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Relationship between fluorine in drinking water and dental health of residents in some large cities in China

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Abstract

In this project, the relationship between fluorine content in drinking water and dental health of residents in some large cities in China was evaluated. The concentration of fluorine in tap water and in urine of local subjects of 28 cities and 4 high fluorine villages in China shows a strong positive correlation ($r^2 = 0.96$, S.E. = 0.9881). Our studies indicate that drinking water is the most important source of fluorine intake for Chinese people, and in more than 90% of urban cities, fluorine concentrations in drinking water are below levels recommended by the WHO (approximately 0.5–1.0 mg/l). A 1995 investigation by The National Committee on Oral Health of China (NCOH) shows the relationship between average number of decayed, missing and filled teeth (DMFT) of urban residents and fluorine concentration in drinking water to be negatively correlated but not forming a good linear relationship. Our results, together with the previous study, suggest that: (1) dental caries of the study population can be reduced by drinking water fluoridation and that (2) other factors such as economic level, weather, lifestyle, food habits, living condition, etc., of a city can also affect the incidence of dental caries that cannot be predicted by fluoridation alone. Research on the relation between index of fluorosis (IF) and the fluorine concentration in drinking water for the four high fluorine villages showed that the recommended concentration of fluorine in drinking water can protect from dental fluorosis.

Keywords: Fluorine; Dental health; Drinking water; Urine; DMFT; Index of flourosis; China

1. Introduction

Fluorine is an essential element for human health. However, excess fluorine may cause dental and/or skeletal fluorosis, whereas in areas that are deficient in fluorine, fluoridation of drinking water or other methods of fluorine supplementation may reduce the incidence of dental caries. Research on the relationship between fluorine concentration in drinking water and dental caries has been conducted for more than 60 years (Hinman et al., 1996; USPHS, 1991). Fluoridation of drinking water has been widely accepted as a valuable public health measure in several countries. Examples where drinking water fluoridation has been carried out include Australia, Brazil, Canada, Colombia, Hong Kong, Ireland, Malaysia, New Zealand, Singapore, Spain, U.K. and the U.S. (WHO, 1986). By 1993, fluoridated water was provided to 145 million residents in the U.S. living in 42 of the 50 largest cities (Hinman et al., 1996). In 1984, WHO defined drinking water fluoridation as a safe and economical measure of preventing dental caries and recommended that it be adopted in fluorine deficiency countries. A great deal of research supported the concept that drinking water fluoridation is a safe method for human beings (IARC, 1987; USNRC, 1993; USPHS, 1991; Knox, 1985; WHO, 1996; Bucher et al., 1991; Collins et al., 1995; Sprando et al., 1996).

Research on drinking water fluoridation in China has been difficult. In the 1960s, a tap water fluoridation experiment was conducted in Guangzhou City but the experiment did not produce reliable results due to disruptions caused by the Cultural Revolution. Because of difficulties caused by social unrest and a slight fluorosis problem in Guangzhou, the local government stopped this experiment in 1983 and no further relevant research was conducted (Working Group on Drinking Water Fluorida-

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tion of Guangzhou City, 1973). Opponents of drinking water fluoridation believed that because the amount of daily calcium intake of Chinese people is far less than their counterparts in the West, drinking water fluoridation may result in dental fluorosis. Moreover, due to the large differences in foods between China and the West, in general, Chinese people take in sufficient fluorine in their diet, thus the supplementing the fluorine content in drinking water is not as important in China, and widespread drinking water fluoridation has not been necessary. Nevertheless, the optional concentration of fluorine in tap water should be sufficient to prevent dental caries without causing fluorosis. In this study, we report on the relationship between the fluorine content in drinking water and dental health in some Chinese cities. In order to determine the safe range of fluorine concentration in drinking water, dental investigations were also conducted on residents of four villages in the Bazhou region of Hebei Province having excess exposure to environmental fluorine.

