

# Fluoride exposure and dental fluorosis in Newburgh and Kingston, New York: policy implications

Jayanth V. Kumar and  
Philip A. Swango

Bureau of Dental Health, New York State  
Department of Health, Albany, NY, USA

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**Abstract – Objectives:** This analysis was conducted to determine the changes in the effect of exposure to fluoridation and other sources of fluoride on dental fluorosis in children attending Newburgh and Kingston school districts in New York State. **Methods:** Data for this analysis were obtained from two surveys conducted in the 1986 and 1995 school years. Analyses were limited to 3500, 7–14-year-old lifelong residents of a fluoridated or a nonfluoridated community. Dean's classification and DMFS index were used for recording dental fluorosis and caries, respectively. A questionnaire was used to collect fluoride exposure data. Regression procedures were used to estimate the effect of fluoridation, fluoride supplements, and brushing before the age of 2 years on dental fluorosis. **Results:** Children examined in 1996 were at higher risk for both questionable and very mild to severe dental fluorosis if they received fluoride from water or daily tablet use, or started brushing before the age of 2 years. The increase in risk from 1986 to 1995 was greater for African-American children. **Conclusion:** This analysis showed that the risk of developing dental fluorosis did not decline over time in these communities. Continuous exposure to water fluoridation had an observable effect on dental fluorosis. However, implementation of fluoridation in Newburgh Town did not result in an increase in dental fluorosis prevalence.

Key words: dental caries; dental fluorosis; fluoridation; fluoride exposure

Jayanth V. Kumar, Bureau of Dental Health,  
New York State Department of Health,  
Empire State Plaza Building, Albany,  
NY 12237-0619, USA  
e-mail: jvk01@health.state.ny.us

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Many studies have been conducted in recent years in the United States to determine the prevalence of dental fluorosis. A national survey of schoolchildren conducted in 1986–87 showed that the prevalence of fluorosis ranged from 13.5% to 41.4% depending on the fluoride level in water (1). The occurrence of fluorosis is dependent on exposure to fluoride from sources such as water, dietary supplements, dentifrices, infant formulas, and the risk increases with exposure to multiple sources (2–4). Apart from fluoride intake, a number of factors such as altitude of residence, composition of diet, and altered acid-base status may increase the susceptibility to dental fluorosis

or fluorosis-like lesions (5). Some studies also suggest that African-American children are at higher risk for fluorosis than children of other racial groups (3, 6–8).

Several investigators have attempted to estimate the risk of dental fluorosis in relation to specific sources of fluoride, and study the changes in risk over time. Pendry noted an increase in dental fluorosis in nonfluoridated areas in recent years, and pointed out that the relative risk of developing dental fluorosis in a fluoridated community compared to a nonfluoridated community has diminished accordingly, from 18 four decades ago to 2, today (9). Recently, Heller et al. estimated the odds

ratios associated with water fluoridation in US schoolchildren to be 3.3 (1).

The association between dental fluorosis and fluoride exposure from sources other than drinking water has also been explored. In a Toronto study reported in 1988, Osuji et al. found the odds ratio with the reported use of infant formulas for more than 1 year to be as high as 10.5 (10). Since that time, however, the fluoride content in many of the formulas has been reduced, and Pendrys et al. have reported that this reduction in fluoride has eliminated the risk for dental fluorosis, at least in non-fluoridated populations (11). Fluoride supplements and fluoride in dentifrices have also been shown to increase the risk for fluorosis and therefore may have contributed significantly to the increase in dental fluorosis prevalence (2, 11). Pendrys et al. reported that exposure to supplements according to the older dosage schedule combined with a higher socioeconomic status conferred a 28-fold increase in the risk of developing dental fluorosis, but found a much weaker association in a later study using the revised dosage schedule: for those children who received fluoride supplementation during years 2 to 8, the adjusted odds ratios for Fluorosis Risk Index classification I and II were 2.25 and 7.97, respectively (9, 11). The association between fluoride dentifrice use and dental fluorosis has been less consistent. Ripa's 1991 review of 10 studies did not find an association, but more recent studies have shown an association when brushing was initiated before the age of 2 years (11–13). Although some beverages and fruit juices have been shown to contain fluorides, the risks associated with their use are not known.

Of interest is the impact of recommendations made in the 1980s to reduce fluoride intake on dental fluorosis risk in the United States. In 1979, manufacturers were advised to reduce fluoride in infant formulas (14). Around the same time, the recommended dosage schedule for fluoride dietary supplements was also revised downward (15). Recommendations were also made to give only a pea-size amount of toothpaste to young children and to emphasize the appropriate use of fluoride mouthrinses and topical fluoride applications in dental offices (16). In 1994, the fluoride dosage schedule was further revised (17). Two dental surveys conducted in Newburgh and Kingston, New York, in 1986 and 1995 provide an opportunity to determine whether the risk imposed by fluoride exposure has changed in that time period. Data from these surveys can also assist in determining the effect of

water fluoridation and other known sources of fluoride on dental fluorosis in children attending Newburgh and Kingston school districts.

