WELL WATER FLUORIDE, DENTAL FLUOROSIS, AND BONE FRACTURES IN THE GUADIANA VALLEY OF MEXICO

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SUMMARY: In the Guadiana Valley (the city of Durango and its surroundings in northwestern Mexico), the drinking water supply comes from underground wells and is characterized by a high content of fluoride. In this study, a quantitative assessment of dental fluorosis was made in the school age (6-12 years) and adult (13-60 years) population of Guadiana valley through a multistage sampling by conglomerates of the population. The Dean index of dental fluorosis was correlated with the fluoride concentration in drinking water. In those parts of the valley with fluoride concentrations higher than 12 mg/L, all the children surveyed exhibited dental fluorosis, and 35% of them had suffered serious damage to their teeth. A linear correlation between the Dean index of dental fluorosis and the frequency of bone fractures was also observed among both children and adults.

Keywords: Bone fractures, Dental fluorosis, Drinking water, Durango City, Guadiana Valley, Mexico, Water fluoride.

INTRODUCTION

Durango is the capital city of the state of the same name in the northwestern part of Mexico. The valley where the city is located, together with 23 small communities, is named Guadiana Valley. In this semi-arid region, well water is used to supply drinking water, after *in situ* disinfection.

In an epidemiological study, made in 1982, a Dean community index of dental fluorosis of 1.42 was reported for the 6-12 year-old child population in the city of Durango.[1] Later, Trejo-Vázquez *et al*[2] measured the fluoride content of the wells supplying drinking water and concluded that, with few exceptions, most of the fluoride concentrations were 200 to 300% above the 1.5 mg/L limit permitted by Mexican regulations. Moreover, Diaz-Barriga *et al*[3] found that endemic fluorosis is an environmental health problem that affects around 5 million people in Mexico. They correlated endemic hydrofluorosis with mining activities of fluorspar deposits in the subsoil in several states in Mexico and showed that it results from natural contamination of aquifers with fluoride. In their study they found areas of endemic fluorosis in the state of Durango.

Recently, Ortiz *et al*[4] reported that fluoride levels in Durango City ranged mainly from 1.54 to 4.7 mg/L, with 5.67 mg/L as the highest concentration.

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They used a geographic information system to identify four different risk areas, identifying a high-risk area in the northeast and southeast sectors of the city. A low risk area was detected in the south sector of the city. They reported that almost 95% of the people living in Durango City are exposed to fluoride levels higher than 2.0 mg/L, but they did not measure health damage in the people.

MATERIALS AND METHODS

Methodology: The present investigation has two components: (1) sampling of water sources and (2) survey of the population. The former included fluoride analysis of the water in all the municipal and village wells, and the latter involved a survey of the 1990 population of Guadiana Valley: 397,687 inhabitants in Durango City and 20,817 inhabitants in the other 23 small communities of the valley.

Statistical design: Water samples of all wells were taken, 51 in the city and 23 more in the surrounding areas (Figure 1). Five different areas were defined according to the F concentration levels (Table 1).

Population surveys were conducted according to a descriptive transverse correlated design. Through a polystage conglomerate random sampling, 380 families were selected and prorated into 77 to 80 families per concentration area zone. This division yielded a total of 1,437 individuals from the five different areas. Since the dental effects of fluoride are easily detected in school-age children, only 6-12 year-old children were considered for this part of the study, and from them, only those who had established permanent residence in the area (333 children).

