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Associations among dental caries experience, fluorosis, and fluoride exposure from drinking water sources in Saudi Arabia

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Abstract

Objectives: a) To correlate fluoride levels in drinking water sources with caries experience and dental fluorosis in Saudi Arabia, and suggest appropriate fluoride concentration for drinking water in the country.
Methods: Fluoride levels were determined from 3,629 samples obtained from drinking water sources in 11 regions of Saudi Arabia. Based on the fluoride concentrations, a stratified sample of subjects aged 6-7, 12-13, and 15-18 years was obtained from the regions. A total of 12,200 selected subjects were examined for dental caries according to the World Health Organization criteria, and dental fluorosis, using Thylstrup and Fejerskov classification.
Results: There was an inverse relationship between fluoride exposure and caries experience, but the prevalence of dental fluorosis increased with increase in fluoride concentration. There was no significant difference in caries experience or in the prevalence of dental fluorosis when fluoride levels increased from 0.3 ppm to 0.6 ppm. In contrast, caries experience was lower, while severity of fluorosis was significantly higher at fluoride levels above 0.6 ppm.
Conclusions: a) Fluoride levels in drinking water sources in Saudi Arabia correlate significantly with caries experience and prevalence of dental fluorosis. b) Appropriate fluoride concentration for drinking water in Saudi Arabia may be about 0.6 ppm.

Introduction

Dental caries experience is high among Saudi children, and most studies indicate the prevalence of the disease in the primary dentition to be about 70-90 percent (1,2). Furthermore, caries intensity among Saudi children appears to be on the increase. Alamoudi *et al*. (1) reported mean decayed, missing, and filled teeth (dmft) of 4.23 among 6- to 9-year-olds in Jeddah, but in a more recent study, mean dmft higher than 6 has been reported (2).

In the permanent dentition, Akpata *et al*. (3) observed caries prevalence to be 69-84 percent among 12- to 13-year-old children in Riyadh, while mean decayed, missing and filled teeth (DMFT) was 1.67-2.43. In a national study carried out in Saudi Arabia, Al-Shammery (4) recorded mean DMFT of approximately 2.69 in urban and rural areas.

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Al-Khateeb *et al*. (5) reported that caries experience was considerably higher in Jeddah with fluoride level of 0.3 ppm in drinking water than Mecca and Rabagh with fluoride levels of 2.5 ppm and 0.8 ppm, respectively. Similarly, Al-Dosari *et al*. (2) observed lower caries prevalence among children exposed to higher fluoride levels in the Central Province of Saudi Arabia.

Exposure to excessive or even recommended fluoride levels may result in dental fluorosis (6,7). In temperate countries, recommended fluoride concentration in drinking water has been reported to be 1 ppm (6). Because of higher water consumption, appropriate fluoride level is lower in tropical countries. Galagan and Vermillion (8) suggested a formula for calculating appropriate fluoride levels at different ambient temperatures. Based on this formula, the appropriate fluoride concentration in countries where mean maximum ambient temperatures is higher than 27 °C was calculated to be approximately 0.7 ppm. Nevertheless, severe dental fluorosis has been reported in communities exposed to apparently appropriate fluoride concentration in drinking water in Senegal (9), Saudi Arabia (10), and Pakistan (11). Thus, there is a need to determine appropriate fluoride concentration in drinking water for different communities with different climatic conditions.

As there is a wide variation in fluoride levels in drinking water in different parts of Saudi Arabia (5,10), it is desirable to study the correlation among caries experience, dental fluorosis, and fluoride levels in drinking water sources in the Kingdom, bearing in mind that dental fluorosis is endemic in some parts of the country (10). The purpose of this study was to: a) determine the correlation among fluoride levels in drinking water sources in Saudi Arabia with the prevalence of dental fluorosis and caries experience in different parts of the country; and b) suggest appropriate fluoride level for drinking water in the country. This was part of a larger national study on caries experience, dental fluorosis, and fluoride exposure from drinking water sources in Saudi Arabia.

