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Dental fluorosis in children in areas with fluoride-polluted air, high-fluoride water, and low-fluoride water as well as low-fluoride air: A study of deciduous and permanent teeth in the Shaanxi province, China

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Abstract

Objective. The aim of the study was to assess dental fluorosis (DF) in the deciduous and permanent teeth of children in areas with high-F coal (area A) and high-F water (area C) compared to children from area B, with low-F water and coal. ***Material and Methods.*** 596 children were examined. DF was assessed by TF-score. F-content of indoor air, drinking water, coal, tea, rice, and maize was analyzed. ***Results.*** F-content of air and coal ranged from 3.2 $\mu g/m^3$ and 25.8 mg/kg (area B), 3.8 $\mu g/m^3$ and 36.3 mg/kg (area C) to 56.8 $\mu g/m^3$ and 713.1 mg/kg (area A). Likewise, mean F-content of water ranged from ~0.50 mg/l (areas A and B) to 3.64 mg/l (area C). F-content of tea leaves was similar in all three areas. Maize and rice contained <5 mg F/kg. Prevalence of primary teeth with DF was 49.1%, 2.0%, and 66.8% in areas A, B, and C, respectively. Similarly, DF was found in 96.7% (area A), 19.6% (area B), and 94.4% (area C) of the permanent teeth. Severe fluorosis (TF $\geq$5) was found in area A (47.0%) and area C (36.1%) ($p<0.01$). Early erupting teeth had slightly higher mean TF-scores in area A than in area C. ***Conclusions.*** DF was prevalent in both dentitions in areas A and C. Similarity in percentages of DF may indicate that indoor air with ~60 µg F/m^3 and drinking water with 3.6 mg F/L are similarly toxic to developing permanent teeth. The percentage of deciduous teeth with DF was significantly lower in area A compared to area C. Where low-F coal and low-F water were used (area B), ~20% of permanent teeth had DF, indicating a relatively low tolerance to fluoride in Chinese children brought up under the present living conditions.

Key Words: *Air pollution, coal, dental fluorosis, fluoride, primary teeth*

Introduction

Dental and skeletal fluorosis is of increasing concern in China. The main source of fluoride is drinking water, but other sources may add to the general fluoride-load and/or influence the susceptibility of an individual. Thus, air pollution [1], standard of living [2], and even the altitude of habitation [3,4] have been shown to influence the mineralization of enamel and, thereby, the prevalence of dental fluorosis.

Fluoride-rich coal mines are found in about half of China's 31 provincial regions. Previous local studies have indicated prevalence of dental fluorosis of between 30% and 99% in fluoride-rich coal areas [5]. Most of the reports have been published in Chinese, and the focus has primarily been on the permanent dentition.

For drinking water, China relies heavily on subsurface water reservoirs. High-fluoride water sources are prevalent.While fluoride from water is absorbed via the gastrointestinal tract, fluoride released through combustion of coal may enter the body through intake of contaminated food or, more importantly, by inhaling polluted air. A child born in an area with high-fluoride water would seem to be more or less prevented from excessive fluoride intake during the breastfeeding period [6]. In the present study areas, most children are breastfed for approximately 4 months. In areas with fluoride-polluted air, the child may be exposed to fluoride from the first breath. Some variation in the severity and pattern of

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dental fluorosis might, therefore, be expected between areas with air polluted by combustion of high-fluoride coal and areas served by high-fluoride water. To our knowledge, no comparison has previously been made between the consequences of water-borne and air-borne fluoride.

The aim of the present study was to assess dental fluorosis in the primary as well as in the permanent dentition of children in three areas: 1. Haoping, an area served by fluoride-rich coal and low fluoride drinking water (area A). 2. Baoji, an area with low-fluoride coal and low-fluoride drinking water (area B). 3. Jingbian, an area with high-fluoride drinking water and low-fluoride coal (area C).

