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Changes in dental fluorosis following the cessation of water fluoridation

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Abstract – *Objectives:* To determine changes in the prevalence of dental fluorosis, and in perceptions of aesthetic concerns due to dental fluorosis after water fluoridation ceased. *Methods:* Schoolchildren in second and third grades were examined in 1993–94, 1996–97 and 2002–03 to determine changes in the prevalence of dental fluorosis following fluoridation cessation of the public water supplies in 1992. The Thylstrup–Fejerskov Index (TFI) was used to quantify dental fluorosis. Perceptions of aesthetics were assessed by questionnaires which were sent home to parents. Residence and dental histories were confirmed on all children to determine the extent of exposure to all types of fluorides. Comparisons between the three surveys were used to establish the influence of fluoridated water and other fluoride sources on the occurrence and severity of dental fluorosis. Aesthetic ratings from parents were used to assess the aesthetic conditions of maxillary anterior teeth across the three surveys. *Results:* When fluoride was removed from the water supply in 1992, the prevalence and severity of TFI scores decreased significantly from the 1993–94 survey cycle when compared with the 1996–97 and 2002–03 survey cycles. The use of fluoride supplements and fluoride dentifrice also decreased during this study period. Analyses were unable to determine the influence of these different fluoride exposures on the changes in TFI scores over time. Comparisons of aesthetic ratings from parents between survey cycles failed to show any significant differences.

Key words: aesthetics; dental fluorosis; fluoridation

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In the last 30 years, the caries experience of many population groups in North America has improved dramatically (1). Experts attribute much of the improvement to the widespread use of fluorides (2). During the past few decades, considerable scientific attention was paid to the safety and effectiveness of fluorides (3–8). This scientific attention was driven to some degree by the varied and complex fluoride exposures and ingestion patterns of the public today (9) and the need to consider fine adjustments in the total amount of fluoride delivered to populations exposed to several fluoride sources (10, 11).

This reassessment has focused on risks and benefits of fluoride exposure, and has prompted considerable attention on the question of changing prevalence and severity of fluorosis (2, 8, 9, 12–19). Recent North American reviews indicate that, in general, there has been a substantial increase in the prevalence of dental fluorosis both in fluoridated and nonfluoridated communities (20, 21). Recent reports (22, 23) have also found that dental fluorosis prevalence between fluoridated and never-fluoridated communities has narrowed considerably.

Much of the discussion on fluorosis has focused on the causes for this increase (18, 21, 24–31). While there is considerable evidence to associate the different fluoride ingestion patterns with dental fluorosis (14, 32, 33), the study designs are primarily retrospective and consequently limited in validity and predictive power. However, this literature consistently identifies similar risk factors, i.e. consumption of fluoridated water, use of fluoridated dentifrices, fluoride supplements and the use of infant formula before the age of 6.

More recently, investigators have looked at the aesthetic problems relating to dental fluorosis. In an earlier study, Clark and others found that parents, children and dentists were able to distinguish between teeth with and without fluorosis. They also found that aesthetic problems increased as Tooth Surface Index of Fluorosis scores increased (34). Dentists rated the teeth's aesthetics significantly better than did parents for low levels of fluorosis, or for nonfluorosis problems. They also found that parents were more critical of their children's tooth colour than were the children. More recently, Shulman et al. showed that parents, dentists and patients appear to see the potential aesthetic problem from dental fluorosis differently (35).

The effects of fluoridation cessation and interruption on dental caries prevalence have been studied retrospectively by many different investigators (36–45). However, the relationship between fluorosis and water fluoridation has been investigated in only one study following a permanent change of fluoride level (46). In 1978, the fluoride in the water supply in Hong Kong was reduced from 1.0 to 0.7 ppm. The prevalence of dental fluorosis among children aged 7–12 decreased from 64% in 1979 to 47% in 1985, and the Community Fluorosis Index decreased from 1.01 to 0.75. While only a modest-to-moderate change, it does provide strong evidence of an association. Another recent study investigated a temporary stoppage of fluoridation and found that an 11-month break showed strong cohort effects for fluorosis (47, 48). Tooth brushing frequency and use of fluoride supplements were also significant predictors of fluorosis. More recently investigators from Brazil reported the changes in fluorosis prevalence after a 7-year interruption in water fluoridation (49). The results from this study indicated a low prevalence and severity of Thylstrup–Fejerskov Index (TFI) scores overall, and yet a small but significant increase in TFI scores for children born and reared in an environment when no fluoride was available in the public water supply.