2. Methods

2.1. Study population

Fluorine concentrations were determined in drinking water and in urine in 24 large cities in 9 provinces as well as in 4 villages with high environmental fluorine (Fig. 1). In the Beijing and Shanghai metropolitan areas, samples were taken in six districts. The urine of around 100–150 subjects aged from 16 to 18 years from each city was tested for fluorine, but fewer subjects were available in the four high fluorine villages in the Bazhou region. The subjects were second year high school students who had lived in their respective communities for more than 15 years. In addition, The National Committee on Oral Health of China (NCOH) obtained dental epidemiological data from the same cities as our research. The subjects of dental epidemiological study consisted of four groups, aged 5, 12, 15 to 18 years old, 440 residents in each age group of each city received the dental caries investigation (540 in the biggest districts of Beijing and Shanghai and in the capital of each province).

2.2. Tap water and urine investigation

Tap water samples were collected from the wellhead, water treatment plants and some homes in every investigated city. It is understood that the fluorine concentrations in urine excreted can vary at different periods of a day, but random one-time urine samples can substitute for a 24-h urine sample if the sample quantity is large enough. In this study, urine samples from each community were collected between 8 and 10 in the morning. Almost all of the urine samples in the collection represent the same period of the day, making data comparison easier. Polypropylene containers typically used for medical analysis were distributed. The tap water samples and urine samples were analyzed on the same day as sample collection.

2.3. Fluorine determination method

A high-sensitive monocrystalline fluorine electrode-based potentiometer (PHS-3, Hangzhou Yamei, 2000 June) was used to determine fluoride concentrations in tap water as well as in urine. This method has excellent specificity (low response to interfering ions), wide linear range and low detection limits (0.04 mg/l). The advantages of this approach include: short analysis time (less than 5 min), elimination of sample pretreatment in the majority of cases and easy reduction of possible matrix effects. The system is simple to operate and is relatively inexpensive. Fluoride ion concentrations were determined on 3175 urine samples and 74 tap water samples. All samples were analyzed in the direct reading mode.

2.4. Dental health investigation

The National Committee on Oral Health of China (NCOH) conducted an epidemiological investigation in 1995 on oral health in 33 large cities and 33 villages, which provided us

Fig. 1. Location of cities and villages studied.

Table 1
Average fluorine concentrations in urine of subjects and in tap water in the investigation cities and villages

Investigated cities and areas	Number of subjects	Average fluorine content in urine (mg/l)	Standard deviation	Max	Min	Average fluorine content in tap water (mg/l)
Lanzhou	109	0.196	0.147	1.470	0.053	0.064
Jiayuguan	102	0.200	0.079	0.376	0.086	0.107
Tianshui	132	0.247	0.137	0.923	0.067	0.101
Guangzhou	114	0.588	0.243	1.270	0.142	0.034
Zhuhai	61	0.373	0.251	1.386	0.093	0.373
Shaoguan	109	0.339	0.165	1.042	0.074	0.007
Wuhan	115	0.329	0.150	0.868	0.048	0.222
Xianning	168	0.280	0.106	0.709	0.104	0.089
Dujiangyan	115	0.715	0.299	1.530	0.150	0.140
Neijiang	105	1.180	0.536	2.600	0.360	0.570
Chengdu	105	0.578	0.310	1.890	0.120	0.190
Jinan	114	0.700	0.344	1.920	0.120	0.340
Qingdao	103	0.731	0.294	1.650	0.310	0.448
Linyi	73	0.469	0.216	1.320	0.150	0.200
Hangzhou	108	0.552	0.310	1.530	0.083	0.178
Shanghai Huangpu	43	1.080	0.513	2.440	0.160	0.644
Shanghai Hongkou	47	0.943	0.258	1.580	0.494	0.699
Shanghai Xuhui	46	0.893	0.260	1.390	0.239	0.657
Xiangfan	146	0.361	0.160	1.130	0.111	0.107
Kunming	147	0.286	0.131	1.080	0.066	0.105
Dali	141	0.317	0.155	1.110	0.097	0.104
Beijing Dongcheng	159	0.495	0.179	1.080	0.095	0.248
Beijing Chongwen	139	0.291	0.120	0.731	0.051	0.270
Beijing Haidian	92	0.340	0.135	0.851	0.113	0.156
Yimen	155	0.131	0.035	0.288	0.065	0.020
Shenyang	93	0.562	0.257	1.400	0.126	0.050
Dalian	100	0.763	0.315	1.630	0.219	0.300
Chaoyang	102	0.980	0.414	3.010	0.292	0.400
Fluorine Exposure Villages						
Nanhao Village	30	4.360	1.610	8.510	2.345	2.730
Hongxing Village	39	4.985	1.400	6.670	0.942	3.680
Nanmeng Village	46	1.780	0.726	4.121	0.686	1.021
Yuanli Village	17	2.610	0.975	4.092	0.030	2.060

