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Fluorosis and Dental Caries in Mexican Schoolchildren Residing in Areas with Different Water Fluoride Concentrations and Receiving Fluoridated Salt

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Key Words
Fluoride · Fluorosis · Mexico · Salt fluoridation

Abstract
Objective: To explore the association between fluoride in drinking water and the prevalence and severity of fluorosis and dental caries in children living in communities receiving fluoridated salt. ***Material and Methods:*** Participants were schoolchildren (n = 457) living in two rural areas of the State of Morelos, Mexico, where the water fluoride concentration was 0.70 or 1.50 ppm. Dental caries status was assessed using Pitts' criteria. Lesions that were classified as D_3 (decayed) were identified to determine the decayed, missing, and filled teeth index (D_3MFT). Fluorosis was assessed using the Thylstrup-Fejerskov Index (TFI). Information regarding drinking water source and oral hygiene practices (tooth brushing frequency, dentifrice use, and oral hygiene index) was obtained. ***Results:*** The prevalence of fluorosis (TFI ≥1) in communities with 0.70 and 1.50 ppm water fluoride was 39.4 and 60.5% (p = 0.014), respectively, while the prevalence of more severe forms (TFI ≥4) was 7.9 and 25.5% (p < 0.001), respectively. The mean D_3MFT was 0.49 (±1.01) in the 0.70 ppm community and 0.61 (±1.47) in the 1.50 ppm community (p = 0.349). A logistic regression model for caries (D_3 >1) showed that higher fluorosis categories (TFI 5–6 OR = 6.81, p = 0.001) were associated with higher caries experience, adjusted by age, number of teeth present, tooth brushing frequency, bottled water use, and natural water fluoride concentration. ***Conclusions:*** The prevalence of fluorosis was associated with the water fluoride concentration. Fluorosis at moderate and severe levels was associated with a higher prevalence of dental caries, compared with lesser degrees of fluorosis. The impact of dental fluorosis should be considered in dental public health programs.

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The use of fluoride is considered to be an essential part of dental caries prevention programs. Currently, the availability of multiple sources of fluoride [Weyant, 2004; Martins et al., 2008] has caused many residents to live in environments with an increased availability of fluoride. This has been associated with increases in the prevalence and severity of dental fluorosis, which have been observed in communities both with and without fluoridated water [Mascarenhas and Mashabi, 2008]. Despite the widespread use of fluoride, dental caries is highly prevalent, particularly in low-income populations of developed countries and in many Latin American countries. In Mexico City, for instance, the prevalence of dental caries is approximately 80% among schoolchildren aged 12 years [Dufoo et al., 1996; Irigoyen et al., 2001; Solórzano et al., 2005].

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To prevent the development of dental caries, several countries have adopted salt fluoridation programs as an alternative to water fluoridation. The fluoridation of salt is a measure recommended by the Pan American Health Organization and has been widely adopted in Latin America and in over 30 countries around the world [Gillespie and Baez, 2005]. In Mexico, health authorities established the National Salt Fluoridation Program, which has been in operation since 1991 [NOM, 1995]. Other countries that have used table salt as a vehicle to increase fluoride exposure have found a significant decline in dental caries, similar to the declines from water fluoridation programs [Beltrán-Aguilar et al., 1999].

In Mexico, there are no accurate data on the distribution of dental fluorosis throughout the population. Some reports show a high prevalence of fluorosis, though they were mainly performed in the northern and central states of the country. Other studies in Mexico have shown an association between higher levels of fluorosis and the high altitude of the locality [Irigoyen et al., 1995; Loyola-Rodríguez et al., 2000; Azpeitia-Valadez et al., 2008].

Severe degrees of dental fluorosis produce not only aesthetic deterioration but also functional problems that may affect the quality of life of children [Aguilar-Díaz et al., 2011]. Depending on the temperature of the area, it has been indicated that the optimal level of fluoride in water varies from 0.6 to 1.2 ppm [Galagan and Vermillion, 1957]. However, with the increased availability of fluoride, this figure may not be appropriate in certain populations, particularly in those where other sources of fluoride are available for the population.

The inverse relationship between the fluoride concentration in water and the incidence of dental caries has not yet been completely verified in developing countries [Birkeland et al., 2005]. Studies that show low levels of fluorosis (mild or very mild) have also shown an association with lower caries indices, compared to groups without dental fluorosis [Berndt et al., 2010]. Nevertheless, the results among groups with severe levels of fluorosis point in a different direction.