Despite the increasing number of cross-sectional surveys following discontinuation of fluoridation, there has never been an investigation to determine the effect of total fluoridation cessation on the prevalence of dental fluorosis or on the changing perceptions of the aesthetics of children's teeth (35, 50).

Methods

This report presents results from a follow-up epidemiological survey from 2002–03 and compares results to surveys conducted at baseline in 1993–94 and in 1996–97. Results represent data from children with permanent residency status who were in either second or third grade at the time of examination. For a detailed description of methods refer to previous papers (45, 51). The Comox/Courtenay and Campbell River communities in British Columbia (BC), Canada stopped fluoridating their water supplies in 1992. The fluoride levels have therefore gone from an average of about 1 ppm to essentially 0 ppm. All children examined in 1993–94 had their permanent teeth develop during the time water supplies were fluoridated. Children under the age of 9 who were examined in 1996–97 would have had a mixed exposure to fluoridated water during the development of their permanent teeth. For example, a 9-year-old born in 1988 would have had exposure to fluoridated water until about 4 years of age. None of the children examined in the 2002–03 survey had been exposed to fluoridated water. All children in the study communities were sent home with consents and oral health questionnaires requesting parental permission for participation and information concerning residency status and use of home care products. Only 62% of children in grades 2 and 3 responded to three rounds of sending consents and questionnaires home. Only 55% of the total population had negative systemic fluoride histories.

The TFI (52) and an instrument for assessing dental aesthetics (53) were used in the 2002–03 survey. Analysis of aesthetic ratings from earlier studies suggested that children in grades 2 and 3 gave unpredictable aesthetic evaluations compared with older children; therefore, aesthetic assessments were not included in the 2002–03 survey. However, parents were asked to evaluate the perceived aesthetics of their child's teeth by indicating an opinion about the reference statement, 'The colour of my child's teeth is pleasing and looks nice', using a Likert-like scale. In the first two surveys the same two examiners were used. For the 2002–03 survey, one new examiner was trained and calibrated by an experienced oral epidemiologist who also consulted and calibrated examiners at the baseline survey in 1993. Training and calibration were the same as in the previous surveys. Information concerning the participants' residence history, use of bottled water (birth–6 months, 7–12 months, 13–24 months, after 24 months), consumption of breastmilk, infant formula, cow's milk and solid food (birth–3 months, 4–6 months, 7–9 months, 10–12 months, 1–2 years of age), existence of home filtration devices (2002–03 only), history of exposure to fluoride supplements (<1, 1–2, 2–3, 3–4, 4–5, 5–6 years) and supplement frequency (daily, 4–6, 1–3, <1 time/week), mouthrinses (≥3, <3 times/week, rarely, not at all), aesthetic ratings by parents, and educational attainment of parents was again obtained by questionnaires. No duplicate questionnaires were sent out. It is acknowledged that there is considerable error in parental historical recollections about home care practices. Despite these problems, there is no other way to collect these data. All examinations were performed in schools using portable chairs and lights. No pressurized air source was used. Teeth were dried and cleaned if necessary with gauze prior to viewing. Teeth were viewed both with and without a dental light, and a score was assigned to each tooth according to the highest classification seen.

In parallel with the baseline and follow-up stages of this project, descriptive statistics were used to summarize demographic factors, percentage distribution by TFI and percentage of children using specified preventive products. Descriptive statistics were also used to depict TFI prevalence, reported as the percentage of affected subjects by highest-score on individual teeth and tooth types. Bivariate relationships between fluorosis status, aesthetic classifications and fluoride exposure variables were first tested for significance. Exposure variables included exposure to water fluoridation, fluoride supplements, bottled water (<3, 4–6, 7–9, 10–12, 13–24 months), amount of dentifrice used (<2, 2–4, 4–6 years; 1996–97 and 2002–03 only), and age brushing started (<1 year, 1–2, 2–3, 3–4, ≥4 years), and brushing frequency. In addition, we used the parents' education level (≤ grade 7, grade 8–high school, >high school) as a surrogate measure of socioeconomic status. Significant predictors from the bivariate analysis were then used as predictors in the multivariate analysis to model the probability of experiencing dental fluorosis.

