

Investigation of the possible associations between fluorosis, fluoride exposure, and childhood behavior problems

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Abstract

Purpose: *This study investigated the potential association between fluoride exposure and behavior problems in children, as well as the prevalence of and risk factors for fluorosis.*

Methods: *Children between the ages of 7 and 11 years ($N = 197$) were included in the study and were examined for dental fluorosis using the Modified Dean's Index. Parents of subjects completed and returned three questionnaires which investigated their children's history of exposures to fluoride, social and medical backgrounds, and behavior using the Child Behavior Checklist (CBCL).*

Results: *Sixty-nine percent of the study participants demonstrated fluorosis with very mild fluorosis being the most common (39%), while 13% demonstrated moderate to severe fluorosis. Using a summation of the Modified Dean's index (Sum of 8), we divided the children into high fluorosis (HF) and low fluorosis (LF) groups. These groups were compared to each other with respect to fluoride exposures and behavior.*

Conclusion: *Although there was no association between the fluoride exposures in aggregate and fluorosis, there was a significant association between supplemental fluoride exposure from ages 0–3 years and fluorosis. There was no association between behavior problems and dental fluorosis in this population. (Pediatr Dent 20:244–52, 1998)*

For five decades, fluoride has been added to public water supplies to reduce the incidence of dental caries. Dean and others determined 1 ppm to be the optimal level of fluoridation for caries reduction¹ while minimizing levels of dental fluorosis.² Since then however, sources of fluoride have increased, resulting in a commensurate increase in the prevalence and severity of dental fluorosis.^{3–12} These additional sources of fluoride include toothpaste, professional topical applications, dietary supplementation, mouthrinses, processed food and beverages, and pesticides.^{9, 12–18} Investigators have attempted to elucidate which of these exposures are primarily responsible for the increase in dental fluorosis, with varied results.^{7, 8, 11, 14, 18, 19–25} In

1994, Pendrys et al.²⁶ reported a case-control study in which infant formula, frequent brushing, and inappropriate fluoride supplementation were strongly associated with dental fluorosis. Similarly, Lalumandier and Rozier²⁷ reported dental fluorosis to be associated with dietary fluoride supplementation and the child's age when brushing was initiated. Skotowski²⁸ also showed fluoride toothpaste to be associated with fluorosis. Due to this rise in fluoride exposure and dental fluorosis, the American Dental Association (ADA) and American Academy of Pediatric Dentistry (AAPD) changed the fluoride supplementation guidelines to reduce fluoride exposure in 1994.²⁹ The American Academy of Pediatrics (AAP) endorsed the new dosage schedule in May 1995.³⁰

Since the institution of fluoridation as a public health measure, human and animal studies on the effect of fluoride on teeth have continued. Histological, biochemical, and molecular studies have better defined the fluorotic lesion and have helped to differentiate dental fluorosis from other enamel lesions.^{34–40} Additionally, they have led to a better understanding of the mechanism by which fluoride acts on the developing tooth to produce fluorosis.^{12, 15, 31–33}

Fluoride has been studied extensively for its effects on skeletal, reproductive, genitourinary, gastrointestinal, and respiratory systems, as well as for possible genotoxic and carcinogenic effects. A review conducted in 1991 by the Ad hoc Subcommittee on Fluoride of the Committee to Coordinate Environmental Health and Related Programs¹⁵ found no conclusive evidence of the adverse effects of fluoride other than on teeth (dental fluorosis), bones (skeletal fluorosis), and the gastrointestinal tract (chronic gastritis) with chronic high exposure.

Until recently, effects on the nervous system have not been studied. In 1982, Rotton et al.⁴¹ reported subtle transient attention deficits induced by the sublingual application of 0.01 mg of fluoride in healthy human volunteers. This exposure was significantly less than the fluoride exposure obtained from brushing with fluoridated toothpaste (1 mg) or from a professional topical

fluoride treatment (50 mg). In 1995, Li et al.⁴² reported that children living in areas with a medium or high prevalence of fluorosis demonstrated lower intelligence quotients than those living in areas with only slight or no fluorosis. More than 900 children between the ages of 8 and 13 years were examined and tested using the China Rui Wen's Scaler for Rural Areas. Numerous other studies have reported an association between enamel defects and various neurologic, learning, behavioral, and language disorders in children,⁴³⁻⁵⁸ but none have specifically examined the association between fluoride-induced enamel defects and behavioral problems.

