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The association between enamel fluorosis and dental caries in U.S. schoolchildren

Hiroko Iida, DDS, MPH; Jayanth V. Kumar, DDS, MPH

The use of fluoride is the only known practical measure for controlling dental caries at the population level. However, the ingestion of fluoride during the development of teeth is associated with an increased risk of development of enamel fluorosis. Whereas enamel fluorosis is not considered an adverse health effect by national agencies,^{1,2} the National Research Council's (NRC) 2006 report titled *Fluoride in Drinking Water: A Scientific Review of EPA's Standards* recommended that severe enamel fluorosis be considered an adverse health effect.³ This NRC recommendation was based primarily on the conclusion that the hypothesis of a causal relationship between severe enamel fluorosis and caries is plausible, and the evidence for that is mixed but supportive.³ The authors of the NRC report, however, considered the effect of only severe fluorosis on caries; focused on the studies conducted in areas in which the water fluoride level was greater than optimal; excluded normal teeth without fluorosis from its assessment; and did not consider the potential benefits that milder forms of enamel fluorosis confer in terms of dental caries prevention.

Although the milder forms of fluorosis typically are not noticeable to laypeople,⁴ questions about the clinical significance of enamel fluorosis often are raised by policy-

ABSTRACT

Background. The authors assessed the association between enamel fluorosis and dental caries to determine if there is any beneficial effect of enamel fluorosis in U.S. schoolchildren.

Methods. The authors used data from a National Institute of Dental Research survey of the oral health of U.S. children conducted in 1986 and 1987 to determine the prevalence of caries and mean decayed, missing or filled surfaces on permanent maxillary right first molars in children 7 to 17 years of age who had a history of a single residence. (To date, this is the only national oral health data set in the United States with detailed information on fluoride exposures.) They examined the association between enamel fluorosis and caries using logistic regression analysis, controlling for potential confounders in communities with water at or above optimal fluoridation levels and in communities with nonfluoridated or suboptimally fluoridated water.

Results. Permanent maxillary right first molars with fluorosis consistently had lower levels of caries experience than did normal molars. Adjusted odds ratios for caries prevalence in molars with fluorosis were 0.71 (95 percent confidence interval [CI], 0.56-0.89) in communities with nonfluoridated or suboptimally fluoridated water and 0.89 (95 percent CI, 0.74-1.06) in communities with water at or above optimal fluoridation levels.

Conclusion. This study's findings suggest that molars with fluorosis are more resistant to caries than are molars without fluorosis.

Clinical Implications. The results highlight the need for those considering policies regarding reduction in fluoride exposure to take into consideration the caries-preventive benefits associated with milder forms of enamel fluorosis.

Key Words. Enamel fluorosis; dental caries; fluoridation.

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makers as societal demand for esthetically pleasing dental appearance has increased.⁵ A 2002 national survey found that the prevalence of enamel fluorosis (all levels of severity combined) among 6- to 19-year-old people in the United States had increased from 23 percent in the 1986-1987 survey period to 32 percent in the 1999-2002 survey period.⁴ When the optimal level of fluoride in drinking water was established in the United States, it was done to achieve maximal caries protection with a minimal amount of enamel fluorosis in the population.⁶ In the 1950s, it was anticipated that about 10 percent of the population would experience milder forms of enamel fluorosis with the introduction of water fluoridation.⁶ This was considered a suitable trade-off, as dental caries was a widespread disease in the early 20th century⁴ and an inverse relationship between “mottled teeth” and caries was evident from Dean’s ecological studies of the 1930s.⁷ The question as to whether enamel fluorosis might have any beneficial effect in today’s low-caries U.S. environment, however, has not been answered adequately. It is important, therefore, to investigate the relationship between enamel fluorosis and dental caries to better facilitate the discussion with regard to the trade-off between the benefit and risk of recommended levels of fluoride exposure.