Materials and methods

Determination of fluoride levels in drinking water sources

The sources of drinking water in every town and village with a school in Saudi Arabia (excluding Central Province) were identified by making inquiries from school headmasters and local inhabitants. In large towns with central water supply, water samples were obtained from randomly selected school premises at the center, east, west, north, and south of the town, and also from the waterworks, if accessible. If the school was closed for any reason (e.g., at weekends), sampling was from a household near the school. In villages and small towns, water samples were obtained from all the schools and from nearby households, if the schools were closed. In all cases, wherever possible, samples were also obtained from the central source of water supply, such as well, private or public storage tanks.

From each water collection point, samples were obtained, in triplicate, using 250-mL polythene bottles. The bottles were first washed three times with the water, prior to the collection of about 250 mL of the sample. Each of the three samples from each water collection point was analyzed for fluoride within 1 week of collection by the same technician, using the atomic absorption spectrophotometer (HACH, model DR 4000[0], Loveland, CO, USA), calibrated against known standards. The technician was trained and calibrated against a senior technician at the main laboratory of Riyadh Municipality Water Testing Department, until there was agreement to the nearest 0.01 ppm between their readings.

Estimation of sample size

Using the results of analysis of the water samples, zones with similar fluoride concentrations were identified. A list of these zones was considered as the sampling frame for the schools. According to the sample requirement, municipalities were randomly chosen from each zone to represent the urban area. Additionally, rural areas (populations < 100,000) in the municipality with at least one school was surveyed.

From each selected municipality, one each of primary, secondary, and intermediate school was obtained from each of the selected urban and rural areas. From these schools, the required number of subjects in each of the age groups (6-7, 12-13, and 15-18 years) was selected. The size of the subjects sampled was proportionate to the size of the population residing in the region. All the subjects examined were Saudi nationals and lifetime residents of the areas. Fluoride exposure was determined by the fluoride zone in which a subject resided and attended school.

Clinical examination

Ethical clearance for the research was given by the College of Dentistry Research Center, King Saud University, Riyadh, Saudi Arabia. Informed consent for the clinical examination was obtained from parents through the heads of the various schools. The clinical examination was carried out in corridors, under natural lighting conditions, by two dentists using sterilized packaged hand instruments. The subjects were seated upright on a portable chair during the dental examination. The diagnosis of dental caries was according to the World Health Organization criteria (12), while the classification of dental fluorosis was by Thylstrup and Fejerskov's index, TFI (7) (Table 1). All the teeth (excluding third molars)

Table 1 Classification of Dental Fluorosis according to Thylstrup and Fejerskov Index*, TFI (7)

TFI	Features on enamel surface
0	Normal creamy surface after drying
1	Faint white lines
2	Distinct white lines, with some merged
3	Cloudy opacities between white lines
4	Paper white opacity on entire surface
5	Pitted and opaque surface
6	Merged pits form rows <2 mm high
7	Irregular pattern of enamel loss (<1/2)
8	>1/2 surface enamel loss, remaining enamel being opaque
9	Cervical rim of opaque enamel

* Staining was not a criterion for scoring, as this is considered to be a post-eruptive phenomenon due to uptake of extrinsic stains.

were scored, and the teeth dried with dental gauze before scoring. Dental caries and fluorosis were not scored in permanent teeth of the 6- to 7-year-olds.

Each of the two examiners was calibrated against the consultant (E.S.A.). Unweighted Kappa statistics, at tooth level, obtained in the calibration of the dentists against the consultant in the diagnosis of dental caries were 0.75 and 0.70, respectively, while inter-examiner reproducibility between the two examiners was 0.77. In the classification of dental fluorosis according to TFI (diagnostic accuracy = ±1TFI score), the corresponding Kappa statistics were higher than 0.8.

Statistical analysis

Prevalence of dental fluorosis among the subjects was calculated as the percentage of subjects with at least one tooth with TFI $\geq$ 1 (i.e., nonzero TFI). In addition, the percentage of subjects having the right maxillary central incisor with TFI $\geq$ 1 (nonzero TFI) was calculated as the prevalence of fluorosis in the incisors. Caries experience was measured by the DMFT index in permanent dentition and decayed, extracted and filled teeth (deft) index in primary dentition.

