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Decline in the prevalence of dental fluorosis among South Australian children

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Abstract – *Background:* The use of fluoride involves a balance between protection against dental caries and risk of dental fluorosis. Fluorosis in Australian children was highly prevalent in the early 1990s. Policy measures were introduced to control fluoride exposure so as to reduce the prevalence of fluorosis. *Objective:* To evaluate the effectiveness of policy measures in reducing the prevalence of fluorosis among Australian children. *Methods:* A random sample of South Australian children born in 1989–1994 was selected in 2002/2003, stratified by fluoridation status and urban/rural residence. Children were targeted to form three successive birth cohorts: those children born in 1989/1990, 1991/1992 and 1993/1994, respectively. Fluoride exposures were assessed by questionnaire. One dentist examined 677 children for fluorosis using the Thylstrup and Fejerskov (TF) Index. Data were reweighted to reflect the state's child population. Case definitions of fluorosis were: having a TF score of 1+ (TF1+) or a TF score of 2+ (TF2+) on one or both maxillary central incisors. *Results:* A higher proportion of children in the later birth cohorts used low-concentration fluoridated toothpaste, and a smaller amount of toothpaste was used when they commenced toothbrushing. The fluorosis experience in this population was mostly very mild to mild. There was a significant decline in the prevalence of fluorosis across the three successive birth cohorts. The prevalence of fluorosis by TF1+ case definition declined from 34.7% to 22.1% and by TF2+ case definition from 17.9% to 8.3%. Risk factors for fluorosis were use of standard-concentration fluoridated toothpaste, an eating and/or licking toothpaste habit and exposure to fluoridated water. *Conclusion:* The experience of fluorosis among the South Australian child population was mostly very mild to mild. There was a marked decline in the prevalence of fluorosis across the three successive birth cohorts. The decline was mainly linked with the reduction in exposure to fluoride from fluoridated toothpaste.

Key words: Australia; children; fluoride exposure; fluorosis

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Dental fluorosis is a developmental defect in tooth enamel that is caused by excessive intake of fluoride during the enamel formation period (1). In the population, fluorosis can serve as 'the canary in the coal mine', alerting both members of the dental profession and public health authorities to potential overexposure to sources of fluoride. The improvement in oral health in Australia that followed the onset of fluoridation in the 1960s and 1970s reduced the attention given to the low prevalence of fluorosis. However, as the prevalence of fluorosis increased during the 1980s, research began to refocus on fluorosis.

In Australia, the prevalence of fluorosis became significantly higher than historically expected (2). Riordan and Banks (3) and Riordan (4), using the Thylstrup and Fejerskov (TF) Index and a case definition of TF score of 1+ on the right maxillary central incisor, reported on the prevalence of fluorosis in Western Australian (WA) children.

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The prevalence was 40.2% in fluoridated and 33.0% in nonfluoridated areas among 12-year olds in 1989 and 48% among 7-year olds in a fluoridated area in 1990. Puzio et al. (5), investigating fluorosis in 10- to 15-year-old South Australian children in 1992/1993, reported that the prevalence of fluorosis, using Dean's Index and a case definition of having a Dean's 'very mild' score or higher on the right maxillary central incisor, was 34.3% and 19.0% in fluoridated and nonfluoridated areas, respectively. These figures were well above historical standards, i.e. 12.2% in an area with a fluoride level of 0.9 ppm and 1.1% in an area with 0.2 ppm, as reported by Dean using a classification of mottled enamel, i.e. having 'very mild' score or higher on the two most affected teeth (6).