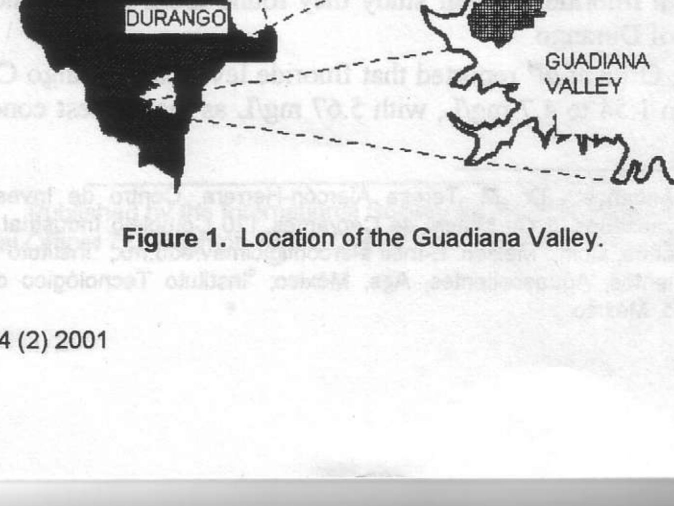

Figure 1. Location of the Guadiana Valley.

Table 1. Fluoride concentration areas in Guadiana Valley

	Fluoride concentration ranges mg/L	Number of wells City	Rural	Population (1990 census)
Zone I	Non-detectable - 1.5	2	10	9,428
Zone II	1.51 - 4.99	47	5	400,591
Zone III	5.0 - 8.49	2	4	3,823
Zone IV	8.5 - 11.9	—	2	4,270
Zone V	> 12	—	2	392
	Totals	51	23	418,504

Study Instruments: The following instruments were used in this study: a mixed questionnaire form to gather relevant social, demographic, and clinical information; the Dean index of dental fluorosis;[5] stomatology information; bone fracture data; and analytical chemical techniques for fluoride concentration determinations.

Reliability and validation of study instruments: A questionnaire was devised according to the stated objectives, and a pilot test was made prior to its formal application. The staff personnel who assisted with the fieldwork were carefully trained to conduct a uniform interview procedure. The staff in charge of evaluating the dental information did not have information concerning water F concentration.

The analytical technique used for fluoride determination was the SPADNS method 4500-F^- D.[6] Primary standard reference solutions were always analyzed before and after measurements, the relative error during measurements was 2.7%. Water samples were taken every three months for one year.

RESULTS AND DISCUSSION

Fluoride water concentrations: Figures 2 and 3 show the locations of the wells and their water fluoride concentrations. In the city of Durango only 2 wells situated in the south and southeast sectors had a concentration level below 1.5 mg/L. About 94% of the wells had concentrations in the range of 1.5 to 4.9 mg/L and 76% of these were between 3.0 and 4.9 mg/L. The highest fluoride concentration (5.4 and 5.11 mg/L) was found in 2 wells situated in the northeast sector of the city, and the lowest concentration was found in the two wells in the southern part of the city already mentioned.

Ortiz *et al*[4] reported fluoride levels ranging mainly from 1.9 to 4.7 mg/L, which corresponds roughly to the 94% of wells in our study that have these concentrations. Their highest fluoride concentration, 5.67 mg/L, is close to the 5.11 mg/L found here for a well in the northeast sector, identified by them as a high-risk area. They considered a fluoride concentration range of

3.6 to 5.6 mg/L as high-risk areas.[4] Since in the southeast sector of the city there are 8 wells, 7 of which have fluoride concentrations in the range of 3.0 to 4.9 mg/L, we conclude that there is a general agreement with their results. However, we cannot establish a direct comparison because they defined the risk areas with a geographic information system, which included overlapping concentration ranges. We also need to take into account that they took their samples from homes, whereas we took ours from supply wells. Since the municipal water distribution system combines water from wells with different fluoride levels, it is not unusual to find different fluoride concentrations in the tap water. For the dental analysis, we took care to select only dwellings that were supplied by a well of known fluoride concentration.

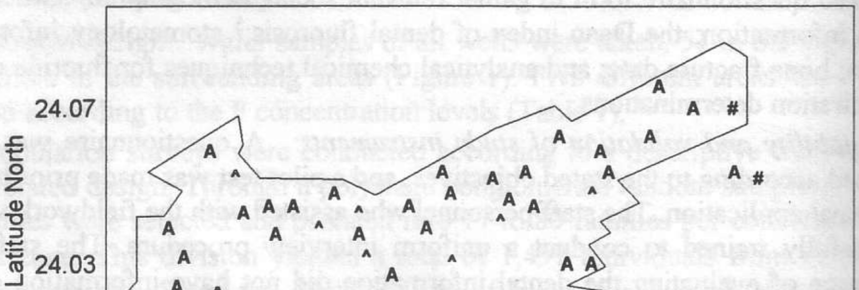

Figure 2. Fluoride concentrations in Durango City.