Chi-square test, *t*-test, and analysis of variance together with Dunnett's T3 post hoc test were employed to determine the significance of the differences between caries experience and prevalence of dental fluorosis among the subjects exposed to varying fluoride levels in drinking water sources. In addition, binary logistic regression analyses were used to determine the association between fluoride exposure and the occurrence of dental fluorosis, as well as caries experience, controlling for age. The probability level of $P < 0.05$ was considered significant. The data management and analysis were carried out, using statistical software SPSS-PC version 15.0 (Chicago, IL, USA).

Results

Sample size

Over 95 percent of the subjects sampled were examined. Those not examined included non-Saudis or those absent from school on the day of dental examination. Approximately 31 percent each of the subjects examined were aged 6-7 years and 12-13 years, the remaining 38 percent being aged 15-18 years. The sample comprised approximately equal number of boys and girls.

Caries experience

Caries experience was quite high in many parts of the country. In the primary dentition, caries prevalence among the 6- to 7-year-olds was 74-90 percent, while it was 59-80 percent in the permanent dentition. Furthermore, the mean number of DMFT varied between 2.68 and 7.07 in the primary dentition, and 1.81-4.70 in the permanent dentition.

The decayed component contributed 86 percent of the deft index among the 6- to 7-year-olds,, while it contributed about 90 percent of the DMFT values in the subjects aged 12-13 years and 15-18 years.

Fluoride levels and dental fluorosis

Fluoride levels in drinking water sources varied widely in different parts of the country, being less than 0.14 ppm in most samples of desalinated water and rainwater, while they were up to 2.5 ppm in wells in some parts of the country.

The prevalence of dental fluorosis in the entire primary and permanent dentition in each of the age groups was about 30-40 percent higher than in the maxillary central incisors, while its prevalence was higher in permanent than primary dentition.

Generally, at all ages, severity of fluorosis increased as fluoride exposure became higher (Tables 2 and 3); although there were a few exceptions. For example, among the children aged 12-13 years, those exposed to 1.01-1.50 ppm of fluoride had more fluorosis than those exposed to 1.51-2.00 ppm (Table 3). Chi-square test showed that there was a statistically significant relationship between fluoride exposure and severity of fluorosis ($P < 0.001$). Among the subjects aged 12-13 years exposed to 0.31-0.60 ppm of fluoride, 79 percent had no fluorosis of the right maxillary central incisors, and 19 percent had mild fluorosis (TFI = 1-2); only about 2 percent had moderate to severe fluorosis (TFI = 3+) of the tooth type. On the other hand, among the children exposed to 1.51-2.00 ppm of fluoride, 58 percent had no fluorosis and 25 percent had mild fluorosis; 17 percent had moderate to severe fluorosis (Table 3) of the tooth type. A similar pattern was obtained in the right maxillary central incisors of the 6- to 7-year-old children and the adolescents aged 15-18 years; the prevalence of severe fluorosis (TFI = 7-9) of the maxillary incisor was rather high in the primary dentition, compared with the permanent dentition (Tables 2-3).

Chi-square test showed no statistically significant difference in the prevalence of dental fluorosis of the maxillary incisor among the 12- to 13-year-olds exposed to 0.00-0.30 ppm and 0.31-0.60, ppm of fluoride. However, there was a significant difference in the prevalence of dental fluorosis among the children exposed 0.00-0.06 ppm, compared with those exposed to 0.61+ ppm (chi-square = 2.609, $P < 001$).

Relationship between fluoride exposure and dental caries

In general, there was an inverse relationship between fluoride exposure and caries experience (Table 4). For example, in the

Table 2 Number and Distribution (Percent) of Right Maxillary First Primary Central Incisors with Varying Severity of *Fluorosis in 6- to 7-Year-Old Children Exposed to Different Fluoride Levels in Drinking Water in 11 Regions of Saudi Arabia, by Fluoride Level, and Thylstrup and Fejerskov Index (TFI) Score