The policy response to this situation in Australia was developed through the National Health and Medical Research Council (NHMRC) Working Group report on the Effectiveness of Water Fluoridation (7), an NHMRC Expert Panel on the Use of Discretionary Fluorides (8) and the Consensus Conference on the Appropriate Use of Fluorides sponsored by the Western Australian Department of Health and University of Western Australia (9). These separate review processes targeted reductions in exposure to the known risk factors for dental fluorosis. The factors were infant formula powders that might contain a high level of fluoride (10) (other forms of infant formula such as ready-to-feed formula or liquid concentrate are not available in Australia), the ingestion of fluoridated toothpaste and regimens for fluoride supplementation in young children. By 1993, the fluoride concentration in infant formula powder manufactured in Australia or imported from New Zealand was reduced. A brand of children's low-concentration fluoridated toothpaste was introduced in 1991, following a recommendation letter from one of the authors (AJS) at the University of Adelaide. By 1993, all three major toothpaste manufacturers had introduced children's low-concentration (400–550 ppm) fluoridated toothpaste and greater attention was given to consumer advice on its use. The advice was directed at using a pea-sized amount of toothpaste, using children's low-concentration fluoridated toothpaste for children younger than 7 years old, delaying toothbrushing with any toothpaste until after 24 months of age and encouraging expectorating without rinsing after brushing. The NHMRC Expert Panel on the Use of Discretionary Fluorides (8) issued a new dosage schedule for fluoride supplements, entailing a reduced dosage of fluoride for children younger than 8 years.

If these policy measures were both widely implemented and effective, children born post-1993 should show reduced prevalence and severity of fluorosis. Available evidence from other countries suggests a reduction in the prevalence of fluorosis as a result of reduction in exposure to fluoride in water (11–13). However, the effect of the reduction in exposure to discretionary fluoride was yet to be established when this study commenced in 2003. Therefore, it was necessary to document the change in dental fluorosis in the study population following the implementation of the policy measures.

The recent contribution by Riordan (14) was aimed at evaluating the effect of the policy measures. It reported a reduction in the prevalence of fluorosis in WA children 10 years of age compared with the findings of a previous study (3). The prevalence of fluorosis in fluoridated Perth was reduced from 40.2% in 1990 to 22.2% in 2000. The prevalence figures in nonfluoridated Bunbury were 33.0% in 1990 and 10.8% in 2000 (14). However, the 10-year-old children examined in that study were born in 1990 before all the policy measures were implemented. Therefore, the full effect of the measures might not be reflected in that cohort. However, Riordan's study has set the background for further evaluation of the policy measures to control fluoride intake among children in Australia.

The measures would have affected Australian children born at and after its introduction because fluorosis is a product of fluoride intake in early childhood. The outcomes would best be assessed by comparing children who were likely to be affected by the policy measures (test group) and children who were not, i.e. having their tooth development period before the introduction of the measures (comparison group).

The study was aimed at evaluating the outcomes of the policy measures introduced in Australia in the early 1990s to reduce exposure to discretionary fluorides with the objective of reducing the risk of fluorosis.

Methods

Sample selection of the study

South Australian children who attended the school dental service (SDS), which includes up to 89% of the state's child population, were stratified by fluoridation and urban/rural status. Children living in fluoridated metropolitan Adelaide, who comprised around 75% of the state's child population, as well as children from other South Australian regional nonfluoridated areas with negligible fluoride levels naturally in their water, were included in the Child Oral Health Study (COHS). Study sites were randomly selected from all regional towns with a probability of selection proportional to population size.

The target population to pursue the study's aim was South Australian children who were born immediately before, during and after the introduction of the policy measures which occurred in 1991–1993. The study design is presented in Fig. 1. The study was nested in the COHS of Australian children 2002/2003. The COHS is a large-scale population-based study that employed a multi-staged, stratified random sampling approach. The population consisted of children enrolled in the SDS. Children were selected randomly by date of birth based on sampling ratios calculated for each stratum. Parents who gave consent for their child to participate were given a questionnaire that collected information about child's fluoride exposure history at different stages since birth. It included a detailed residential history, patterns of toothbrushing practice when toothbrushing started, at the age of 5 years and at the time of the study, use of infant formula and use of fluoride supplements (tablets or drops).

The sample of this nested study was drawn from the pool of COHS participants in South Australia, who were born from 1 January 1989 to 31 December 1994. Those children formed three successive birth cohorts: children born in 1989/1990 (comparison group), children born in 1991/1992 (transitional group) and children born in 1993/1994 (test group). Children and their parents were approached with a package containing an information sheet and a consent form. Parents whose consent was received were contacted by phone to organize a clinical examination for their child at their local SDS clinic. Those who failed to attend their appointment were contacted again for another appointment.

Ethics approval was obtained from the University of Adelaide Human Research Ethics Committee.