## Methods

Data for this analysis were obtained from surveys conducted in the 1986 and 1995 school years in the Newburgh and Kingston school districts (18, 19). The analysis is limited to 3500 7–14-year-old life-long residents of Newburgh City, Newburgh Town, New Windsor, Kingston and the town of Ulster. The city of Newburgh was fluoridated in 1945 and has maintained the fluoride level at  $1 \pm 0.2$  mg/L except for a 3-year period from 1978 to 1981. The town of Newburgh is an entirely different municipality that started fluoridation in 1984. The other areas remain nonfluoridated.

The two surveys were similar in design except for the number of children studied. Children who agreed to participate in the study were screened for dental fluorosis and caries on the basis of standardized diagnostic criteria. For recording dental fluorosis, Dean's classification was used at the subject level (20). Dental caries was recorded using the DMFS index and visual-tactile examinations (21). Data concerning place of residence and history of fluoride exposure were obtained from a questionnaire. Additional details of the study methods have been reported previously (18, 19).

There were some differences between the surveys with respect to the questionnaire design. First, although the questions were similar, the responses in the 1986 survey were primarily open-ended for the two questions related to the use of fluoride toothpaste and fluoride tablets. In the 1995 study, responses from the previous survey were used to create categories for these two items. Second, questions relating to school lunch participation, education of the head of the household, and breast-feeding were not included in the earlier study. Third, the response rate for participation was lower in 1995 than in 1986. Fourth, children from the town of Ulster could not be identified from the 1986 survey because we had not included a question regarding their place of residence. Finally, although the examiners in each survey were trained by the same dentist, different examiners were used in 1995.

The analytical techniques involved comparison of frequency distributions of Dean's fluorosis categories to examine changes over time, including a ridit analysis to examine the changes in severity

(22, 23). Second, the proportion of children exposed to known fluoride sources was calculated for each of the following categories: (a) water fluoridation alone; (b) water fluoridation in addition to either the daily use of fluoride supplements during the first 8 years, or toothbrushing before the age of 2 years, or both; (c) daily use of fluoride supplements alone; (d) early toothbrushing alone; (e) combined use of fluoride supplements and early toothbrushing; and (f) a reference group consisting of the remaining children who reported none of these exposures. Third, adjusted odds ratios and 95% confidence intervals were calculated for the variables associated with dental fluorosis in the bivariate analysis ( $P < 0.1$ ). This model included race and the previously mentioned categories of fluoride exposure variables. The fluoride exposure variable was introduced as an indicator variable and the reference group consisted of children from nonfluoridated areas who did not belong to any of the exposure categories. Logistic regression procedures were used to estimate the association between factors and dental fluorosis separately for the two surveys. Finally, logistic regression procedures were used to fit a generalized logit model for examining the effect of year, race, fluoride exposure and their interactions (22, 24, 25).

Generally, dental fluorosis is analyzed as a dichotomous variable comparing 'very mild and greater' categories with 'normal' and 'questionable' categories of fluorosis. However, Dean's definition of questionable dental fluorosis is imprecise especially when 1–2 mm of white opacities are present at the tip of the summit of the cusps of first molars or incisors. Because this definition can result in a shift in the application of the diagnostic criteria and affect estimation of odds ratios, we considered a polytomous logistic regression model. Although the response variable is ordinal (none, questionable, and very mild to severe categories of fluorosis), data did not meet the assumptions required for a cumulative logit model. For ease of understanding, two separate regression models were constructed: one to compare the questionable category with the normal, and another to compare the very mild or greater category with the normal (22). Because the examination of two-way and three-way interaction terms requires larger sample sizes, the exposure categories were combined and defined as: (a) water fluoridation alone or water fluoridation in addition to either the daily use of fluoride supplements during the first 8 years, or toothbrushing before the age of 2 years, or both; (b) daily use of fluoride supplements or early tooth-

Table 1. Percentage distribution of children in study communities according to age group, gender, race, and fluoride exposure by year

		Newburgh City		Newburgh Town		New Windsor		Kingston		Ulster <sup>5</sup>
		1986 <sup>2</sup>	1995	1986	1995 <sup>3</sup>	1986	1995	1986	1995	1995
	Fluoridation status <sup>1</sup>	F	F	NF	F	NF	NF	NF	NF	NF
	Number	459	847	289	289	134	237	425	646	174
Age group	7–10	54.5	59.6	47.8	54.7	51.5	51.1	49.7	59.3	38.5
	11–14	45.5	40.4	52.2	45.3	48.5	48.9	50.3	40.7	61.5
Sex	Male	47.9	49.0	58.8	49.1	52.2	41.8	50.3	50.8	50.0
	Female	52.1	51.0	41.2	50.9	47.8	58.2	49.7	49.2	50.0
Race	Whites and others	48.4	58.9	91.7	89.6	94.8	93.2	84.0	80.8	95.4
	African-American	51.6	41.1	8.3	10.4	5.2	6.8	16.0	19.2	4.6
Exposure	Fluoridation+tablet and/or early brushing	50.3	49.2	–	58.5	–	–	–	–	–
	Fluoridation only	49.7	50.8	–	41.5	–	–	–	–	–
	Tablet+early brushing	–	–	21.1	14.2 <sup>4</sup>	20.9	18.1	18.4	19.3	16.7
	Early brushing	–	–	40.1	36.7 <sup>4</sup>	43.3	34.6	36.0	34.8	35.1
	Tablet	–	–	10.0	7.6 <sup>4</sup>	3.7	14.8	12.9	10.5	15.5
	None of the above	–	–	28.7	–	32.1	32.5	32.7	35.3	32.8

<sup>1</sup> F=fluoridated; NF=nonfluoridated.

