Changes in Dental Fluorosis Following an Adjustment to the Fluoride Concentration of Hong Kong's Water Supplies

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CHANGES IN DENTAL FLUOROSIS FOLLOWING AN ADJUSTMENT TO THE FLUORIDE CONCENTRATION OF HONG KONG'S WATER SUPPLIES

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ABSTRACT

In June, 1978, the fluoride concentration in Hong Kong water supplies was reduced from 1.0 to 0.7 mg/L. The objectives of this study were (1) to determine whether, as a result of this minor adjustment, a consequent reduction in the prevalence and severity of dental fluorosis came about, and (2) to determine whether dental fluorosis develops during enamel secretion and primary mineralization or during the maturation stage of enamel development. Dental fluorosis was assessed by Dean's community fluorosis index (CFI) on upper central incisors in 2382 children aged from 7 (exposed to 0.7 mg/L only) to 13 years. The children were selected from four districts served with drinking water by four different water treatment stations. Differences in the distributions of dental fluorosis scores across ages were significant in all districts. The susceptibility to fluoride was assessed statistically through a series of analyses whereby the fluoride concentration in the drinking water (both coincident with enamel secretion and periods of enamel maturation) was correlated with CFI. It was concluded (1) that CFI values were reduced following a minor adjustment to the fluoride concentration in drinking water, (2) that dental fluorosis develops during the maturation stage of enamel development, (3) that the development of dental fluorosis may occur over a period of 16 to 24 months, commencing from 12 to 32 months following enamel secretion, and (4) that Dean's index is a suitable instrument for monitoring the effects on dental fluorosis of minor adjustments to the fluoride concentration in drinking water.

INTRODUCTION

The emergence of signs of dental fluorosis in Hong Kong, which arose following an increase in the fluoride concentration in the community water supplies in 1967, prompted a decision to make a further readjustment. The fluoride concentration was reduced from 1.0 to 0.7 mg/L on 1 June 1978 (Evans *et al.*, 1987).

In relation to the need to evaluate the outcome, a question was raised as to whether the effects of such a minor adjustment could be readily measurable. While major adjustments to the fluoride concentration in drinking water elsewhere have been accompanied by clear-cut reductions in, or elimination of, dental fluorosis (McKay, 1933; Dean *et al.*, 1938; Horowitz *et al.*, 1967; Horowitz and Heifetz, 1972; Ishii and Nakagaki, 1984; Ishii and Suckling, 1986), the effects of a very minor adjustment have been hitherto unreported. The situation in Hong Kong therefore presented a unique set of problems to be confronted. Chief among these was that of selecting a suitable instrument which would be sufficiently sensitive to detect the changes, if any, resulting from the fluoride reduction. There was also the important consideration that valid assessments of such changes should be made as soon as possible following the adjustment to the fluoride level—that is, when the first permanent teeth erupted in the cohort of children exposed to the new level.

Since the upper central incisors of the children born immediately following the change in 1978 would be

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erupting in 1985, when the children were aged 7 years, and could be examined for the purpose of assessing the full extent of the reduction in fluorosis, a preliminary investigation was conducted over the period July to December, 1985. The primary objective of this preliminary investigation was to ascertain whether there were measurable changes in the level of dental fluorosis in Hong Kong since the reduction in the fluoride concentration in June, 1978, by testing the hypothesis that the prevalence and severity of dental fluorosis have decreased in selected samples of Hong Kong schoolchildren, following a decrease in the fluoride concentration in the drinking water supplies. In view of the discussion raised by Fejerskov *et al.* (1977) with regard to the pathogenesis of dental fluorosis, a secondary objective of this study was to explore the hypothesis that dental fluorosis arises as a result of a fluoride-induced interference during the maturation stage of enamel development rather than during the stage of enamel secretion and primary mineralization.

Materials and Methods

Apparent variations among tooth types to sensitivity to dental fluorosis and differences in the tooth eruption status of the 7–13-year-old children examined were potential confounding factors. By confining of the measurements to an index tooth, the introduction of these age-related biases was eliminated. The index developed by Dean (1942) was used to obtain data in relation to the upper right central incisor only. A tooth was not scored unless 3 mm of the crown had erupted. The possibility existed that Dean's index might not have sufficient discriminatory power to detect the likely change, and thus a new measurement system was developed and used in addition to Dean's method. This paper deals only with the application of Dean's method.