Data collection

The presence of fluorosis was assessed using Russell's criteria of differential diagnosis of dental fluorosis (15), which are based on area affected, demarcation, colour and shape of lesion and teeth affected. The TF Index (1) was used to evaluate fluorosis severity on the labial surface of eight maxillary permanent teeth from right first premolar to left first premolar. The TF Index was designed with the aim to classify clinical features of fluorosis reflecting the histological changes in enamel associated with differing degrees of fluorosis severity. This index requires the drying of teeth before examining for fluorosis.

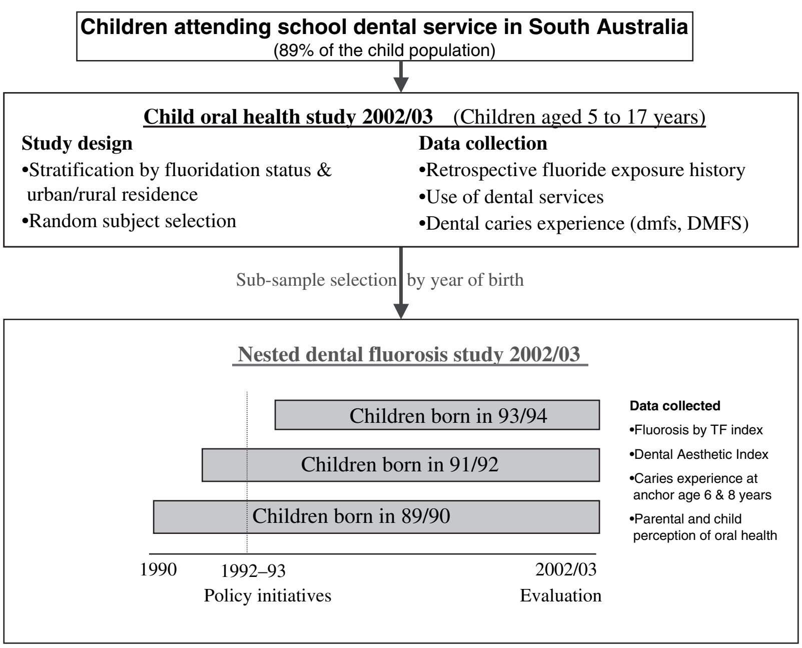

Fig. 1. The study design and data collection process.

All children were examined by one trained dentist (LGD) in their local SDS clinic. Children were examined under standard clinical lighting using disposable mirrors and disposable triplex syringe tips for drying teeth with compressed air. Before the fieldwork, the examiner underwent slide viewing and clinical training sessions at an SA SDS clinic with epidemiologists experienced in using the TF (Professor A. J. Spencer and Dr A. Puzio from the University of Adelaide).

Data management and analysis

The COHS questionnaire data were used to calculate per cent lifetime exposure to fluoride in water using a method described elsewhere (16). The questionnaire asked parents to list all locations where the child had lived and the time period for each location. Those locations were linked with a database of fluoride levels in Australian public water supplies. Other nonpublic waters were assumed to have negligible fluoride levels. Parents were also asked to estimate the child's proportion of public water usage for all periods listed of residency and whether a reverse osmosis water filter, which is capable of removing fluoride from water (17), was used. The formula used in the calculation of per cent lifetime exposure E was given as follows:

$$E = \sum[\text{time (months) at a residency during age period i}] \times \text{fluoride level in public water (adjusted for filtration)} \times \text{percentage of public water usage} \div \text{age (months)} \times 100.$$

The formula can be used to calculate lifetime exposure to fluoridated water for any life period. The present paper used the life period from birth to 6 years of age (total age included in the above formula equal to 72 months). The estimate of lifetime exposure was used to classify children into three groups: having 0% lifetime exposure, having >0% and ≤50% lifetime exposure and having >50% lifetime exposure. The period from birth to 6 years of age was used because it is the risk period for fluorosis.