Outside the city the situation is different, since these are small communities and have only one well supply for each village. Here 10 of the 23 wells had fluoride concentrations below 1.5 mg/L, 9 wells had concentrations ranging from 3.0 to 8.4 mg/L, and 4 had values between 9.88 and 16 mg/L.

To determine if there was a seasonal variation in fluoride concentration, results from all the sampling periods were analyzed through an ANOVA procedure for 2 sources of variation, considering sampling periods as blocks.

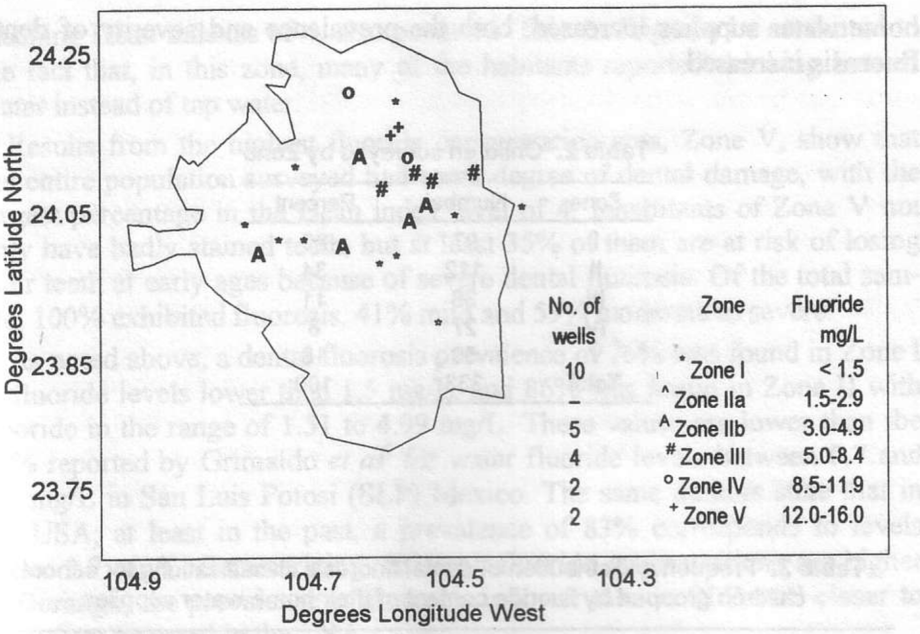

Figure 3. Fluoride concentrations in the Guadiana Valley.

Results showed a highly significant variation between well concentrations (p = 2.13E-166), and a significant variation for sampling periods (p = 4.43E-20). The chi-squared (χ^2) test was used to determine the variance in every well for the different sampling periods. The level of significance used was $\alpha^2 = 0.05$, and the hypothetical variance (mean of all sample variances) was $\sigma_o^2 = 0.21$.

Results showed that from the 74 wells, only 4 located in the valley presented a significant variance. However, since the 3.4 mg/L fluoride concentration range for each Zone is quite wide compared with the much smaller seasonal variation, the latter does not affect the analysis.

Dental surveys: The distribution of school-age children (6-12 years old) selected for the study belonging to the five fluoride concentration zones is shown in Table 2. The number of children surveyed was different for each zone because the sample included the whole population and therefore had different numbers of children identified by zones.

Dental damage by zone: Absolute and percentage frequencies for the five fluorosis classifications according to the range of fluoride concentrations in the five zones are presented in Table 3. As the fluoride concentrations in the home water supplies increased, both the prevalence and severity of dental fluorosis increased.