Material and methods

Study areas and subjects

The primary study was performed in Haoping, a town in Ziyang County in the southern part of the Shaanxi province. Haoping is known for severe endemic fluorosis, approximately 7000 households, and a population of 27,000. All inhabitants are exposed to smoke from locally mined, fluoride-rich coal. The fluoride content of the drinking water is low.

A central primary school that serves residents of the central part of Haoping as well as four suburban villages was selected for the study (area A). All 7–8 and 12–13-year-old children registered in the school were invited to participate. The children were informed about the investigation and were given the possibility to withdraw at any stage of the study. Relevant information about participants, such as date and place of birth, was recorded according to the registry forms of the schools.

A total of 289 registered students were available in area A. Out of these, 278 (96.2%) attended the examination; 11 (3.8%) were lost due to absence from school or unwillingness to be examined. Among the examined participants, 7 were excluded: 2 were not lifelong residents of their villages and 5 had teeth that were unrecordable due to calculus.

For comparison, 198 children 7–8 years of age and 12–13-year-old children from Baoji (area B; low-fluoride drinking water and low-fluoride coal), and 127 from Jingbian (area C; high-fluoride water and low-fluoride coal) were selected. The distribution of participants according to age, gender, and dentition in the various areas is given in Table I.

Table I. Frequency distribution of participants from rural areas of the Shaanxi province, China, by gender and age according to area

	A *n* (%)	B *n* (%)	C *n* (%)
Primary teeth group			
Age			
7 years	87 (58)	39 (44)	24 (57)
8 years	62 (42)	50 (56)	18 (43)
Gender			
Male	77 (52)	48 (46)	22 (52)
Female	72 (48)	41 (54)	20 (48)
Permanent teeth group			
Age			
12 years	107 (88)*	69 (63)	20 (24)*
13 years	15 (12)	40 (37)	65 (77)
Gender			
Male	71 (58)	51 (47)	49 (42)
Female	51 (42)	58 (53)	36 (58)

*$p < 0.05$.

The population of these rural/semi-rural areas is relative homogeneous; nearly all (99.4%) are ethnic Hans, i.e. they belong to the major ethnic group in China. Traditional agriculture is the main source of living. Social-economic status is fairly low. No organized dental service was available to the people in any of the three areas. Geographically, Baoji and Ziyang are mountainous areas, altitudes ranging from 1000 to 1300 m (Ziyang) and 500 to 800 m (Baoji), while Jingbian is characterized by tableland at an altitude of 800–1000 m. Shaanxi is in a warm/temperate zone and has a continental monsoonal climate, Ziyang being slightly more humid than Baoji and Jingbian. Mean annual temperature is 14–15, 11–13, and 7–11°C in areas A, B, and C, respectively, and annual rainfall is in the range 400–900 mm.

In all three areas, heating and cooking are by the use of open stoves without a chimney. Locally mined coal is used in all the examined areas. According to popular belief, the smoky chimneyless stove provides more heat and is therefore preferred to a more modern fireplace.

Fluoride analysis of water, coal, air, and staple food

During the summer and autumn of 2002, water samples (500 ml) were collected from all the wells ($n = 18$) serving the three selected areas. The samples were analyzed for fluoride by the use of a fluoride selective electrode (Model PF-1; Electric and Optic Accessory Factory, Shanghai, China) at the laboratory of the Shaanxi Institute of Endemic Disease Control. Standard methods, including the use of TISAB (NaCL, citric acid, and acetyl acid, pH 5.2) were employed.

In order to assess the fluoride content of air, coal, maize, rice, and tea, 15 households were randomly selected: 9 from area A, and 3 from each of areas B and C.