<sup>2</sup> Children examined in Newburgh City in 1986 had an interruption in fluoridation.

<sup>3</sup> The town of Newburgh fluoridated in 1984.

<sup>4</sup> These children also received fluoridation and are therefore shown in the fluoridation+tablet and/or brushing category.

<sup>5</sup> Data for 1985 not available.

brushing or combined use of fluoride supplements and early toothbrushing; and (c) a reference group consisting of the remaining children who reported none of these exposures. The purpose of this analysis was to determine whether there were changes in the risk associated with fluoride exposure between the two survey periods for African-American children and children of other racial groups.

Analyses of crude, covariate-adjusted and ranked DMFS scores were performed to determine the relationship between caries and dental fluorosis. For this analysis, normal, questionable, very mild, and mild to severe categories of fluorosis were constructed. Other variables included in the model were age, poverty status in fluoridated and nonfluoridated areas, presence or absence of sealants, and education of the head of the household based on college attendance. Poverty status was based on participation in the free-lunch program in schools. To satisfy the assumption required for analysis of covariance, the dependent variable (DMFS) was converted to a rank and the tests of significance were based on the rank of analysis of covariance (22, 26).

## Results

Table 1 shows the number of children in 1986 and 1995 who were lifelong residents of either the fluoridated or the nonfluoridated areas. Between-survey comparison of the characteristics of the sample shows some differences within each of the geo-

graphic areas. In both 1986 and 1995, there were proportionately more African-American children in Newburgh City compared to other areas. Also, there were differences in gender between 1986 and 1995 in Newburgh Town and New Windsor.

In Newburgh City, which was fluoridated, the percentage of children exposed to daily fluoride tablets or early brushing or both did not change between the surveys (50.3% *vs* 49.2%). In the town of Newburgh, the daily use of fluoride tablets declined from 31.1% to 21.8% after the introduction of fluoridation. In other areas, the reported use of fluoride tablets in the first 8 years of life varied from a low of 24.6% in New Windsor in 1986 to a high of 32.9% in New Windsor in 1995. In 1995, more than half of the children reportedly started brushing before the age of 2 years.

The distribution of dental fluorosis according to Dean's index is shown separately by the residency status (Table 2). The highest prevalence of the very mild to severe categories was observed in the city of Newburgh in 1995. Between-survey comparisons show that neither the prevalence nor the severity of dental fluorosis increased after the town of Newburgh was fluoridated. The case was the same for nonfluoridated areas. However, changes were evident in the fluoridated city of Newburgh, where a ridity analysis showed that the odds were 4 to 3 (0.58/0.42) that a child examined in 1995 would have at least questionable fluorosis, compared with a similar child in 1986.

The adjusted odds ratios for questionable and

Table 2. Dental fluorosis prevalence in percent according to Dean's classification by place of residence and year of examination

Place	Year	Status	Number	Dean's index					
				Normal	Questionable	Very mild	Mild	Moderate	Severe
Newburgh City	1986	F	459	78.4	13.7	4.8	2.2	0.9	–
	1995 <sup>1</sup>	F	847	62.9	18.5	12.8	5.3	0.4	0.1
Newburgh Town	1986	NF	289	73.0	13.1	8.7	4.2	1.0	–
	1995 <sup>2</sup>	F	289	71.6	13.5	10.0	2.8	1.7	0.3
New Windsor	1986	NF	134	76.1	9.7	8.2	3.7	2.2	–
	1995	NF	237	75.5	10.1	8.9	5.1	0.4	–
Kingston	1986	NF	425	81.4	11.3	4.5	2.1	0.7	–
	1995	NF	646	81.4	7.4	7.7	3.1	0.3	–
Ulster	1986	NF	–	–	–	–	–	–	–
	1995	NF	174	70.7	14.9	9.8	2.9	1.1	0.6

<sup>1</sup> Ridity for this group was 0.58 relative to 0.50 for the 1986 survey (statistically significant,  $P < 0.05$ ). All other between-survey comparisons yielded ridity values of less than 0.51.

<sup>2</sup> The prevalence of very mild to severe dental fluorosis among children born after the implementation of fluoridation in Newburgh Town was 14.7 (37/252).

