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Determining the optimal concentration of fluoride in drinking water in Pakistan

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Abstract – *Objectives:* This study was designed to determine the optimal concentrations of fluoride for drinking water in Pakistan. Clinical dental examination of 1020 school children aged 12 years was carried out in 19 cities of Pakistan. Correlation between concentrations of water fluoride, caries and fluorosis was investigated by analyzing the data on fluoride concentrations in drinking water in the sampled population for which the caries and the fluorosis levels were also measured. *Methods:* The optimal level of fluoride in drinking water is universally calculated by applying the equation of Galagan and Vermillion, which permits the calculation of water intake as a function of temperature. The annual mean maximum temperatures (AMMT) recorded during the last 5 years were collected from the meteorological centres of the 28 divisional headquarter stations. The average AMMT of Pakistan is 29°C at which the optimal fluoride in drinking water of Pakistan was calculated to be 0.7 ppm. As drinking habits differ in various parts of the world, determination of optimal concentration of fluoride for drinking water in Pakistan was performed using a modified Galagan and Vermillion equation, which applies a correction factor of 0.56 to the equation. The optimal fluoride in drinking water in Pakistan using this modified equation was determined to be 0.39 ppm. *Results:* Observation of the correlation showed that a fluoride concentration of 0.35 ppm in drinking water was associated with maximum reduction in dental caries and a 10% prevalence of fluorosis. *Conclusions:* Determining the most appropriate concentrations of fluoride in drinking water is crucial for communities. It is imperative that each country calculates its own optimal level of fluoride in drinking water based on the dose–response relationship of fluoride in drinking water with the levels of caries and fluorosis. Climatic conditions, dietary habits of the population and other possible fluoride exposures need to be considered in formulating these recommendations.

Key words: caries; dose–response; fluoride concentrations; fluorosis; optimal

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Fluoridation of drinking water in communities having access to piped water supplies has been practised for nearly six decades. The 'optimal' concentration of fluoride in drinking water was based on the investigations by Dean (1, 2) which established that water fluoride concentrations near 1.0 ppm produce the best balance of substantial caries reduction with low prevalence of dental fluorosis. In 1957, Galagan et al. (3) reported that varying levels of fluorosis existed at the same fluoride concentration in different temperature zones. They developed an equation to determine the optimal level of fluoride in drinking water based on the calculation of water intake as a function of temperature. The level thus varied within a range of 0.7–1.2 ppm for temperatures between 50 and 90°F.

As a result of the lack of contemporary data, recommendations regarding optimal daily intake of fluoride have traditionally been based on the dose–response data published by Dean (1, 2), and calculated by the Galagan and Vermillion equation (3).

The unsuitability of these guidelines, which also form the basis of the current WHO recommendations for optimal level of fluoride in drinking water, has been investigated (4). By the 1990s it became apparent that the recommended range of optimal concentration of fluoride in drinking water (0.7–1.2 ppm) based on this equation was not appropriate for all parts of the world (5), particularly for the tropical and subtropical parts of Asia and Africa.

Galagan et al. (3) developed their equation by observing the drinking habits of children in the United States in the late 1950s. Their recommendation was based on the assumption that 44% of a child's fluid intake at that time was milk. As milk is a poor carrier of fluoride, compensation for this feature was incorporated into their model when formulating the equation. There is, however, considerable variation in the drinking habits of children in different countries and even within different regions of the same country (4). Changes have therefore been suggested to the original equation of Galagan et al. (3).

The optimal level of fluoride in drinking water for a given community cannot be determined without data on the dose–response relationship; i.e. reduction of caries and increase in fluorosis at differing concentrations of fluoride (7).

This study was aimed at ascertaining the optimal concentrations of fluoride for drinking water in Pakistan. The recommendations of this study were based on the observed dose–response relationship between the prevalence of dental caries and fluorosis at different concentrations of fluoride in drinking water. A modified version of the equation of Galagan et al. (3) was used to determine the optimal concentrations.

Material and methods

Data for this study were obtained in collaboration with the Pakistan Dental Association. The association conducted 'Dental Health Weeks' in 15 cities of the country from December 1999 to March 2000 as part of a school dental health education program.

Clinical dental examination of 1020 school children aged 12 years was carried out to assess the caries and fluorosis levels in this age group.