All the selected houses were heated by indoor, floor-level open fireplaces. Air-samples were taken with an air-collecting machine (Model FCC-4; made in Shenyang, China), while the coal fires were in ordinary use. Care was taken to standardize time from lighting the fires to taking the air samples. Filters, diameter 45 mm, made of acetic fiber and pretreated with K_2HPO_3, trapped gaseous fluoride in air as well as fluorine-covered dust particles bigger than 5 nm. The machines were installed according to given specifications: 1.5 m away from the fireplaces and 1.5 m above the floor. The capacity of the collector was 15 l air/min. During the collection period (1 h for each sample) 900 l air passed through the filter. After use, the filters were removed and stored in sealed plastic bags. Fluoride trapped by the filters was distilled in 0.25 mol/l HCl and analyses were performed at the laboratory of the Center of Clinical Research, Institute of Shaanxi Local Diseases Control, China, using fluoride ion-selective electrodes. Unused filters were used as blank controls.

Samples of coal, maize, rice, and tea collected from the 15 households were analyzed for fluoride at the Laboratory of Dental Research, University of Bergen, Norway, using the ion-specific electrode (Orion model 9409).

Clinical examination

Clinical examinations were carried out in 2002 by the principal investigator (R.J.P.) under field conditions [7]. The participating children were seated on ordinary chairs outside the school building during the examination. Indirect sunlight was used for illumination. Teeth were cleaned and dried using cotton rolls. The buccal surface of each tooth in the mouth was examined and scored for dental fluorosis according to the modified Thylstrup and Fejerskov index (TF index) [8]. All scores were recorded by a medically trained assistant.

In order to test intra-examiner reliability, TF-scores in 4 primary 2nd molars of 44 children (7–8-year-olds) and of 4 upper permanent incisors of 39 children (12–13-year-olds) were re-examined. The agreement of TF-score between the two examinations was, according to Cohen's kappa [9], 0.55 and 0.78 for primary and permanent teeth, respectively.

Data analysis

The percentage of teeth with dental fluorosis, based on TF-scores on the buccal surfaces, was selected as the individual's TF-score [8]. The individual scores were used to test the severity of dental fluorosis in the children of the various groups.

The TF-scores of each primary or permanent tooth on the right side of the individual were used to show the distribution of TF-scores according to tooth type.

Data analyses were carried out using the SPSS-PC program (v. 12.0, SPSS Software, Chicago, Ill., USA). Binomial tests were used to assess the population distribution in gender and age within area and dentition group. The mean percentage of teeth with dental fluorosis at various levels (TF-score ≥ 1 and TF-score ≥ 3 for both primary and permanent teeth, and TF ≥ 5 for permanent teeth) by area and adjusted for age and gender was examined using GLM ANOVA and *post hoc* Bonferroni test. The *post hoc* Bonferroni test was used to test the difference in the mean fluoride content in water, air, coal, and tea among the different areas. The significance level was set at $p < 0.05$.

Results

Table I gives the percentage distribution of participants according to age, gender, and area. Age and gender did not vary systematically by area in the primary dentition group. In the permanent dentition group, the participants from areas A and C were distributed unequally according to age group, i.e. more younger subjects (12-year-olds) were examined in A than in C ($p < 0.05$).

As demonstrated by Table II, a statistically significant difference in the mean fluoride concentration of indoor air was found between area A and the other areas (F = 12.47 and $p = 0.001$). No statistically significant difference in the fluoride content of air was found between areas B and C. Compared to areas B and C, the fluoride content of indoor air in area A was 15 to 18 times higher (Table II). Also the mean fluoride content of locally mined coal differed significantly by area (F = 8.77, $p = 0.004$), i.e. the difference was between area A and B and between area A and C ($p = 0.02$). Compared to areas B and C, the coal from area A contained, on average, 20–27 times more fluoride.