Fluoride levels (ppm)	TFI scores 0	1-2	3-4	5-6	7-9	Total
0.00-0.30	1,202 (85.2)	84 (6.0)	3 (0.2)	0 (0.0)	109 (7.8)	1,398 (36.8)
0.31-0.60	1,026 (85.6)	74 (6.2)	7 (0.6)	1 (0.1)	91 (7.6)	1,199 (31.6)
0.61-1.00	499 (80.6)	76 (12.3)	5 (0.8)	0 (0.0)	39 (6.3)	619 (16.3)
1.01-1.50	209 (67.4)	68 (21.9)	15 (4.8)	0 (0.0)	18 (5.8)	310 (8.2)
1.51-2.00	72 (71.3)	16 (15.8)	6 (5.9)	0 (0.0)	7 (6.9)	101 (2.7)
2.01-2.50	33 (66.0)	11 (22.0)	4 (8.0)	0 (0.0)	2 (4.0)	50 (1.3)
≥2.51	77 (65.8)	20 (17.1)	13 (11.1)	1 (0.9)	6 (5.1)	117 (3.1)
Total	3,118 (82.2)	349 (9.2)	53 (1.4)	2 (0.1)	272 (7.2)	3,794

* Mild fluorosis: TFI = 1-2; moderate fluorosis: TFI = 3-4; severe fluorosis: TFI ≥ 5.
$P < 0.001$ (chi-square test, after collapsing TFI ≥ 3 columns).
Numbers in parentheses are percentages of the number of subjects in the various fluoride zones.

primary dentition, mean deft among children exposed to drinking water containing 0.00-0.30 ppm of fluoride was 6.15, while it was 5.37, 4.03, and 3.55 in those exposed to 0.61-1.00 ppm, 1.01-1.50 ppm, and 1.51-2.00 ppm, respectively. This amounts to 13 percent, 35 percent, and 53 percent differences in caries experience, respectively. There was no significant difference between mean deft among children exposed to 0.00-0.30 ppm and 0.31-0.60 ppm, but mean deft among the children exposed to higher fluoride levels (>1.00 ppm) was significantly lower than the deft in the 6- to 7-year-olds exposed to 0.00-0.60 ppm of fluoride (Table 4).

In the permanent dentition, mean DMFT was 2.93 and 4.08 among 12- to 13-year-olds and 15- to 18-year-olds, respectively, exposed to drinking water containing 0.00-0.30 ppm. Among those exposed to 1.01-1.50 ppm, the corresponding mean DMFT values were 2.08 and 3.47. This amounts to a difference in caries experience of 30 percent among the 12- to 13-year-olds and 15 percent among the 15- to 18-year-olds (Table 4). However, among the 12- to 13-year-olds exposed to 0.61-1.00 ppm, mean DMFT was 2.74, amounting to a difference in caries experience of approximately 7 percent; the corresponding difference in caries experience among the 15- to 18-year-olds was approximately 8 percent (Table 4).

Binary logistic regression analysis showed that exposure to 0.31-0.60 ppm of fluoride was not significantly associated with presence or absence of dental fluorosis (Table 5). In contrast, increase in fluoride exposure above 0.60 ppm was significantly associated with the occurrence of dental fluorosis. However, among the children aged 6-7 years and 12-13 years, association between fluoride exposure and dental caries was significant only at fluoride levels higher than 1.00 ppm (Table 5).

Table 3 Number and Distribution (Percent) of Right Maxillary First Permanent Central Incisors with Varying Severity of *Fluorosis in 12- to 13-Year-Old Children Exposed to Different Fluoride Levels in Drinking Water in 11 Regions of Saudi Arabia, by Fluoride Level, and Thylstrup and Fejerskov Index (TFI) Score

Fluoride levels (ppm)	TFI scores 0	1-2	3-4	5-6	7-9	Total
0.00-0.30	1,173 (80.3)	247 (16.9)	40 (2.7)	0 (0.0)	1 (0.1)	1,461 (37.6)
0.31-0.60	932 (78.9)	223 (18.9)	22 (1.9)	1 (0.)	3 (0.3)	1,181 (30.3)
0.61-1.00	439 (70.7)	152 (24.5)	25 (4.0)	3 (0.5)	2 (0.3)	621 (15.9)
1.01-1.50	134 (42.4)	109 (34.5)	72 (22.8)	1 (0.3)	0 (0.0)	316 (8.1)
1.51-2.00	71 (57.7)	31 (25.2)	19 (15.4)	2 (1.6)	0 (0.0)	123 (3.2)
2.01-2.50	22 (27.2)	42 (51.9)	14 (17.3)	3 (3.7)	0 (0.0)	81 (2.1)
≥2.51	47 (42.3)	45 (40.5)	16 (14.4)	3 (2.7)	0 (0.0)	111 (2.8)
Mean	2,818 (72.4)	849 (21.8)	208 (5.3)	13 (0.3)	6 (0.2)	3,894 (100.0)

* Mild fluorosis: TFI = 1-2; moderate fluorosis: TFI = 3-4; severe fluorosis: TFI ≥ 5.
$P < 0.001$ (chi-square test, after collapsing TFI ≥ 3 columns).
Numbers in parentheses are percentages of the number of subjects in the various fluoride zones.