The two largest schools (one each for boys and girls) in each city were selected for the survey. The average number of students in the sixth grade of each school was 64. Thirty of these students randomly selected from each school were included in the study, yielding a sample size of 900 children. Oral examination for levels of caries and fluorosis was carried out on these 900 children.

Fifteen cities selected by the Pakistan Dental Association had varying concentrations of fluoride in drinking water. Thirteen of these cities had a fluoride concentration below 0.35 ppm, while this level was 0.9 and 1.2 ppm for the remaining two cities. This variation was, however, insufficient to allow construction of a dose–response graph between water fluoride concentration and the levels of caries and fluorosis among 12-year-old children. It was, therefore, decided to conduct a similar survey in at least four more cities where the fluoride concentrations in drinking water were within the missing range, i.e. 0.35–0.9 ppm; Khanpur (0.4 ppm), Sammundari (0.53 ppm), Hasilpur (0.6 ppm) and Khairpur (0.73 ppm). A sampling technique similar to the first survey was used and an additional 120 children from these four cities were examined, bringing the total sample size to 1020 children in 19 cities of Pakistan. The survey in these four cities was conducted in June 2000.

Examination for caries was performed by one examiner (A.A.K.). Training and calibration exercises were conducted at the Oral Health Services Research Centre, Cork, Ireland. The kappa score for inter-examiner reliability was 90%. One hundred and twenty students from four schools examined in January to March 2000, were re-examined in June 2000 to ensure intra-examiner reliability. The kappa score for intra-examiner reliability was 95%.

Teeth were not cleaned prior to the examination except for the removal of food debris with a paper napkin, if necessary. Natural light was used for clinical examination. Examination for caries was largely visual and in accordance with the WHO criteria. Teeth were examined wet and a CPITN probe was used to remove food debris and confirm cavitations.

Dean's index for fluorosis was used to indicate the level of fluorosis in the child. The examiner stood in front of the patient to inspect the teeth along a horizontal plane, noted the distribution pattern of any defects and decided if they were typical of fluorosis. Dean's index was scored on the condition of the two most severely affected teeth.

In his studies, Dean (8) had suggested a category of questionable fluorosis in borderline areas, when comparing two large groups. However, this entity is considered a misnomer in Dean's classification system (8). Children classified as having questionable fluorosis have usually been grouped with children classified as having no fluorosis, which is one of the reasons for developing alternate indices (9, 10). In the present study, children having questionable fluorosis were also considered as having no fluorosis.

Data on fluoride concentrations of drinking water for these 19 cities was derived from earlier studies (11, 12).

Scatter plots were constructed to correlate fluoride, DMFT and fluorosis concentrations for 12-year-olds in 19 cities of Pakistan. Fluorosis and caries concentrations were plotted on the y-axis and fluoride concentration in drinking water on the x-axis. Logarithmic trend lines were drawn between datapoints for both caries and fluorosis levels, demonstrating the dose–response relationship of fluoride levels to caries and fluorosis. A subsequent analysis was also carried out to plot the actual DMFT data on percentage values of different degrees of fluorosis in order to observe the correlation of varying degrees of fluorosis and DMFT score with the fluoride concentration in drinking water, which was then used to determine the optimal fluoride levels in water.

The optimal level of fluoride content in drinking water has traditionally been calculated on the basis of annual mean maximum temperature (AMMT) and varied from 0.7 to 1.2 ppm depending on the climate of the country (13). These standards were based on the formula by Galagan et al. (3), which estimated the daily water intake under different temperature conditions in United States during the late 1950s.

If the original metric units employed by Galagan and Vermillion are converted to SI units, the equation to calculate the optimal level of fluoride in drinking water (mg/l) becomes:

$$\text{Optimal fluoride concentration} = \frac{0.022}{0.0104 + 0.000724 \times \text{AMMT}}$$

where AMMT is the annual mean maximum temperature in °C (7). The equation, which was proposed for American children, presumed that 44% of their total fluid intake was milk with negligible fluoride levels (14).

Although Pakistan is the fourth largest milk-producing country in the world, per capita consumption of milk as a drink is low (15), with 15% of milk available in homogenized packed form, 10% utilized by the dairy product industry and approximately 25% converted into powdered milk (15). For a vast majority of the population, milk is a luxury, and even infants are given milk diluted with water (16). Hence the widely practised Galagan and Vermillion's equation cannot be used for Pakistan.