Patterns of toothbrushing practice at the time when toothbrushing with toothpaste started were used in the analysis. Specific questions were asked about age (in months) when brushing with toothpaste commenced, type and amount of toothpaste used, frequency of toothbrushing and whether the child had an eating and/or licking toothpaste habit. Those questions were specific for the time when brushing with toothpaste commenced. Type of toothpaste was classified as using low-concentration fluoridated (400–550 ppm), standard fluoridated (1000 ppm) or nonfluoridated toothpaste. Amount of toothpaste used was asked using three pictures: small (thin, short smear of toothpaste), medium (small pea-sized) and large (full head of toothbrush) amount. Age in months when toothpaste use commenced was used to classify children into groups who commenced toothpaste use before or at 24 months and after 24 months. Use of fluoride supplements and infant formula were also used as number and percentage of children who reportedly to have ever used fluoride supplements or infant formula.

For analysing the trend of fluorosis across birth cohorts, the TF assessment of fluorosis on maxillary central incisors was used because the three birth cohorts would have a similar number of those teeth present for examination. Fluorosis was defined by two case definitions: having a TF score of 1+ or having a TF score of 2+ on one or both of those teeth. Bivariate statistics were used to test for possible associations with fluoride exposures. The three birth cohorts were also compared for differences in the prevalence of fluorosis. Multivariate logistic regression models were generated to identify explanatory factors for the prevalence of fluorosis. All fluoride exposures in early childhood were included in the models because all can theoretically be a risk factor for fluorosis. Exploratory models were initially generated using the stepwise algorithm to examine the importance of individual exposures and their potential interaction. However, the final models included all exposures to fluoride. Birth cohort was also included to explore the change in fluorosis prevalence across birth cohorts. The significance level was set at 0.05.

Data were reweighted by age, sex and residency distribution to correct for different sampling ratios and to provide estimates representative of the state's child population. In tables and figures, where indicated, numbers of children are unweighted, while percentages and mean values are weighted. Therefore, multiplying the estimates by number of subjects may not yield integers of individuals.

Results

The study sample

A total of 1401 children who took part in the COHS were approached for the first stage of the study, which gained parental consent and collected information on children's oral health-related quality of life using a perception questionnaire. Respondents were then invited for a clinical examination for fluorosis at their local SDS clinics. A total of 684 attended the examination. A total of 677 children had valid examination data yielding a response rate of 52.2% of the initial sample (adjusted for number of households with incorrect addresses). Comparison of examined children and nonexamined children revealed no statistically significant difference in terms of sex, urban/rural residency or caries experience.

The three birth cohorts did not significantly differ in sex and current residency distribution (Table 1). There were more children from the youngest birth cohort in the sample than the oldest group.

Examiner reliability

Study participants were not re-examined during the fieldwork. Instead, photographs of the front teeth of children were taken using a clinical digital camera. When the fieldwork was completed, those photographs were used to calculate intra-examiner reliability. The same examiner re-evaluated the two upper front teeth using the TF Index. Those scores were used to calculate per cent agreement and kappa score for each of the two teeth independently and for both of the teeth. The absolute agreement was above 80% of all scores and the kappa scores ranged from 0.74 to 0.79. Inter-examiner reliability was not applicable.

Fluoride exposure history

The three cohort groups did not significantly differ in their per cent lifetime exposure to fluoride in water from birth to 6 years of age (Table 2). Almost two-thirds of the population were reported to have commenced their toothbrushing with toothpaste before the age of 25 months. There was a significant increase across birth cohorts in the use of low-concentration fluoridated toothpaste (containing 400–550 ppm) when toothbrushing with toothpaste started. The vast majority of children were reported to have used a small or medium amount of toothpaste per brushing, while less than half of the children were reported to have brushed twice a day or more. Almost half of the children were reported to have had a habit of eating and/or licking toothpaste when they started toothbrushing.

Fluorosis experience

A total of 145 (26.9%) of children had fluorosis with TF score from 1 to 3 on one or both maxillary central incisors. Of those, 113 children had similar fluorosis scores on both of the teeth, while the remaining 32 children had different scores on the two teeth. A total of 57 (11.8%) had a TF score of 2 or 3 on one or both maxillary central incisors. No child had a TF score of 4 or higher.

