3 presents the linear regression model of primary caries experience (dfs) as the outcome variable with sex, age, water fluoride level (in ppm F), and dichotomous variables for having ever used fluoride drops, tablets, professional fluoride treatments, or school fluoride rinses as the exposure variables. Being female was associated with lower dfs (regression coefficient=–0.35). Age was not associated with dfs in this model.

Table 3 shows that higher water fluoride levels were significantly associated with lower dfs status. The regression coefficient of –1.08 indicates that, on average, dfs decreased by 1.08 for each 1 ppm increase in water fluoride level. The use of fluoride drops was also significantly associated with lower dfs (regression coefficient=–0.88). Reported use of professional fluoride treatments, however, was significantly associated with higher dfs levels (regression coefficient=0.80).

Table 4 presents a linear regression model for DMFS outcome. In this table, increasing age and being female were associated with higher DMFS scores. As in the previous model, increasing water fluoridation levels were significantly associated with lower DMFS, and the reported use of fluoride tablets was significantly associated with lower DMFS levels (regression coefficient=–0.52). In addition, the interaction term between water fluoride level and fluoride tablet use was significant, indicating that the ef-

FIGURE 1
DMFS for Children Aged 5–17 Years, and dfs Scores for Children Aged 5–10 Years, by Water Fluoridation Level for US Schoolchildren with a History of a Single Residence(Scores are age- and sex-standardized to children with one residence aged 5–10 years for dfs and aged 5–17 years for DMFS.)

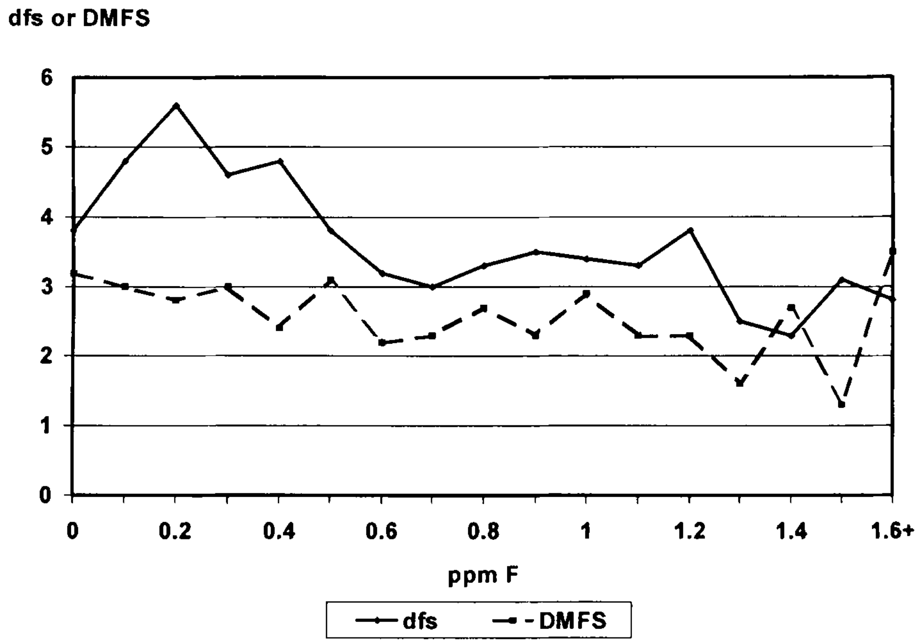

TABLE 3
Linear Regression Model of dfs*

Variable	Regression Coefficient	SE	*T*-test	*P*-value
Intercept	5.05	0.83	6.05	<.001
Sex (female)	–0.35	0.17	–2.05	.046
Age (years)	–0.04	0.09	–0.45	.653
ppm F	–1.08	0.37	–2.94	.005
Fluoride drops	–0.88	0.29	–3.07	.004
Fluoride tablets	0.07	0.34	0.19	.850
Professional fluoride treatment	0.80	0.23	3.47	.001
School fluoride rinses	0.41	0.32	1.26	.212

*US schoolchildren aged 5–10 years with a history of a single residence (*n*=9,470). R^2=0.011.

fect of fluoride tablets varies with water fluoride level. The observed effect was that the decrease in DMFS attributable to fluoride supplements diminished as water fluoride level increased. As was found with the primary dentition, the reported use of professional fluoride treatments was significantly associated with higher DMFS levels.