with a large amount of data on the incidence of dental caries in these communities. Our results indicate that fluorine contents of tap water systems in 24 of those 33 cities have not changed since 1995 (NCOH, 1999). Furthermore, our urine investigation subjects were all local residents who had lived in each city or village for more than 15 years. This made the data from

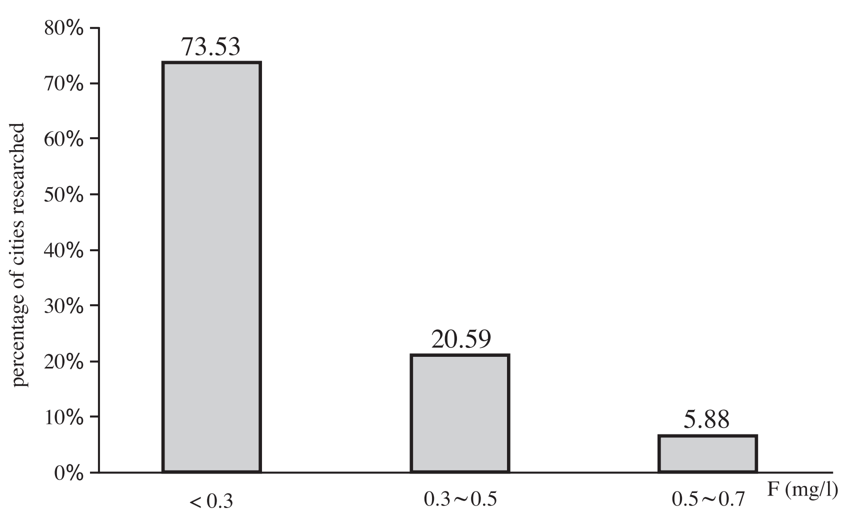


Fig. 2. The frequency of fluorine concentrations in the city tap water.

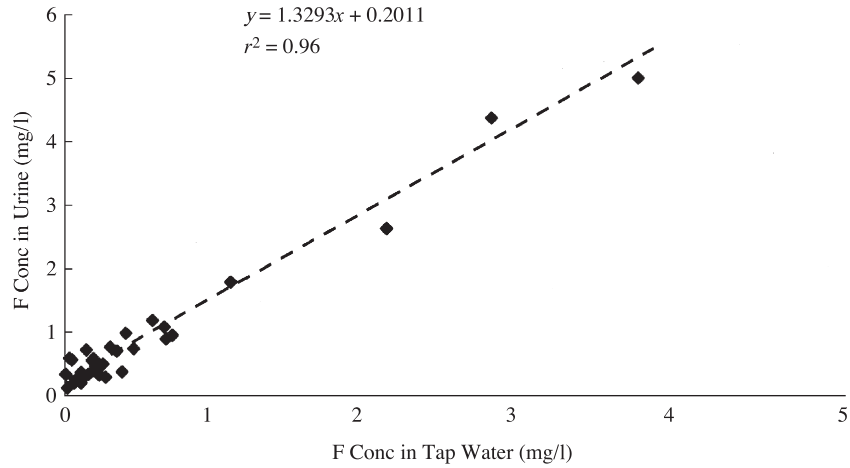


Fig. 3. The relation between fluorine concentrations in tap water and in urine of local residents of the investigated cities and villages.

the dental caries investigation of 1995 comparable with our 2002 investigation of fluorine concentration in tap water. Dentists who participated in the NCOH investigation in 1995 also conducted an investigation of dental caries and fluorosis in the four fluorine exposure villages in Bazhou City of Hebei Province in 2002.