Statistical analysis was performed using SAS 9.1 (SAS Institute, Cary, NC, USA). We used Kruskal–Wallis analysis of variance (ANOVA) to compare differences in TFI prevalence and the extent to which parents agreed/disagreed with the reference statement for aesthetic ratings among the three surveys. To explore pairwise differences between studies, we used the Wilcoxon test with an experimentwise error rate of $\alpha = 0.0167$ (0.05/3) to adjust for multiple comparisons. Prevalence of fluoride supplement use for each age group was compared using one-way ANOVA and Tukey's test to compare pairwise differences with $P < 0.0167$ as the threshold for significance. As the distribution of TFI was highly skewed with a mode of zero, we first performed a bivariate Poisson regression using the TFI score for the six anterior teeth as the outcome variable and the study period as the independent variable. We then performed separate bivariate Poisson regressions (GENMOD) for each study period (1992–93; 1996–97; 2002–03) to model the association between TFI and the previously described exposure variables with $P < 0.15$ as our significance level for entry into a multivariable model. Using forward selection, we started with the variable with the largest Wald chi-square. We added variables one at a time, removing those that did not meet the $P < 0.05$ retention criterion. We then tested all first and second order interactions, keeping those interactions meeting the $P < 0.05$ retention criterion.

Results

The communities of Courtenay and Comox stopped water fluoridation in March of 1992, and Campbell River stopped in June of 1992. Children selected for these analyses from the 1993–94 survey had all been exposed to fluoridated water for their entire life. In the 1996–97 follow-up survey, children were examined from November of 1996 to May of 1997. The age of participants at the time of examination ranged from 6.2 to 9 years of age (mean = 8.2; SD = 0.45). At the time of fluoridation cessation, the majority of children were 7.3–8.7 years of age, and would have been about two and a half to three and a half years old when fluoridation was stopped. Therefore, the data from the 1996–97 survey represent a partial exposure to fluoride in the water during the development of the permanent teeth. The 2002–03 children had no exposure to fluoridated water. The examiner for 2002–03 completed 36 duplicate examinations on participating children and the measure of agreement was $\kappa = 0.654$. In 1993–94, intra-examiner reliability was $K = 0.65$ and 0.74 and the inter-examiner reliability was $K = 0.64$. Certain items from our questionnaire were tested for reliability by telephoning parents and guardians after return of the questionnaire and asking them to respond to certain repeat items. Two items, one referring to the use of fluoride supplements and the other referring to brushing frequency, were retested and the weighted kappas were 0.6588 and 0.8154, respectively.

Data from Table 1 show the percentage distribution of maximum TFI scores per subject for the three surveys, and for maximum TFI scores for children from 1993–94 who also had exposure to fluoride supplements during the first 4 years of life in addition to exposure to fluoridated water. TFI scores were significantly different among the survey years ($P < 0.0001$). TFI scores were significantly greater (Wilcoxon test) in 1993–94 than 1996–97 ($P < 0.0001$) and 2002–03 ($P < 0.0001$). Scores were not significantly different between 1996–97 and 2002–03 ($P = 0.86$). TFI scores from 1993–94 were not significantly different for the fluoridated water-only group and the group that was exposed to both fluoridated water and fluoride supplements in the first 4 years of life.

Data in Table 2 show the percentage distribution of maximum TFI scores for maxillary anterior teeth (incisors and canines) per subject, and again for children who had exposure to fluoride supplements and fluoridated water. Again the TFI scores were significantly different (Kruskal–Wallis ANOVA) among the survey cycles ($P < 0.0001$). Moreover, maximum TFI scores were significantly higher (Wilcoxon test) in 1993–94 than 1996–97 ($P < 0.0001$) and 2002–03 ($P < 0.0001$). Again the differences between the children with and without exposure to fluoride supplements in the 1993–94 survey were not significant. Unlike the results from maximum TFI scores of all teeth per subject, the maximum TFI scores for anterior teeth per subject only from 1996–97 were significantly higher than 2002–03 ($P < 0.0005$). The age of subjects at the time of the 1996–97 survey cycle perhaps explains the difference in prevalence between 1996–97 and 2002–03 for all teeth and maxillary anterior teeth only. The higher prevalence of maximum TFI scores greater than zero for anterior teeth in 1996–97 suggests that many of these anterior teeth were developed before fluoridation had stopped. The data from the three survey cycles also reflect a marked decrease in severity of TFI scores. In 2002–03 all fluorosis scores were <3, and only 1% of subjects were scored a maximum TFI of 2 (Table 1).

Data in Table 3 show parental ratings for aesthetics among the three survey cycles. The ratings from these surveys were not significantly different (Kruskal–Wallis test: $P = 0.86$). Pairwise differences (Wilcoxon test) between the years were also not statistically significant. Very few ratings indicated the presence of an aesthetic problem due to the colour of the teeth.