Galagan and Vermillion assumed that, on average, 44% of the American children's fluid intake was milk. In Pakistan, the true milk intake by children is probably similar to the study carried out in Chile by Villa et al. (6). Therefore the correction factor of $1 - 0.44 = 0.56$ was applied to the original equation.

$$\text{Optimal fluoride concentration} = \frac{0.022 \times 0.56}{0.0104 + 0.000724 \times \text{AMMT}}$$

This modified equation was used to calculate the optimal level of fluoride in drinking water of Pakistan.

Results

The relationship between levels of water fluoride, caries and fluorosis was investigated by observing the data on fluoride concentrations in drinking water of 19 cities of Pakistan in which caries and fluorosis levels were also measured. The three data figures were amalgamated in Table 1.

Based on the observation of the trend lines for fluorosis and dental caries, it can be seen in Fig. 1 that at 0.35 ppm of fluoride concentration in water, maximum reduction in dental caries was observed while the level of fluorosis was 10%. Only very mild and mild degrees of fluorosis were observed at 0.35 ppm of fluoride (Fig. 2). However, at fluoride concentrations of 0.4 ppm, moderate fluorosis was observed in 3% of the children examined, while no further reduction in the caries level was seen.

In order to calculate the optimal level of fluoride in drinking water for Pakistan on the basis of the original (3) and modified equation of Galagan and Vermillion (7), AMMT recorded during the last 5 years (1995–2000) were collected from Meteorological Centres of all the 28 Divisional Headquarter stations of Pakistan (Table 2). It can be seen in Table 2 that the AMMT of Pakistan is 29°C. According to the original formula of Galagan et al. (3), the recommended optimal fluoride in drinking water in Pakistan should be 0.7 ppm.

Table 1. Level of dental caries (DMFT) and fluorosis (Dean's index) for 12-year-olds, according to the varying concentrations of fluoride in drinking water of 19 cities in Pakistan

City	Fluoride level	DMFT	Dean's index (%)				Total fluorosis (%)
			Very mild	Mild	Moderate	Severe	
Mirpur Khas	0.03	2.20	0	0	0	0	0
Islamabad	0.07	1.86	7	3	0	0	10
Jehlum	0.10	0.64	0	0	0	0	0
Sialkot	0.14	1.05	3	3	0	0	6
Karachi	0.15	1.08	10	10	0	0	20
Lahore	0.15	1.07	3	10	0	0	13
Peshawar	0.15	1.02	3	0	0	0	3
Hyderabad	0.16	0.97	3	0	0	0	3
Faisalabad	0.20	0.78	12	3	0	0	15
Rahimyar Khan	0.22	0.76	3	3	0	0	6
Gujranwala	0.29	0.51	0	0	0	0	0
Sukkur	0.30	0.46	3	2	0	0	5
Sahiwal	0.33	0.42	7	3	0	0	10
Khanpur	0.40	0.50	7	3	3	0	13
Sammundari	0.53	0.60	12	15	12	3	42
Hasilpur	0.60	0.60	10	12	10	3	35
Khairpur	0.73	0.60	10	20	10	18	58
Quetta	0.91	0.60	7	30	18	10	65
Mianwali	1.40	0.90	3	15	45	30	93
Pakistan (total)		0.90	6	7	5	3	21

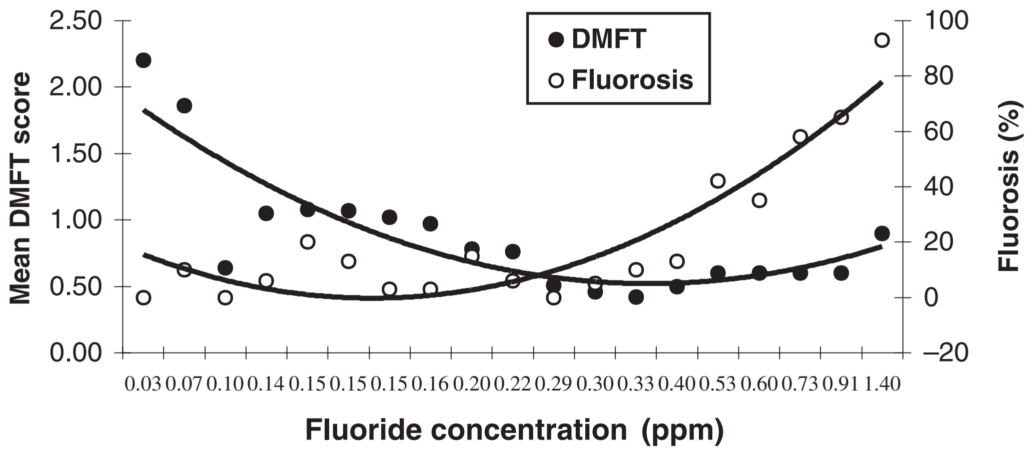

Fig. 1. The dose–response relationship of dental fluorosis and dental caries among 12-year olds to the fluoride concentrations in drinking water of 19 cities in Pakistan (logarithmic trend line drawn between data points).