Table 3. Odds ratios associated with fluoride exposure and race by year of study

Year	Variable	n	Questionable fluorosis odds ratio (CI)	Very mild to severe fluorosis odds ratio (CI)
1986	Fluoride exposure			
	Fluoridation+early brushing or tablet	231	1.3 (0.8, 2.3)	2.1 (1.0, 4.4)
	Fluoridation alone	228	1.1 (0.6, 1.9)	1.8 (0.8, 4.0)
	Fluoride tablet+early brushing	167	1.5 (0.8, 2.6)	5.0 (2.5, 10.2)
	Early brushing	327	1.0 (0.6, 1.7)	2.6 (1.3, 5.1)
	Fluoride tablet	89	1.4 (0.7, 2.9)	3.4 (1.5, 8.0)
	None of the above	265	1.0	1.0
	Race			
	African-American	336	1.3 (0.8, 1.9)	0.9 (0.5, 1.5)
	Whites and others	971	1.0	1.0
1995	Fluoride exposure			
	Fluoridation+early brushing or tablet	586	4.4 (2.6, 7.2)	3.3 (2.1, 5.2)
	Fluoridation alone	550	3.5 (2.1, 5.8)	2.5 (1.5, 3.9)
	Fluoride tablet+early brushing	197	2.8 (1.5, 5.3)	4.0 (2.4, 6.9)
	Early brushing	368	2.3 (1.3, 4.1)	2.0 (1.2, 3.3)
	Fluoride tablet	130	2.4 (1.2, 4.9)	2.9 (1.3, 4.7)
	None of the above	362	1.0	1.0
	Race			
	African-American	526	1.6 (1.2, 2.1)	2.3 (1.8, 3.0)
	Whites and others	1667	1.0	1.0

Model (1986-questionable fluorosis) chi-square=4.566, P=0.6; goodness of fit=1.34, P=0.96.

Model (1986-very mild-severe fluorosis) chi-square=26.95, P=0.0001; goodness of fit=7.88, P=0.44.

Model (1995-questionable fluorosis) chi-square=62.59, P=0.0001; goodness of fit=0.62, P=0.98.

Model (1995-very mild-severe fluorosis) chi-square=83.69, P=0.0001; goodness of fit=1.04, P=0.98.

Table 4. Logistic regression analysis for fluorosis and the effect of year as determined by the logit difference for African-American and children of other racial groups by fluoride exposure categories

Variable	Model I <sup>1</sup>		Model II <sup>2</sup>	
	Regression coefficient for very mild to severe	P	Regression coefficient for questionable	P
Age group (11–14 years)	0.18	0.092	0.15	0.158
African-American	0.41	0.610	0.40	0.447
Fluoridation <sup>3</sup>	0.43	0.310	0.13	0.652
Tab/brush <sup>4</sup>	1.38	0.000	0.26	0.298
Year	0.44	0.268	-0.81	0.017
African-American*fluoridation <sup>3</sup>	0.06	0.942	-0.03	0.956
African-American*tab/brush <sup>4</sup>	-2.14	0.049	-0.69	0.312
African-American*year	-0.11	0.911	0.24	0.751
Year*fluoridation <sup>3</sup>	0.48	0.328	1.26	0.002
Year*tab/brush <sup>4</sup>	-0.52	0.227	0.75	0.050
African-American*year*fluoridation <sup>3</sup>	0.54	0.605	-0.09	0.916
African-American*year*tab/brush <sup>4</sup>	2.54	0.040	0.03	0.974
Constant	-3.07	0.000	-2.14	0.000

<sup>1</sup> Model I chi-square=132.12, P=0.0001; c statistic=0.66; Hosmer-Lemeshow goodness-of-fit statistic=2.09 (P=0.98).

<sup>2</sup> Model II chi-square=70.82, P=0.0001; c statistic=0.62; Hosmer-Lemeshow goodness-of-fit statistic=1.26 (P=0.99).

<sup>3</sup> Children in fluoridated areas.

<sup>4</sup> Children in nonfluoridated areas

Effect of year on African-American children living in fluoridated areas – OR<sub>Very Mild – Severe</sub>=3.9; OR<sub>Questionable</sub>=1.7.

Effect of year on children of other racial groups living in fluoridated areas – OR<sub>Very Mild – Severe</sub>=2.5; OR<sub>Questionable</sub>=1.7.

Effect of year on African-American children who received fluoride from daily supplements or early brushing or both – OR<sub>Very Mild – Severe</sub>=10.5; OR<sub>Questionable</sub>=1.0.

Effect of year on children other racial groups who received fluoride from daily supplements or early brushing or both – OR<sub>Very Mild – Severe</sub>=0.9; OR<sub>Questionable</sub>=1.0.