Table 4 Mean Number of Decayed, Missing, and Filled Teeth (together with Standard Deviations) among Subjects of Various Ages Exposed to Different Fluoride Levels in 11 Regions of Saudi Arabia

Fluoride level (ppm)	Age					
	6-7 years		12-13 years		15-18 years	
	No. of children	Mean deft (±SD)	No. of children	Mean DMFT (±SD)	No. of adolescents	Mean DMFT (±SD)
0.00-0.30	1,398	6.15 (4.29) a	1,469	2.93 (2.84) a	1,808	4.08 (3.86) a
0.31-0.60	1,199	5.80 (4.35) ab	1,181	2.57 (2.85) b	1,358	3.65 (3.66) b
0.61-1.00	619	5.37 (4.22) b	621	2.74 (2.70) ab	640	3.77 (3.47) ab
1.01-1.50	310	4.03 (3.99) c	317	2.08 (2.70) bdc	320	3.47 (3.43) ab
1.51-2.00	101	3.55 (3.45) c	123	1.53 (1.84) bc	118	2.34 (2.42) cd
2.01-2.50	50	3.48 (4.47) bc	81	2.17 (2.48) abc	70	2.30 (2.21) d
≥2.51	117	3.39 (3.38) c	111	2.09 (2.46) bc	153	2.24 (2.69) cd

a, b, c, and d are significantly different from one another.
Analysis of variance and Dunnet's T3 test: $P < 0.05$.
SD, standard deviation.

Discussion

The types of drinking water sources in Saudi Arabia are few, being mainly from wells and desalinated water plants (13); and water consumed at school and at home is obtained from the same few sources. Thus, fluoride exposure (from drinking water) of the subjects at school is not likely to be significantly different from that at home. Some Saudis occasionally drink bottled water, but it is our impression that less than 10 percent of the population drinks it daily or exclusively because of cost and unavailability. Similar estimates have been obtained from preliminary unpublished results from ongoing research in neighboring Kuwait. Consumption of bottled water is therefore not likely to affect the results of this study significantly.

Table 5 Binary Logistic Regression Analysis, Controlling for Age, Showing the Association between Fluoride Exposure and Occurrence of Fluorosis*, as well as Dental Caries (presence or absence)

Age	Fluorosis		Dental caries	
	P-value	Odds ratio	*P*-value	Odds ratio
6-7 years				
0.31-0.60 ppm	0.48	1.09	0.23	0.86
0.61-1.00 ppm	<0.01	1.74	0.08	0.77
1.01-1.50 ppm	<0.01	2.66	<0.01	0.43
1.51-2.00 ppm	0.01	2.36	<0.01	0.40
2.01-2.50 ppm	<0.01	3.49	0.01	0.34
>2.50 ppm	<0.01	4.2	<0.01	0.36
12-13 years				
0.31-0.60 ppm	0.09	0.83	0.19	0.88
0.61-1.00 ppm	<0.01	2.1	0.82	0.97
1.01-1.50 ppm	<0.01	3.4	<0.01	0.53
1.51-2.00 ppm	<0.01	2.37	0.12	0.71
2.01-2.50 ppm	<0.01	4.60	0.01	0.49
>2.50 ppm	<0.01	10.62	<0.01	0.44
15-18 years				
0.31-0.60 ppm	0.51	0.93	0.01	0.76
0.61-1.00 ppm	<0.01	2.70	0.04	0.79
1.01-1.50 ppm	<0.01	4.79	<0.01	0.61
1.51-2.00 ppm	<0.01	5.55	<0.01	0.49
2.01-2.50 ppm	<0.01	6.81	0.32	0.75
>2.50 ppm	<0.01	17.09	<0.01	0.45

* Fluorosis: 0 = No fluorosis (TFI = 0);, 1 = Fluorosis (TFI = 1+).
The regression analysis was carried out separately for dental fluorosis and caries experience.