In 1995, Mullinix et al.⁵⁹ reported that systemic exposure to sodium fluoride was neurotoxic to rats. Behavioral deficits were objectively identified using computer pattern-recognition technology. Deficits occurred whether exposure was prenatal, at weaning, or in adulthood. Levels of fluoride in serum and the brain, specifically the cerebellum and hippocampus, correlated with the behavioral alterations. The levels of fluoride used are known to induce fluorosis in rats,⁶⁰ and resulted in serum levels that were similar to levels found in humans who are exposed to environmental fluoride of 5-10 ppm⁶¹⁻⁶⁴ and similar to levels reported in children following professional topical applications of 1.23% acidulated phosphate fluoride gel.^{65,66}

Although the mean fluoride exposure in the United States would be expected to result in serum levels well below those reported by Mullinix et al.,⁵⁹ fluoride is pervasive within our environment and any behavioral effects, however subtle, would have a significant public health impact.

The purpose of this historical cohort study was to investigate if an association exists between fluoride exposure and behavior problems in children. In addition, the prevalence of fluorosis and potential risk factors for fluorosis were investigated.

Methods

Patients

Patients were recruited from a pediatric dental practice in a suburb of Boston. A letter was sent to parents of potential subjects requesting their participation in a study investigating possible associations between oral health and childhood behavior. Parents whose children fulfilled the following criteria were asked to participate.

1. 7-11 years of age
2. Presence of permanent incisors and first molars
3. No history of pervasive developmental disorders or mental retardation
4. No sibling enrolled in the study.

This last criterion insured statistical independence of observations.

TABLE 1. MODIFIED DEAN'S INDEX OF DENTAL FLUOROSIS⁶⁹ USED TO SCORE INDIVIDUAL TEETH.

Score	Type	Description
0	None	Normal
0.5	Questionable	Few opacities
1	Very Mild	< 25% with opacities
2	Mild	25-50% with opacities
3	Moderate	> 50% with opacities
4	Severe	100% with opacities and pitting
5	Very Severe	Confluent pitting

Parent questionnaires

Following enrollment and written informed consent, a packet of three questionnaires was given to the parents with written and verbal instructions (fluoride exposure history, social/medical history, and CBCL). Parents were given the option of completing the questionnaires at home and returning them in a pre-addressed and prestamped envelope, or completing them in the office while waiting for completion of their child's dental visit. Parents who did not complete and return the questionnaires within 2 months were sent a reminder letter. A second packet of questionnaires and instructions was sent out to parents who still had not responded within 6 months.

Fluoride history

The fluoride history questionnaire consisted of 64 close-ended questions. A parent was asked to identify all the towns in which their child had lived and attended school, methods of infant feeding, use of bottled or tap water, use of water filters, use of supplementary fluoride and over-the-counter fluoride products, professional fluoride treatments, initiation and frequency of toothbrushing, adult assistance with toothbrushing, use of fluoride toothpaste, and amount of toothpaste used.

Most of the questions requested information about the child's first 8 years of life because fluorosis of the permanent first molars and incisors would have occurred within that time.

Social/medical history

The social and medical questionnaire consisted of 122 open- and close-ended questions. A parent was asked about their child's height, weight, birth length and weight, gestational age at birth, educational problems, medical diagnoses, hospitalizations, and history of prescription medication use. It also requested information about parents, including their heritage, age, marital status, employment and time spent at job, high-

TABLE 2. FLUOROSIS COMPILATION INDICES USED TO ASSIGN EACH PATIENT ONE FLUOROSIS SCORE

<i>Scoring Index</i>	<i>Description</i>
Sum of 12	The fluorosis scores for all 12 teeth that were examined were summed. When scores were available for fewer than 12 teeth, a weighted score was calculated by dividing the sum by the number of teeth present and multiplying by 12.
Sum of 8*	The fluorosis scores for the incisors (eight teeth) that were examined were summed. When scores were available for fewer than eight teeth, a weighted score was calculated by dividing the sum by the number of teeth present and multiplying by eight.
Dean's†	Dean ⁶⁹ expressed fluorosis as the highest score assigned to two teeth.
Maximum	The highest fluorosis score for any one tooth.
Median	The median score of all 12 teeth examined.
Mode	The score that occurred most frequently among all 12 teeth that were examined.