The fluoride concentration of drinking water was low in areas A (0.48 mg/l) and B (0.51 mg/l). In area C, however, the fluoride concentration of water was significantly higher (3.64 mg/l) (F = 488.9, $p < 0.001$). The fluoride content was slightly, but not significantly, higher in tea leaves from area A, compared to tea from areas B and C. In all areas, the

Table II. Fluoride concentration of air, coal, drinking water, and tea; collected from rural areas of the Shaanxi province, China, according to area

Samples	Area	n	Mean	Range
Air (μg/m^3)	A	9	58.6*	26.8–102.5
	B	3	3.2	2.3–3.7
	C	3	3.8	3.6–4.1
Coal (mg/kg)	A	9	713.05*	372.5–1644.8
	B	3	25.78	18.4–32.5
	C	3	36.31	28.0–43.7
Water (mg/kg)	A	9	0.48	0.25–0.65
	B	6	0.51	0.30–0.76
	C	3	3.64*	3.52–3.79
Tea (mg/kg)	A	6	210.06	122.0–351.6
	B	3	117.05	57.8–156.3
	C	3	164.09	84.2–143.6

*$p < 0.001$.

Table III. Mean percentage of the primary teeth with dental fluorosis and 95% CI of 7–8-year-old children from the rural areas of the Shaanxi province, China, according to area

		Mean* percentage of the teeth with dental fluorosis			
Area	Participants (*n*)	TF ≥1	95% CI	TF ≥3	95% CI
A	149	49.1	44.2–54.6	40.4	35.4–45.4
B	89	2.0#	0.0–8.7	0.0#	0.0–6.3
C	42	66.8##	57.0–76.6	55.5##	46.3–64.9

*Adjusted for age and gender.
#Mean percentage of teeth with dental fluorosis significantly lower than in the other two areas ($p < 0.001$).
##Mean percentage of teeth with dental fluorosis significantly higher than in the other two areas ($p = 0.007$).

fluoride content of maize and rice was too low to be detected by the method used in the present study (<5 mg/kg) (Table II).

TF-score

As indicated in Tables III and IV, a statistically significant main effect of area on dental fluorosis was found in both primary and permanent teeth: for TF-score ≥1 (F = 80.0, $p < 0.001$ and F = 406.3, $p < 0.001$) and for TF-score ≥3 (F = 63.7, $p < 0.001$ and F = 327.7, $p < 0.001$). The mean percentage of teeth with dental fluorosis at TF-score ≥1 differed significantly between areas A and B, and between areas B and C both in the primary and the permanent tooth group. With respect to primary teeth, there was a statistically significant difference also between areas A and C (mean percentages of teeth with DF: 49.1 versus 66.8, $p = 0.007$).

Also at TF-score ≥3, multiple comparisons between subject analyses revealed significantly higher mean percentages of both primary and permanent teeth with dental fluorosis in children from area A, as compared to children from area B. Compared to area C, area A had a lower mean percentage of primary teeth with dental fluorosis at TF-score ≥3 (40.4 versus 55.5, $p = 0.007$).

Even in the low-fluoride area B, approximately 20% of the permanent teeth were found to have dental fluorosis, all at a severity TF <3. Table III shows the adjusted mean percentages of primary teeth with TF-score ≥1 and TF-score ≥3 according to area. Table IV shows the adjusted mean percentages of permanent teeth with dental fluorosis at TF-score ≥1, TF-score ≥3 and TF-score ≥5, by area.

The primary mandibular central incisors were excluded when analyzing the distribution of fluorosis according to tooth type, since 90% of these teeth were missing. However, at least one-third (area A) or more than half (areas B and C) of the primary mandibular lateral incisors and maxillary central and lateral incisors were recorded and included in the analyses. The mean TF-scores varied among the various groups of primary teeth (Figure 1), thus, a slight decrease of the mean TF-score was observed from posterior teeth to anterior teeth. The highest mean TF-score was recorded in the second primary molars. In contrast to this general tendency, the mean TF-score in the primary maxillary central incisors was higher than that of the maxillary lateral incisors. This was evident in the children of both area A and area C. Interestingly, the mean TF-scores of primary molars and canines were higher in the children in area C (high water-F) compared with children in area A (F-rich coal). However, the mean TF-score of primary maxillary incisors of the children in area A was higher than that of the children in area C (Figure 1).

As indicated by Figure 2, the maxillary permanent central incisors – among all the inspected maxillary teeth – had the highest mean TF-score. This was the case in high-fluoride areas A and C, and also in low-fluoride area B. In area C, the mean TF-score of lateral incisors, canines, and premolars was higher than the mean TF-score of the 1st molars. This was in contrast to findings in area A.

