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Estimation of optimal concentration of fluoride in drinking water under conditions prevailing in Chile

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Abstract – The purpose of this comparative study of caries and dental fluorosis experience in Chilean children was to estimate the optimal range of fluoride concentration in tap water under conditions currently prevailing in Chile. The sample included 2431 schoolchildren 7, 12 and 15 years old, life-long residents of five communities with fluoride concentrations in their tap water in the range 0.07–1.1 mg/L. The study population received an oral clinical examination including caries experience and an enamel fluorosis evaluation of the permanent dentition (Dean's scoring system). For 15-year-old children, the DMFT index changed from 5.06 to 2.60, and for 12-year-olds it changed from 3.10 to 1.36 when fluoride water concentration changed from 0.07 to 1.10 mg/L. For 7-year-old children the dmft index correspondingly changed from 3.67 to 1.59. The relationship between DMFT for 12-year-olds and water fluoride concentration was best fitted by a logarithmic function (r^2=0.98). The Community Fluorosis Index (CFI) was used to assess enamel fluorosis in the study population, and it showed a linear relationship (r^2=0.983) with increasing fluoride concentration of water for the 12-year-old group. Results obtained suggest that under current Chilean conditions, the optimal range of fluoride concentration in potable water should lie in the 0.5–0.6 mg/L range.

Key words: caries experience; Chilean children; enamel fluorosis

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A sustained decrease in dental caries experience during the last decades was reported in many studies carried out in developed countries (1–4). At the same time a continuous increase in enamel fluorosis prevalence and severity was also reported in optimally fluoridated and also in non-fluoridated areas (5–8). These findings were mainly attributed to the increase of systemic and topical fluoride exposure in the populations. A caries preventive program through water fluoridation was implemented in the Fifth Region of Chile in 1986, reaching a population of about 1 million. The fluoride concentration was adjusted to 0.95 mg/L, following international recommendations (9). In April 1996, water fluoridation was started in Santiago, the capital city of Chile, with over 4 million inhabitants.

An early study on geographical and nutritional factors in dental caries was carried out in Chile (10). Data collected in five northern Chilean communities in 1960 showed that the average DMFT index for children aged 12–14 years was as low as 1.81, while their average Community Fluorosis Index (CFI) was 0.58. These five communities presented naturally occurring water fluoride concentrations in the range 0.3–0.6 mg/L (10). The authors pointed out that children's milk intake from powdered milk prepared with tap water might explain "the biological effects reported" (10).

Recent epidemiological information on caries experience and fluorosis prevalence among Chilean children is scarce. Only two, as yet unpublished, national surveys are available comprising clinical

data collected in 1992 (11) and 1996 (12). Results of these reports suggest that the caries experience of 12-year-old children in several urban districts, including the capital city, might be considered at the lowest end of the "moderate" category according to international criteria (13). Recent studies indicated a relatively high prevalence of dental fluorosis among children residing in the optimally fluoridated Fifth Region (14).

It was previously pointed out that certain Chilean dietary habits might contribute to an increased fluoride intake among very young children (10,14). These include prolonged use of powdered milk (prepared with tap water) and tea ingestion.

The purpose of the present study was to obtain an epidemiological estimate of an appropriate fluoride concentration range in potable water, under local conditions. This estimate could assist National Health Authorities in the decision-making process on this issue.

Material and methods

The experimental protocol of this study was approved by the Ethics Committee of INTA, University of Chile. Enrolment of the study population was through and with the co-operation of the selected schools. Written or verbal informed consent was obtained from parents of the participating subjects.

This comparative study was carried out in five Chilean urban centres with different fluoride concentrations in their tap water: Rancagua (0.07 mg/L), Santiago (0.21 mg/L), La Serena (0.55 mg/L), San Felipe (0.93 mg/L), and Iquique (naturally occurring 1.10 mg/L). The fluoride concentrations quoted correspond to averages of monthly data reported in the last 10 years (15). Iquique and La Serena are northern coastal cities of the Pacific Ocean, while the other three communities are located in the central part of Chile at altitudes not higher than 700 m above sea level. Their annual mean maximum temperatures lie in the range 18–22°C (16). At San Felipe, the fluoride concentration in potable water has been adjusted since January 1986. The fluoride concentration reported for Santiago corresponds to its historic average before potable water was fluoridated in April 1996. The clinical examinations reported in this study were carried out in May–October 1996 for Santiago, San Felipe and Rancagua and in March–July 1997 for La Serena and Iquique.

The estimation of sample size was based on previous determinations of DMFT and dmft values for 12- and 6-year-old children from Santiago (11) and aimed to identify at least a 20% difference between such values and those from fluoridated communities at 95% confidence level and statistical power of 90% (17). The appropriate number of subjects for each age group and socio-ecomomic status (SES) was 73. Thus, a sample size of about 80 children was established for each age group and SES. Selection of the schools for each community was made at random from the complete list of private schools that charge more than USD 150 monthly per child, and whose pupils are considered to have high socio-economic status (HSES), and from the complete list of publicly supported elementary schools where children of low socio-economic status (LSES) attend. This categorisation is based on Chilean Ministry of Social Development criteria (14).