* Sum of 8 used for comparison between HF and LF groups with respect to behavior, fluorosis, and fluoride exposure.

† Dean's used to report prevalence.

est level of education attained, and history of learning, neurologic, or psychiatric problems. The same questions were asked about the child's biologic parents if the child was adopted. Parents were also asked to identify who provides after-school supervision for the child and how often, and to identify stressful events in the child's life such as death, divorce, and abuse.

Behavior questionnaire

The CBCL⁶⁷ is the most widely used measure of behavior problems in childhood psychiatric epidemiologic studies.⁶⁸ It consists of 143 open- and close-ended questions. Parents are asked to rate many possible behaviors as either never occurring, sometimes occurring, or often occurring. Parents are also asked to judge their child's performance in sports, hobbies, games, clubs and organizations, jobs, and school subjects. Questions are also asked about relationships with friends and siblings. The CBCL yields a total problem behavior score and two broad-band summary scores (internalizing and exter-

nalizing). The internalizing score reflects the prevalence of behaviors that are overcontrolled or inhibited (e.g., social withdrawal, depression, anxiety). The externalizing score reflects behaviors that are undercontrolled or represent "acting out" (e.g., aggression, hyperactivity, antisocial).

Fluorosis examination

Oral examinations were performed on each subject to evaluate the presence of dental fluorosis. This fluorosis examination was conducted by the principal investigator (LM) using direct vision with the standard overhead light and a dental mirror. The modified Dean's index⁶⁹ (Table 1) was used both to quantify fluorosis for the scoring of individual teeth and to quantify the prevalence of dental fluorosis in this population. This index was chosen because it is the most commonly used index in studies evaluating dental fluorosis, thus permitting comparison of our findings with those of other prevalence studies. Only the labial/buccal surfaces of the maxillary and mandibular permanent incisors and first molars were scored. Enamel opacities were considered fluorotic in origin if they were symmetrically distributed, were diffuse in nature, followed the perichymata, and were more visible in tangential reflected light. These criteria are consistent with those used by Moller,³⁶ Russell,³⁵ and Zimmerman.³⁴ Fourteen percent of the subjects were re-examined by the principal investigator 6 months after the initial fluorosis examination to assess intrarater reliability using the kappa statistic ($N = 336$ teeth).⁷⁰ To assess intrarater reliability, the Modified Dean's scores were collapsed as follows; 0 and 0.5 = 0, 1 and 2 = 1, and 3 or greater = 2. Intrarater reliability analysis yielded kappa scores of 0.58 to 0.89 for the lower incisors, 0.53 and 0.57 for the right molars, and 0.15 to 0.46 for the upper incisors and left molars. With exception of the lower incisors, kappa scores for each right tooth were higher than those for the contralateral tooth.

Statistical analysis

Initially, six methods were used to combine the scores for individual teeth in order to determine an overall fluorosis score for each patient (Table 2). Of these six summation indices, the sum of the fluorosis scores for the eight incisor teeth (Sum of 8) was most highly correlated with the fluoride exposures reported by parents. Therefore, the Sum of 8 was used as the fluorosis index in the remainder of the analyses.

Because few children did not have any fluorosis and because the fluorosis scores were not normally distributed, subjects were categorized as either LF or HF. Those with a score of 12 or less (76%) were classified as LF, while those with a score greater than 12 were classified as HF (24%).

Data were entered into a database using dBase III Plus (Ashton-Tate, Torrance, CA) on an IBM personal computer. Data analyses were conducted using SAS

TABLE 3. FLUORIDE EXPOSURES (N = 197)

Exposure	%
Lived in a fluoridated community any time between birth and 6 yr	86
Lived in a fluoridated community any time between birth and 3 yr	80
Used fluoridated toothpaste before second birthday	74
Received F supplementation any time from birth to 6 yr	53
Received F supplementation any time from birth to 3 yr	52
Received any form of topical fluoride treatment from birth to 3 yr	30
Received concentrated formula mixed with fluoridated water	25
Used fluoridated toothpaste before first birthday	19

(SAS Institute, Cary NC) and Stata (Stata Corporation, College Station, TX).