Discussion

According to the present study, the percentage of permanent teeth with dental fluorosis was similar in

Table IV. Mean percentage of permanent teeth with dental fluorosis at various TF-scores and 95% CI among the 12–13-year-old children from rural areas of the Shaanxi province, China, according to area

		Mean* percentage of the teeth with dental fluorosis					
Area	Participants (*n*)	TF ≥1	95% CI	TF ≥3	95% CI	TF ≥5	95% CI
A	122	96.7	92.4–100.0	89.4	84.5–94.4	47.0	41.7–52.3
B	109	19.6#	15.4–23.9	7.2#	2.2–12.1	0.9#	0.0–6.1
C	85	94.4	89.0–99.7	81.9	75.7–88.0	36.1	29.5–42.8

*Adjusted for age and gender.
#Mean percentage of teeth with dental fluorosis significantly lower than in the other two areas.

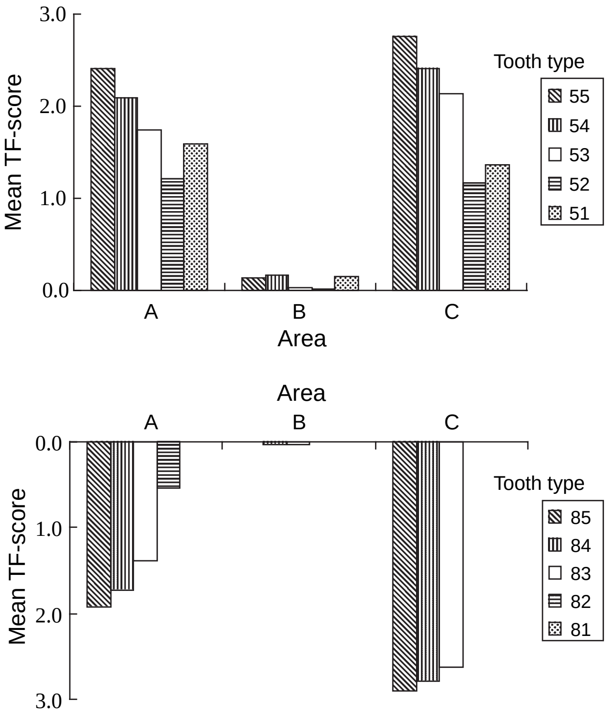

Figure 1. Mean TF-score in primary teeth of 7–8-year-old children from rural areas of the Shaanxi province, China, by tooth type and area.

areas A and C. Compared to findings in the low-fluoride area B, the percentage of teeth with fluorosis was about five times higher in areas A and C.

Coal mined in area A had a fluoride content approximately 20 times higher than coal from areas B and C. Combustion of the local coal resulted in more than 18 times higher fluoride content in the indoor air of area A.

In Uganda, Rwonyonyi [3] found that environmental factors such as elevation influenced children's susceptibility to dental fluorosis. However, the difference in elevation between the areas presently investigated (A, B, and C) is small. Factors such as ethnicity, diet, and standard of living were similar, and may probably be disregarded in the present material. Thus, the high percentage of teeth with dental fluorosis in areas A and C in all probability is due to, respectively, inhalation of fluoride-polluted air and intake of high-fluoride drinking water. According to the present findings, the prevalence of dental fluorosis in permanent teeth (TF-score ≥ 1) in children brought up in an environment with indoor air containing ~ 60 μg F/m^3 was similar to what was found in children with daily intake of drinking water containing ~ 3.5 mg F/L. More teeth with severe fluorosis (TF-score ≥ 3) were found in area A, however. This may possibly reflect the fact that children in area A were exposed to fluoride at an earlier age, and thus over a slightly greater part of the dental mineralizing period.