The association between enamel fluorosis and caries risk has been investigated at different levels of fluoride exposure: population, person and tooth.^{8,9} The studies that focus on tooth-level analysis are the strongest,⁸ as the exposure measurement defined as the prevalence of enamel fluorosis at the population and person levels may lead to misclassification errors owing to the ecological nature of such assessments. Therefore, we evaluated the tooth-level association between enamel fluorosis and dental caries in permanent first molars by using the data from a large national survey.

SUBJECTS, MATERIALS AND METHODS

We used the publicly available data from the survey titled Oral Health of United States Children: The National Survey of Oral Health of U.S. School Children—1986-1987,¹⁰ conducted by what then was known as the National Institute of Dental Research (NIDR) (now the National Institute of Dental and Craniofacial Research). This survey is the only national oral health data set in the United States with detailed information

regarding fluoride exposures, enamel fluorosis and caries in large numbers of U.S. school-children ($n = 40,693$). Results regarding the association between fluoridation status and dental caries and enamel fluorosis have been published; therefore, we do not discuss them here.^{10,11}

Fluorosis and dental caries data. Details of the dental examination, sampling and procedures of this survey have been described elsewhere.¹⁰⁻¹² In summary, 14 field examiners assessed the caries status of coronal tooth surfaces and the presence of dental sealants by using a visual and tactile assessment, but without using radiographs. Examiners evaluated the presence of fluorosis in fully erupted permanent teeth in children in grades 2 through 12 of which no more than one-half of the visible surface was obscured by a restoration, caries or an orthodontic appliance. They examined each tooth by using a good source of artificial light and assigned each tooth to one of six categories (normal [no fluorosis], questionable, very mild, mild, moderate or severe fluorosis) in Dean’s fluorosis index.¹³ The details of the reliability of examinations for enamel fluorosis and caries are described elsewhere.¹¹

Demographic, residential history and water fluoride data. Parents or guardians of the children surveyed completed a written questionnaire that included questions regarding their child’s age, sex, race or ethnicity and residential history. Survey personnel obtained a 500-milliliter water sample from each surveyed school and analyzed it in a laboratory for fluoride content.

Study subpopulation and analyses. To improve the validity of information about water fluoride content, we included in our analyses only children 7 to 17 years of age who had a history of a single continuous residence. As a result of these restrictions, a total of 16,873 children 7 to 17 years of age were available for further analyses.

We first estimated the mean count of permanent decayed, missing or filled surfaces (DMFS) and the prevalence of caries experience (percentage with DMFS > 0) for the sample children according to study variables such as fluorosis status, age, sex, race or ethnicity, metropolitan

ABBREVIATION KEY. **DMFS:** Decayed, missing or filled surfaces. **DMFS₃:** Decayed, missing and filled surfaces of permanent maxillary right first molars. **NIDR:** National Institute of Dental Research. **NRC:** National Research Council. **ppm:** Parts per million.

status, region in which the child's school was located and water fluoride content (in parts per million [ppm]) at the school. We based the child-level case definition of fluorosis on the highest Dean's fluorosis index score assigned to at least two teeth in a child. We determined each school's metropolitan status from the 1985 Quality Education Data.¹⁰

To analyze the association between enamel fluorosis and dental caries at the tooth level, we focused our analysis on the permanent maxillary right first molar (tooth no. 3) as a response variable. We selected this tooth as an index tooth for several reasons:

- selection of multiple teeth from a single person leads to difficulties in estimating standard errors owing to clustering of teeth;
- the permanent first molar is one of the teeth most susceptible to dental caries and fluorosis;
- there is no preceding primary tooth and, therefore, no chance that a primary tooth could affect (either positively or negatively) the eruption and formation of the permanent first molar;
- all four permanent first molars presented similar patterns of caries experience and enamel fluorosis, according to our preliminary analysis;
- focusing on late-erupting teeth leads to exclusion of younger children and thus to a reduced sample size.

Before selecting an index tooth, we also evaluated the prevalence of enamel fluorosis and caries in permanent maxillary right central incisors, but the prevalence of caries was low. Approximately 99 percent of permanent maxillary right central incisors had no caries, and 15 percent had enamel fluorosis.