Table 2. Children surveyed by Zone

Zone	Number	Percent
I	97	29
II	112	34
III	38	11
IV	27	8
V	59	18
Total	333	100

Table 3. Frequency distribution of dental fluorosis classifications for school children grouped by fluoride content of their home water supplies

Fluoride range (mg/L)	No. of children	Dental fluorosis classification (Dean Index) Normal 0 No. (%)	Very mild 1 No. (%)	Mild 2 No. (%)	Moderate 3 No. (%)	Severe 4 No. (%)
< 1.50	97	23 (24)	57 (59)	10 (10)	5 (5)	2 (2)
1.51 - 4.99	112	16 (14)	63 (56)	19 (17)	12 (11)	2 (2)
5.00 - 8.49	38	2 (5)	25 (66)	10 (26)	1 (3)	0 (0)
8.50 - 1.99	27	4 (15)	13 (48)	5 (18)	4 (15)	1 (4)
12.00 - 16.00	59	0 (0)	10 (17)	14 (24)	14 (24)	21 (35)
Total	333	45 (14)	168 (50)	58 (17)	36 (11)	26 (8)

In the lowest fluoride group (Zone I), in which the average fluoride concentration was 0.75 mg/L, 24% of the group did not exhibit dental damage. The remaining 76% had varying degrees of dental fluorosis, with the highest incidence of 1 on the Dean scale, or very mild damage.

Results obtained from Zone II show that the percent of children without dental fluorosis decreased to 14%, while the percentage with Dean indexes of 2 and 3 rose. In Zone III, where the average fluoride concentration was 6.7 mg/L, only 5% of the children were free from dental fluorosis and 95% had Dean index values of 1, 2, or 3.

Results from Zone IV differ from those of the previous zones. In Zone IV, an increase in the percentage of non-affected children was seen; however, an increased percentage of children with higher degrees of dental damage, reaching Dean indexes of 4, also occurred. This finding can be attributed to the fact that, in this zone, many of the habitants reported drinking bottled water instead of tap water.

Results from the highest fluoride concentration area, Zone V, show that the entire population surveyed had some degree of dental damage, with the largest percentage in the Dean index level of 4. Inhabitants of Zone V not only have badly stained teeth, but at least 35% of them are at risk of losing their teeth at early ages because of severe dental fluorosis. Of the total sample, 100% exhibited fluorosis, 41% mild and 59% moderate to severe.

As noted above, a dental fluorosis prevalence of 76% was found in Zone I at fluoride levels lower than 1.5 mg/L, and 86% was found in Zone II with fluoride in the range of 1.51 to 4.99 mg/L. These values are lower than the 87% reported by Grimaldo *et al*[7] for water fluoride levels between 0.7 and 1.2 mg/L in San Luis Potosi (SLP) Mexico. The same authors state that in the USA, at least in the past, a prevalence of 83% corresponds to levels above 3.7 mg/L. Summarizing, although fluoride concentrations are higher in Durango, the prevalence of fluorosis is lower than in SLP, and closer to the values reported in the USA.

The community index of dental fluorosis (CIDF)[5] for each of the five fluoride exposure groups is presented in table 4.

As seen in both Table 3 and Table 4, the prevalence and severity of dental fluorosis exhibited a positive correlation with levels of fluoride in the drinking water. Since the CIDF is not supposed to exceed 0.6 for public health purposes, the values found in this study are therefore too high.

The weighted mean CIDF for the total sample was 1.49, somewhat higher than the 1.42 weighted figure found in 1982.[1]

Unfortunately, there are no data on fluoride concentrations in the water from 1982. During the last two decades, according to verbal information from the National Water Commission, many existing underground water levels became depleted, and, to sustain demand, deeper wells were drilled, giving lower quality water.