Previous studies carried out in China (2004) have found a positive relationship between the fluoride content of the indoor air and that of the coal used. It has also been reported (1988) that the fluoride content of indoor air varied during the combustion period; the highest values were registered shortly after the coal was put into the stove. Based on clinical investigation and literature review, Chinese health workers (2002) found a positive relationship between the prevalence of dental fluorosis and the fluoride concentration of the coal. According to the linear correlation that they found between dental fluorosis and the fluoride bontent of coal, a threshold of fluoride concentration of coal was stipulated at 250 mg/kg: under this level, dental fluorosis seemed to be rare. In the present study, the fluoride content in the coal used in area A was about three times higher than the threshold concentration.

Our analyses of indoor air in areas where fluoride-rich coal is used for heating and cooking give slightly higher F-concentrations, but are otherwise in harmony with previous reports. Thus, by analyzing the particulate matters of indoor air in fluoride-rich coal areas, Chinese scientists (1990) found that the levels of fluoride adsorbed by, or absorbed to, the particles ranged from 16 to 46 μg/m^3. In addition, gaseous and soluble fluorides constituted a considerable proportion of the inorganic fluorides.

Apart from fluoride-containing water and fluoride-polluted air, consumption of tea is a possible fluoride source. Tea is popular in the adult Chinese population, but in the three relevant areas is rarely introduced to children younger than 5 years of age. Owing to the precipitation of fluoride-polluted soot and other particles, one might have expected more fluoride in locally produced tea-leaves in area A.

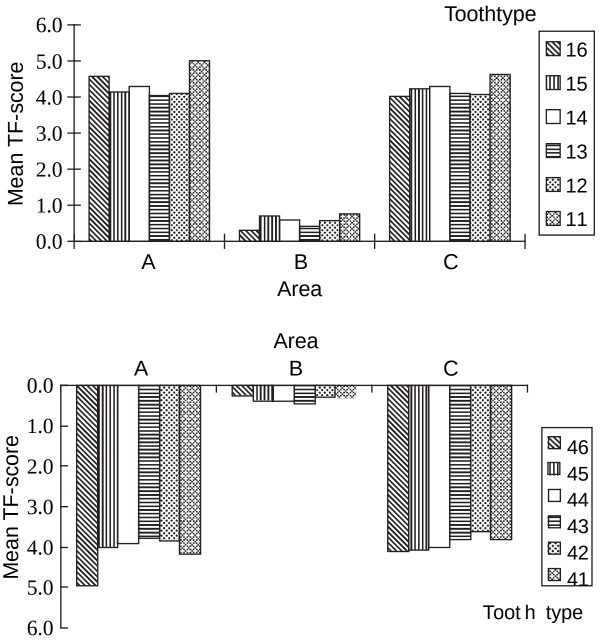

Figure 2. Mean TF-score in permanent teeth of 12-13-year-old children from rural areas of the Shaanxi province, China, by tooth type and area.

The slight, non-significant difference in fluoride concentrations found in tea leaves from areas A, B, and C may indicate that fluoride contamination from combustion of high-fluoride coal is primarily an indoor problem in these areas. Tea and tea-drinking may probably be ruled out as a relevant factor in the etiology of dental fluorosis under the present conditions.

The socio-economic situation is similar and low in the three areas. Dental service and fluoride supplement programs are not available for the local population. In most cases, children do not start to brush their teeth until high school, or even later. Fluoride exposure from dental products, fluoride tablets, chewing gum, etc., may be ruled out for these children. Furthermore, according to our analyses, the fluoride concentration of staple foods like maize and rice was below detection limit (5 mg/kg) in all three sampled areas. Climatic differences between the areas are negligible. No data were available to calculate the relation between fluoride intake from the various fluoride sources in the various areas. As teeth are the most obvious biologic marker of fluoride intake, the prevalence and degree of dental fluorosis may be used to compare the effect of alternative fluoride sources. The fact that the present study shows similarity in the prevalence of dental fluorosis in areas A and C (in permanent teeth, at TF-score ≥ 1) does not, however, allow prediction of possible later development of skeletal fluorosis in the two areas. A follow-up study of skeletal fluorosis in the three areas would be of considerable interest.