Table 3 shows the prevalence of fluorosis by the two case definitions used and different fluoride exposures. Commencing toothbrushing with fluoridated toothpaste in the first 2 years was significantly associated with an increased prevalence of fluorosis defined by both case definitions. Children who used a standard 1000-ppm fluoridated toothpaste when toothbrushing commenced had a higher, but not significantly, fluorosis prevalence defined by TF1+. However, the difference became significant for the prevalence of fluorosis defined

Table 1. Sex and residency distribution of the study sample by birth cohort (unweighted *n*, weighted column %)

	Born in 1989/1990	Born in 1991/1992	Born in 1993/1994	All
Total (row %)	171 (25.3)	224 (33.1)	282 (41.7)	677 (100)
Sex				
Male	86 (50.3)	117 (52.2)	146 (51.8)	349 (51.6)
Female	85 (49.7)	107 (47.8)	136 (48.2)	328 (48.4)
Current residency				
Adelaide (fluoridated area)	75 (43.9)	95 (42.4)	129 (45.7)	299 (44.2)
Other areas (nonfluoridated area)	96 (56.1)	129 (57.6)	153 (54.3)	378 (55.8)

Comparison by sex and current residency, chi-square, $P > 0.05$.

Table 2. Exposure to different fluoride measures (weighted column %) by birth cohort

Exposure to fluoride	Born in 1989/1990 (n = 171)	Born in 1991/1992 (n = 224)	Born in 1993/1994 (n = 282)
Lifetime exposure to fluoride in water, birth to 6 years			
0% lifetime	28.4	24.9	25.3
>0% and ≤50% lifetime	38.5	41.5	44.6
>50% lifetime	33.1	33.6	30.2
Toothbrushing practice when brushing started			
Starting toothbrushing before the age of 25 months[a]	76.6	67.3	75.2
Used 400- to 550-ppm fluoride toothpaste[a]	28.2	74.5	82.9
Used a pea-sized or less amount of toothpaste	94.1	94.8	97.2
Brushing 2+ times a day	39.4	41.5	39.4
Eating/licking toothpaste	49.4	42.7	54.6
Fluoride supplements use (% ever used)	10.8	6.2	4.7
Infant formula (% ever used)	61.7	60.9	66.2

[a]Comparison between birth cohorts, chi-square, $P < 0.05$.

Table 3. Prevalence of fluorosis by TF1+ and TF2+ case definitions by fluoride exposures

	TF1+			TF2+		
	Unweighted n	Weighted %	Crude OR (95% CI)	Unweighted n	Weighted %	Crude OR (95% CI)
Total	145	26.9		57	11.8	
Age when toothbrushing with toothpaste started[a] (dichotomized at the age of 24 months)						
24+ months	28	20.9*	1	9	6.5*	1
≤24 months	101	30.0	1.44 (1.02–2.03)	41	13.4	1.88 (1.05–3.38)
Brushing frequency when toothbrushing started						
Once/day or less	73	24.7	1	32	11.1	1
Twice/day or more	60	28.9	1.23 (0.84–1.78)	19	11.0	0.96 (0.57–1.62)
Type of toothpaste when toothbrushing started						
400- to 550-ppm fluoride toothpaste	58	26.9	1	17	6.4*	1
1000-ppm fluoride toothpaste	75	29.3	1.12 (0.77–1.65)	34	16.2	1.81 (1.08–3.04)
Amount of toothpaste when toothbrushing started						
Small amount	83	24.5*	1	18	13.4	1
Medium or large	49	34.2	1.60 (1.10–2.34)	33	10.6	1.31 (0.77–2.22)
Eating/licking toothpaste when toothbrushing started						
Never	56	22.5*	1	19	8.7*	1
Yes	78	33.3	1.72 (1.19–2.50)	32	14.5	1.80 (1.06–3.04)
Exposure to fluoride in water, birth to 6 years[a]						
0% lifetime	37	14.2*	1	10	2.7*	1
>0% and ≤50% lifetime	53	30.5	2.65 (1.55–4.53)	23	11.5	4.63 (1.56–13.74)
>50% lifetime	41	31.3	2.75 (1.58–4.78)	16	14.8	6.22 (2.17–17.85)
Use of fluoride supplements[b]						
Never	43	14.4	1	13	4.8	1
Yes	10	25.0	1.74 (0.73–4.15)	4	9.5	1.98 (0.43–9.18)
Use of infant formula						
Never	38	24.9	1	16	11.0	1
Yes	95	27.4	1.33 (0.90–1.79)	34	12.9	1.03 (0.62–1.71)