Dental Fluorosis. The distributions of fluorosis severity scores for children in the four categories of water fluoride level are presented in Table 5. All values in this table were derived using age- and sex-standardization for all children aged 7 to 17 years with a history of a single residence. Fluorosis prevalence was determined by whether or not the child had at least two teeth scored with fluorosis of Dean's score 1 (very mild) or greater. Overall, 23.5 percent of the children had at least very mild fluorosis, and this percentage increased with increasing water fluoride level. Only 5.7 percent of the children exhibited fluorosis higher than the very mild level.

An overall fluorosis severity score was calculated for each child, this score being the smaller of the two highest tooth fluorosis scores among all the scored teeth for the child. The mean fluorosis scores for these analyses were calculated in a manner similar to Dean's Community Fluorosis Index (CFI) scores (15). Overall mean fluorosis severity was 0.47 (Table 5). Mean fluorosis severity in the current study increased with increasing water fluoride level, ranging from 0.30 for the <0.3 ppm F group, to 0.80 for the >1.2 ppm F group. Using *T*-tests for comparisons of the means, the mean fluorosis severity scores for the children in the <0.3 ppm F group were significantly less than that for the 0.7–1.2 ppm F group (*T*-test, $P<.001$) and the >1.2 ppm F group (*T*-test, $P<.001$). The mean fluorosis severity score of the >1.2 ppm F group was also significantly greater than that for the 0.3–<0.7 ppm F group (*T*-test, $P=.007$) and the 0.7–1.2 ppm F group (*T*-test, $P=.045$). Other comparisons of fluorosis severity were not significant at $P<.05$.

Figure 2 presents age- and sex-standardized fluorosis prevalence (percent fluorosis) and mean fluorosis severity scores by water fluoride levels. Fluorosis prevalence patterns are similar to those for fluorosis severity, and a pattern of increasing fluorosis prevalence and severity with increasing water fluoride level is evident. A similar graph limited to children who reported no history of fluoride drops or tablet use (not shown) was almost identical to Figure 2.

Fluorosis prevalence and severity generally decreased with increasing age, as shown in Figure 3. Fluorosis prevalence ranged from 27.2 percent in 8-year-old children to 17.7 percent in the 16-year-old children. Similarly, fluorosis severity ranged from 0.53 in the 8-year-old children to 0.36 in the 17-year-old children.

Logistic regression was used to model the association between fluorosis prevalence outcome (at the very mild or greater level) and demographic and fluoride exposure predictor variables. Variables for sex, urban/rural status, and race/ethnicity

TABLE 4
Linear Regression Model of DMFS*

Variable	Regression Coefficient	SE	*T*-test	*P*-value
Intercept	–5.01	0.21	–24.01	<.001
Sex (female)	0.44	0.09	4.94	<.001
Age (years)	0.69	0.02	31.54	<.001
ppm F	–0.59	0.19	–3.01	.004
Fluoride drops	0.13	0.18	0.72	.475
Fluoride tablets	–0.52	0.22	–2.31	.026
Professional fluoride treatment	0.34	0.09	3.77	<.001
School fluoride rinses	–0.01	0.17	–0.08	.936
ppm F * fluoride tablets	0.94	0.30	3.19	.003

*US schoolchildren aged 5–17 years with a history of a single residence (n=18,165). R^2=0.258.