However, using the modified version of the equation (7) and by applying the multiplication factor of 0.56 to this equation, the optimal fluoride in drinking water in Pakistan is recommended at 0.39 ppm.

Discussion

There were limitations in this study; first, the selection of the school sample was not randomized, as it was a convenience sample. Secondly, the cities included in the survey provided only a limited range of fluoride concentration in water supplies. This limitation was addressed by adding four cities to the sample.

Although the school sample was not randomized, it was considered reasonably representative of the school-going 12-year-old children of Pakistan in the middle socioeconomic class. The results of this survey can only be extrapolated to the school-going 12-year-old children of Pakistan in this socioeconomic class.

Exposure to fluoride in the modern world has expanded far beyond the degree envisaged by the

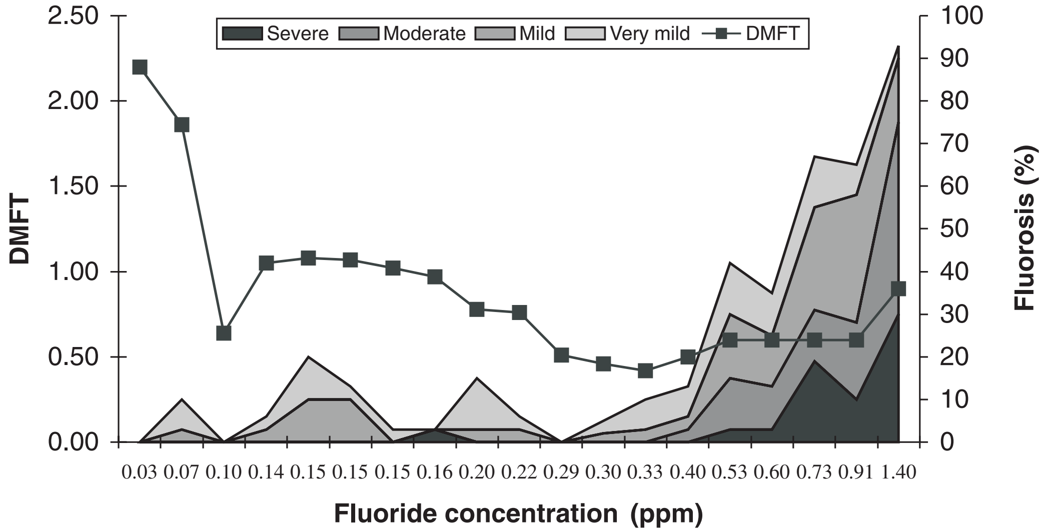

Fig. 2. The relationship of varying degree of dental fluorosis and dental caries among 12-year olds to the fluoride concentrations in drinking water of 19 cities in Pakistan.

Table 2. Annual mean maximum temperatures (AMMT) during 1995–2000 at Divisional Headquarter (DHQ) stations in Pakistan

DHQ station	AMMT (°C)
Rawalpindi	29
Jhelum	30
Sargodha	30
Faisalabad	30
Sialkot	30
Lahore	30
Sahiwal	31
Multan	32
Bahawalpur	32
Jacobabad	34
Sukkur	33
Hyderabad	33
Karachi	30
Quetta	22
Zhob	24
Sibi	34
Kalat	21
Lasbela	30
Naushki	29
Panjgur	29
Turbat	30
Chitral	22
Dir	26
Abbottabad	26
Haripur	29
Peshawar	29
Kohat	29
D.I. Khan	32
Pakistan (total)	29

fluoride pioneers 60 years ago. They dealt most exclusively with fluoride in drinking water, and their careful research on the appropriate concentrations was conducted from that viewpoint (17). The research approach and sampling scheme of this study was also designed to evaluate exposure to fluoride in water only and this has limited the capacity of the study to comment on other factors such as fluoride toothpaste and other dietary exposure to fluoride.