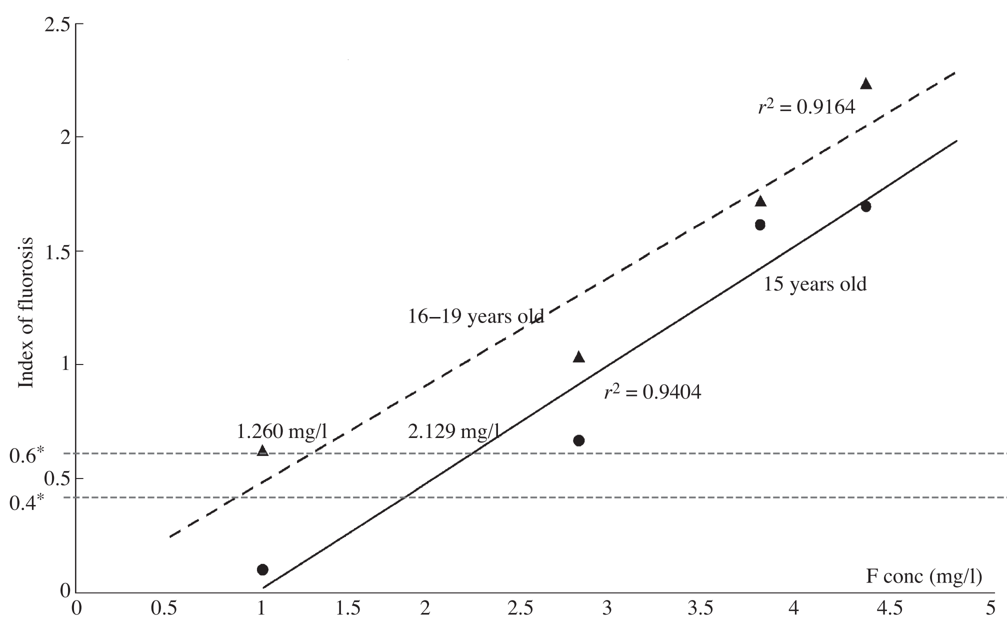
2.5. Statistics

A spreadsheet-based Microsoft EXCEL 2000 statistical package was used for data collection as well as for liner correlation analysis.

3. Results and discussion

3.1. Drinking water vs. urine

Table 1 shows the average fluorine concentrations in urine and tap water from each investigated city and village. Fluorine concentrations in tap water from the cities were very low (Fig. 2). In about 75% of the cities, fluorine concentrations in tap water was less than 0.3 mg/l, and in more than 90% of the cities, the fluorine concentration was less than 0.5 mg/l. Only two cities (Shanghai and Neijiang) have tap water with the fluorine



*0.6 represents the level of index of dental fluorosis which inducing slight prevalence of fluorosis; 0.4 represents the level of dental fluorosis which inducing suspicious prevalence of fluorosis.

Fig. 4. Relation between fluorine concentration in drinking water and the index of dental fluorosis of local residents of fluorine exposure areas in Bazhou City of Hebei province in China.

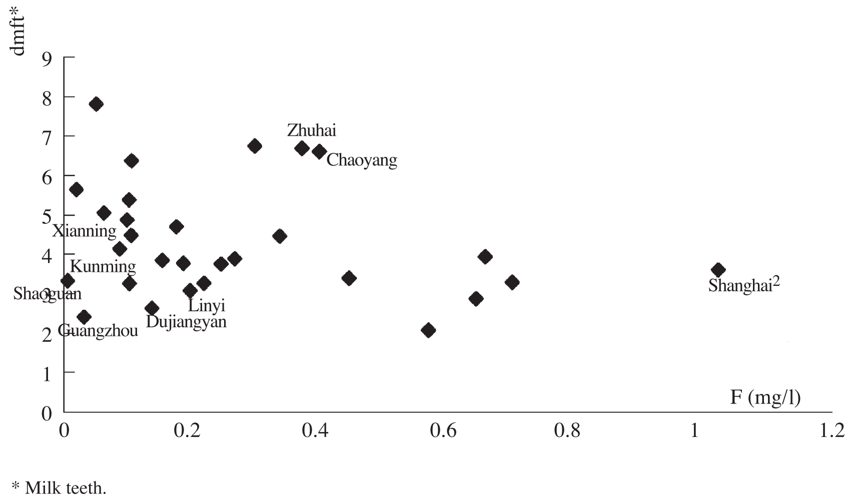


Fig. 5. The relation between fluorine concentration in drinking water DMFT* of 5-year-old residents of some big cities in China (NCOH, 1999).