Fluoridated water is supplied throughout Hong Kong from 14 treatment stations and is distributed to districts in the vicinity of each station. However, blending of water between some districts occurs to greater or lesser extents, and because of this, the scope for detailed comparisons between districts was limited. Monthly mean fluoride concentrations, found by the analysis of daily samples from the 14 water treatment stations in Hong Kong, were made available in relation to the period from January, 1966, through April, 1985, inclusive. Four water districts were selected in which preliminary investigations were to be conducted—namely, Aberdeen and Kowloon City (both urban), Yuen Long (rural), and Peng Chau (an island). The mean fluoride concentrations in the drinking water from the treatment stations during the 48-month period, both immediately before and following June, 1978, are given in Table 1. Although the fluoride concentration was scheduled to be reduced from 1.0 to 0.7 mg/L in June, 1978, the mean concentration maintained in the drinking water before June, 1978, was 0.9 mg/L or less and was reduced to levels closer to 0.6 mg/L than to 0.7. The change in the fluoride level in water from the Sha Tin treatment station was, in fact, only 0.15 mg/L, while the change was 0.27 mg/L in water from the Aberdeen treatment station. Fluctuations in the fluoride concentration *above* the scheduled level were rare, whereas they frequently fell *below* it.

Data were made available from the Department of Education concerning primary school locations in the districts and on school roll size. One large school having both morning and afternoon sessions was selected in both Aberdeen and Kowloon City. Both primary schools in Peng Chau were selected, and six schools were selected in the Yuen Long district. The principals at the selected schools were contacted, and their permission was sought for conducting a survey of the pupils. All children enrolled in the selected schools were invited to have a dental examination. Over 90% of parents gave written consent for the examination, and information relating to date of birth and residence history was obtained from a completed questionnaire attached to the consent form.

The subjects were grouped retrospectively into cohorts according to date of birth with respect to 1 June 1978. Children from Aberdeen and Yuen Long were grouped into 12-month cohorts, but since smaller numbers of children were examined in Kowloon City and Peng Chau, it was necessary to group children from these locations into fewer categories for purposes of the statistical analysis, and thus, they were grouped into 16-month cohorts. The cohort, as bound by the birth dates of June 1978-May 1979, was designated 12-month cohort 0, while the cohorts born during the periods of June 1977-May 1978, June 1976-May 1977, and so on, were designated 12-month cohort −1, −2, etc. Similarly, 16-month cohorts with respect to 1 June 1978 were designated 16-month cohort 0, −1, etc.

While it was assumed that the developmental time of the upper central incisors was 48 months (Haavikko, 1970), enamel maturation, on the other hand, could occur during a shorter time, and for this analysis, exposure to fluoride levels over multiples of eight-month periods (16, 24, 32, 40, and 48 months) was investigated.

If dental fluorosis is primarily a secretory-stage defect, then it was hypothesized that the correlation between fluorosis and the fluoride concentration in the drinking water coincident in time with the secretory stage of enamel would be significant. Alternatively, if fluorosis was primarily a maturation-stage defect, then the correlation between fluorosis and the fluoride concentration in the water coincident with the time interval of maturation would be significant. If, for example, the incisal third of the tooth matures during the interval when the middle third of the tooth is being secreted, it could be said that the maturation interval is out of phase, by a difference of 16 months,

TABLE 1
MEAN FLUORIDE CONCENTRATIONS (mg/L) IN DRINKING WATER FROM WATER TREATMENT STATIONS DURING THE 48-MONTH INTERVALS BOTH IMMEDIATELY BEFORE AND AFTER 1 JUNE 1987

	Treatment Station			
	Aberdeen	Yuen Long	Sha Tin (Kowloon City)	Silvermine Bay (Peng Chau)
Before 1978	0.90 (0.13)*	0.83 (0.12)	0.78 (0.20)	0.85 (0.21)
After 1978	0.63 (0.11)	0.63 (0.18)	0.63 (0.10)	0.61 (0.10)
Difference	0.27	0.20	0.15	0.24

* Standard deviations.

with the fluoride concentration in the water during enamel secretion (with secretion of the middle third of the crown commencing 16 months after the commencement of secretion of the incisal third). According to a maturation hypothesis, it could be inferred that dental fluorosis is a maturation-stage defect if the correlation between dental fluorosis and the fluoride concentration in the drinking water , x months out of phase with the developmental interval, is both positive and significantly different from zero. On the other hand, if x was not significantly different from zero, it could be inferred that dental fluorosis is a developmental defect.