Dental fluorosis in primary teeth is considered to be relatively rare [10], and/or to be less severe compared to dental fluorosis in the permanent dentition [11–13]. This has been explained by a "placental barrier". However, nearly 50% of the primary teeth in the children from the fluoride-rich coal area and two-thirds of the teeth in the high-fluoride water area were found to have fluorosis. It is, however, interesting to note a difference in the fluorosis pattern in areas A and C: While the percentage of deciduous teeth with DF was higher in area C, the severity of fluorosis in the early erupting deciduous incisors was greater in area A. This might seem to underscore our hypothesis that children in areas relying on high-fluoride coal are exposed to excessive amounts of fluoride earlier than children brought up in areas with high-fluoride water.

Fomon et al. (1996) stated that the fluoride content of the diet is extremely low in breast-fed infants and in infants fed undiluted milk from other mammals. Thus, infants may start the intake of fluoride from drinking water only after the start of the weaning; in China, this is normally 4 or 5 months after birth. Breathing, however, starts as soon as the baby is born. Fluoride may therefore enter the human body earlier in children inhaling fluoride-polluted air than in children exposed to fluoride-rich food and water. Considering the fact that dental fluorosis was found to be significantly more prevalent in primary teeth in area C, might, however, indicate that children in area A after infancy have been kept away from the polluted air in the kitchen. This needs further investigation.

Fluoride affects tooth development only during "critical" periods, i.e. during the period of mineralization, which varies according to the type of teeth. Fluoride entering the human body at different periods may therefore leave different marks on the teeth, and may thus act as a "dental black box" recording fluoride intake. The teeth, however, do not discriminate between sources of fluoride, nor between ways of entering the body. As demonstrated by Figure 1, a systematic difference of mean TF-scores in primary teeth is observed in areas A and C. Thus, late developing teeth (primary canines, the 1st and 2nd primary molars) are more severely affected in area C (high-fluoride water), while the teeth that start mineralizing at the earliest stage (e.g. primary central incisors) are more severely affected in children born and raised in area A. As previously stated, this may reflect a difference in the onset of postnatal fluoride exposure. It might also indicate differences in prenatal fluoride exposure. An analysis of the fluoride content of blood from expecting mothers in areas A, B, and C might therefore be of considerable interest.

Conclusion

DF was prevalent in area A, where high-fluoride coal was used for heating and cooking, as well as in the area relying on high-fluoride drinking water (area C). The similarity in prevalence of fluorosis in the permanent dentition of 12–13-year-old children of areas A and C indicates similarity in the toxic effect of indoor air containing $\sim 60\ \mu g/m^3$ and drinking water with a fluoride content of 3.6 mg/l. As compared to area C, however, the prevalence of dental fluorosis in the deciduous dentition was significantly lower in area A. The pattern of dental fluorosis caused by high-fluoride air and high-fluoride water may therefore be somewhat different. The fact that approximately 20% of permanent teeth are found to have dental fluorosis in an area with low-fluoride coal and low-fluoride water (area B) may indicate a relatively low tolerance to fluoride in Chinese children brought up under the present living conditions.

As the weather is wet and cold in Ziyang (area A), people tend to gather around the ground stove, eating, chatting, or watching TV. Thus, children as well as grown-ups may daily inhale smoke from fluoride-rich coal for a substantial period of time; especially during the winter. In agreement with previous Chinese reports, we believe that high-fluoride air is a major cause of endemic fluorosis in areas with high-fluoride coal. Our study would seem to verify the harmful effect of high-fluoride coal used for heating and cooking in chimney-less stoves. Dental fluorosis in new generations might be significantly reduced by switching to low-fluoride coal. Likewise, the installation of improved stoves with chimneys directing the smoke outside the combined kitchen and living room should be encouraged. Finally, efforts should be made to provide low-fluoride drinking water. Further studies are needed.

Acknowledgments

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