Table 5. Crude, covariate adjusted mean DMFS and adjusted mean rank of DMFS by fluorosis categories, 1995 survey

Fluorosis	<i>n</i>	Crude mean DMFS	Adjusted mean DMFS	Adjusted mean rank of DMFS	<i>P</i>
Normal	1568	1.24	1.06 (0.08)	1097	–
Questionable	294	0.82	0.65 (0.15)	994	0.001
Very mild	225	1.57	1.39 (0.17)	1147	0.156
Mild to severe	106	0.99	0.77 (0.24)	1068	0.57

Other variables in the model included age, poverty status in fluoridated and nonfluoridated areas, college level education of the head of household, and presence of sealant. Three children with severe dental fluorosis had a mean DMFS of 5.3.

very mild to severe categories are shown separately for 1986 and 1995 by fluoride exposure and racial variables (Table 3). Children who reported the combined use of fluoride tablets and brushing had the highest odds ratios for very mild to severe fluorosis in both survey years. Elevated odds ratios were observed for all the fluoride exposure variables in both years; however, exposure to fluoridation alone in 1986 was not statistically significant. African-American children studied in 1995 were at higher risk for dental fluorosis than children of other racial groups. While elevated odds ratios were observed for questionable fluorosis in 1995, none of the odds ratios for the questionable category in 1986 was statistically significant. Unlike the other models shown in Table 3, the model chi-square value for the 1986 questionable fluorosis category was not statistically significant, indicating that the inclusion of the fluoride exposure variables in the model did not improve the prediction of questionable fluorosis. For the other models shown in Table 3, the Hosmer-Lemeshow goodness-of-fit test shows that the difference between the observed and the model predicted values was not statistically significant.

The results of the logistic regression procedures performed on the combined data set show a different pattern of effect of year on race among those who used fluoride from sources other than water (Table 4). The computation of the difference in logit shows that among African-American children who received fluoride from sources other than water, the risk for very mild to severe fluorosis increased from a baseline OR of 1.0 in 1986 to 10.5 in 1995, whereas for children of other racial groups there was a suggestion of slightly decreased risk (OR 0.9). Among those living in fluoridated areas the risk for very mild to severe fluorosis increased for both racial groups and was slightly higher for African-American children (OR 3.9 for African-American children and 2.5 for children of other racial groups).

A similar analysis conducted on questionable fluorosis cases showed that the risk for questionable dental fluorosis did not change from 1986 in nonfluoridated areas for either group (OR 1.0); however, a change was noticeable in fluoridated areas (Table 4). Table 5 shows an inconsistent relationship between caries and fluorosis. The adjusted mean DMFS varied from a high of 1.39 among those with very mild fluorosis to a low of 0.65 among those with questionable fluorosis.

## Discussion

This analysis was based on two cross-sectional surveys of volunteer children. Although steps were taken to ensure the quality of the data, the extent to which factors such as examiner variation, population differences, representativeness of the sample and recall of past events have affected the results are difficult to judge. However, it should be pointed out that these problems are common to all cross-sectional studies conducted over time and that researchers and policy-makers should use caution in interpreting the results. Of particular concern is the potential for shift in the classification of 'questionable' categories of dental fluorosis over time and its effect on the estimation of risks. Therefore, we treated this category as a separate outcome in the regression procedures. Another issue that needs to be considered is the decline in the participation rate. Although all the selected schools participated, the response rate declined from 58% in 1986 to 38% in 1995. Our previous analysis showed that the primary reason for nonparticipation was that the children already had a dentist; however, among participants there was no association between having a dentist and dental fluorosis (19, 27). Therefore, it is unlikely that this lower participation rate affected the results. Furthermore, if this participation rate affected the estimation, it also occurred in 1986 to some extent. Notwithstanding these methodological issues, we consider that the

two surveys are sufficiently similar to allow a determination of the changes of risk over time.

This analysis shows that the risk of developing dental fluorosis did not decline over time in these communities. Water fluoridation exerted an observable effect on dental fluorosis as evidenced by a significant increase in the prevalence and severity of dental fluorosis in Newburgh City. This increase can be largely attributed to the difference in the duration of exposure to fluoridation between the two surveys. While city of Newburgh residents in 1995 had continuous exposure since birth, there was a 3-year interruption in fluoridation in the 1986 cohort. However, the increased risk associated with continuous exposure to water fluoridation may not result in an increase in dental fluorosis prevalence in every community after fluoridation has been implemented.

In the town of Newburgh, which was fluoridated in 1984, neither the prevalence nor the severity of dental fluorosis changed between 1986 and 1995. Although this finding was unexpected, data appear to support the likelihood that the total intake of fluoride in children did not change in this town and therefore, fluorosis was not measurably affected. First, 71.3% of the Newburgh Town children examined in 1986, although not exposed to water fluoridation during their critical childhood years, did report exposure to a known risk factor such as the use of daily supplements or early toothbrushing. Second, children from Newburgh Town were overwhelmingly white, and the prevalence of very mild or greater fluorosis observed in Newburgh Town in 1995 was similar to that observed among non-African-American children in Newburgh City (14.8% vs. 13.6) (19). Third, children examined in the towns of Newburgh, New Windsor and Ulster were predominantly white, and had remarkably similar levels of dental fluorosis, ranging between 13.9% and 14.4%. Finally, these findings are unlikely to be the result of examiner bias because the examiners were not aware of either the residential or the fluoridation status of children.