concentrations greater than 0.5 mg/l. Fig. 3 shows the strong positive correlation between the fluorine concentrations in tap water and the concentration of fluorine in urine. The correlation was significantly positive (linear regression coefficients, $r^2 = 0.96$, S.E. = 0.9881), indicating that the concentration of fluorine in the drinking water was the primary factor affecting the fluorine concentration in the resident's urine and that the amount of fluorine intake from foodstuff and air are minor variables. Because drinking water is the primary source of fluorine intake for the residents of the major cities in China and because this water has extremely low fluorine concentrations, our results suggest that water fluoridation could be beneficial in preventing dental caries in the urban population.

3.2. Fluorine exposure villages

In the range of 1–4.5 mg/l, there is a positive correlation between fluorine concentration in drinking water and the index of dental fluorosis (IF). Fig. 4 shows that the lowest concentrations of fluorine in drinking water indicate slight prevalence of fluorosis (IF = 0.6 or above) between 15-year-old and 16- to 19-year-old subjects of Bazhou region are 2.13 and 1.26 mg/l, respectively. It is understood that the appropriate choice of subject age range can generate data representing the dental health situation of residents of all age ranges and can reduce the difficulty and load of research work. In this project, 15- to 19-year-old residents were chosen because at this period of human growth, all adult teeth have germinated and the abrasion of enamel is

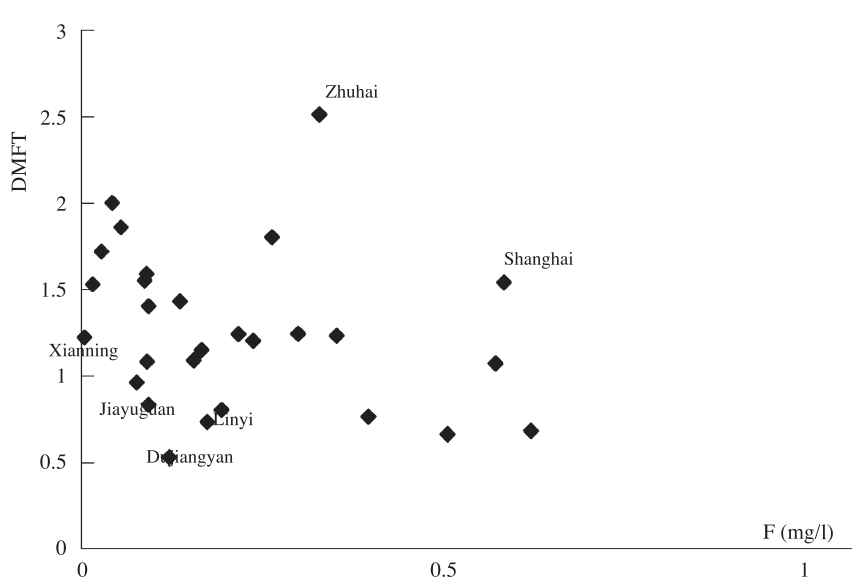


Fig. 6. The relation between fluorine concentration in drinking water and DMFT of 12-year-old residents of some big cities in China (NCOH, 1999).