Finally, this study assumed that the fluoride exposure of each child in the city corresponded to the average fluoride level in drinking water of that city. The use of average fluoride level of the city water to determine the child's fluoride exposure status was perhaps not the best approach, as some children did not reside in the same area where the schools were located. It was not possible because of the lack of resources to either determine water fluoride level of multiple samples from various sources in the geological disparate areas of the city or to ask the children to bring a water sample from the drinking source at home for testing.

This study recommends an optimal fluoride level of 0.35 ppm. Although the majority of water sources in Pakistan have less than even this recommended fluoride level (11, 12), under the present conditions, the country cannot implement a community-based water fluoridation system as almost 80% of the population have no access to a piped water supply and the provision of piped water to the majority of the population cannot be a possibility in the near future. In addition, the country does not have the technical or financial resources to implement a community-based water fluoridation system. There is, however, a case for defluoridation of local water sources in certain parts of the country.

The debate on the optimal level of fluoride in drinking water began with Dean's 21-city study in the United States (2). Based on a comprehensive review of his work, Dean (2) recommended that the fluoride in drinking water of the United States might be adjusted to 1.0 ppm in order to achieve maximum benefit of caries protection and a minimum risk of acquiring fluorosis. The basis of his recommendation was that 1.0 ppm level of fluoride in the drinking water gave near maximal reduction of caries, i.e. 60% and only 'sporadic instances of the mildest form of dental fluorosis of no practical or aesthetic significance were observed'. He further showed that there is very little advantage to be gained in further reducing caries by using water higher in fluoride concentration than about 1 ppm, as the risk of acquiring fluorosis increased considerably. Based on this dose–response relationship, the optimal level of fluoride in drinking water was first recommended. However, a critical review of the classical studies of Dean, who conducted a series of epidemiological studies in 21 cities in four states of United States (5), reveals that Dean's data had only three observation points between 0.5 and 0.9 ppm, and none between 0.9 and 1.2 ppm. A subsequent study, which had 15 datapoints over the critical range, suggested that caries declined only marginally between 0.6 and 1.2 ppm (18, 19), and concluded that an appropriate trade-off between dental caries and fluorosis occurs at around 0.7 ppm.

Galagan et al. (3), noted that varying concentrations of fluorosis existed at the same level of fluoride concentration in different temperature zones. They collected data on the drinking habits of children in different temperature conditions. The aggregate data were used to formulate a range (0.7–1.2 ppm) of optimal fluoride concentrations for mean maximum temperatures between 50 and 90°F. The optimal level of fluoride in drinking water has since then universally been calculated by applying the equation of Galagan et al. (3), which permits the calculation of water intake as a function of temperature.

Studies have shown that these guidelines cannot be universally applied especially in hot tropical countries. A fluoride level of 0.7–1 ppm, which is considered optimal for Austria (20), may be considered to be too high for Bophuthatswana (21) and Sudan (22), where fluorosis has been observed at 0.5 ppm. Upper limits of fluoride in the drinking water of Senegal have been recommended at 0.6 ppm (23). In Sri Lanka, the recommended level of fluoride in drinking water is 0.6–0.8 ppm (24), while in Chile the optimal level is recommended at 0.5–0.6 ppm (7). Fluorosis was seen in 100% of children drinking water with 2 ppm of fluoride in Kenya (25), while an optimal level of 0.34 ppm was calculated for a fluorotic zone of western India (26). The World Health Organisation has more recently recommended a much more conservative range of 0.5–1.0 ppm (13).

The results of this study indicate that the recommended level of fluoride in drinking water of Pakistan may be set between 0.35 and 4 ppm. The optimal concentration has been calculated to be 0.39 by the modified equation of Galagan and Vermillion (7) and authenticated by the dose–response study, which also indicates a very close cut-off value at 0.35 ppm concentration of fluoride in drinking water.

There is, therefore, no gold standard for setting up a universal optimal level of fluoride in drinking water. Determining the most appropriate concentrations of fluoride in drinking water is crucial for communities; however, the extreme heterogeneity in findings, across various countries, makes the definition of explicit criteria and universal guidelines especially difficult, and suggest the need for a more pragmatic approach (6).

It is therefore imperative that each country calculates its own optimal level of fluoride in drinking water in accordance to the dose–response relationship of fluoride in drinking water with the levels of caries and fluorosis. Climatic conditions, dietary habits of the population and other possible fluoride exposures also need to be considered in formulating these recommendations.

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