Analyses were conducted in which the prevalence of dental fluorosis of each cohort was correlated with the mean fluoride concentration in the drinking water during the 48-month period when the upper central incisor crowns were developing. In addition, analyses were conducted in which the mean concentration of fluoride in the drinking water was calculated in relation to periods of fewer than 48 months (multiples of eight months), and in which the correlation between fluorosis prevalence and fluoride concentration was both coincident with the commencement of enamel secretion and out of phase with this event. In relation to the 12-month cohorts, phase differences of 12, 24, 36, and 48 months were tested, and for the 16-month cohorts, the phase differences tested were 16, 32, and 48 months.

The children came to the examination site in groups. The dental examination of the children was conducted in daylight. The children stood facing a window in front of the examiner, or they were examined outside in an open shaded area. Their teeth were not cleaned prior to the examination, although in some cases heavy plaque was removed from the central incisors by means of a cotton roll. The assessments were carried out on the upper right central incisor, except that the upper left was substituted if it was obviously at a more advanced stage of eruption, or if the upper right incisor was traumatized.

Bias in relation to examiner prejudice was reduced in that the children in each class were of mixed age, and the fluoride history was not known to the two examiners. The data collected in relation to children who were not continuous residents of the district in question were excluded retrospectively. Calibration of the examiners was carried out prior to the survey, and both within- and between-examiner variability was monitored throughout by re-examinations of approximately 10% of the children. The reproducibility, or level of agreement, achieved by the two examiners was assessed by consideration of the Kappa statistic, as illustrated by Fleiss and Chilton (1983).

RESULTS

Altogether, 3537 children were examined in the four districts. Data in relation to 23% of the children who had not been continuously resident in the respective districts since birth were excluded from the analysis, and children not having erupted upper central incisor teeth were excluded. Thus, the results given here related to 2382 individuals comprising 67% of the total number examined. All schools enrolled boys and girls, there being approximately equal numbers of each in the total sample.

Frequency distributions of Dean's fluorosis scores for each cohort were obtained together with their corresponding dental fluorosis prevalence and community fluorosis index values (Tables 2, 3, 4, and 5). From an analysis of the proportional distribution of Dean's fluorosis scores among cohorts, it was found that from cohort −5 to cohort 0, there was a progressive shift in the increasing proportion of lower scores, and a consequent decreasing proportion of higher scores. In relation to a comparison of the differences in proportion found in each district between the combined cohorts (−4, −3) and (−1, 0), the differences were significant (Aberdeen, chi-squared = 52.42, DF = 5, $p < 0.001$; Yuen Long, chi-squared = 11.68, DF = 3, $p < 0.01$; Kowloon City, chi-squared = 17.50, DF = 3, $p < 0.001$; and Peng Chau, chi-squared = 19.45, DF = 3, $p < 0.001$).

Variations in dental fluorosis were evident between the regions studied. The highest levels of dental fluorosis were found in Aberdeen, where the CFI values

TABLE 2
COHORT-SPECIFIC DISTRIBUTION OF COMMUNITY FLUOROSIS INDEX VALUES AND DENTAL FLUOROSIS SCORES (BASED ON UPPER RIGHT CENTRAL INCISORS) – ABERDEEN