At the tooth level, we performed bivariate analysis relating mean DMFS (hereafter referred to as "mean DMFS₃," to indicate the DMFS of tooth no. 3) and caries prevalence in the index tooth (refers to percentage with DMFS₃ > 0) to enamel fluorosis and potential covariates such as age, sex, race or ethnicity, water fluoride content, metropolitan status, school region and sealant status. We further evaluated the association between enamel fluorosis and DMFS₃ and the prevalence of caries in the bivariate analysis, which was stratified by the level of fluoride in school water (the levels assigned were < 0.3, 0.3 to < 0.7, 0.7-1.2 and > 1.2 ppm). We explored the tooth-level association between enamel fluorosis and caries in the index tooth using the logistic regression analysis, controlling for the potential

confounders separately for two water fluoride-level strata (< 0.7 ppm, suboptimal level; ≥ 0.7 ppm, optimal level or higher). As the DMFS₃ count was largely zero or one, we performed regression analysis for the caries prevalence only. Furthermore, only about 3 percent of all teeth had more than three affected carious surfaces. We used water fluoride levels for stratification to control for the influence of posteruptive exposure to water fluoride. Because of uncertainty associated with Dean's "questionable" fluorosis category, we excluded it in the logistic regression analyses. We examined adjusted odds ratios (AORs) and statistical significance from the test for β coefficients and Wald F tests. We used SUDAAN version 9.0.1 (Research Triangle Institute, Research Triangle Park, N.C.) to estimate appropriate variances for all of the analyses, including bivariate analysis and multivariable logistic regressions. We weighted the results to be representative of the population of U.S. schoolchildren according to the sampling weights provided by the NIDR.

RESULTS

Table 1 shows the characteristics of the selected sample according to study variables. Mean DMFS of permanent teeth was consistently lower in children with enamel fluorosis when compared with that in children without enamel fluorosis. Table 2 (page 859) shows the distribution of permanent maxillary right first molars according to study variables for caries prevalence and mean DMFS₃. An estimated 35 percent of permanent maxillary right first molars had caries experience, and an average of 0.6 surfaces per tooth were affected by caries. Molars without fluorosis had a higher count of DMFS₃ and a higher prevalence of caries than did molars with fluorosis. The degree of fluorosis exhibited an inverse dose-response relation to both mean DMFS₃ and the prevalence of caries. When we stratified the data with fluoride level in school water, the molars without fluorosis also had greater DMFS₃ and higher caries prevalence than did the molars with fluorosis (very mild to severe), regardless of water fluoride level. Other variables associated with caries prevalence and mean DMFS₃ in permanent maxillary right first molars were age, sex, metropolitan status, school region and sealant status.

Tables 3 and 4 (pages 860 and 861, respectively) show the results of logistic regression analyses for caries prevalence. Permanent maxillary right first molars with fluorosis in children in

TABLE 1

Weighted child-level estimates of caries prevalence and mean DMFS* of permanent teeth, according to study variables (n = 16,873).†