Table 4. Community index of dental fluorosis for children grouped by fluoride content of their home water supplies

Fluoride range (mg/L)	Average concentration (mg/L)	No. of children	Community index of dental fluorosis (CIDF)
< 1.50	0.75	97	1.03
1.51 - 4.99	3.25	112	1.29
5.00 - 8.49	6.74	38	1.26
8.50 - 11.99	10.24	27	1.44
12.00 - 16.00	14.00	59	2.78
Total		333	Weighted mean = 1.49

Epidemiological interpretation: From the results presented, a clear trend of increased dental damage with higher fluoride concentration in the drinking water can be observed. Based on Dean's indexes, the most epidemiologically favourable conditions exist for people living in Zone I areas, where water fluoride concentrations are below 1.5 mg/L. The most unfavourable conditions exist for people living in Zone V areas. However, this does not necessarily imply that a direct cause-effect relationship exists. What can be inferred is that inhabitants of areas with higher fluoride concentrations are at higher risk.

Bone fracture susceptibility: The clinical information gathered in the survey also permitted an analysis of bone fracture frequency in the population and its correlation with the individual Dean dental fluorosis indexes independently of the fluoride zone. Data selection for this analysis was done taking into account only individuals who had permanent residence in the zone, and selecting only bone fractures that had ever occurred without apparent cause, where a bone fracture would not normally be expected to occur. This indicates that the fractures were not the result of a clear major or minor trauma. Validation of such an event was a difficult task because we depended on the subjectivity of both the interviewer and the interviewed.

Tables 5 and 6 show the number of fractures found in both children (6-12 years: mean = 8.89, median = 9) and adults (13-60 years: mean = 30.28, median = 30) in relation to their Dean index classifications of dental fluorosis and their corresponding fluoride concentration zone. Plotting normalized bone fracture incidence versus corresponding Dean index revealed a linear association with a correlation of $R^2 = 0.94$ for children and $R^2 = 0.98$ for adults (Figure 4). As is shown in these tables, the highest fracture incidence for both groups was found in the fluoride concentration levels of 1.51 to 4.99 mg/L, which is one of lower concentration zones rather than one of the higher ones, as we expected. Plotting the incidence of fractures versus the average corresponding fluoride concentration in each zone for the adults indicated a third order polynomial correlation with $R^2 = 0.9995$ (Figure 5).

Table 5. Number of fractures (fr) identified in children age 6 to 12 years associated with different degrees of dental fluorosis

Fluoride range (mg/L)	No. of Children	Dental fluorosis classification Normal 0 fr/no.	Very mild 1 fr/no.	Mild 2 fr/no.	Moderate 3 fr/no.	Severe 4 fr/no.
< 1.50	97	1/23	3/57	1/10	0/5	0/2
1.51 - 4.99	112	0/16	4/63	3/19	2/12	1/2
5.00 - 8.49	38	0/2	1/25	0/10	0/1	0/0
8.50 - 11.99	27	0/4	1/13	1/5	0/4	1/1
12.00 - 16.00	59	0/0	0/10	0/14	2/14	3/21
Total	333	1/45	9/168	5/58	4/36	5/26

Table 6. Number of fractures (fr) identified in adults age 13 to 60 years associated with different degrees of dental fluorosis

Fluoride range (mg/L)	No. of Adults	Normal 0 fr/no.	Very mild 1 fr/no.	Mild 2 fr/no.	Moderate 3 fr/no.	Severe 4 fr/no.
		Dental fluorosis classification				
< 1.50	192	0/67	4/79	1/21	1/19	0/6
1.51- 4.99	330	5/96	7/122	3/46	5/46	6/20
5.00 - 8.49	146	1/10	2/57	3/34	4/35	3/10
8.50 - 11.99	138	0/40	2/47	3/18	4/19	1/14
12.00 - 16.00	96	2/3	1/29	1/17	2/25	0/22
Total	902	8/216	16/334	11/136	16/144	10/72