Undoubtedly, the increased availability of fluoride in nonfluoridated areas also has the potential to significantly increase the prevalence of fluorosis. For example, in Kingston, which was not fluoridated, the prevalence of very mild or greater fluorosis increased from 0% in 1955 to 11% in 1995 (18, 19). In comparison, the increase in fluoridated areas has been relatively smaller, especially when the proportions of children classified as normal are compared to historical data. In earlier studies,

Dean reported that 36.8 to 72.3% of 12–14-year-old white children had dentition classified as normal in areas where fluoride was naturally occurring at 0.4 to 1.3 mg/L (28). With the exception of the 1986–87 national survey, a review of studies conducted since that time shows that the percentage of children with normal dentition has not changed in recent years (1, 18, 29–33). The finding that a large majority of the population do not have dental fluorosis in spite of exposure to multiple sources of fluoride is somewhat reassuring; however, while Dean did not notice moderate and severe fluorosis cases in communities with fluoride level ranging from 0.4 to 1.3 mg/L, it is now not unusual to observe these cases in the United States.

The higher risk for dental fluorosis observed among African-American children is consistent with several other studies. Russell noted that dental fluorosis was twice as prevalent among African-American children than white children in the Grand Rapids fluoridation study (6). Because this study was conducted in an era when other sources of fluoride products were not available, this finding suggests either that fluorosis is more likely to occur in African-American children due to biologic susceptibility, or that their fluoride intake was greater.

In both the surveys, the combined use of daily supplements and early brushing had the highest odds ratios for very mild to severe dental fluorosis. In this report, the association between the use of daily supplements or early brushing alone and very mild to severe dental fluorosis was also significant. This finding is not consistent with a previous report where we did not find such an association (19). Rather than using a polytomous regression model comparing very mild and greater degrees of fluorosis to normal categories, we had used a dichotomous regression model in the previous report. Therefore, the traditional method of comparing very mild and greater degrees to normal and questionable categories underestimated the odds ratios.

Although the three-way interaction term (year-race-fluoridation) was not statistically significant, the between-survey risk increase for very mild to severe fluorosis among children in fluoridated areas was higher for African-Americans. The between-survey change in the effect of fluoride supplements and/or early brushing was much more dramatic among African-American children. While African-American children exposed to fluoride supplements and/or early brushing were more likely to develop fluorosis in 1995 compared to 1986, the reverse was true for children of other ra-

cial and ethnic groups. This pattern of effect seems to suggest that the recommendations to reduce fluoride intake from fluoride tablets and dentifrices made in the 1980s were not sufficient to reduce the risk for African-American children. While the changes in risk for very mild to severe fluorosis varied among racial groups, no such difference was found for questionable fluorosis. For this category, changes in prevalence were similar for both racial groups, increasing from 1986 to 1995 in fluoridated areas, but not changing among children exposed to fluoride tablets and/or early brushing.

The level of dental fluorosis observed in this study as well as in other recent studies raises a more fundamental question regarding what is an acceptable level of dental fluorosis. When Dean reported that water fluoridation resulted in a fluorosis prevalence of approximately 10%, he considered this level to be an acceptable trade-off for the substantial benefits obtained, especially since no cases of moderate to severe fluorosis were observed (34). However, dental caries has dramatically declined in recent years in the United States, and many researchers have argued for a reexamination of fluoride levels in all sources, including drinking water (33). Another observation that will influence the policy in the United States is that the relationship between dental fluorosis and caries was inconsistent. Other investigators have reported similar findings with respect to the association between dental fluorosis and caries (29, 35–37). In the earlier studies, the presence of dental fluorosis was found to be inversely associated with dental caries, and therefore, a low level of dental fluorosis was acceptable because the risk of milder forms of fluorosis was outweighed by the benefits of caries prevention (38). Clark & Berkowitz suggest that, although very few people consider dental fluorosis to be an esthetic problem, it cannot be treated as insignificant (39). Recently, Lalumandier & Rozier showed a strong association between dental fluorosis and parental dissatisfaction (40). It seems appropriate now to adopt measures that will reduce the occurrence of moderate and severe cases, rather than to focus solely on overall prevalence.

Another policy objective worth considering is to reduce the difference in fluorosis among population subgroups. Some subsets of the population studied appear to experience higher levels of fluorosis than others. However, the argument that low-socioeconomic children benefit from additional fluoride exposure should be taken into account when considering such a policy (19, 41, 42).

There are several options that could be recommended to balance the benefits of fluoride against the risk of dental fluorosis in the United States. The first option is to continue the practice of fluoridating water at the current level based on annual mean maximum temperature level. This argument is bolstered by the fact that water fluoridation will result in dental fluorosis only in a minority of children. Further, the results seem to suggest that fluoridating a community may not increase the prevalence more than exposing children to alternative sources of fluoride. Concurrently, additional studies should be conducted to determine whether the recommendations to reduce fluoride ingestion from sources other than water are sufficient to control the occurrence of dental fluorosis.