VARIABLE	SAMPLE SIZE	CARIES PREVALENCE % (SE‡)	P VALUE	MEAN DMFS (SE)	P VALUE
Total No. of Subjects	16,873	54.8 (0.5)		3.31 (0.1)	
Degree of Fluorosis[§]			.01		.006
Normal	8,261	54.3 (0.7)		3.56 (0.1)	
Questionable	5,089	56.3 (0.9)		3.24 (0.1)	
Very mild	2,685	55.4 (1.2)		2.97 (0.1)	
Mild	602	48.1 (2.5)		2.40 (0.2)	
Moderate	190	45.9 (4.5)		2.64 (0.5)	
Severe	46	52.6 (8.9)		2.24 (0.5)	
Fluorosis Status, According to Water Fluoride Content (Parts Per Million)[¶]					
< 0.3			< .001		< .001
Normal	3,921	54.9 (1.1)		3.78 (0.1)	
Questionable	1,818	60.1 (1.6)		3.67 (0.2)	
Fluorosis present#	981	49.3 (2.3)		2.57 (0.2)	
0.3 to < 0.7			.04		.02
Normal	1,084	54.7 (1.9)		3.66 (0.2)	
Questionable	507	59.0 (2.6)		3.60 (0.3)	
Fluorosis present	388	48.4 (3.3)		2.70 (0.3)	
0.7 to 1.2			.5		.02
Normal	2,875	54.1 (1.2)		3.35 (0.1)	
Questionable	2,493	53.8 (1.2)		2.96 (0.1)	
Fluorosis present	1,809	55.7 (1.4)		2.96 (0.1)	
> 1.2			.06		.40
Normal	248	52.3 (3.8)		2.96 (0.3)	
Questionable	236	64.1 (4.0)		3.39 (0.4)	
Fluorosis present	329	54.0 (3.4)		2.81 (0.3)	
Age (Years)			< .001		< .001
7-11	8,918	35.4 (0.6)		1.27 (0.0)	
12-17	7,955	74.0 (0.7)		5.33 (0.1)	
Sex			< .001		< .001
Male	8,385	52.6 (0.7)		3.07 (0.1)	
Female	8,488	57.1 (0.7)		3.56 (0.1)	
Race/Ethnicity			.008		< .001
White, non-Hispanic	11,370	55.8 (0.6)		3.16 (0.1)	
African-American, non-Hispanic	2,713	53.4 (1.1)		3.63 (0.1)	
Hispanic	2,272	51.6 (1.3)		3.20 (0.1)	
Other	518	58.3 (2.7)		4.36 (0.4)	
Metropolitan Status			.009		.04
Metropolitan	9,562	54.2 (0.6)		3.26 (0.1)	
Nonmetropolitan	7,311	56.8 (0.8)		3.47 (0.1)	
School Region			< .001		.004
New England	1,781	58.6 (1.8)		3.59 (0.2)	
Northeast	3,257	57.4 (1.1)		3.58 (0.1)	
Midwest	3,423	55.3 (1.0)		3.28 (0.1)	
Southeast	2,948	55.7 (1.0)		3.30 (0.1)	
Southwest	1,627	48.5 (1.5)		2.85 (0.2)	
Northwest	2,191	54.4 (1.3)		2.90 (0.1)	
Pacific	1,646	50.4 (1.7)		3.43 (0.2)	

* DMFS: Decayed, missing and filled surfaces.

† Source: National Institute of Dental Research, Epidemiology and Oral Disease Prevention Program.¹⁰

‡ SE: Standard error.

§ Determined according to the highest score on the Dean's fluorosis index¹³ assigned to at least two teeth in a child.

¶ Measured in water samples taken from subjects' schools. Total may not add up to N because of missing data.

Scores on Dean's fluorosis index¹³ ranged from very mild to severe.