In Saudi Arabia, it is mandatory for children to attend school till the age of 15 years, and many of them aged 16-18 are still at school. Thus, the large sample of subjects (12,200), randomly selected from schools, is most likely to be representative of the age groups in the present study. The Central Province (Riyadh and Qassem Regions) was excluded from the present study because this area of Saudi Arabia had been covered in an earlier study (14).

The deft index was recorded for the primary dentition to avoid errors because of tooth exfoliation. Decayed, missing, and filled surfaces (DMFS) were not recorded for the permanent dentition because the index comprises two dissimilar components: the initial caries attack and the extent to which caries progression has been influenced by restorative care or its neglect. Besides, an extracted tooth means that five surfaces are missing, while only two surfaces might have been carious at the time of extraction. Thus, DMFS may introduce errors over and above those inherent in the use of DMFT index.

The high caries experience recorded in the present study is similar to reports from recent studies in the neighboring countries (15,16), but contrasts sharply with trends in many industrialized countries (17). This underscores the need for effective caries preventive measures at community level in Saudi Arabia. The inverse relationship between fluoride exposure and caries experience observed in the present study has been reported in previous studies in Saudi Arabia (5) and other countries, e.g., Australia (18) and Ireland (19).

The amount of caries reduction that can be achieved from fluoride exposure in Saudi Arabia would depend on the severity of dental fluorosis that is acceptable to the various communities. Caries reduction, as high as 50 percent, could be obtained in the primary dentition, and about 30 percent in the permanent dentition, if the communities are exposed to 1.01-1.5 ppm of fluoride. At this level of fluoride exposure, the prevalence of dental fluorosis in maxillary central incisors may be 33 percent in the primary dentition (Table 2), with 10.6 percent having moderate to severe fluorosis (TFI = 3+); similarly, among the 12- to 13-year-olds, the prevalence of dental fluorosis in the tooth type could be approximately 58 percent, while 23 percent may have moderate to severe fluorosis (Table 3).

On the other hand, if fluoride exposure were reduced to 0.60-1.00 ppm, the prevalence of dental fluorosis in the right maxillary central incisors may be much lower in both primary and permanent dentitions. Caries reduction in the primary dentition may be only 13 percent (Table 4), while it may be only 7-8 percent in the permanent dentition (Table 4). This is not much different from reports from other parts of the world. In a systematic review of literature, water fluoridation was reported to reduce caries experience by an average of 2.3 dmft/DMFT in children aged 5-14 years, while the percentage of persons with caries decreased by 15 percent (20).

The percentage difference in caries experience resulting from fluoride exposure was lower in the permanent dentition than in the primary dentition. For example, at fluoride exposure of 0.60-1.00 ppm, caries reduction of 13 percent may be achievable in the primary dentition, and 7-8 percent in the permanent dentition. This difference may be due to more varied caries etiological factors (e.g., more varied diet and oral hygiene practices) affecting the occurrence of dental caries in the older children and adolescents. It has also been suggested that such differences may be related to the post-eruptive age of the permanent teeth of 12-year-olds when compared with the primary dentition of 6- to 7-year-olds (21). This view is not supported by results from the present study: the difference in caries experience among 12- to 13-year-olds exposed to 1.01-1.50 ppm when compared with those exposed to 0.00-0.30 ppm of fluoride was 30 percent, but only 15 percent among the 15- to 18-year-olds (Table 4).

Clearly therefore, it is to be expected that adjusted fluoridation of drinking water in areas of Saudi Arabia, where natural fluoride concentrations are low (e.g., <0.6 ppm), may result in significant caries reduction. Depending on the level of adjusted fluoridation, fluorosis associated with it may not be esthetically objectionable to a large proportion of the population. Fluoride exposure of 0.61-1.00 ppm in drinking water may, in general, result in either no fluorosis or mild fluorosis (TFI = 1-2) in the right maxillary permanent central incisors of 92 percent of the Saudi population, provided there are no other sources of fluoride ingestion. The severity of fluorosis that is esthetically acceptable in Saudi Arabia needs to be determined by future research. In Australia, Do and Spencer (22), for instance, reported that TFI = 2 was considered more favorable esthetically than TFI = 0.