A study in Ethiopia evaluated the association between caries and dental fluorosis and found that a higher prevalence of fluorosis was associated with a higher caries index [Wondwossen et al., 2004]. Additionally, South African children were studied in three areas with different water fluoride concentrations (0.19, 0.48, and 3.0 ppm). The prevalence of dental fluorosis was 47, 50, and 95%, respectively. The prevalence of caries was similar in the two areas with low fluoride concentrations, but the area with a higher fluoride concentration (3.0 ppm) also showed a higher prevalence of caries [Grobleri et al., 2001]. On the other hand, additional studies have found that fluoride, even at high concentrations, prevents the development of dental caries [Al Dosari et al., 2010; Marya et al., 2010].

The purpose of this study was to investigate (i) the association between the presence of dental fluorosis and fluoride concentration in drinking water and (ii) the association between the severity of fluorosis and dental caries experience in schoolchildren residing in two rural towns in Mexico (with water fluoride concentrations of 0.70 and 1.50 ppm) that also receive fluoridated salt.

Materials and Methods

Study Design

The study was conducted in two towns in the State of Morelos in 2010. Both communities have a low socioeconomic level, according to the National Population Council (Consejo Nacional de Población, CONAPO) [CONAPO, 2005]. This indicator places both communities at a medium degree of marginalization, which indicates that there is no drainage system, high illiteracy, and approximately two fifths of the people aged 15 years or older have not completed elementary school. According to the 2005 census, the numbers of inhabitants per community were 3,552 and 7,861, respectively. The studied towns are located at 1,250 and 1,150 m above sea level, respectively [CONAPO, 2005].

Each of the localities studied was supplied by a single water well. The water fluoride concentration was obtained through samples taken both at low water levels and during rainy seasons. The concentrations found were 0.56–0.76 ppm (mean = 0.70 ppm) and 1.45–1.61 ppm (mean = 1.50 ppm). The fluoride concentrations from these wells have been available since 2001. Bottled water was widely distributed in the localities studied, with the most popular water presentation in these localities being a 20-liter container. These bottles often contain lower fluoride levels (0.3–0.6 ppm) than local tap water. To determine the fluoride concentration in water, the specific electrode (Orion™) method was performed in all of the samples in duplicate [NOM, 1996].

Study Group

Children between the ages of 8 and 12 who attended a public school in each community were asked to participate in the study (there are no private primary schools in either community).

Inclusion criteria: Children who had been born in the community, lived in the community a year after they were born, or had not moved in or out of the community for more than 6 months were included in the study.

Exclusion criteria: Children who had systemic diseases requiring premedication, those who had brackets, and those who were absent on the days of the oral examination were not included in the study.

The children's parents were informed of the study's objective and the procedures to be undertaken during the study. Parents signed the informed consent form on behalf of their children. The local authorities were also informed of the study's purpose and procedures. Parents responded to a questionnaire about their children's birthplace, history of their residence, drinking water source, and oral hygiene habits. Among the participating parents, 95.6% completed the study questionnaire. The ethical aspects of this protocol were evaluated and approved by the Division of Graduate Studies and Research, Faculty of Dentistry at The National Autonomous University of Mexico.

Study Variables

The following variables were chosen in this study: concentration of fluoride in water (ppm); source of drinking water (tap or bottled); dentifrice use; dental caries assessed through D_3MFT; dental fluorosis evaluated through Thylstrup and Fejerskov Index (TFI); age (years); sex (female or male); tooth brushing (number of times brushing teeth per day); dentifrice (brand); the Simplified Oral Hygiene Index (OHI-S), and the number of permanent teeth present (using WHO criteria) [World Health Organization, 1997].

Clinical Examination

International standards were followed for infection control during oral examinations [Kohn et al., 2004]. Pitts' [2004] criteria were used for the diagnosis of dental caries (D_3, dentin lesions clinically detectable; open or closed). The caries index in permanent teeth (decayed, missing, and filled; D_3MFT) was obtained. The TFI was used to assess dental fluorosis on the buccal, occlusal, and lingual surfaces of all erupted permanent teeth [Thylstrup and Fejerskov, 1978].

The oral cavity examinations were performed by placing the child in a supine position on a table, illuminating the mouth with a white light lamp, and cleaning and drying the teeth prior to examination. WHO probes and plain mirrors were used.

An experienced standardized examiner then carried out the measurements on caries and fluorosis indices; the kappa value obtained was 0.92 for the caries index and 0.87 for the TFI. Ten percent of the exams were duplicated; an 89% agreement was obtained for the caries index and 85% for the fluorosis index.