TF, Thylstrup and Fejerskov; OR, odds ratio; CI, confidence interval.
[a]Crude ORs were calculated on 2 × 2 tables with 'having 0% lifetime exposure' as the reference group.
[b]Nonfluoridated areas' residents only.
*Chi-square, $P < 0.05$.

by the TF2+ case definition. Children who were reported to have had an eating/licking toothpaste habit had a significantly higher prevalence of fluorosis defined by both case definitions. Children who had been exposed to fluoridated water in their first 6 years of life had a significantly higher prevalence of fluorosis compared with children who had no exposure to fluoridated water. There was a dose–response effect in terms of exposure to fluoride in water, which was more linear for the TF2+ definition. Children who were reported to have had used fluoride supplements when living in nonfluoridated areas had a higher, but not significantly, prevalence of fluorosis. The use of infant formula was not associated with the prevalence of fluorosis.

Fluorosis prevalence across birth cohorts

Fluorosis prevalence across birth cohorts was evaluated by birth cohort analysis (Fig. 2). The earliest birth cohort had a significantly higher prevalence of fluorosis defined by either case definition compared with the latest birth cohort. The crude odds ratios were from 1.3 to 1.6 for the two case definitions, respectively. The birth cohort 1991/1992 had a prevalence of fluorosis which was intermediate compared with the other two cohorts. The difference in the prevalence of fluorosis between the intermediate group and other groups was not statistically significant. The difference in the prevalence of fluorosis between the earliest and the latest birth cohort was mostly explained by the proportion of children who had a TF score of 2 or higher on their maxillary central incisors. About 15.8% children of the earliest and 14.5% children of the latest cohorts had a TF score of 1, whereas 17.9% of the earliest cohort and 8.3% of the latest cohort had a TF score of 2 or 3.

Factors associated with fluorosis experience and the change in fluorosis across birth cohorts

Several factors were found to be significant in the multivariate logistic regression model for fluorosis defined as having a TF score of 1+ on one or more maxillary central incisors (Table 4). Exposure to fluoride in water and toothpaste was a risk factor for fluorosis in this study population. Exposure to fluoride in water between birth and 6 years of age and using a medium or larger amount of toothpaste when toothbrushing with toothpaste started had a significant association with the prevalence of fluorosis. An eating and/or licking toothpaste habit when toothpaste use commenced was also a risk factor for fluorosis. Type of toothpaste, frequency of toothbrushing, after-brushing routine when toothbrushing started, use of fluoride supplements and infant formula were not significant in the model. No two-way interaction between variables was found to be significant in the exploratory models. Therefore, interactions were not included in the final model.

A number of factors were significant in the multivariate logistic regression model for fluorosis defined as having a TF score of 2+ (Table 5). Those factors were exposure to fluoride in water, use of standard-concentration fluoridated toothpaste in early childhood and having eating and/or licking toothpaste habit. The cohort effect was not significant in the first model. When the type of toothpaste used when brushing started was removed from the model, the cohort effect became statistically significant. The earliest birth cohort had 2.7

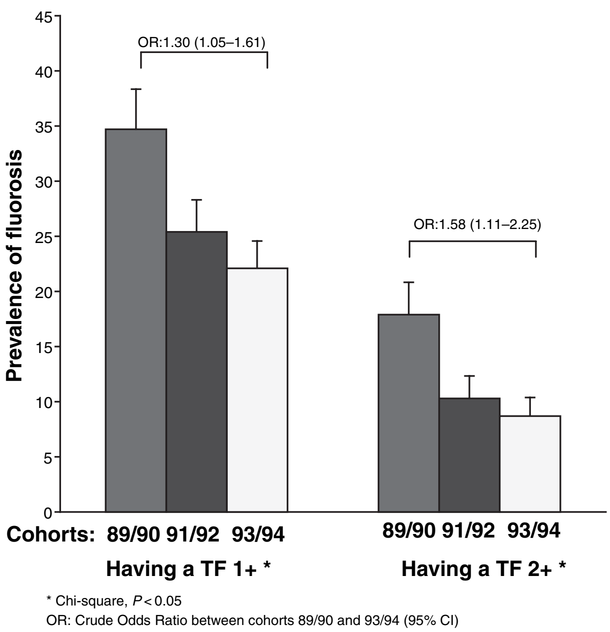

Fig. 2. Prevalence of fluorosis across birth cohorts.