TABLE 2

Weighted tooth-level estimates of caries prevalence and mean DMFS₃* according to study variables (n = 16,873).†					
VARIABLE	SAMPLE SIZE	CARIES PREVALENCE (SE‡)	P VALUE	MEAN DMFS₃ (SE)	P VALUE
Total No. of Subjects	16,873	34.9 (0.50)		0.57 (0.01)	
Degree of Fluorosis[§]			< .001		< .001
Normal	8,143	39.9 (0.72)		0.64 (0.01)	
Questionable	4,110	33.2 (0.92)		0.51 (0.02)	
Very mild	2,036	32.2 (1.37)		0.49 (0.02)	
Mild	454	25.7 (2.65)		0.43 (0.05)	
Moderate	110	20.1 (4.31)		0.30 (0.07)	
Severe	31	15.9 (7.16)		0.24 (0.12)	
Fluorosis Status, According to Water Fluoride Content (Parts per Million)[¶]					
< 0.3			< .001		< .001
Normal	3,839	40.2 (1.09)		0.66 (0.02)	
Questionable	1,383	35.8 (1.80)		0.56 (0.03)	
Fluorosis present [#]	731	28.4 (2.34)		0.43 (0.04)	
0.3 < 0.7			< .01		< .001
Normal	1,017	38.9 (1.90)		0.62 (0.03)	
Questionable	360	31.3 (2.95)		0.46 (0.05)	
Fluorosis present	308	26.6 (3.47)		0.38 (0.06)	
0.7-1.2			< .001		< .001
Normal	2,903	40.3 (1.15)		0.63 (0.02)	
Questionable	2,121	32.5 (1.20)		0.49 (0.02)	
Fluorosis present	1,326	31.6 (1.56)		0.50 (0.03)	
> 1.2			.16		.10
Normal	254	39.1 (3.54)		0.63 (0.06)	
Questionable	220	31.4 (3.93)		0.52 (0.07)	
Fluorosis present	262	30.2 (3.62)		0.48 (0.07)	
Age (Years)			< .001		< .001
7-11	8,918	18.7 (0.52)		0.28 (0.01)	
12-17	7,955	51.1 (0.74)		0.86 (0.02)	
Sex			< .001		< .001
Male	8,385	33.2 (0.67)		0.54 (0.01)	
Female	8,488	36.8 (0.68)		0.60 (0.01)	
Race/Ethnicity			< .001		.4
White, non-Hispanic	11,370	36.6 (0.61)		0.58 (0.01)	
African-American, non-Hispanic	2,713	32.1 (1.05)		0.56 (0.02)	
Hispanic	2,272	32.4 (1.27)		0.53 (0.02)	
Other	518	33.5 (2.55)		0.57 (0.05)	
Metropolitan Status			.02		.04
Metropolitan	9,562	34.4 (0.57)		0.56 (0.01)	
Nonmetropolitan	7,311	36.7 (0.83)		0.60 (0.02)	
School Region			< .001		< .001
New England	1,781	42.7 (1.87)		0.67 (0.03)	
Northeast	3,257	35.9 (1.09)		0.58 (0.02)	
Midwest	3,423	37.0 (0.99)		0.60 (0.02)	
Southeast	2,948	34.4 (1.00)		0.55 (0.02)	
Southwest	1,627	28.3 (1.37)		0.47 (0.03)	
Northwest	2,191	33.9 (1.25)		0.54 (0.02)	
Pacific	1,646	32.8 (1.60)		0.59 (0.03)	
Sealant Status			< .001		< .001
Fully sealed	174	4.30 (1.91)		0.05 (0.03)	
Partially sealed	657	8.90 (1.40)		0.12 (0.02)	
Not sealed	16,042	36.3 (0.49)		0.59 (0.01)	

* DMFS₃: Decayed, missing or filled surfaces of permanent maxillary right first molars.
 † Source: National Institute of Dental Research, Epidemiology and Oral Disease Prevention Program.¹⁰
 ‡ SE: Standard error.
 § According to Dean's fluorosis index.¹³
 ¶ Measured in water samples taken from subjects' schools. Total may not add up to N because of missing data.
 # Scores on the index ranged from very mild to severe.

communities with lower water fluoride concentration (< 0.7 ppm) had decreased odds of having caries as compared with molars without fluorosis (AOR, 0.71; 95 percent CI, 0.58-0.89; P = .003) (Table 3). Although we observed a similar trend

in communities with fluoridated water (≥ 0.7 ppm), the OR was not statistically significant (AOR, 0.89; 95 percent CI, 0.74-1.06; P = .18) (Table 4). Factors such as younger age, African-American compared with white race and the pres-

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TABLE 3

Logistic regression for caries prevalence in permanent maxillary right first molars in locations with nonoptimal water fluoride content (< 0.7 ppm*) (n = 5,893).†

VARIABLE	AOR‡	95% CONFIDENCE INTERVAL
Degree of Fluorosis		0.56-0.89
Normal	1.00	
Fluorosis present§	0.71	
Age (Years)		0.22-0.31
7-11	0.26	
12-17	1.00	
Sex		0.75-1.02
Male	0.88	
Female	1.00	
Race/Ethnicity		
White, non-Hispanic	1.00	
African-American, non-Hispanic	0.72	0.57-0.91
Hispanic	0.99	0.79-1.26
Other	1.02	0.70-1.49
Metropolitan Status		0.95-1.35
Metropolitan	1.13	
Nonmetropolitan	1.00	
School Region		
New England	1.00	
Northeast	0.76	0.56-1.05
Midwest	1.14	0.78-1.65
Southeast	0.84	0.60-1.17
Southwest	0.55	0.38-0.81
Northwest	0.81	0.58-1.12
Pacific	0.66	0.47-0.93
Sealant Status		0.05-0.22
Sealed¶	0.10	
Not sealed	1.00	

*r*² 0.122636; -2 × normalized log-likelihood with intercepts only: 7,835.39; -2 × normalized log-likelihood full model: 7,064.13; approximate χ^2 (-2 × log-L ratio): 771.26; degrees of freedom: 10; approximate *P* value: < .01.