Wilcoxon's rank-sum test was used to assess associations between fluorosis, fluoride exposures, and behavior as measured by the CBCL total, externalizing, and internalizing scores. Relationships between fluorosis and fluoride exposures were examined using Fisher's exact test. Fisher's exact and Wilcoxon's rank-sum tests were used to assess the associations between children's social/medical history and their fluorosis scores and fluoride exposure. The measure of fluoride exposure used was reported use of supplemental fluoride.

Canonical correlation analyses were conducted to assess the association between aspects of a child's fluoride exposure history and the severity of fluorosis (Sum of 8 score) and between aspects of a child's fluoride exposures and CBCL scores (total, internalizing, externalizing). In these analyses, the following factors constituted the set of fluoride history variables; residence in a town with fluoridated water during various time intervals, use of concentrated formula, whether formula was reconstituted using tap water, whether the tap water was the primary source of water, the number of years that the tap was the primary source of water, whether supplemental fluoride was given during different time intervals, whether topical fluoride was applied, the frequency and amount of fluoridated toothpaste used, and the age at which fluoridated toothpaste was first used.

The power of our hypothesis tests was calculated assuming a Student's *t* test comparison of CBCL scores (SD = 10) for HF (N = 50) and LF (N = 150) children (alpha = 0.05; two-tailed, beta = 0.20). A sample of 200 children would provide 80% power to detect an effect size of 4.6 points, or approximately one-half of a standard deviation on the summary CBCL scales.

Results

Sample

Two hundred and forty-six children were examined and met the study criteria. Two participants withdrew

and 197 participants returned completed questionnaires yielding a response rate of 81% (197/244).

In general, the study participants were healthy, Caucasian (97%) children living in intact families (95%). The majority of mothers were employed (65%) and nearly 90% of both parents held at least a college degree.

Fluorosis and fluoride exposure

Fig 1 shows that the distribution of Sum of 8 fluorosis scores was not normal because very few children had high fluorosis scores while many had low fluorosis scores.

Fig 2 shows that the distribution of fluorosis scores using Dean's Index was more normal, with a central tendency corresponding to very mild fluorosis. The prevalence of fluorosis in this population using this index was 69%, with very mild fluorosis being the most common (39%) and 13% demonstrating moderate to severe fluorosis.

Table 3 presents the most common reported sources of exposure to fluoride. Most of the children lived in a fluoridated community (86%) and used fluoridated toothpaste early in life (74%). In addition, more than half of the subjects received fluoride supplementation.

Comparison between the HF and LF groups revealed only the use of supplemental fluoride prior to age 3 to be significantly higher in the HF group ($P = 0.049$). The

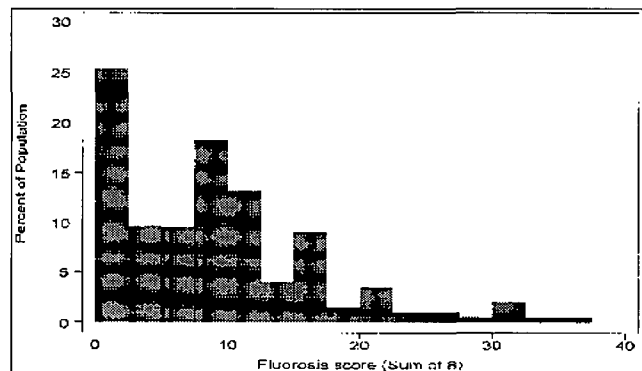


Fig 1. Distribution of fluorosis score (Sum of 8) in study population (N = 197).

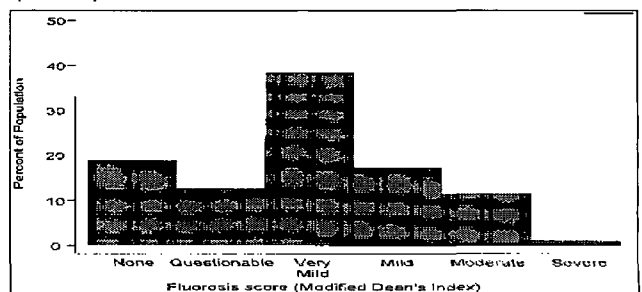


Fig 2. Prevalence of fluorosis (Modified Dean's Index) in study population (N = 197).