Table 1. Percentage distribution of maximum TFI scores among life-long participants under 9 years of age from years 93–94, 96–97, 2002–03 – all teeth[a]

		TFI scores				
Survey year	n	0	1	2	3	4–7
1993–94[b,c]	437	42	35	15	8	0.6
1993–94 children with supplement exposure[d]	261	43	34	17	6	0.4
1996–97[b,e]	293	77	17	6	0	0
2002–03[c,e]	146	76	23	1.4	0	0

[a]Scores significantly different among the survey years ($P < 0.0001$).
[b]Scores significantly different between 1993–94 and 1996–97 ($P < 0.0001$).
[c]Scores significantly different between 1993–94 and 2002–03 ($P < 0.0001$).
[d]Scores from children with permanent residence status who also reported exposure to fluoride supplements during first 4 years of life; differences not significantly different from scores of children with exposure to fluoridated water only.
[e]Scores not significantly different between 1996–97 and 2002–03 ($P = 0.86$).

Table 2. Percentage distribution of maximum TFI scores among life-long participants under 9 years of age from years 93–94, 96–97, 2002–03 – maxillary anterior teeth[a]

		TFI scores				
Survey year	n	0	1	2	3	4–7
1993–94[b,c]	437	57	28	11	6	0.4
1993–94[d]	261	52	30	12	5	0.4
1996–97[b,e]	293	67	23	9	1.4	0
2002–03[c,e]	146	78	21	1	0	0

[a]Scores significantly different among the survey years ($P < 0.0001$).
[b]Scores significantly different between 1993–94 and 1996–97 ($P < 0.0001$).
[c]Scores significantly different between 1993–94 and 2002–03 ($P < 0.0001$).
[d]Scores from children who reported exposure to fluoride supplements during first 4 years of life; differences not significantly different from scores from children with exposure to fluoridated water only.
[e]Scores significantly different between 1996–97 and 2002–03 ($P < 0.0001$).

Table 3. Percentage distribution of aesthetic responses of parents[a,b]

	93–94	96–97	02–03
Strongly agree	22	17	13
Agree	48	52	60
Neutral	22	23	23
Disagree	9	7	5
Strongly disagree	1	1	0

[a]Prevalence of aesthetic problems – agreement with reference statement 'the colour of my teeth looks nice'.
[b]Differences between responses from three cycles not significantly different.

Table 4. Percentage distribution of life-long participants taking fluoride supplements by age and year[a,b,c,d]

Age (years)	1993–94	1996–97[b]	2002–03[c]
<1	36[b,c]	52[a,c]	11[a,b]
1–2	37[c]	39[c]	4[a,b]
2–3	44[b,c]	22[a,c]	4[a,b]
3–4	47[b,c]	15[a]	4[a]
4–5	48[b,c]	11[a]	3[a]

[a,b,c]$P < 0.017$ for paired differences (Wilcoxon test).
[d]Fluoride supplement recommendations changed in Canada in 1997 and 2000.

Based on data from questionnaires taken home by children and completed by parents, it was possible to estimate fluoride ingestion from the use of fluoride supplements and fluoride dentifrice across the three survey cycles. Data from Table 4 show the prevalence of fluoride supplement use by age group. What first seems quite remarkable is the high percentage of children taking fluoride supplements while also being exposed to fluoridated water. In Canada, paediatricians as well as dentists have traditionally prescribed fluoride supplements. However, no data exist to determine the extent of this practice during the study period. It seems apparent that supplement use has all but disappeared in the 2002–03 survey cycle, a time when children would not have been exposed to fluoridated water.

Data from Table 5 demonstrate the percentage of children using fluoride dentifrice by age. Results suggest that between 1993–94, 1996–97 and 2002–03, the age when children started using a fluoride dentifrice increased. However, some of these increases were not statistically significant. For the children ranging in age from 1 to 2 and 2 to 3 years, there were no significant differences in the percent of children exposed to fluoride dentifrice.

The odds of having a TFI score above the mean (Poisson regression) were greater in 1993–94

Table 5. Percentage distribution of life-long participants using fluoride dentifrice by age and year[a]

Age (years)	1993–94[b,c]	1996–97[b,d]	2002–03[c,d]
<1[e]	38.3	20.4	10.4
1–2	79.2	88.4	84.0
2–3	92.0	95.9	98.6

[a]Scores significantly different among the survey years ($P = 0.00005$).
[b]Scores significantly different between 1993–4 and 1996–7 ($P = 0.0002$).
[c]Scores not significantly different between 1993–4 and 2002–3 ($P = 0.073$).
[d]Scores not significantly different between 1996–7 and 2002–3 ($P = 0.079$).
[e]Scores significantly different between 1993–94 and 1996–97 ($P = 0.001$) and 2002–03 ($P = 0.001$).