Statistical Analysis

The sample size necessary to attain 0.8 power and $\alpha = 0.05$ was calculated to be 430 participants, to detect an OR = 2.5. This calculation was based on the prevalence rates of fluorosis and dental caries generated from previous studies in the State of Morelos [Irigoyen et al., 2010]. We initially targeted 550 students. Informed consent forms were sent home, and 479 (81.7%) were collected. Based on the exclusion criteria, 22 children were not included in the study; therefore, 457 children were evaluated.

In order to assess the integrity of the data and to describe the study group, an exploratory analysis of each variable was performed. Central tendency and dispersion measurements were calculated. In the case of categorical variables, frequency and percentages were calculated for each variable. Bivariate analysis was performed between the prevalence of caries and the fluoride level in water, and likewise, between caries experience and the level of dental fluorosis. The χ^2 test for categorical variables was applied. Nonparametric statistical tests were performed in order to examine differences in the mean caries index by the level of fluorosis, because the caries and dental fluorosis variables do not satisfy the normality assumption (Kruskal-Wallis test). Subsequently, we constructed a logistic regression model for the prevalence of caries ($D_3 > 1$) and dental fluorosis at different categories (TFI ≥2, TFI ≥3, TFI ≥4, and TFI ≥5–6), controlling for possible confounding variables or effect modifiers (age, sex, number of teeth, and consumption of bottled water). The variables with $p < 0.25$ or those supported by the theory were included in the construction of the models. The significance level for the hypothesis tests was $p < 0.05$. STATA v10 (STATA Corp., Computing Resource Center, College Station, Texas, USA) was used for statistical analysis of the data [STATA, 2007].

Results

A total of 457 children were examined; their mean age was 9.92 (±1.29) years. The percentage of boys and girls examined was similar: 49.8% (n = 228) girls and 50.2% (n = 229) boys (p = 0.894). The mean age for girls was 9.91 (±1.28) years, and the mean age for boys was 9.93 (±1.31) years (p = 0.911).

Fluorosis

Compared to the community with 1.50 ppm of water fluoride, children in the community with 0.70 ppm of water fluoride had a lower prevalence of fluorosis (TFI ≥1) in all permanent teeth (60.5 vs. 39.4%; p = 0.014), a lower prevalence of fluorosis (TFI ≥1) in the central incisors (50.3 vs. 38.7%; p = 0.003), and a lower prevalence of more severe forms of fluorosis (TFI ≥4, 25.5 vs. 8.0%; p < 0.001) by age 9 (19.7 vs. 8.0%; p = 0.008). Figure 1 shows the percentage of dental fluorosis, by category of TFI and tooth type, in the community with 0.70 ppm of water fluoride. Fluorosis between TFI 1 and TFI 3 was most often present in the central incisors, lateral, and first upper and lower molars. In addition, 3.1% of first upper molars had a level of TFI ≥4. Figure 2 shows the percentage of dental fluorosis of TFI, by category and type of tooth, in the community with the higher (1.50 ppm) concentration of water fluoride. As seen, the first upper and lower molars were affected more strongly, followed by the central incisors. In the first upper molars, 17.0% had reached a level of TFI 4.

Regarding bottled water intake, 73.0% of the children in the 0.70 ppm community reported that they usually drank bottled water, with the remainder (27.0%) drinking tap water. In the 1.50 ppm community, 93.2% of the children said they usually drank bottled water, and 6.8% drank tap water (p = 0.001). Intake of bottled water was not associated with fluorosis in either community. In the locality with 0.70 ppm of water fluoride, the prevalence of fluorosis (TFI ≥3) in children who drank tap water was 54.6%, while it was 46.0% in those who reported drinking bottled water (p = 0.34). In the community with the higher concentration of water fluoride, the prevalence of fluorosis (TFI ≥3) in children who drank tap water was 65.0%; in those who reported using bottled water, it was 47.1% (p = 0.120).