TABLE 5
Distribution and Mean of Fluorosis Severity Scores, and Fluorosis Prevalence, by Water Fluoridation Status*

			Fluorosis Severity (%)						Mean Severity¶	% Fluorosis§
	n†	*N* %‡	0	0.5	1	2	3	4	(SE)	(SE)
<0.3 ppm F	6,239	35.2	59.8	26.6	10.7	2.4	0.4	0.1	0.30 (0.03)	13.5 (1.9)
0.3 – <0.7 ppm F	1,793	10.4	47.4	31.0	17.3	3.1	1.2	0.0	0.43 (0.08)	21.7 (6.0)
0.7–1.2 ppm F	6,728	51.1	33.6	36.5	22.5	5.8	1.3	0.0	0.58 (0.04)	29.9 (3.4)
>1.2 ppm F	772	3.3	28.1	30.5	27.2	7.0	5.3	2.0	0.80 (0.10)	41.4 (4.4)
All	15,532	100	44.1	32.3	17.9	4.3	1.1	0.3	0.47 (0.04)	23.5 (2.6)

*Scores are standardized to the age and sex distribution of US schoolchildren aged 7–17 years who had a history of a single residence.
†Sample size.
‡Weighted population percentage.
¶Determined as Dean's CFI (Dean, 1942).
§Having at least two teeth with Dean's fluorosis score 1 (very mild) or greater.

were not significantly associated with fluorosis severity or prevalence and were not included in the final models. Variables for region of residence were significant, but were not included in the final models due to multicollinearity with the water fluoride variables. Fluoride product exposures were described by dichotomous variables representing whether or not the child had ever used that fluoride product. A linear regression model for fluorosis severity showed similar results to the logistic regression model for prevalence and is therefore not described.

Table 6 uses three indicator variables to represent 0.3 to <0.7 ppm F, 0.7–1.2 ppm F, and >1.2 ppm F fluoride level groups with <0.3 ppm F as the referent group. This model indicates that controlling for age and fluoride product use, children who consumed water at 0.3 to <0.7 ppm F, 0.7–1.2 ppm F, or >1.2 ppm F had respective odds ratios (ORs) of 2.07 (95% CI=0.92, 4.67), 3.32 (2.25, 4.91), and 4.96 (2.87, 8.58) for developing fluorosis compared to children who consumed water at <0.3 ppm F. Fluoride drop use was significantly associated with fluorosis (overall OR=1.49; 95% CI=1.11, 1.99).

Discussion

While our restriction of the analyses to those children who resided at a single residence for their whole life necessarily reduces the generalizability and external validity of the findings, the reliability and internal validity of the results are enhanced. Recall errors in the questionnaire data were likely to introduce random error, rather than bias, and therefore should not affect our findings adversely.

An important methodologic issue was our use of the fluoride level of school water to determine the child's water fluoride status. This approach assumes that the children were exposed to the same fluoride level at home as at school. While this may not always be the case, the alternative of trying to determine water fluoride level from the residential histories was seen as a less reliable method of determining exposure to fluoride from water. Using the residential data provides only an indication of whether or not that community was listed as being optimally fluoridated in the 1985 Fluoridation Census (18), but not the actual fluoride level. Any error intro-

FIGURE 2
Fluorosis Prevalence and Mean Severity Scores by Water Fluoridation Level for US Schoolchildren Aged 7–17 Years with a History of a Single Residence (Scores are age- and sex-standardized to children aged 5–17 years with a history of a single residence. Fluorosis prevalence was defined as having two or more teeth with very mild fluorosis or greater; mean severity scores were derived in a manner similar to Dean's CFI scores.)