(OR = 3.01; $P < 0.0001$) and 1996–97 (OR = 1.96; $P < 0.0005$) compared with 2002–03; and greater in 1993–94 compared with 1996–97 (OR = 1.96; $P < 0.0001$). Results from regression analyses for each study period failed to identify any statistically significant associations ($P < 0.05$) between TFI and bottled water consumption, fluoride rinse frequency, breastfeeding, and age at which solid food, cow's milk and infant formula consumption began. Statistically significant associations were found for fluoride supplement use from birth to 1 year of age in 1996–97 (OR = 1.54; $P = 0.040$); toothbrushing ≥3 times/day (compared with <1 time/day) in 1996–97 (OR = 2.67; $P = 0.014$) and 2002–03 (OR = 3.52; $P = 0.045$). No multivariable model was statistically significant for any of the study years.

Discussion

As anticipated, TFI scores decreased following fluoridation cessation. The percentage of children with dental fluorosis dropped from 58% to 24%. The distribution of TFI scores also suggested that the severity of existing fluorosis also decreased. In 1996–97 and 2003–03, almost all fluorosis scores were below a TFI of 3. Obviously children's exposure to pre-eruptive fluorides decreased significantly over the study period. Again, the results indicate that other fluoride exposures also decreased during this time period. As indicated, our analyses were unable to determine the impact of changes for each of the different fluoride exposures to the total decrease in TFI scores. Apparently fluoride ingestion patterns are too complex and changing to reveal much meaningful information.

Further, other changes have certainly occurred in the study community over the study period. Repeated cross-sectional studies traditionally suffer from changes in the demographics of the reference population, as well as shifts in the application of diagnostic criteria by the examiners. Despite the inclusion of a repeated standardization training exercise from the same consultant who participated in 1993–94, shifts in diagnosis are bound to occur. Anecdotally, the teeth developed after fluoridation generally have a different appearance beyond the existence of fluorosis. The effect of seeing child after child with fluorosis early in the study might also influence the examiner's application of diagnostic criteria.

Results also suggest that the overall aesthetic ratings of parents concerning the colour of their children's teeth did not change despite significant changes in the prevalence and severity of fluorosis scores. Most parents across all cycles rated the colour of their children's teeth to be aesthetically acceptable or better. These results support the conclusion that fluorosis-related aesthetic problems are rare (35, 50).

Parents from a high proportion of children surveyed during the 1993–94 survey cycle reported exposure to fluoride supplements. Our questionnaires asked whether supplement use occurred in a particular age range, and how frequently supplements were administered. Despite the reported high use of supplements, there were no significant differences in maximum TFI scores between children exposed to fluoride supplements and those not exposed. Still perhaps more perplexing is the observation that fluoride supplement use increased with age, up to the age of 5 years. These findings are inconsistent with other reports (18, 24–28) and suggest that there is either confusion about fluoride supplements in multi-vitamins for children or there are problems with recall of this information. Nonetheless, the results speak to the problem of using fluoride supplements appropriately.

The recommendations for supplement use have changed during the study period. Throughout this period in Canada, supplements have been available to children through prescription only either from a dentist or a paediatrician. In 1997, fluoride supplement use was recommended for high risk children only who had low exposure to other fluorides and who lived in nonfluoridated areas. Supplementation was recommended starting at the age of 6 months (54). In 2000, supplement use was recommended for high risk children starting at age 6, or when the first permanent teeth had begun eruption (55). Both reports recommended brushing with a pea-sized amount of fluoride toothpaste twice a day as soon as primary teeth erupt into the mouth. Prior to these reports, recommendations did not indicate an amount of dentifrice for use. These changes appear to have diffused through the profession to the public. These data further suggest that perhaps the most recent recommendations of the Canadian Dental Association are being complied with, that being that only high risk children are taking supplements and then only after permanent teeth are present in the mouth. Changes in the use of supplements have dropped off significantly, and the use of fluoride toothpaste before the age of 1 year has decreased as well.

Conclusions

Following fluoridation cessation of the public water supply, the prevalence and severity of dental fluorosis decreased significantly. However, during this same time period the reported use of fluoride supplements and fluoride dentifrice decreased as well. Our analyses were unable to determine the influences of these different fluoride exposures and decreases and therefore suggest that different fluoride sources have played a role in declining TFI scores; their exact contribution to the relative effect is unclear. Furthermore, the decreases in TFI scores did not seem to affect the aesthetic ratings of parents during the study period.

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