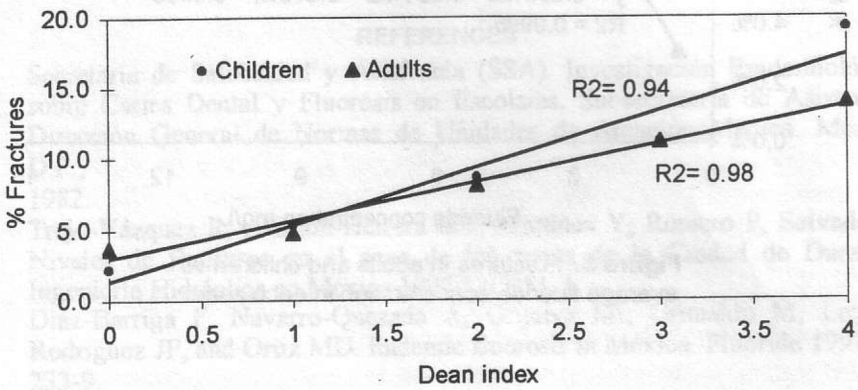

Figure 4. Bone fractures *vs* Dean dental fluorosis index for the adults and the children.

In Figure 5, the incidence of fractures among the children is similar to that of adults, with the exception of the third point, corresponding to the number of fractures presented in Zone 3. However, the total length of exposure in years for the children (mean age 8.99 years) is only one-third that of the adults (mean age 30.28 years), who have lived 3.4 times as long as the children. The overall similarity of percentages of nontrauma fractures in the two groups (children = 7.2%; adults = 6.8%) suggests that the relative prevalence of such fractures among the children in relation to years of exposure to fluoride is greater than in the adults. It is also possible that most of the adult fractures occurred during childhood, but unfortunately we did not obtain this information during the population survey. Results from fractures versus fluoride concentrations in children (Table 5) could not be analysed statistically.

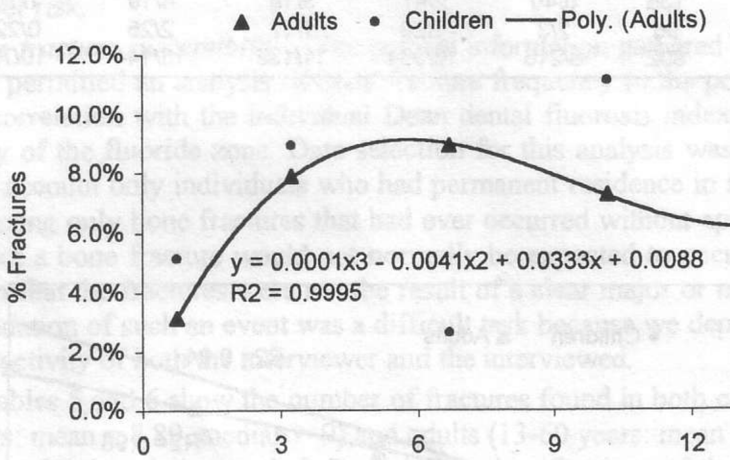

Figure 5. Fractures in adults and children vs average fluoride concentration in each zone.

The difference between the cases of bone fractures among adults in Zone I and 2, and Zone I and 3 are statistically significant by chi-squared analysis (χ^2 with the Yates correction factor = 3.97 [p = 0.0461] and 4.188 [p = 0.0407], respectively).

It is known that fluoride has negative effects on bone cell metabolism.[9] It may increase bone quantity, but it can also decrease bone quality and strength. In other specific studies, fluoride has shown paradoxical effects, like the inhibition of human prostatic acid phosphatase at higher concentrations.[8] The fact that the incidence of fractures was found to decrease at higher fluoride concentrations may reflect a paradoxical effect. The correlation of bone fractures and dental fluorosis seems to be linear, but bone fractures and fluoride water concentrations show a third order polynomial curve.

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We have no explanation for this finding, although a clear tendency was observed, and this must be analyzed in future studies.

CONCLUSIONS

Our findings show that nearly 84% of the wells that supply drinking water to inhabitants of the Guadiana Valley exceed the maximum fluoride concentration limits established by both Mexican and international regulations. A higher risk of increased dental damage is directly related to persons living in areas with higher fluoride levels in their drinking water. A positive correlation between the Dean index of dental fluorosis and the occurrence of bone fractures also exists. A paradoxical behaviour was observed between the occurrence of fractures and fluoride concentration in water.

ACKNOWLEDGMENTS

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