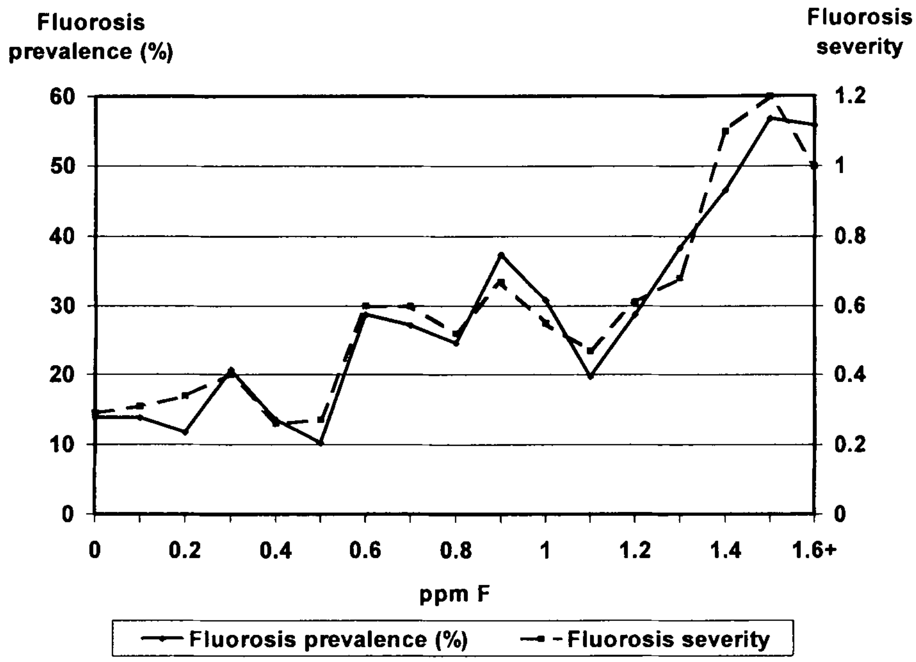

FIGURE 3
Fluorosis Prevalence and Mean Severity Scores for US Schoolchildren Aged 7–17 Years by Age with a History of a Single Residence (Fluorosis prevalence was defined as having two or more teeth with very mild fluorosis or greater; mean severity scores were derived in a manner similar to Dean's CFI score.)

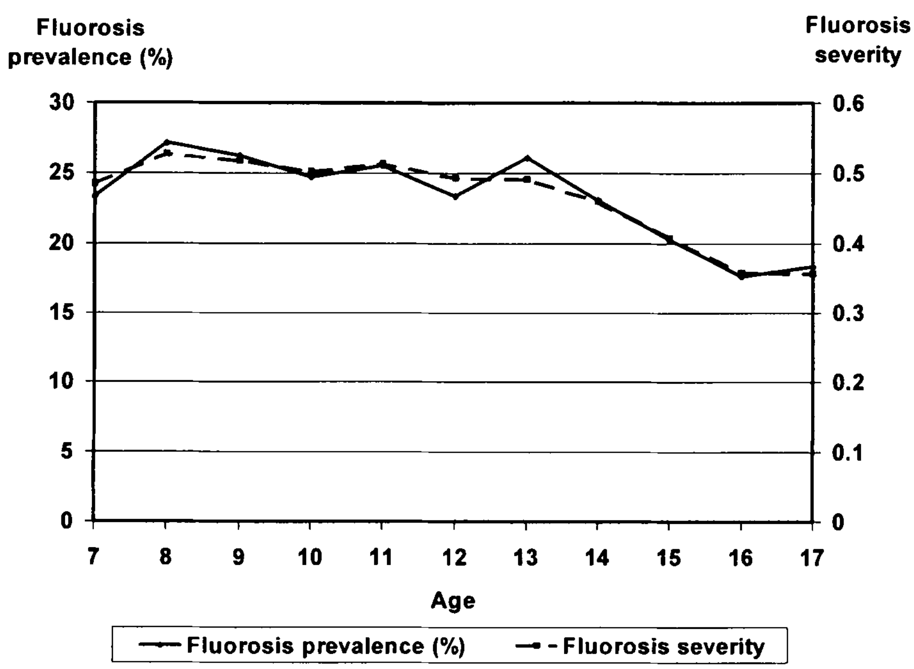

TABLE 6
Logistic Regression Model of Fluorosis Prevalence (Very Mild or Greater), Using Categorical Levels for Water Fluoride Concentration*