* ppm: Parts per million.
 † Source: National Institute of Dental Research, Epidemiology and Oral Disease Prevention Program.¹⁰
 ‡ AOR: Adjusted odds ratio.
 § Scores on Dean's fluorosis index¹³ ranged from very mild to severe.
 ¶ Sealed either fully or partially.

ence of a sealant were associated with decreased odds of having caries experience in permanent maxillary right first molars regardless of the fluoride level in school water. Children attending school in the Southwest region consistently had a lower prevalence of caries and lower mean DMFS₃ in both bivariate and multivariate analyses.

DISCUSSION

Our analysis showed that first permanent molar teeth with fluorosis consistently had lower caries experience than did molars without fluorosis. These data are consistent with those of two pre-

vious studies conducted in the United States that showed that teeth with mild fluorosis are more resistant to caries.^{8,9} Our finding that even molars with moderate-to-severe fluorosis had lower caries prevalence than did teeth without fluorosis is consistent with that reported by Eklund and colleagues.⁸ In contrast, Driscoll and colleagues⁹ found a higher proportion of teeth with severe fluorosis to be decayed or filled, a finding they attributed to pitting of teeth, staining of teeth or both. Such surface imperfections are not present in teeth with mild fluorosis.

The chemical, morphological and histologic characteristics of molars with fluorosis may explain the reduced caries experience found in this study. First, the presence of enamel fluorosis is a marker of meaningful fluoride exposure during the development of teeth. Also, a higher concentration of fluoride in the enamel is likely to provide resistance to acid attack and promote remineralization.¹⁴ Finally, posteruptive mechanical attrition may lead to morphological alterations that may make the fissures less susceptible to caries attack.^{14,15} Previous studies that investigated the surface-specific effect of waterborne fluoride reported that high pre-eruptive exposure to fluoride significantly lowered the risk of developing pit-and-fissure caries.^{16,17} It has been speculated that the pits and fissures in molars (especially deep fissures) offer physical conditions less favorable for the posteruptive uptake of fluoride ions and may receive a relatively smaller beneficial effect from posteruptive fluoride on the occlusal surface than

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on the other surfaces.^{16,18}

In communities with fluoridated water (≥ 0.7 ppm), the protective effect of enamel fluorosis was observable, but the statistical significance was borderline. This could be explained partly by the pre-eruptive and posteruptive protective effect of community-water fluoride on molars without fluorosis as well. Another issue is that the diagnosis of enamel fluorosis is subject to misclassification error.³ In such a case, the association between enamel fluorosis and dental caries is attenuated if it is assumed that such a misclassification is nondifferential.

Cross-sectional studies generally are limited in their ability to determine whether the exposure of interest occurred before the outcome under study. In this study, we know that enamel fluorosis occurred during enamel formation and thus preceded the development of caries. However, the presence of enamel fluorosis does not necessarily mean that fluoride exposure at the level that resulted in fluorosis was sporadic, nor does it mean it was continuous throughout the child's life. The occurrence of enamel fluorosis indicates that the tooth was exposed to a relatively high level of fluoride during enamel formation. As such, a tooth with fluorosis can be considered a marker for meaningful fluoride exposure. Our attempt to control the influence of posteruptive exposure to fluoride in water has a limitation owing to the use of the fluoride level of school water as a variable, because the exposure from fluoride at the children's residences is not known. If such errors occurred, they could have led to imprecise estimates.¹¹