	Weight	12-month Cohorts −5	−4	−3	−2	−1	0
Normal	0	10 (7)§	17 (10)	16 (10)	17 (12)	22 (17)	21 (18)
Questionable	0.5	10 (7)	17 (10)	24 (15)	19 (14)	30 (23)	33 (28)
Very mild	1	59 (43)	60 (35)	51 (32)	48 (34)	53 (41)	46 (38)
Mild	2	38 (28)	53 (31)	51 (32)	44 (31)	18 (14)	12 (10)
Moderate	3	6 (4)	10 (6)	8 (5)	6 (4)	5 (4)	4 (3)
Severe	4	15 (11)	13 (8)	11 (7)	7 (5)	1 (1)	4 (3)
Sum of frequencies		138	170	161	141	129	120
Total score*		218	256.5	233	191.5	123	114.5
Community fluorosis index+		1.580	1.509	1.447	1.358	0.953	0.954
Prevalence of dental fluorosis‡		0.855	0.800	0.752	0.745	0.597	0.550

* Sum of frequency times weight.
+ Total score divided by sum of frequencies.
‡ Proportion with very mild or more.
§ Percentages (may not total 100 due to rounding).

for cohorts −5 and 0 were 1.58 and 0.95, respectively. In the other districts, the CFI levels shifted from approximately 1.0 to 0.7, although the shift in relation to Kowloon City was from 1.10 to 0.85.

The results of the correlation analyses with regard to one of the districts, Kowloon City, are given in Table 6. An inspection of the data in this Table indicates two general trends: (1) that the coefficients increase in value from top to bottom in each column—that is, correlation between fluorosis prevalence and fluoride concentration appears to increase with increasing exposure to the fluoride in drinking water; and (2) that the coefficients increase across columns from left to right, peak at phase 32, and then decrease—that is, the highest coefficient values did not coincide with a phase difference of zero. These trends were clearly evident in all districts. The correlation results relating fluorosis prevalence to fluoride concentration over exposure periods of 16 months only are given in the Fig. The peaks of the coefficient profiles were all associated with phase differences not equal to zero. The peak coefficients—Aberdeen, 0.939

TABLE 3
COHORT-SPECIFIC DISTRIBUTION OF COMMUNITY FLUOROSIS INDEX VALUES AND DENTAL FLUOROSIS SCORES (BASED ON UPPER RIGHT CENTRAL INCISORS) – YUEN LONG

	Weight	12-month Cohorts −6	−5	−4	−3	−2	−1	0
Normal	0	23 (21)§	23 (21)	12 (13)	21 (17)	19 (20)	23 (25)	9 (14)
Questionable	0.5	33 (31)	31 (28)	33 (36)	34 (28)	32 (33)	31 (34)	28 (44)
Very mild	1	22 (20)	32 (29)	30 (33)	36 (29)	28 (29)	28 (30)	21 (33)
Mild	2	27 (25)	18 (16)	13 (14)	27 (22)	14 (15)	7 (8)	5 (8)
Moderate	3	3 (3)	6 (6)	4 (4)	5 (4)	3 (3)	3 (3)	
Severe	4							
Sum of frequencies		108	110	92	123	96	92	63
Total score*		101.5	101.5	84.5	122	81	66.5	45
Community fluorosis index+		0.940	0.923	0.918	0.992	0.884	0.723	0.714
Prevalence of dental fluorosis‡		0.481	0.509	0.511	0.553	0.469	0.413	0.413

* Sum of frequency times weight.
+ Total score divided by sum of frequencies.
‡ Proportion with very mild or more.
§ Percentages (may not total 100 due to rounding).

TABLE 4
COHORT-SPECIFIC DISTRIBUTION OF COMMUNITY FLUOROSIS INDEX VALUES AND DENTAL FLUOROSIS SCORES (BASED ON UPPER RIGHT CENTRAL INCISORS) – KOWLOON CITY

		16-month Cohorts				
	Weight	−4	−3	−2	−1	0
Normal	0	8 (10)§	11 (8)	17 (11)	22 (16)	2 (5)
Questionable	0.5	16 (20)	35 (24)	59 (38)	43 (31)	18 (45)
Very mild	1	37 (46)	57 (39)	57 (37)	54 (39)	15 (38)
Mild	2	17 (21)	38 (26)	19 (12)	18 (13)	5 (13)
Moderate	3	2 (2)	3 (2)	4 (3)	3 (2)	
Severe	4	1 (1)	1 (1)			
Sum of frequencies		81	145	156	140	40
Total score*		89	163.5	136.5	120.5	34
Community fluorosis index+		1.099	1.128	0.875	0.861	0.850
Prevalence of dental fluorosis‡		0.704	0.683	0.571	0.536	0.500

* Sum of frequency times weight.
+ Total score divided by sum of frequencies.
‡ Proportion with very mild or more.
§ Percentages (may not total 100 due to rounding).