TABLE 4. COMPARISON OF MEDIAN CBCL SCORES FOR HIGH (HF) AND LOW (LF) FLUOROSIS GROUPS.

CBCL Score	HF (N = 47)	LF (N = 150)	P value
Total	41 (26-65)	44 (24-76)	0.22
Externalizing	40 (30-60)	44 (30-73)	0.07
Internalizing	46 (33-71)	46 (31-77)	0.96

canonical correlation analyses indicated that the fluoride history variables, in aggregate, were not significantly associated with clinical assessments of fluorosis (likelihood ratio statistic = 0.78; $df = 41, 155$; $P = 0.41$).

Behavior, fluorosis, and fluoride exposure

Table 4 shows that there were no significant associations between the three CBCL scores (total, externalizing, and internalizing) and fluorosis group, where higher CBCL scores indicate more behavior problems.

Only one of the fluoride exposure variables was significantly associated with a high CBCL score. Children who both used topical fluoride between the ages of 3 and 6 years and fluoridated toothpaste between the ages of 1 and 2 years were more likely to have more behavior problems ($P = 0.05$). The canonical correlation analyses indicated that the fluoride exposure variables, in aggregate, were not significantly associated with children's CBCL scores; total score (likelihood ratio statistic = 0.87; $df = 41, 155$; $P = 0.98$), externalizing score (likelihood ratio statistic = 0.88; $df = 41, 155$; $P = 0.99$), and internalizing score (likelihood ratio statistic = 0.82; $df = 41, 155$; $P = 0.77$).

Social and medical variables

We examined social and medical variables to see if they confounded the relationship between the fluorosis score and the CBCL score or the relationship between fluoride exposure and the CBCL score. We found no significant relationships.

Table 5 compares the HF and LF groups with respect to social, demographic, and medical characteristics. There were no significant differences between these two groups, with the exception of those in the LF group with a history of more remedial help in reading ($P = 0.02$). The ages of the participants were similar in both groups.

A positive history for fluoride supplementation between ages 0 and 6 years was more frequent among children with a college graduate mother ($P = 0.08$) or an unmarried father ($P = 0.05$). A negative history of fluoride supplementation was associated with having a history of allergy ($P = 0.05$), a nonbiologic mother or father ($P = 0.02, 0.05$), a mother with a history of a psychiatric problems ($P = 0.05$), or a sibling with a learning disability ($P = 0.05$).

Discussion

The purpose of this study was to investigate if an association exists between fluoride exposure and behavior problems in children. Fluoride exposure was measured by the clinical presence of enamel fluorosis on the permanent incisors and by history of fluoride exposure as reported by parents. Epidemiologic studies by Dean and coworkers⁷¹ and animal studies⁷²⁻⁷⁴ have shown a linear dose-response relationship between fluoride exposure and severity of fluorosis. Fluoride histories have been used by many to confirm the diagnosis of fluorosis and to identify which sources have been most influential in its development.^{5, 8, 14, 26-28} In addition, we also examined the prevalence of fluorosis and risk factors for fluorosis by comparing fluorosis scores with reported fluoride histories and social/medical histories.

The prevalence of fluorosis in this study was 69%, which is much higher than early prevalence studies conducted when community water was the predominant source of systemic fluoride exposure.^{71, 75, 76} The higher prevalence is undoubtedly due to an increase in the number of systemic sources of fluoride exposure.^{3-12, 18, 26-28} Similarly, the prevalence of 69% is also higher than the prevalences reported in more recent studies, which range between 22 and 36%.^{5, 6, 8} However, two of the most recent studies^{27, 28} did report fluorosis prevalences of 78 and 72%, which are more similar to our findings. Lalumandier and Rozier²⁷ derived their population from a private dental practice in North Carolina where only half of the subjects lived in a fluoridated area. Fluorosis in subjects living in fluoride-deficient areas was associated with dietary fluoride supplementation and age at initiation of toothbrushing. For subjects drinking fluoridated water, fluorosis was also associated with age of initiation of brushing. Skotowski et al.²⁸ derived their population from a dental clinic in Iowa City, Iowa, which, like ours, was highly educated. Amount of toothpaste use and greater exposure to fluoridated water were judged to be risk factors.