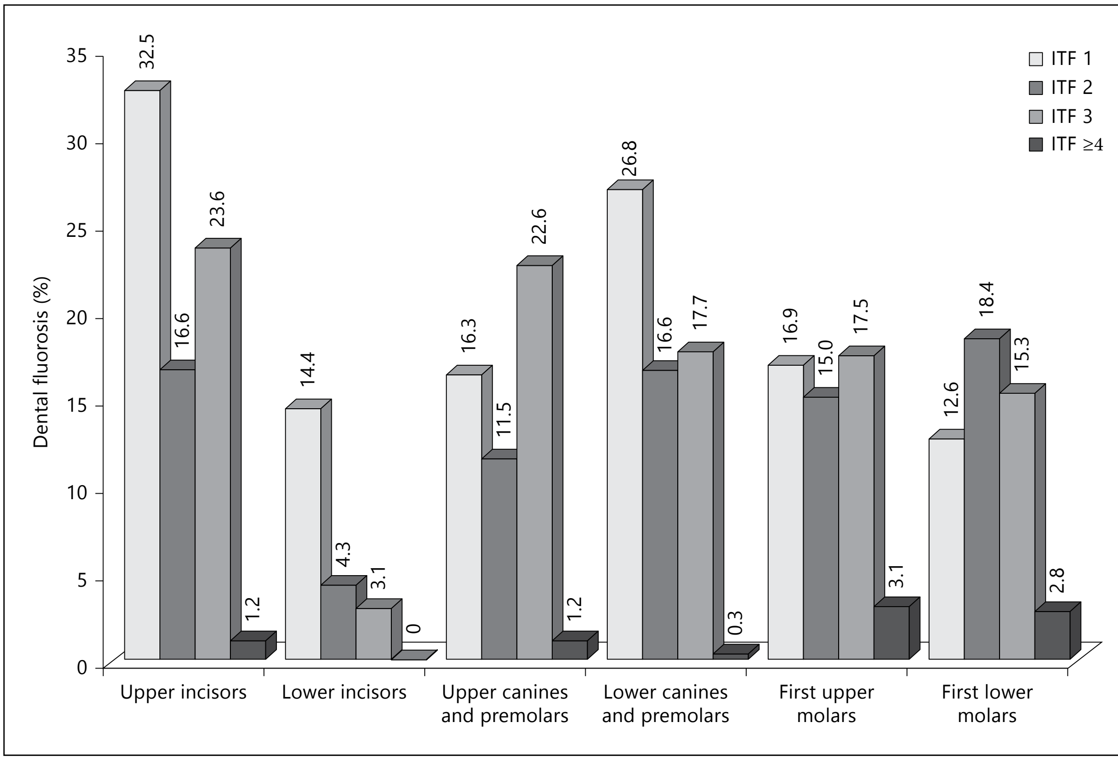

Fig. 1. Percentage of dental fluorosis for each permanent tooth in order of severity in schoolchildren aged 8–12 years in an area with fluoride concentration of 0.70 ppm in Morelos.

Schoolchildren were classified into two age groups: 8–9 years of age and 10–12 years of age. The prevalence of fluorosis (TFI ≥3), in both communities, was 41.5 and 52.5% in the younger and older groups, respectively (p = 0.023).

In relation to tooth brushing, nearly all participants reported brushing their teeth (96.3%); 47.9% brushed 3 times a day, 28.2% brushed twice a day, and 20.1% brushed once daily. The remaining 3.7% did not brush their teeth at all. There were no differences in the frequency of tooth brushing between the lower and higher water fluoride communities (98.2 vs. 95.6%, respectively; p = 0.150). Additionally, all of the toothpaste brands that the children reported using contained fluoride (approximately 1,000–1,450 ppm).

Dental Caries

There was a significant difference in the prevalence of caries among children living in the community with 1.50 ppm of water fluoride, compared to the residents of the 0.70 ppm of water fluoride community (D_3MFT >0; 85.9 vs. 75.9%; p = 0.011). In general, the mean caries in permanent teeth (D_3MFT) for 9-year-old children was 0.22 (±0.64), and for 12-year-old children, it was 1.03 (±2.09). The overall mean D_3MFT index was 0.56 (±1.32), from which the most important component was that of decayed teeth (D_3 = 0.45), which accounted for 80.4% of the index. The filled component (F = 0.11) accounted for 19.6% of the caries index, more than three quarters (76.5%) of restorations were found in posterior teeth, and no permanent teeth were lost due to caries. There was also no significant difference in caries experience (D_3MFT) between the communities with low and high water fluoride (0.49 ± 1.01 vs. 0.61 ± 1.47, respectively; p = 0.349).

Oral hygiene was deficient in the children; 44.6% of the schoolchildren had a high oral hygiene index (OHI-S ≥2). The schoolchildren who had higher levels of plaque (OHI-S ≥2) exhibited a 52.8% prevalence of caries, while the schoolchildren with better oral hygiene (OHI-S <2) had a prevalence of 47.1% (p = 0.037).