Although the data we evaluated were from the late 1980s, we believe that the association between enamel fluorosis and caries found in this study still is applicable to today's environment. Dental caries in children has declined, but it still affects 68 percent of 16- to 19-year-olds as opposed to 84 percent of 17-year-olds in the 1980s.^{4,12} By the mid-1980s, fluoride-containing dentifrices accounted for nearly 90 percent of all dentifrices sold in the United States.¹² In addition,

the increased prevalence of enamel fluorosis in communities with nonfluoridated or suboptimally fluoridated water was evident by the late 1980s.¹ Therefore, it is reasonable to assume that all children in this study—those living in communities with water fluoridation at or above optimal levels, as well as those living in communities with nonfluoridated or suboptimally fluoridated water—were exposed to fluoride from sources other than water, at least to some degree, as children today generally are. We could not use more recent national surveys, because they do not con-

TABLE 4

Logistic regression for caries prevalence in permanent maxillary right first molars in locations of optimal or higher water fluoride content (≥ 0.7 ppm*) (n = 4,745).[†]

VARIABLE	AOR [‡]	95% CONFIDENCE INTERVAL
Degree of Fluorosis		0.74-1.06
Normal	1.00	
Fluorosis present [§]	0.89	
Age (Years)		0.21-0.29
7-11	0.25	
12-22	1.00	
Sex		0.67-0.92
Male	0.79	
Female	1.00	
Race/Ethnicity		0.60-0.92
White, non-Hispanic	1.00	
African-American, non-Hispanic	0.74	
Hispanic	0.79	0.60-1.04
Other	0.91	0.53-1.54
Metropolitan Status		0.81-1.20
Metropolitan	0.99	
Nonmetropolitan	1.00	
School Region		
New England	1.00	
Northeast	0.63	0.44-0.90
Midwest	0.58	0.42-0.79
Southeast	0.50	0.36-0.70
Southwest	0.42	0.28-0.63
Northwest	0.63	0.43-0.91
Pacific	0.22	0.07-0.71
Sealant Status		0.11-0.32
Sealed [¶]	0.19	
Not sealed	1.00	

*r*² 0.128149; -2 × normalized log-likelihood with intercepts only: 6,260.22; -2 × normalized log-likelihood full model: 5,609.50; approximate c2 (-2 × log-L ratio): 650.72; degrees of freedom: 14; approximate *P* value: < .01.

* ppm: Parts per million.
 † Source: National Institute of Dental Research, Epidemiology and Oral Disease Prevention Program.¹⁰
 ‡ AOR: Adjusted odds ratio.
 § Scores on Dean's fluorosis index¹³ ranged from very mild to severe.
 ¶ Sealed either fully or partially.

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tain such data on fluoride exposures.

Many steps have been taken to lower fluoride intake during early childhood with the intention of reducing the occurrence of enamel fluorosis.¹⁹⁻²¹ The concern expressed in the NRC report about the potential for a higher risk of caries development associated with severe forms of enamel fluorosis is of academic interest in areas with fluoridated water, because the recommended concentration is about 1 milligram per liter and the prevalence of severe fluorosis is virtually zero below 2 mg/L of fluoride in water.³ The occurrence of a substantial degree of moderate-to-severe fluorosis on anterior permanent teeth outweighs any additional benefits of protection in posterior teeth and, therefore, should be avoided. However, the effect of the lower caries experience observed among teeth with mild fluorosis on overall health care cost savings could be substantial. According to these data, fluorosis in just four or five permanent first molars in a population may be associated with an average of approximately one fewer DMFS in that population. To produce the same effect, one would have to seal, and maintain sealants on, four to 15 permanent first molars, a process that would cost a great deal more.^{22,23} Therefore, anyone formulating guidance regarding the reduction of fluoride exposures must take into consideration the protection associated with the milder forms of enamel fluorosis.

CONCLUSION

The results of this study suggest that teeth with fluorosis were more resistant to caries in U.S. schoolchildren than were teeth without fluorosis. Our results highlight the need for those considering policies regarding reduction of fluoride exposure to take into consideration the caries-preventive benefits associated with milder forms of enamel fluorosis. ■

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