The distribution of fluorosis in this study was interesting. Although most children exhibited very mild fluorosis (39%), we also found a significant number of patients with moderate to severe fluorosis (13%). This is similar to the distribution reported by Lalumandier and Rozier²⁷ who noted 19% of patients to have moderate or more severe fluorosis. This, however, is in contrast to most other recent studies, which have reported an increase in the prevalence but not the severity of fluorosis.^{3, 12, 28, 77}

The finding of a fluorosis prevalence of 69% in our study is much higher than the national average of 22%,⁶ but reflective of the population. Eighty-six percent of the population lived in a fluoridated community, yet 53% also received fluoride supplementation. In addition, 74% had early exposure to toothpaste and 30% had early exposure to topical fluo-

TABLE 5. SOCIAL, DEMOGRAPHIC, AND MEDICAL CHARACTERISTICS OF HF AND LF CHILDREN (COLUMN PERCENTS)

Characteristic	HF (N = 47)	LF (N = 150)	P value
Sex			
Male	55	49	0.27
Race			
Caucasian	98	97	0.66
Education			
Mother with college or graduate degree	87	87	0.57
Father with college or graduate degree	87	85	0.43
Maternal Employment			
Full time	47	45	0.95
Part time	19	21	
Nonemployed	34	33	
Child's School History			
History of a school problem	6	13	0.17
Repeated a grade	2	5	0.32
Remedial help in reading	11	25	0.02*
Remedial help in math	9	7	0.50
Child's Medical History			
Hospitalization	9	10	0.51
History of ear infection	87	77	0.10
History of allergy	26	29	0.38
History of asthma	9	10	0.51
History of ADHD	6	4	0.37
History of LD	6	9	0.44
Residence			
Live with both biological parents	89	95	0.13
Marital Status			
Divorced parents	4	6	0.49
Number of Siblings			
Only child	9	5	0.63
Three or more	6	9	
History of Traumatic Event	64	61	0.45
Age (median years)	10.0	9.8	0.45

* $P < 0.05$.

ride treatment. These excessive fluoride exposures most likely contributed to the high prevalence of fluorosis in this study group. The children were predominantly from families of high socioeconomic status as reflected by the high percentage of parents with college degrees (90%). These families would tend to have better oral hy-

giene practices and are more likely to use fluoridated toothpaste and topical and systemic fluorides. They are also more likely to make their child's first dental appointments early in the child's life, which may result in more fluoride exposure.

Comparison between fluoride exposure variables and the Sum of 8 scores for fluorosis revealed supplemental fluoride given before the age of 3 years to be more frequent in the high fluorosis group, which is consistent with findings in other studies.^{8, 19, 21, 22, 26, 27, 78} It is also consistent with the most critical time for the development of fluorosis in upper anterior teeth, 22–26 months of age.⁷⁹ Our analyses failed to demonstrate any significant associations between the fluoride history variables in aggregate and the clinical assessments of fluorosis. Many investigators have reported sources of fluoride other than supplementation to be risk factors for the development of fluorosis, including use of fluoridated toothpaste, use of infant formula, and higher socioeconomic status.^{5, 12, 14, 22, 26, 27} Although our fluoride questionnaire investigated all these exposures, presumably we would need a larger study sample to demonstrate statistically significant associations with fluorosis. In addition, if we had been able to extract two groups with distinctly different fluorosis scores from this population, more exposure risk factors may have been identified. Furthermore, the elucidation of dental fluorosis risk factors is a difficult task given the ubiquitous nature of fluoride, the difficulty in obtaining accurate and complete fluoride exposure histories, and the difficulty in accurately measuring dental fluorosis.

Behavior problems were evaluated by having parents complete the CBCL. Comparison of the three summary behavior scores for the HF and LF groups did not show any significant association to exist between fluorosis and childhood behavior problems. Similarly, fluoride exposure variables in aggregate were not significantly associated with behavior problems in children. Of the 369 individual comparisons made, only one association was significant at the 0.05 level (children who both used topical fluoride between 3 and 6 years of age and fluoridated toothpaste between 1 and 2 years of age). However, this finding may be due to chance as it is expected that 18 significant associations would exist by chance alone at the 0.05 confidence level.