Association between Dental Caries and Dental Fluorosis

An association was found between D_3MFT and dental fluorosis (TFI) for the categories of TFI ≥3 and TFI

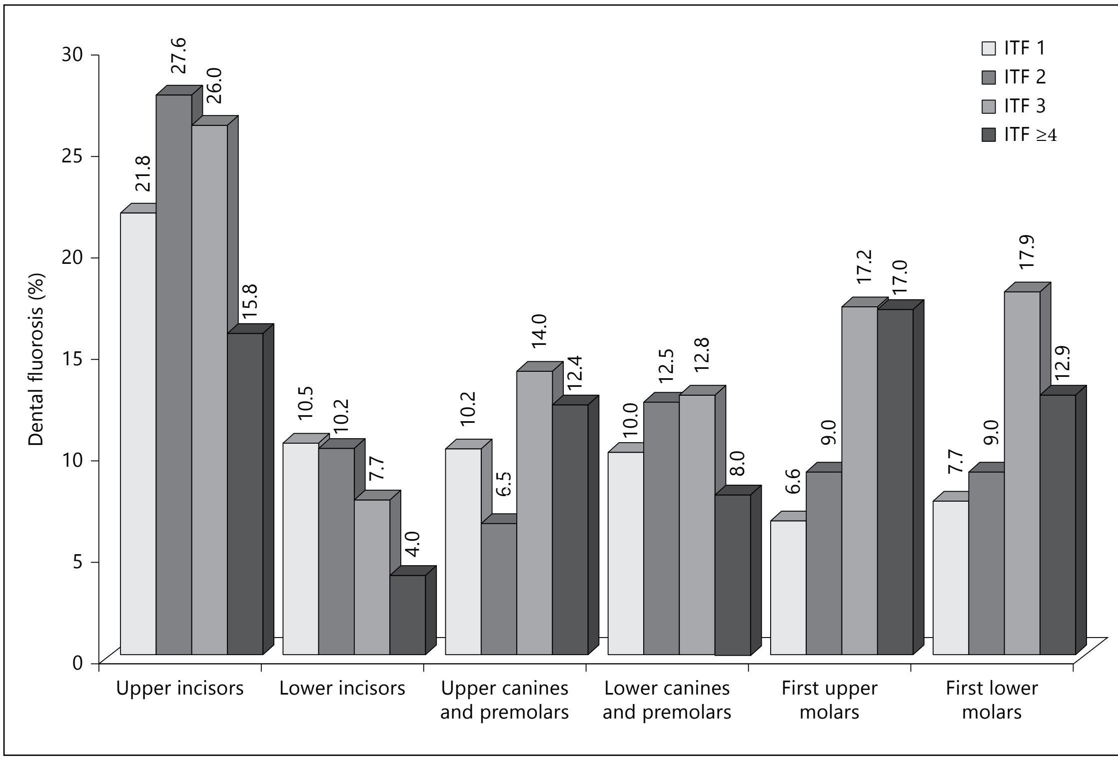

Fig. 2. Percentage of dental fluorosis for each permanent tooth in order of severity in schoolchildren aged 8–12 years in an area with fluoride concentration of 1.50 ppm in Morelos.

≥4 ($p < 0.05$). With the more mild levels of dental fluorosis, caries experience was lower than in higher degrees of dental fluorosis (table 1). Also, an association was observed between the decayed component of the index (D_3) and the degree of dental fluorosis in both communities. Schoolchildren with high levels of fluorosis (TFI ≥4) had a mean D_3 of 1.44 (±2.29; n = 88), and those with lesser degrees of fluorosis had a mean of 0.36 (±0.83; n = 369; $p < 0.001$).

Table 2 shows the bivariate analysis between dental caries (D_3 >1) and age (p = 0.001), number of permanent teeth erupted (p = 0.001), and dental fluorosis (TFI 5–6; p = 0.001). Oral hygiene variables and water source were not significant. In addition, a multiple logistic regression model was fitted for dental caries (D_3 >1) and for different categories of dental fluorosis (TFI 2, TFI 3, TFI 4, TFI 5–6) and was adjusted by selected variables (table 2). The results indicated an association with age (OR = 1.32; p = 0.011), number of teeth present (OR = 1.26; p = 0.001), and tooth brushing frequency (OR = 1.29; p = 0.039). In this model, bottled water intake (OR = 0.84; p = 0.645), OHI-S (OR = 1.31; p = 0.249), and natural water fluoride concentration (OR = 1.02; p = 0.921) were not significantly associated. Furthermore, in the logistic regression model for dental caries (D_3 >1), the lower categories of dental fluorosis were not significant (TFI 2: OR = 0.81, p = 0.583; TFI 3: OR = 1.47, p = 0.287), while the more severe catego-