(n = 6); Yuen Long, 0.897 (n = 7); Kowloon City, 0.990 (n = 5); and Peng Chau, 0.960 (n = 5)—were all significant (one-tailed test, $p < 0.005$).

A kappa coefficient of 0.61, in relation to the between-examiner agreement in the application of Dean's index, indicates a substantial level of agreement in measurement. This was also the rating for the within-examiner reproducibility of Examiner 2 (K = 0.76). The within-examiner agreement achieved by Examiner 1 (RWE) was rated as excellent beyond chance (K = 0.83).

DISCUSSION

This study has demonstrated that there were variations in the extent of the overall reduction in the fluoride level as a result of the implementation of the decision to lower the fluoride concentration from 1.0 to 0.7 mg/L in June, 1978. The level of dental fluorosis decreased significantly, not only in statistical terms, but in clinical terms also. Although the actual mean

TABLE 5
COHORT-SPECIFIC DISTRIBUTION OF COMMUNITY FLUOROSIS INDEX VALUES AND DENTAL FLUOROSIS SCORES (BASED ON UPPER RIGHT CENTRAL INCISORS) – PENG CHAU

		16-month Cohorts				
	Weight	−4	−3	−2	−1	0
Normal	0	6 (18)§	8 (10)	13 (17)	8 (14)	1 (4)
Questionable	0.5	5 (15)	18 (22)	24 (31)	23 (39)	12 (52)
Very mild	1	15 (46)	29 (36)	25 (32)	23 (39)	9 (39)
Mild	2	6 (18)	25 (31)	12 (15)	4 (7)	1 (4)
Moderate	3	1 (3)	1 (1)	4 (5)	1 (2)	
Severe	4					
Sum of frequencies		33	81	78	59	23
Total score*		32.5	91	73	45.5	17
Community fluorosis index+		0.985	1.123	0.936	0.771	0.739
Prevalence of dental fluorosis‡		0.667	0.679	0.526	0.475	0.435

* Sum of frequency times weight.
+ Total score divided by sum of frequencies.
‡ Proportion with very mild or more.
§ Percentages (may not total 100 due to rounding).

TABLE 6
COEFFICIENTS OF CORRELATION BETWEEN THE PREVALENCE OF DENTAL FLUOROSIS AND THE FLUORIDE CONCENTRATION IN DRINKING WATER BOTH COINCIDENT WITH ENAMEL SECRETION, OR OUT OF PHASE WITH THIS EVENT BY 16, 32, OR 48 MONTHS – KOWLOON (SHA TIN WATER SUPPLY)

Period in Months over which Mean Fluoride Levels were Calculated	Coincidence with Enamel Secretion			
	Phase 0	Phase 16	Phase 32	Phase 48
16	−0.275	0.412	0.990‡	0.695
24	−0.063	0.571	0.997§	0.887+
32	0.114	0.874*	0.976‡	0.904+
40	0.441	0.904+	0.974‡	0.833*
48	0.694	0.967‡	0.980‡	0.880+

* $p < 0.05$ (where n = 5, one-tailed test).
\+ $P < 0.025$.
‡ $p < 0.005$.
§ $p < 0.0005$.

reduction in fluoride in the water from the Sha Tin treatment station was 0.15 mg/L, Dean's index proved to be sufficiently sensitive to detect the decreasing trend in both the prevalence and severity of dental fluorosis in that water district (Kowloon City). It was concluded that the effects on dental fluorosis of carrying out minor adjustments to the fluoride concentration in community water supplies can be measured. The smaller reduction with regard to the Sha Tin treatment station was due to the situation prior to 1978, when the average fluoride concentration maintained there was well below the scheduled level.

The testing of the developmental-maturation hypothesis rested on the assumption that upper central incisors of the sample children developed during an interval of 48 months, commencing at birth. This developmental interval was considered to be the best estimate available, following a literature review which revealed considerable variations in the determination of this parameter.