Table 4. Multivariate logistic regression model for fluorosis (case definition of TF1+)

Explanatory variables	Odds ratio (95% CI)
Birth cohorts	
Born in 1989/1990	1.27[a] (0.63–2.57)
Born in 1991/1992	1.15[a] (0.64–2.07)
Born in 1993/1994	Ref
Lifetime exposure to fluoride, birth to 6 years	
>50% lifetime	2.89** (1.54–5.42)
>0% and ≤50% lifetime	2.83* (1.47–5.55)
0% lifetime	Ref
Amount of toothpaste when brushing started	
Medium or large amount	1.79* (1.08–2.98)
Small amount	Ref
Eating/licking toothpaste when brushing started	
Yes	2.61** (1.52–4.48)
Never	Ref

Multivariate logistic regression model. Dependent variable: fluorosis, case definition of having TF1+ on one or both maxillary central incisors.
Other not listed nonsignificant factors were: type of toothpaste, frequency of toothbrushing, after-brushing routine, use of fluoride supplements and infant formula.
TF, Thylstrup and Fejerskov; CI, confidence interval.
[a]NS: $P > 0.05$.
Ref, reference group.
*$P < 0.05$; **$P < 0.01$.

Table 5. Multivariate logistic regression models for fluorosis (case definition of TF2+)

	With toothpaste type	Without toothpaste type
Explanatory variables	Odds ratio (95% CI)	Odds ratio (95% CI)
Birth cohorts		
Born in 1989/1990	0.94[a] (0.34–2.52)	2.71* (1.27–5.78)
Born in 1991/1992	1.02[a] (0.41–2.52)	1.94[a] (0.88–4.29)
Born in 1993/1994	Ref	Ref
Lifetime exposure to fluoride, birth to 6 years		
>50% lifetime	7.81** (2.44–24.96)	7.14** (2.27–22.40)
>0% and ≤50% lifetime	5.22* (1.56–17.42)	5.19* (1.57–17.13)
0% lifetime	Ref	Ref
Type of toothpaste when brushing started		
1000-ppm fluoride toothpaste	2.70** (1.37–5.34)	NA
400- to 550-ppm fluoride toothpaste	Ref	NA
Eating/licking toothpaste when brushing started		
Yes	2.27* (1.03–5.03)	2.15* (1.00–4.64)
Never	Ref	Ref

Multivariate logistic regression model. Dependent variable: fluorosis, case definition of having TF2+ on one or both maxillary central incisors.
NA: type of toothpaste was removed from the model; therefore, its odds ratios were not available.
Other not listed nonsignificant factors were: amount of toothpaste used, frequency of toothbrushing, after-brushing routine, use of fluoride supplements and infant formula.
TF, Thylstrup and Fejerskov; CI, confidence interval.
[a]NS: $P > 0.05$
Ref, reference group.
$^{*}P < 0.05$; $^{**}P < 0.001$.

times odds of having fluorosis compared with the latest cohort.

Discussion

Overview

This study employed complex data collection procedures. Retrospective and concurrent data were collected on a number of inter-related aspects of oral health and contributory factors. The detailed questionnaire that was used in the COHS retrospectively collected fluoride exposure history at different time points. These data facilitated the estimation of fluoride exposures that could be related to the prevalence of fluorosis. The study analyses the change of fluorosis across birth cohorts not only by bivariate comparison of the prevalence of fluorosis but also by multivariate models used to identify factors that might be responsible for the change.

The time factor was important in examining the outcome of the policy measures in reducing fluorosis that have been implemented from the early 1990s. These policy measures were aimed at reducing the fluoride ingestion by young children from discretionary fluorides. This study was considered as timely for this purpose for several reasons. First, retrospective data on fluoride exposures would be better collected as soon as possible after the relevant behaviours commenced because recall bias can increase with time. Second, fluorosed enamel may be affected by external factors after eruption, such as wear or dental treatment, although this change would probably be minimal across a limited number of years among children with mild fluorosis. Children up to adolescent years would also be less likely to have aesthetic dental treatment. Third, the expected outcome of the policy measures (reduced prevalence of fluorosis on permanent teeth) must be present at a recordable level. Children who were expected to be affected by the policy measures (born at or after the changes) would be 8–9 years old in 2002/2003. This age group would also have fully erupted permanent central incisors which could be examined for fluorosis.