Table 1. Mean caries index (D_3MFT) in permanent teeth and dental fluorosis categories (Thylstrup and Fejerskov Index) in schoolchildren residing in the state of Morelos, Mexico

Dental fluorosis TFI n	D_3MFT mean ± SD	p[a]
TFI <1 (148)	0.39±0.85	0.351
TFI ≥1 (309)	0.65±1.49	
TFI <2 (179)	0.36±0.83	0.057
TFI ≥2 (278)	0.70±1.55	
TFI <3 (236)	0.35±0.84	0.002
TFI ≥3 (221)	0.80±1.66	
TFI <4 (369)	0.36±0.83	<0.0001
TFI ≥4 (88)	1.44±2.29	

n= Number of children.
TFI = Thylstrup and Fejerskov index. [a] Kruskal-Wallis tests.

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Table 2. Crude and adjusted odds ratio (OR) of the logistic regression model for the dependent variable dental caries (D_3), and oral hygiene habits, drinking water source and dental fluorosis categories

Variables	Crude OR[a] (95% CI)	p	Adjusted OR[b] (95% CI)	p
Age, years	1.51 (1.27–1.80)	0.001	1.32 (1.06–1.64)	0.011
Number of teeth	1.32 (1.18–1.47)	0.001	1.26 (1.10–1.43)	0.001
Bottled water consumption[c]	0.78 (0.41–1.51)	0.479	0.84 (0.40–1.73)	0.645
Toothbrushing frequency[d]	1.16 (0.93–1.45)	0.175	1.29 (1.01–1.65)	0.039
OHI-S[e]	1.27 (0.83–1.94)	0.260	1.31 (0.82–2.09)	0.249
Natural water fluoride concentration[f]	1.01 (0.65–1.58)	0.933	1.02 (0.61–1.71)	0.921
Dental fluorosis				
TFI 2[g]	0.65 (0.33–1.27)	0.216	0.81 (0.38–1.70)	0.583
TFI 3[g]	0.97 (0.51–1.86)	0.944	1.47 (0.71–3.04)	0.287
TFI 4[g]	1.44 (0.80–2.57)	0.213	2.14 (1.10–4.15)	0.024
TFI 5–6[g]	4.45 (1.98–10.0)	<0.001	6.81 (2.74–16.94)	<0.001

[a] Logistical regression crude OR for D_3 as dependent variable (cut off point D_3 >1); OR[b] adjusted by: age, number of teeth, bottled water consumption, tooth brushing frequency, OHI-S (Simplified Oral Hygiene Index), natural water fluoride concentration and dental fluorosis, TFI (*Thylstrup and Fejerskov Index). Reference: [c] no bottled water consumption; [d] Tooth brushing frequency <2/day; [e] OHI-S = Good oral hygiene; [f] natural water fluoride concentration 0.7 ppm; [g] dental fluorosis TFI ≤1.

ries were (TFI 4: OR = 2.14, p = 0.024; TFI 5–6: OR = 6.81, p = 0.001; table 2). This suggests that children with high levels of fluorosis (TFI 4, 5, and 6) were more likely to have dental caries, compared with children without dental fluorosis or with only a slight degree of it (TFI ≤1).

Discussion

It was previously reported that there was a high prevalence of dental caries in a population from Morelos, Mexico [ENC, 2006]. Furthermore, schoolchildren have a great need for dental care, as the main component of the caries index was decayed teeth (80.4%). However, the results of the present study showed a lower decayed component of the DMFT index than the one revealed in the State of Morelos survey in 2001 [ENC, 2006]. This comparison has limitations related to the year that the studies were performed and sample selection: in the present study an area with high water fluoride content was selected. Other surveys in Mexico have shown decreases in caries indices in different parts of the country [Irigoyen and Sánchez-Hinojosa, 2000; Casanova-Rosado et al., 2005].

Dental Fluorosis

In the schoolchildren studied, the prevalence of dental fluorosis (TFI ≥1) was lower in an area with 0.70 ppm of water fluoride compared to an area with 1.50 ppm of water fluoride (40.0 vs. 60.5%, respectively). Also, differences were observed in moderate and severe levels of fluorosis between the two communities studied (TFI ≥4); less than 8.0% of the children examined in the locality with 0.70 ppm and more than 25% of the children in the locality with 1.50 ppm showed this dental fluorosis level. The higher prevalence of fluorosis related to higher concentrations of fluoride in drinking water has been widely documented in international studies and in some groups in Mexico [Azpeitia-Valadez et al., 2008; Mascarenhas and Mashabi, 2008; Juárez-Lopéz et al., 2011].