Variable	Regression Coefficient	SE	*T*-test	*P*-value	Odds Ratio (95% CI)
Intercept	−1.51	0.27	−5.57	<.001	
Age (years)	−0.05	0.02	−3.15	.003	0.95 (0.92, 0.98)
<0.3 ppm F	Referent				1.00
0.3– < 0.7 ppm F	0.73	0.41	1.79	.079	2.07 (0.92, 4.67)
0.7–1.2 ppm F	1.20	0.19	6.18	<.001	3.32 (2.25, 4.91)
>1.2 ppm F	1.60	0.27	5.88	<.001	4.96 (2.87, 8.58)
Fluoride drops	0.40	0.14	2.76	.008	1.49 (1.11, 1.99)
Fluoride tablets	0.18	0.11	1.64	.108	1.20 (0.96, 1.49)
Professional F treatment	0.04	0.10	0.44	.662	1.05 (0.85, 1.28)
School fluoride rinses	0.13	0.15	0.85	398	1.14 (0.84, 1.55)
0.3– <0.7 ppm F * fluoride drops	−0.31	0.35	−0.89	.376	0.73 (0.37, 1.47)
07–1.2 ppm F * fluoride drops	−0.53	0.19	−2.79	.008	0.59 (0.40, 0.86)
>1.2 ppm F * fluoride drops	0.02	0.27	0.06	.952	1.02 (0.59, 1.74)
-2 * normalized log-likelihood with betas=0			20,851.3		
-2 * normalized log-likelihood full model			15,778.0		
Approximate chi-square			5,073.3		
Degrees of freedom			7		
Approximate *P*-value			<.01		

*US schoolchildren aged 7–17 years with a history of a single residence (n=15,041).

duced by the assumption that children consumed water with the same fluoride level at home and at school would introduce imprecision rather than bias. As will be discussed later, the results from this study agree closely with those from the previous analyses using residential histories as an indicator of fluoride status (7,19). This agreement demonstrates good criterion-based validity of the fluoride assessments.

The regression models were able to explain only a small portion of the variance in caries and fluorosis, indicating that other explanatory factors are involved in the caries and fluorosis process that were not measured in this survey. Some of these are fluoride toothpaste use, toothbrushing frequency, fluoride content of the infant and childhood diets, and socioeconomic status indicators. These factors are associated with caries and fluorosis (20-23). While our analysis would have been more complete if these factors had been available, we do not see their absence as a critical limitation.

Increasing water fluoride level was consistently and strongly associated with lower dfs and DMFS scores as shown in the age- and sex-stratified analyses (Tables 1–4 and Figure 1). Brunelle and Carlos (7), from this same data set, used residence history to determine water fluoride status. They detected a 17.7 percent difference in DMFS between children in nonfluoridated (DMFS=3.39) and fluoridated (DMFS=2.79) communities. This finding is similar to the 17.9 percent difference that was computed in this study, and is similar to differences in caries experience found between fluoridated and nonfluoridated communities in recent studies (22,24-29). In an extensive review of studies conducted between 1979 and 1989, Newbrun (30) found differences of 15–35 percent in DMFS between fluoridated and low-fluoride communities. The smaller differences between caries experience in fluoridated and nonfluoridated areas does not mean that water fluoridation is currently less effective than it was in the past. Instead, it reflects the extensive use of fluoride products in all communities, and the widespread diffusion of fluoride from foods and drinks processed in fluoridated areas.

Dean's 21 cities study demonstrated that caries reductions diminished beyond approximately 1.0–1.2 ppm F (31-33). Eklund and Striffler (34,35), however, in plotting the same data but with fluoride level adjusted for annual mean temperature, found little reduction in caries prevalence as the fluoride concentration increased above 0.7 ppm F. In our analysis, most of the caries reductions in both dentitions occurred between 0 and 0.7 ppm F (Figure 1), with little evidence of increased cariostatic benefit beyond this level. The possible shifting of the caries/water fluoridation curve to the left from Dean's time could be due to today's increased fluoride exposure from sources other than drinking water.

The use of fluoride supplements was associated with lower caries levels, but to a lesser extent than water fluoridation. This finding agrees with several other recent reports (27,36-38). In this study, school fluoride rinses were not associated with lower caries experience. While several studies found significant caries reductions with the use of these products (39,40), other field studies were not able to demonstrate significant benefits (41,42). The association detected between professional fluoride treatments and higher caries levels may represent a treatment effect: children might have received professional fluoride treatments as a response to high caries levels. The nature of these data, however, do not allow further assessment of this supposition.