Other possible sources of fluoride ingestion include beverages (23), tooth paste (21), infant formula, and fluoride supplements (24) as well as from sea foods (25). In particular, ingestion of fluoride from toothpastes by young children (e.g., aged 0-3 years) has been associated with increased prevalence of dental fluorosis in several communities (26). Future studies are needed to evaluate the extent to which these sources contribute to fluoride ingestion and fluorosis among young children in Saudi Arabia.

It would, nevertheless, appear that the appropriate fluoride level for drinking water in Saudi Arabia is between 0.61 and 1.00 ppm. However, this would leave about 4.8 percent of the 12- to 13-year-olds with TFI = 3+ of the maxillary permanent central incisors (Table 3). This low level of fluorosis may have to be accepted as a trade-off for caries reduction. It is, however, likely that this percentage would be reduced if fluoride exposure were set at the lower limit of the range (0.61-1.00), i.e., approximately 0.6 ppm. To confirm this, further data analysis would be required to find out whether there are significant differences between fluorosis among the children exposed to 0.60 ppm and 0.70, 0.80 or 0.90 ppm of fluoride. Such an analysis was not possible from our database because, prior to clinical examination, the fluoride levels had to be categorized to obtain the fluoride zones (sampling frame). It should also be remembered that Dean *et al.* (6) were aware of the fact that fluoride ingestion from drinking water will always result in some amount of fluorosis, however low the fluoride level. In parts of the country where fluoride levels in drinking water sources exceed 0.61-1.00 ppm, it may be appropriate for Government to consider making alternative sources of drinking water available to the communities.

Apart from possible geographical variation in fluoride intake in Saudi Arabia, it should be noted that average annual ambient temperature varies widely in the country, being approximately 25.3 °C (average range = 19 °C), and these factors may influence adjusted fluoridation of drinking water sources in the different regions. Furthermore, variation in time spent in air-conditioned rooms may affect the pattern of water consumption and, consequently, fluoride intake (27).

It has been suggested that calcium ions, when added to drinking water, may act independently or synergistically with fluoride in preventing dental caries (28). This idea is particularly pertinent in countries like Saudi Arabia that make use of desalinated water. To improve the quality of the desalinated water, certain ions are added to it, and regulated amount of calcium together with fluoride would then be beneficial. Further research is needed to put this idea into practice.