Besides their exposure to water-borne fluoride, the children who were examined in Morelos, Mexico also consumed table salt with fluoride; consequently, fluorosis levels were high. Several Mexican communities have reported that fluoride concentrations in drinking water are higher than optimal [Pontigo-Loyola et al., 2008], and, therefore, five states of the country [NOM, 1995] are excluded from the salt fluoridation program. The state studied herein, Morelos, is not among these five states, so its population receives fluoridated and iodized salt. In a review article regarding fluorosis in Mexico, Soto-Rojas et al. [2004] mentioned that there is little information for the country on the distribution of dental fluorosis and pointed out the need to determine the levels of fluorosis in areas with higher-than-optimal fluoride concentrations in the water. Similarly, other studies have shown the importance of this information for prevention programs in the country [Irigoyen et al., 1995].

There is little information on the prevalence of dental fluorosis in countries that have some areas with water fluoride near the optimal levels that have also implemented a salt fluoridation program. In a cross-sectional study in Jamaica, which implemented a national salt fluoridation program in 1987, Meyer-Lueckel et al. [2009] investigated the prevalence of dental fluorosis where the water fluoride concentrations ranged from 0.05 to 0.73 ppm. The prevalence of dental fluorosis on the maxillary central incisors (TFI ≥1) was as high as 39% among 12-year-old children in localities with 0.70 ppm fluoride in water [Meyer-Lueckel et al., 2009]. In both this and the Mexican cases, the presence of fluorosis may be the result of multiple sources of exposure, in which the combined exposure to fluoride in the water and in the salt undoubtedly plays a significant role. In addition, the use of fluoridated toothpastes may impact the level of fluorosis experienced by the children [Martínez-Mier et al., 2003]. In the present study, over 90% of the participants reported brushing their teeth with toothpaste that has a fluoride concentration between 1,000 and 1,450 ppm.

Among the children studied, a high percentage reported drinking bottled water, which is consistent with the fact that Mexico is the second largest consumer of bottled water in the Americas [Beverage Marketing Corporation, 2011]. In Mexico, the most popular bottled water is available in a large volume (20 liters) for only 2 or 3 USD, which makes it the cheapest bottled water available. The Mexican water market is different from the market in developed countries, where tap water is of good quality and groups of consumers with higher socioeconomic levels spend money to drink bottled water. In Mexico, even low-income families acquire bottled water. In fact, the National Household Income and Expenditure Survey showed that low- and middle-income families spent approximately 2% of their monthly income on bottled water [INEGI, 2010].

Bottled water distributed in the area studied contains lower levels of fluoride (0.3–0.6 ppm) than tap water. Despite this, the results of this study showed that consumption of bottled water was not significantly associated with dental fluorosis in either of the two localities. This confounding result may be attributed to the fact that the consumption of bottled water is perhaps recent and/or also related to the use of tap water for cooking purposes (as boiling water increases its fluoride concentration). This reasoning is supported by a study carried out in a northern Mexican state, which found that 92% of the families surveyed used tap water for food cooking [Grimaldo et al., 1995]. There is no information regarding the concentration of fluoride in the bottled water consumed by the children in our cohort when they were younger or what was used to constitute their milk formulas.

The present study showed that younger children had a lower severity of dental fluorosis than older children. Other studies support these results as well [Fejerskov, 2008]. One possible reason for this difference is that the affected teeth, with severe porosity levels caused by fluorosis, may experience loss of structure once they are in contact with masticatory forces [Fejerskov, 2008]. Thus, it is possible that, with age, more loss of enamel occurs in areas with poor mineralization, leading to a higher degree of porosity as a result of mechanical stress. Dental treatment may affect the appearance of the teeth and the evaluation of dental fluorosis. Nevertheless, in the group studied, dental restorations had little impact on the evaluation of fluorosis, since few restorations were found.