The inappropriate use of fluoride supplements in fluoridated communities should be strongly discouraged. However, it is difficult for practitioners to judge the boundaries of fluoridated water districts. Also, most state agencies maintain only a census of fluoridated communities, and the boundaries of water districts are not necessarily the same as geographical limits of cities and towns. Often, residents who move from nonfluoridated areas to fluoridated areas continue the fluoride regimen. Therefore, providing maps of fluoridated areas to practicing physicians and dentists will be more useful in preventing inappropriate prescriptions.

A second option is to adjust the optimal level in water downward by an arbitrary level as has been done in Hong Kong (43). On the basis of an analysis of national survey data, Heller et al. suggest a level of 0.7 mg/L in water for the United States (1). Evans et al. found that downward adjustment in fluoride concentration in Hong Kong from 1.0 to 0.7 mg/L significantly decreased the prevalence of fluorosis from 64% to 47% without any effect on caries experience (43). However, the extremely high prevalence of fluorosis observed, even after a reduction in fluoride concentration, suggests that the experience in Hong Kong may be unique to that environment. A similar policy in the United States should be considered by conducting studies in this country to demonstrate if the desired objective can be achieved. It is also not clear if such a downward adjustment of fluoride content in water can eliminate the increased risk of fluorosis among African-American children and also the cases of moderate and severe cases of fluorosis. Whitford has cautioned against such an approach because some of these enamel defects are probably due to factors other than fluoride (5).

The third option is to further lower fluoride exposure from sources other than water. This would require limiting the prescription of fluoride supplements and rinses to high-risk children only and lowering the fluoride content in toothpastes. This would likely expose fewer children to risk and reduce fluoride intake in fluoridated areas as well. However, the implementation of this option is difficult because the fluoride supplement schedule has already been revised several times and the identification of high-risk children is based on subjective criteria. Although lower strength toothpastes can be introduced in the United States, the lowering of fluoride concentration in toothpaste requires additional data to demonstrate that benefits could be maintained at or near the present level; without such evidence, it will be difficult to market these products in the United States.

Our abilities to draw definitive conclusions regarding the effect of changes in fluoride exposure are hampered by the lack of data on the relationship between fluoride intake, exposure, dental caries and dental fluorosis. It is not clear if the relationship between water and beverage consumption, and temperature observed in the 1950s is still valid. Although numerous reports have been published in the last decade regarding the risks and benefits of fluoride, very few large-scale studies have been undertaken to estimate the prevalence of dental fluorosis. National surveys have failed to provide the answer regarding the risk of exposure to fluoride, partly because of the difficulty of obtaining quality data on varied sources of fluoride, especially documentation of continuous exposure to fluoride in water in a broad population sample. These questions regarding risks and benefits will continue to emerge in the future, and may become even more complex. Therefore, it is important that a nationwide monitoring and surveillance system be established, before recommendations to alter fluoride exposure are made.

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## References

- Heller KE, Eklund SA, Burt BA. Dental caries and dental fluorosis at varying water fluoride concentrations. *J Public Health Dent* 1997;57:136-43.
- Burt BA. The changing patterns of systemic fluoride intake in children. *J Dent Res* 1992;71:1228-37.
- National Research Council. Health effects of ingested fluoride. Washington: National Research Council; 1993.
- Public Health Service. Review of fluoride benefits and risks. Department of Health and Human Services; 1991.
- Whitford GM. The metabolism and toxicity of fluoride. New York: Karger; 1996.
- Russell AL. Dental fluorosis in Grand Rapids during the seventeenth year of fluoridation. *J Am Dent Assoc* 1962;65:608-12.
- Williams JE, Zwemer JD. Community water fluoride levels, preschool dietary patterns, and the occurrence of fluoride enamel opacities. *J Public Health Dent* 1990;50:484-90.
- Butler W, Segreto V, Collins E. Prevalence of dental mottling in school-aged lifetime residents of 16 Texas communities. *Am J Public Health* 1985;75:1408-12.
- Pendrys DW, Stamm JW. Relationship of total fluoride intake to beneficial effects and enamel fluorosis. *J Dent Res* 1990;69:529-38.
- Osuji OO, Leake JL, Chipman ML, Nikiforuk G, Locker D, Levine N. Risk factors for dental fluorosis in a fluoridated community. *J Dent Res* 1988;67:1488-92.
- Pendrys DG, Katz RV, Morse DE. Risk factors for enamel fluorosis in a nonfluoridated population. *Am J Epidemiol* 1996;143:808-15.
- Ripa LW. A critique of topical fluoride methods (dentifrices, mouthrinses, operator- and self-applied gels) in an era of decreased caries and increased fluorosis prevalence. *J Public Health Dent* 1991;51:23-41.
- Skotowski MC, Hunt RJ, Levy SM. Risk factors for dental fluorosis in pediatric dental patients. *J Public Health Dent* 1995;55:79-84.
- Adair SM, Wei SHY. Supplemental fluoride recommendations for infants based on dietary fluoride intake. *Caries Res* 1978;12:76-82.
- Committee on Nutrition, American Academy Pediatrics. Fluoride as a nutrient. *Pediatrics* 1979;63:150-2.
- Ripa LW. Topical fluorides: a discussion of risks and benefits. *J Dent Res* 1987;66:1079-83.
- ADA. Council on Access Prevention and Interprofessional Relations. Caries diagnosis and risk assessment. *J Am Dent Assoc* 1995;126(Spec Suppl):1s-24s.
- Kumar JV, Green EL, Wallace W, Carnahan T. Trends in dental fluorosis and dental caries prevalences in Newburgh and Kingston, NY. *Am J Public Health* 1989;79:565-9.
- Kumar JV, Swango PA, Lininger LL, Leske GA, Green EL, Haley VB. Changes in dental fluorosis and dental caries in Newburgh and Kingston, New York. *Am J Public Health* 1998;88:1866-70.
- Dean HT. The investigation of physiological effects by the epidemiologic method. In: Moulton FR, editor. Fluorine and dental health. American Association for the Advancement of Science; 1942. p. 23-31.
- National Institute of Dental Research. Oral health survey methods. Bethesda: NIDR; 1986.
- Stokes EM, Davis CS, Koch GG. Categorical analysis using SAS system. Cary (NC): SAS Institute; 1995.
- Fleiss JL. Statistical methods for rates and proportions. New York: J Wiley; 1981.
- SAS Institute. SAS user's guide statistics, Version 6. Cary (NC): SAS Institute; 1990.