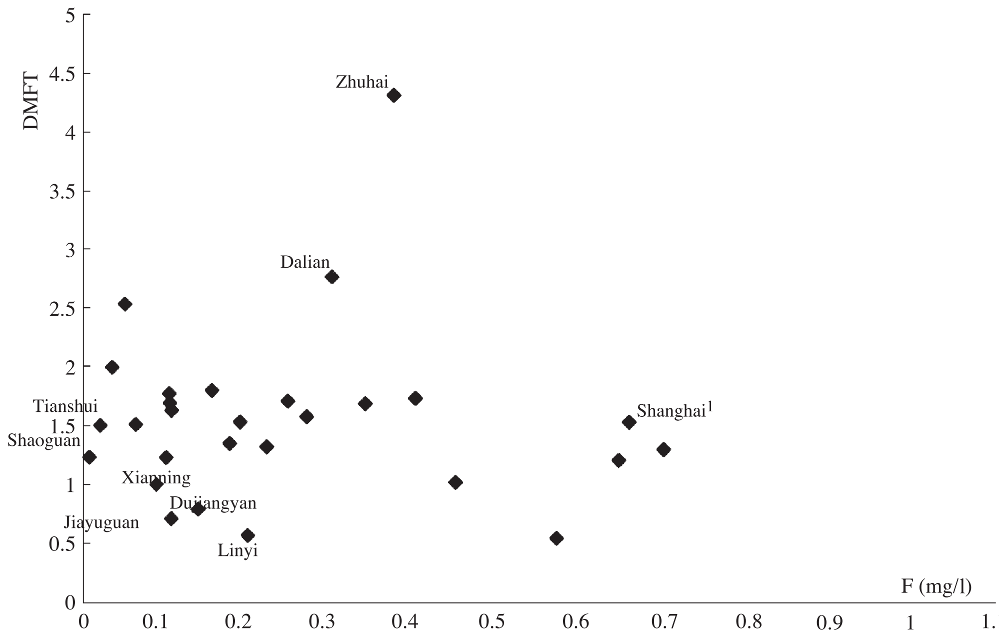


Fig. 7. The relation between fluorine concentration in drinking water and DMFT of 15-year-old residents of some big cities in China (NCOH, 1999).

relatively minor. People older than 18 years commonly have some abrasion or stains on the enamel surface and adult teeth in people younger than 15 years may have not completely germinated (WHO, 1986). Therefore, it is preferable to use 15- to 18-year-old residents to represent the dental health of all age ranges.

3.3. Analysis of DMFT data

Analysis of the average number of decayed, missing and filled teeth (DMFT) data (NCOH, 1999) shows that results for some cities diverged from the overall negative correlation between DMFT and fluorine concentration (Figs. 5–8). Possible reasons for this are:(1) An effect of weather on the relationship between fluorine content in drinking water, and in urine, for fluorine concentrations below 0.3 mg/l. In the cities with high-average air temperature (>18 °C) and/or average relative humidity (>80%) during the month of sample collection, fluorine concentrations in urine were higher than in cities with the same fluorine concentration in drinking water but with lower average air temperature and/or relative humidity, possibly due to the fact that people may consume more water in the condition of high temperature, and lower fluorine will excreted through sweat with high relative humidity.(2) Data of Zhuhai city show the DMFT is much higher comparing with its drinking water fluorine content (Figs. 5–8). It can be explained by two possible reasons: firstly, the majority of local residents immigrated to this city from other places in China during the past 20 years. Thus, the results of the dental investigation of 1995 probably cannot represent oral health situations of local residents of Zhuhai City. Secondly, by comparison with other cities, Zhuhai is an economically well-developed city with a relatively high

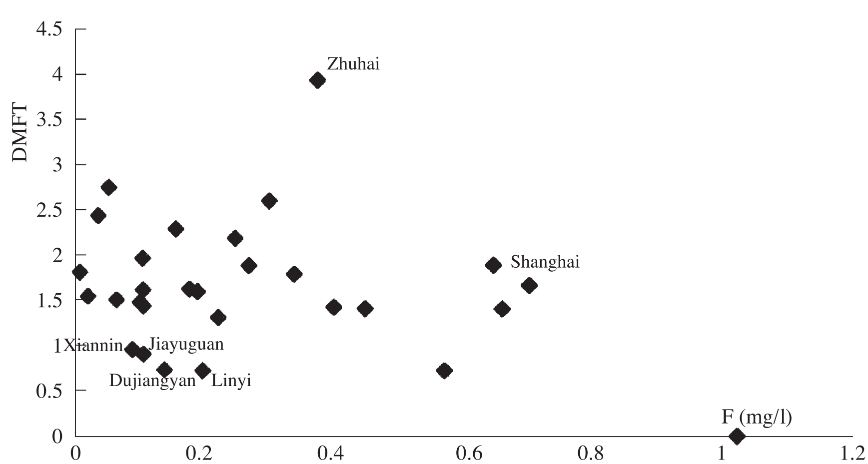


Fig. 8. The relation between fluorine concentration in drinking water and DMFT of 18-year-old residents of some big cities in China (NCOH, 1999).