Caries and Fluorosis

The results of the study did not show a significant association between the community water fluoride concentration and the D_3MFT index. This finding is probably related to the numerous sources of fluoride available in the communities studied (e.g., fluorinated salt and toothpaste). In addition, the majority of the children from different localities consumed bottled waters that had similar concentrations of fluoride. There are numerous studies showing the benefits of fluoride in water to prevent dental caries [Pizzo et al., 2007]. However, in the majority of these studies, the exposure to fluoride was lower than the exposure that is received by the Morelos children examined in this study. Moreover, epidemiological information shows that fluoride concentrations in water above 1 ppm do not offer additional benefits for dental caries prevention [Lewis et al., 1992; Yoder et al., 1998; Angelillo et al., 1999]. Additionally, an analysis conducted in the United States (with data from the National Survey of over 18,000 US schoolchildren) showed that levels higher than 1.2 ppm of fluoride in water provided no additional caries reduction compared with lower concentrations of fluoride [Heller et al., 1997]. In accordance with this evidence, the US Department of Health and Human Services and the US Environmental Protection Agency announced new guidelines on fluoride in drinking water and changed the recommended range to 0.7–1.2 ppm, effectively setting the maximum level at the lower end (0.7 ppm). These new guidelines were proposed to maximize dental caries protection benefits and to prevent excessive fluoride exposure in the population [US Department of Health Human Services, 2011].

In relation to the D_3MFT index and dental fluorosis, it was observed that children with higher levels of fluorosis (TFI ≥4) had significantly higher levels of caries (D_3MFT = 1.44) than children with lower levels of fluorosis (D_3MFT = 0.36). In the adjusted model for the caries index, an association was observed between levels of fluorosis in the TFI 4 and TFI 5–6 categories and caries experience.

Similar results have been found in other studies. For example, a study conducted in Ethiopia showed a positive association between the prevalence of caries and fluorosis in children [Wondwossen et al., 2004]. Another study conducted in Sudan reported that children living in a community with 1.8 ppm of water fluoride had a higher prevalence of dental caries than children living in areas with 0.4 ppm (21 vs. 8%, respectively) [Birkeland et al., 2005]. Furthermore, the results of the national caries survey in Puerto Rico (in which 1,435 schoolchildren were examined) revealed no association between the community's fluorosis index and dental caries; however, when the analysis was performed specifically at the fluorosis level, schoolchildren with moderate and severe fluorosis had higher levels of caries than schoolchildren who had lower levels of dental fluorosis [Elías-Boneta et al., 2006]. The authors mentioned that one of the reasons for this association was likely the presence of aesthetical restorations placed on teeth with fluorosis to improve their appearance. This hardly explains the study results obtained herein, because the filled component of the caries index was close to 20%, and practically all fillings were restorations placed in posterior teeth. Also, in the children studied, higher values of the D_3 component were associated with higher fluorosis levels.

Another possible explanation for the association between severe fluorosis and caries could be that children at high risk for fluorosis also have a high risk for dental caries. It is also possible that the presence of plaque-retaining areas that characterize teeth with severe fluorosis due to enamel loss may ease the accumulation of plaque and make it difficult for children to remove it during brushing, thus facilitating the development of cavitated lesions [El-Nadeef and Honkala, 1998].

Study Limitations and Advantages

One of the limitations of this study is that the results cannot be extrapolated to the entire State of Morelos, mainly due to the fact that the selected schoolchildren are exposed to higher fluoride concentrations in water than those present in other areas of the state. However, many rural localities in the country share similar water fluoride concentrations, have access to the salt fluoridation program, and suffer the same socioeconomic limitations as the localities selected in the State of Morelos.

In addition, it is possible that parents who did not complete the study's questionnaire had reading or/and writing difficulties, compared with parents who completed the questionnaire. This would produce a nonresponse bias. However, the response rate was high, which could reduce the impact of this particular problem. Another limitation of the present study is that it has a cross-sectional design, which does not allow for the identification of causality. Additionally, there is no precise information on the concentration of fluoride in water (tap water and bottled water) and the other products with fluoride that each individual child was exposed to during tooth formation.

An advantage of this study is that it was conducted in areas where there is a registry of water fluoride concentrations for over 10 years. In addition, to improve the comparability of the results, the localities selected had a similar altitude and socioeconomic status. The role of systemic fluoride – particularly in developing counties, where there are several sources of this element – requires further analysis in order to guide public health policy in caries prevention programs.

Conclusions

The results from this study suggest that children with dental fluorosis of moderate and severe levels show a higher experience of dental caries. The benefits and risks of the presence of multiple sources of fluoride should be assessed. It is important to consider the scientific evidence on the main mechanisms of action of fluoride, so that proper fluoride delivery in the communities is achieved, thus reducing the risk of moderate or severe forms of dental fluorosis.

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