In the matter of the correlation analysis, it was considered that the increase in the correlation coefficients with increasing exposure to fluoride should be viewed as a statistical artifact which arose merely as a result of the increase in the stability of the array of means as they were progressively derived from greater numbers of monthly values. On this basis, a conclusion to the effect that fluorosis develops over longer, rather than shorter, time intervals is not warranted, and therefore the results given in the Fig. are based on 16-month exposures only. Of special significance in relation to this study was the existence of the peaks in the coefficient profiles in the four independent data sets. Their tendency to occur both in the same region and remote from a zero-phase difference lends support to the acceptance of the maturation hypothesis.

This is in accordance with the findings at Oakley in the United States, as reported by McKay (1933). Seven years following the change from a water source containing 6.0 mg/L fluoride to one containing 0.5 mg/L, either no dental fluorosis or only questionable signs, confined to the incisal edges of upper central incisors, developed in children born up to 3 1/2 years prior to the change. By this age, up to 3/4 of the tooth crowns of the upper central incisors would have been formed under the influence of the high fluoride levels (Haavikko, 1970). One child at this age had central

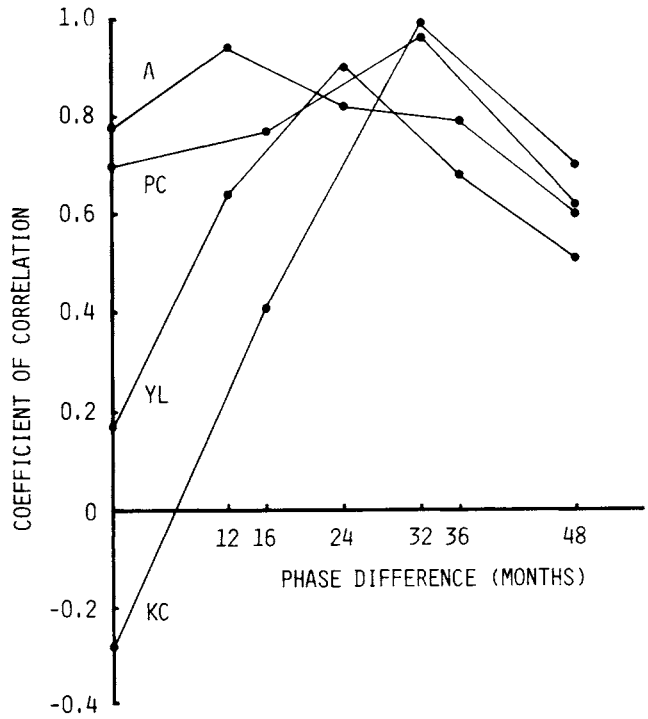

Fig. – Coefficients of correlation between the prevalence of dental fluorosis and fluoride concentration over exposure periods of 16 months. Values relate to a range of phase differences with respect to enamel secretion. A = Aberdeen, PC = Peng Chau, YL = Yuen Long, and KC = Kowloon City.

incisors classified as normal. Similarly, at Ikeno, Japan, where the community water supply was changed from one containing 7.8 mg/L fluoride to one containing 0.2 mg/L, two children (aged 11 and 20 months at the time of the change) had upper central incisors classified as normal. In all other children aged less than 2 years at the time of the change, signs of mild dental fluorosis were confined to the incisal area only, whereas the children aged 40 months at the change had incisors classified as moderate or severe (Ishii and Suckling, 1986). Larsen *et al.* (1985) have reported that six (15%) of 39 children who commenced fluoride tablet supplementation at the age of 5 years had signs of dental fluorosis on their upper central incisors, whereas eight of nine children who commenced supplementation at age 2–3 years had affected upper central incisors. In animal studies, the development of dental fluorosis during the maturation phase has also been demonstrated. In experiments conducted on pigs, premolars exposed to high levels of fluoride after the completion of crown formation were found, on eruption, to be fluorosed (Richards *et al.*, 1986).

In spite of McKay's findings, dental fluorosis has been considered to develop during enamel formation generally and without reference to specific stages in amelogenesis (Adler, 1970). In view of the results from these recent studies, it appears that a differentiation between these stages has been confirmed and that available evidence supports the hypothesis that the development of dental fluorosis is dependent upon the fluoride concentration in drinking water during enamel maturation.

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