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References

1. Alamoudi N, Salako NO, Massoud I. Caries experience of children aged 6-9 years in Jeddah, Saudi Arabia. *Int J Paediatr Dent*. 1996;**6**:101-5.
2. Al-Dosari AM, Wyne AH, Akpata ES, Khan NB. Caries experience and its relation to water fluoride levels among schoolchildren in Central Province of Saudi Arabia. *Int Dent J*. 2004;**54**:424-8.
3. Akpata ES, Al-Shammery AR, Saeed HI. Dental caries, sugar consumption and restorative dental care in 12-13-year-old children in Riyadh, Saudi Arabia. *Community Dent Oral Epidemiol*. 1992;**20**:343-6.
4. Al-Shammery AR. Caries experience of urban and rural children in Saudi Arabia. *J Public Health Dent*. 1999;**59**:60-4.
5. Al-Khateeb TL, Al-Marsafi AI, O'Mullane DM. Caries prevalence and treatment need amongst children in an Arabian community. *Community Dent Oral Epidemiol*. 1991;**19**:277-80.
6. Dean HT, Arnold FA, Evolve E. Domestic water and dental caries. V. Additional studies of the relation of fluoride in domestic water to dental caries experience in 4,425 white children aged 12-14 years, of 13 cities in 14 states. *Public Health Rep*. 1942;**57**:1155-79.
7. Thylstrup A, Fejerskov O. Clinical appearance of dental fluorosis in permanent teeth in relation to histologic changes. *Community Dent Oral Epidemiol*. 1978;**6**:315-28.
8. Galagan DJ, Vermillion JR. Determining optimal fluoride concentrations. *Public Health Rep*. 1957;**72**:491-3.
9. Brouwer ID, Drinks OB, De-Bruin A, Hautvast JGA. Unsuitability of World Health Organization guidelines for fluoride concentrations in drinking water in Senegal. *Lancet*. 1988;**1**:223-5.
10. Akpata ES, Fakiha Z, Khan N. Dental fluorosis in 12-15 years-old rural children exposed to fluorides from well drinking waters in the Hail region of Saudi Arabia. *Community Dent Oral Epidemiol*. 1997;**25**:324-7.
11. Khan AA, Whelton H, O'Mullane D. Determining optimal concentration of fluoride in drinking water in Pakistan. *Community Dent Oral Epidemiol*. 2004;**32**:166-72.
12. World Health Organization. *Oral health surveys – basic methods*. Geneva, Switzerland: WHO; 1997.
13. Abdulla'Aly AI. Fluoride content in drinking water supplies of Riyadh, Saudi Arabia. *Environ Monit Assess*. 1997;**48**: 261-72.
14. Al-Dosari AM, Akpata ES, Wyne AH, Khan NB. A correlative study of fluoride levels, dental caries and fluorosis in the Central Province of Saudi Arabia. Final Report, King Abdulaziz City for Sciences and Technology, 2001.
15. Hashim R, Thomson WM, Ayers KM, Lewsey JD, Awad M. Dental caries experience and use of dental services among pre-school children in Ajman. *Int J Paediatr Dent*. 2006;**16**: 257-62.
16. Al-Mutawa SA, Shyama M, Al-Duwairi Y, Soparkar P. Dental caries experience of Kuwaiti children. *Community Dent Health*. 2006;**23**:31-6.
17. Sundby A, Petersen PE. Oral health status in relation to ethnicity of children in the Municipality of Copenhagen, Denmark. *Int J Paediatr Dent*. 2003;**13**:150-7.
18. Armfield JM. Public water fluoridation and dental health in New South Wales. *Aust N Z J Public Health*. 2005;**29**: 477-83.
19. Whelton H, Crawley E, O'Mullane D, Donaldson M, Kelleher V, Cronin M. Dental caries and enamel fluorosis among fluoridated and non-fluoridated populations in the Republic of Ireland in 2002. *Community Dent Health*. 2004;**21**: 37-44.
20. McDonagh MS, Whiting PF, Wilson PM, Sutton AJ, Chestnutt I, Cooper J, Misso K, Bradley M, Treasure E, Kleijnen J. Systematic review of water fluoridation. *BMJ*. 2000;**321**:855-9.
21. Ellwood RP, Cury JA. How much toothpaste should a child under the age of 6 years use? *Eur Arch Paediatr Dent*. 2009;**10**: 168-74.
22. Do LG, Spencer A. Oral health related quality of life of children by dental caries and fluorosis experience. *J Public Health Dent*. 2007;**67**:132-9.
23. Lodi CS, Ramires I, Neves LT, Buzalar MA. Fluoride concentrations in industrialized beverages consumed by children in the city of Bauru, Brazil. *J Appl Oral Sci*. 2007;**15**: 209-12.
24. Siew C, Strock S, Ristic H, Kang P, Chou HN, Chen JW, Prantsve-Hawley J, Meyer DM. Assessing the potential risk factor for enamel fluorosis: a preliminary evaluation of fluoride content in infant formulas. *J Am Dent Assoc*. 2009;**140**:1228-36.
25. Miziara AP, Philippi ST, Levy FM, Buzalaf MA. Fluoride ingestion from food items and dentifrices in 2-6-year-old Brazilian children living in a fluoridated area using a semi-quantitative food frequency questionnaire. *Community Dent Oral Epidemiol*. 2009;**37**:305-15.
26. Burt BA. The changing patterns of systemic fluoride intake. *J Dent Res*. 1992;**71**:1228-37.
27. Angmar-Masson B, Whitford GM. Environmental and physiological factors affecting dental fluorosis. *J Dent Res*. 1990;**69**(Spec Iss):706-13.
28. Bruvo K, Ekstrand K, Arvin E, Spliid H, Moe D, Kirkeby S, Bardow A. Optimum drinking water composition for caries control in populations. *J Dent Res*. 2008;**87**:340-3.