25. SPSS. SPSS professional statistics. Chicago: SPSS; 1997.
26. Quade D. Rank analysis of covariance. *J Am Stat Assoc* 1967;62:1187–200.
27. Kumar JV, Opima P, Green EL. An assessment of nonresponse in a dental survey. *J Public Health Dent* 1998;58:173.
28. Dean HT, Arnold FA, Elvove E. Domestic water and dental caries. Additional studies of the relation of fluoride domestic waters to caries experience in 4,425 white children, aged 12 to 14 years of 13 cities in 4 states. *Public Health Rep* 1942;57:1155–79.
29. Driscoll WS, Heifetz SB, Horowitz HS, Kingman A, Meyers RJ, Zimmerman ER. Prevalence of dental caries and dental fluorosis in areas with negligible, optimal, and above-optimal fluoride concentrations in drinking water. *J Am Dent Assoc* 1986;114:324–8.
30. Jackson RD, Kelly SA, Katz BP, Hull JR, Stookey GW. Dental fluorosis and caries prevalence in children residing in communities with different levels of fluoride in water. *J Public Health Dent* 1995; 55:79–84.
31. Segreto VA, Collins EM, Camann D, Smith A. A current study of mottled enamel in Texas. *J Am Dent Assoc* 1984;108:55–9.
32. Szpunar S, Burt B. Dental caries, fluorosis, and fluoride exposure in Michigan school children. *J Dent Res* 1988;67:802–6.
33. Leverett DH. Prevalence of dental fluorosis in fluoridated and nonfluoridated communities – a preliminary investigation. *J Public Health Dent* 1986;46:184–7.
34. Dean HT, Jay P, Arnold FA, Elvove E. Domestic water and dental caries. II. A study of 2832 white children, aged 12–14 years of age of 8 suburban Chicago communities, including *Lactobacillus acidophilus* studies of 1761 children. *Public Health Rep* 1941;56:761–92.
35. Ellwood RP, O'Mullane D. Association between dental enamel opacities and dental caries in a North Wales population. *Caries Res* 1994;28:383–7.
36. Ellwood RP, O'Mullane D. The association between developmental enamel defects and caries in populations with and without fluoride in their drinking water. *J Public Health Dent* 1996;56:76–80.
37. Pendry DG, Katz RV. Risk of enamel fluorosis associated with fluoride supplementation, infant formula, and fluoride dentifrice use. *Am J Epidemiol* 1989;130:1199–207.
38. Dean HT. Endemic fluorosis and its relation to dental caries. *Public Health Rep* 1938;53:1443–52.
39. Clark CD, Berkowitz J. The influence of various fluoride exposures on the prevalence of esthetic problems resulting from dental fluorosis. *J Public Health Dent* 1997;57:144–9.
40. Lalumandier JA, Rozier GA. Parent's satisfaction with children's tooth color: fluorosis as a contributing factor. *J Am Dent Assoc* 1998;129:1000–6.
41. Carmichael CL, Rugg-Gunn AL, Ferrell RS. The relationship between fluoridation, social class and caries experience in 5 year old children in Newcastle and Northumberland in 1987. *Br Dent J* 1989;167:57–61.
42. Slade G, Spencer A, Davies M, Stewart J. Influence of exposure to fluoridated water on socioeconomic inequalities in children's caries experience. *Community Dent Oral Epidemiol* 1996;24:89–100.
43. Evans RW, Stamm JW. Dental fluorosis following downward adjustment of fluoride in drinking water. *J Public Health Dent* 1991;51: 91–8.