standard of living. Comprised with other social factors that can affect the incidence of dental caries, economic level appears to be very important and is apparent in other cities. Except for Guangzhou City where dental caries of 5-year-old residents were abnormally low, other economically well-developed cities such as Dalian, Zhuhai, Chaoyang, Yuxi and Shanghai are all high comparing with their fluorine concentration of drinking water, and cities with poor economic conditions such as Dujiangyan, Xiangfan and Li Xianning are all low comparing with their fluorine concentration of drinking water (Figs. 5–8). Some variation in the plots may also be due to difference in clinical standards for dental caries used by dentists in different provinces.

4. Conclusions

The 1995 data of the NCOH epidemiological research (Figs. 5–8) show that despite results for some cities, there was a general negative correlation between the average number of decayed, missing and filled teeth (DMFT) of different age group subjects and the fluorine concentration in drinking water for concentrations less than 1.0 mg/l. Taken together with the present study, two conclusions can be drawn: (1) With increasing fluorine concentrations in drinking water (up to the safe level of 1 mg/l), dental caries can be limited and reduced, as shown by previous research projects in other countries (Hinman et al., 1996; USPHS, 1991; USNRC, 1993; WHO, 1986, 1996); and (2) The incidence of dental caries is not entirely affected by fluorine concentration in drinking water but is also influenced by the eating habits, level of sanitation, economic conditions, etc.

Based on the results from the 15- to 18-year-old residents of high-fluorine villages, we conclude that fluorine concentration in drinking water in Chinese cities can be safely increased to not more than 1.0 mg/l without inducing dental fluorosis. We therefore recommend that this level of fluorine be maintained in the drinking water in China.

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References

Bucher JR, Hejtmancik MR, Toft II JD, Persing RL, Eustis SL, Haseman JK. Results and conclusions of the National Toxicology Programs rodent carcinogen city studies with sodium fluoride. International Journal of Cancer 1991;48(5):733–7.

Collins TF, Sprando RL, Shackelford ME, Black TN, Ames MJ, Welsh JJ, et al. Developmental toxicity of sodium fluorine in rats. Food and Chemical Toxicology 1995;33(11):951–60.

Hinman AR, Sterrit GR, Reeves TG. The US experience with fluoridation. Community and Dental Health 1996;13(Supplement 2):3–5.

IARC (International Agency for Research on Cancer). Overall evaluation of carcinogenicity: an updating of IRAC monographs. Volumes 1–42, Lyon, 208–210, 1987 (IRAC Monographs on the Evaluation of Carcinogenic Risks to Human, Suppl 7).

Knox, EG. Fluoridation of water and cancer: a review of the epidemiological evidence. Report of the Working Party on Fluoridation of Water and Cancer, Her Majesty's stationary office, London, 1985.

NCOH (National Committee For Oral Health). Report of The Second Epidemiological Investigation On Dental Health in China. Beijing: The People's Sanitation Press; 1999. p. 49, 51–110.

Sprando RL. Effect of intratesticular injection of sodium fluoride on spermatogenesis. Food and Chemical Toxicology 1996;34(4):377–84.

USNRC US National Research Council. Health effects of ingested fluoride. Washington (DC): National Academy Press; 1993.

USPHS (US Public Health Service). Review of fluorine: benefits and risks. Report of Ad Hoc Subcommittee on Fluoride. Committee of Co-ordinate Environmental Health and Related Programs, 1991 Feb.

WHO. Second Edition. Health criteria and other supporting information vol. 2. Geneva: WHO; 1986.

WHO. Guideline for drinking-water quality Second Edition. Health Criteria and Other Supporting Information vol. 2. Geneva: WHO; 1996.

Working Group on Drinking Water Fluoridation of Guangzhou City. Effect of drinking water fluoridation. Chinese Medicine Journal 1973; 53:632.