An association between fluoride exposure and behavior problems however, cannot be definitively excluded by this study. This population was generally from the same geographic area, the same socioeconomic status, and had similar fluoride exposures. In fact, most of the children in this population had sig-

nificant fluoride histories, i.e., 86% lived in a fluoridated community, 54% used fluoride supplements, and 73% used a fluoridated toothpaste early in life. The similarities of the groups we compared may have made it difficult to find differences in behavior that might be related to exposure. It would have been ideal to compare children with high exposure to those without any exposure, e.g., comparing children from a community where the water has the legal upper limit of fluoride concentration at 4 ppm with children living in a demographically similar community in which the water contains less than 0.3 ppm of fluoride.

Second, the measure of fluorosis is not an objective measurement, but subjective and difficult to reproduce. This was reflected in the intrarater reliability scores, which were not high for most comparisons. Additionally, there existed a general difference in the scores of teeth on the patient's right and left sides. The higher kappa scores for the right side can be attributed to better visibility by the examiner, who was positioned to the right of patients during the examination. Smaller differences were found between the scores of the lower incisors on the right and left sides because less variability existed in the scores of these teeth, and they had fewer fluorotic lesions than the other teeth examined. The more normal the tooth's appearance (i.e., less fluorosis), the higher the agreement rate will be, because agreement regarding normality is usually greater than agreement regarding abnormality.⁸¹ Conversely, the upper incisors, with lower kappa scores, had greater variability in fluorosis. Thus, the more diagnostic categories there are to consider, the lower the reliability.⁸¹ In addition, it is difficult to reproduce a score when the index is the estimation of the percentage of surface affected rather than a more discrete measure. The reproducibility of fluorosis scores may have been more reliable if broader categories were used, for example, if a tooth were simply scored as demonstrating fluorosis or no fluorosis. This was not feasible in this study because of the small number of subjects without fluorosis.

Third, our measures of fluoride exposure, fluorosis, and fluoride history questionnaires were indirect. Although degree of fluorosis has been shown to correlate with the amount of fluoride exposure,^{69, 71, 80} it is not as effective a measure when the two groups being compared have similar fluoride exposure histories. The fluoride history questionnaire, although extensive, was not able to accurately document all exposures to fluoride nor the extent of exposures that did occur. In addition, the fluoride questionnaire relied on the recall of parents. It is difficult for parents to provide accurate accounts of their child's eating, brushing, and drinking habits from years ago. In addition, parents may have over-reported the use of fluoride due to the setting in which the questionnaire was given. For example, parents may tend to over-report toothbrushing habits to the dentist.

Similarly, the use of the parent CBCL rather than the teacher CBCL may have provided judgments that were not as objective. It would have been preferable to use both the parent and teacher versions of the CBCL to ensure more comprehensive reporting of the children's behavior.

Comparison of the social/medical history with fluorosis and fluoride exposure (as measured by history for fluoride supplement use) showed a few associations, some of which are easily explained, while others are not. The association between remedial help in reading and low fluorosis may have been due to chance. The literature has reported medical problems that are associated with fluorosis, including disorders in acid-base balance, calcium deficiency, disruptions in urinary flow, and kidney problems,^{83, 84} but these were not elucidated in our study. Many authors have reported higher socioeconomic status to be related to fluorosis.^{9, 12, 22, 85-87} Of the two social variables associated with increased fluoride supplementation, only one—mother is a college graduate—follows this trend; however, its association was not a statistically significant finding. Two of the five social and medical variables associated with no fluoride supplementation are logical; children with a mother with a history of a psychiatric problem and children with a sibling with a history of a learning disability. These households may have less structure and may be less able to follow through with a daily regimen such as fluoride supplementation.

In summation, it is of concern that sodium fluoride was recently found to be neurotoxic in rats. However, our study failed to find an association between fluoride exposure and behavior problems in children. Yet our study cannot lay this issue to rest. It is hoped that it serves as an impetus for further investigations on this subject with two populations with disparate fluoride exposures.

Conclusions

1. Sixty-nine percent of children from this population of high socioeconomic-status families living mostly in fluoridated communities demonstrated fluorosis, with mild fluorosis being the most common.
2. The use of supplemental fluoride prior to age 3 was found to be a risk factor for dental fluorosis.
3. No significant association was found between fluoride history variables in aggregate and the clinical assessment of dental fluorosis.
4. Dental fluorosis was not significantly associated with behavior problems in this population.

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