Recall bias is an inherent limitation of retrospective research. The COHS questionnaire was carefully designed to minimize such bias. The fact that the fluoride exposure data of this study were similar to that reported by other studies in Australia including the parent COHS study (unpublished) and the study by Riordan in Western Australia (14) indicated a low level of recall bias. The examiner was blind with regard to the questionnaire data before and during the examination but not blind towards children's current residency because transporting children over hundreds of kilometres between locations was logistically impossible. However, current residency was not used as a direct explanatory factor. Although strongly related, current residency did not always reflect the per cent lifetime exposure to fluoride in water from birth to 6 years of age used in the analyses for this study.

Evaluation of trend of fluorosis-methodological consideration

The time trend analysis of any condition can be affected by three factors inherent to cohort analysis. These factors are age, period and cohort effects. These effects are often not separated from each other and can complicate the time trend analysis. In oral epidemiology, this issue is less of concern with the analysis of the prevalence of fluorosis. Fluorosis is a condition established during the tooth development period. There may be some changes in the clinical appearance of fluorosis after tooth eruption. However, this process has yet to be well documented. Therefore, the ageing effect was assumed to be minimal in the cohort analysis of fluorosis.

There are several frequently used methods of analysing the trend in the prevalence of fluorosis. The first method is the comparison of different samples of a population at different points in time. Such a comparison of the prevalence of fluorosis was made by Riordan (14). The inherent condition to be satisfied with this approach is that the samples must be representative for the population studied. The second method is to compare a number of successive birth cohorts. The birth cohorts must be similarly selected and examined. This method has been used in a number of studies of dental fluorosis (11–13). The present study successfully employed the method of successive cohorts comparison in evaluating fluorosis trend over time.

Exposure to fluoride

The study showed that the use of low-concentration fluoridated toothpaste introduced for use by children was the most marked change in fluoride exposure. The proportion of children using a low-concentration fluoridated toothpaste almost tripled across birth cohorts. The proportion of children in the cohort born in 1989/1990 who used low-concentration fluoridated toothpaste when they started toothbrushing about 1–3 years later was similar to that reported by Riordan (14) (the two cohorts had the same years of birth). Therefore, wide implementation of the policy measures was supported by evidence from two separate Australian states.

Effectiveness of the policy measures

The policy measures introduced in Australia in the early 1990s were aimed at controlling the exposure to discretionary fluoride to reduce the prevalence of dental fluorosis among children. Those policy measures were based on evidence at that time of risk factors for fluorosis. Therefore, they were directed at eliminating or reducing those risk factors. The available data indicate that the policy measures were widely implemented. If those policy measures were effective, available evidence should indicate a reduction in the condition of interest, dental fluorosis. Also, the reduction, if any, should be explained in part by at least one of the introduced policy measures to reduce fluoride exposure.

The present study clearly indicated a decreasing trend of fluorosis across successive cohorts where children might have been affected by the policy measures. This trend was an indicator of effectiveness of the measures. The findings of this study were consistent with those reported by a similar study conducted in another Australian state (14). Results of the logistic regression models showed that the decreasing trend was largely driven by the use of low-concentration fluoridated toothpaste. Our findings were consistent with the limited evidence available, suggesting that the low-concentration fluoridated toothpaste lowers the risk of having fluorosis (18). Young children who use toothpaste can swallow a significant proportion of that toothpaste (19). Therefore, the use of lower concentration fluoridated toothpaste would significantly reduce total fluoride intake.

In conclusion, the experience of fluorosis among the South Australian child population was mostly very mild to mild. The policy measures introduced in the early 1990s in Australia were widely implemented leading to significant changes in exposure to discretionary fluorides, particularly fluoridated toothpaste. The changes have led to a significant reduction in the prevalence of fluorosis of the child population. Future research plans include following this cohort of children to examine change over time of the examined fluorotic teeth, as well as examining other permanent teeth. The possible effect of changes in fluoride exposure in childhood on caries experience is also being examined.

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