While fluoride toothpaste use was not investigated in this survey, it is considered to be one of the most important factors in global reductions in reduced caries experience (43). For this investigation, we considered fluoride from fluoride toothpaste as part of the total background fluoride to which almost all North American children are exposed.

Water fluoride level was consistently and strongly associated with fluorosis prevalence and severity in this study (Tables 5–6 and Figure 2). The overall prevalence of fluorosis at the very mild or greater level was 23.5 percent for continuous residence children, similar to the figure of 22.3 percent determined by Brunelle (19) for all of the surveyed children (not just continuous residents). In our study, children who consumed water with <0.3 ppm F had a fluorosis prevalence of 13.5 percent, while children who consumed water with 0.7–1.2 ppm F had a fluorosis prevalence of 29.9 percent. Other fluorosis studies conducted in the 1980s that used Dean's Index found fluorosis prevalence in communities with very low water fluoride levels ranging from 3–9 percent, while communities with 0.7–1.2 ppm F water had fluorosis prevalences ranging from 15–40 percent (44-47).

Fluorosis prevalence and severity were greater in younger than in older children (Table 6 and Figure 3). Due to the cross-sectional nature of these data, it is not possible to determine whether this finding represents a diminution of the fluorotic markings on the teeth as children grow (such as by attrition, erosion, abrasion, or remineralization) or whether there has been a secular increase in fluorosis in the 10-year age span between the youngest and oldest children in the study. Heifetz et al. (48) did not find a diminution in fluorosis on teeth followed for five years. A secular trend of increasing fluorosis is possible, as several studies and reviews (9-12) have reported an increase in dental fluorosis not only since Dean's time, but also in the past two decades. More research, including longitudinal studies, is called for to help explain this phenomenon of decreased fluorosis with increasing age.

Among the fluoride products, only fluoride drops were found to be significantly associated with fluorosis prevalence or severity. This finding is in accord with the considerable body of literature describing the risk of fluorosis from the use of fluoride supplements in the early childhood years (49).

Because of the dose-response relationship between fluoride and fluorosis, it is likely that some degree of fluorosis will occur at even low levels of fluoride exposure (50). Therefore, any level of water fluoridation will necessarily involve a trade-off between obtaining a desired caries reduction with an acceptable level of concomitant fluorosis. The "optimal" concentration for water fluoridation has commonly been determined by the intersection of the caries and fluorosis lines plotted against water fluoride level (34,51), although Dean himself never plotted caries and fluorosis together on one chart. This intersection of caries and fluorosis curves, by itself, has little significance because of its dependency on the scales used for the two Y axes; alteration of the scales can produce quite different effects. For that reason we did not plot caries against fluorosis.

Using data from the 21 cities studies conducted in 1939 to 1941, Dean concluded that the fluorosis and DMFT curves showed a suitable compromise between sufficient caries reduction and acceptable fluorosis at about 1–1.2 ppm F. From our data, however, a suitable trade-off between fluorosis and caries now appears to be around 0.7 ppm F. At this level, caries experience and fluorosis severity appear to be as low or lower than that seen at 1.0 ppm F.

As stated by Leverett in 1991 (51), "We need to acknowledge that fluoride is no different from many other chemicals deliberately introduced into our environment, in the sense that we should strive to maintain the lowest level capable of producing the desired therapeutic effect." In consideration of the currently understood mechanisms of cariostasis and fluorosis, our efforts should be focused on minimizing levels of ingested fluorides. The control of fluoride levels in infant formulas, the recent reductions in the fluoride supplement schedule, and the calls for lower fluoride pediatric toothpastes are all laudable efforts. We cannot, however, ignore water fluoridation as a major source of ingested fluoride.

The major finding of this paper was that little decline in caries levels was observed between 0.7 and 1.2 ppm F, while considerable dental fluorosis was seen at this water fluoride level. Current standards for water fluoridation in the United States have stood since 1962. Many things have changed since then, however, and these data suggest that perhaps it is time to reconsider these standards.

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