The educational authorities of the selected schools notified parents that their children would receive a dental clinical examination related to a water fluoridation research study and they received a positive 94–100% response rate in the five communities. All of the 7-, 12-, and 15-year-old children who volunteered for the study, who were life-long residents in each community, and who were present at the selected schools during the survey, had an oral clinical examination that included caries experience and an enamel fluorosis assessment of fully erupted permanent teeth. Caries diagnoses and data recording were performed following WHO guidelines (18). Dental fluorosis was assessed and recorded for each fully erupted permanent tooth, using Dean's index (19) and Russell's criteria for differentiating fluoride and non-fluoride opacities (20). Prevalence of dental fluorosis was calculated without taking into account the "questionable" category, while CFI was determined using the standard criteria (WHO) and Dean's method (18, 19).

Caries experience was assessed by one of the authors (JV) and dental fluorosis diagnoses were made by another (SG). Both examiners were previously calibrated. Approximately 10% of the participating children were re-examined in a single-blind fashion to monitor diagnostic standards. Intra-examiner agreement was expressed using the kappa statistic (21).

The formula by Galagan et al. (22) was used for estimating daily water intake under current Chilean conditions. When converted from the original units (ounces per pound of body weight and temperature in degrees Fahrenheit) into the units com-

monly used in Chile (litres per kilogram of body weight and temperatures in degrees Celsius), the originally proposed (23) optimal concentration of fluoride in drinking water (mg/L F) was:

$$\text{Optimal F concentration (mg/L)} = 0.022/[0.0104+0.000724\times\text{AMMT (°C)}] \quad \text{[equation 1]};$$

where AMMT stands for annual mean maximum temperature in degrees Celsius.

This formula was proposed for US children who consumed about 44% of their fluid intake as liquid cow's milk, containing almost negligible amounts of fluoride (24). Therefore, equation 1 was further corrected to allow for the fact that under current Chilean conditions almost all of the children's fluid intake comes from tap water (25), resulting in equation 2:

$$\text{Optimal F concentration (mg/L)} = (0.022\times 0.56)/[0.0104+0.000724\times\text{AMMT (°C)}] \quad \text{[equation 2]}.$$

For the statistical analyses, Student's *t*-test and chi-square tests were used when appropriate to test differences between groups. For the main five city comparison a two-way ANOVA was performed on the dmft, DMFT and CFI data. The level of significance was set at $P<0.05$. The Excel 7.0 software package was used for data management and curve fitting analyses, while other statistical analyses were made with the Epi-Info 6.04 package.

Results

None of the kappa values fell below 0.91 for intra-examiner consistency in caries diagnoses or below 0.86 for fluorosis assessment. Maximum differences in the proportions of boys and girls were found in Rancagua in the 7-year-old group (43.9% girls and 56.1% boys) and San Felipe in the 12-year-old group (44.7% boys and 55.3% girls). For the entire sample this proportion was 48.8% boys and 51.2% girls. The number of children examined in each age group is shown in Tables 1–3. The proportions of children identified as medium-low (LSES) and as medium-high (HSES) socio-economic status were 52% and 48%, respectively, for each community and age group. Preliminary analyses of the data showed that there were no significant differences either in the prevalence of caries experience or in enamel fluorosis between boys and girls within each age group of each community. When comparing caries indices within each age group and community by SES, statistically significant differences (*t*-test; $0.03<P<0.05$) were found in a few cases, better conditions in children of HSES. No significant differences were found for the CFI across SES strata within each age group and community. To facilitate comparison among communities, data on caries experience and fluorosis prevalence and severity within each age group and community were pooled regardless of sex and SES.

Tables 1, 2 and 3 show caries experience data for the 7-, 12- and 15-year-old children, respectively. These tables also show the water fluoride concentration of the study communities and the percen-

Table 1. Caries experience in 7-year-old children

City	Water F conc. (mg/L)	*N*	dmft	Standard deviation	dmft=0 %
	Primary dentition				
Rancagua	0.07	158	3.67	3.54	25.8
Santiago	0.21	205	3.39	2.96	29.0
La Serena	0.55	162	2.38	2.80	41.1
San Felipe	0.93	129	1.72	2.33	55.2
Iquique	1.10	158	1.56	1.90	59.2
	Permanent dentition				
			DMFT		
Rancagua	0.07	158	0.52	1.15	
Santiago	0.21	205	0.26	0.67	
La Serena	0.55	162	0.21	0.61	
San Felipe	0.93	129	0.16	0.43	
Iquique	1.10	158	0.19	0.38	

Table 2. Caries experience in 12-year-old children

City	Water F conc. (mg/L)	*N*	DMFT	Standard deviation	DMFT=0 %
Rancagua	0.07	155	3.10	2.65	22.9
Santiago	0.21	197	2.42	2.74	33.6
La Serena	0.55	160	1.51	1.68	41.0
San Felipe	0.93	152	1.28	1.65	52.0
Iquique	1.10	157	1.32	1.23	41.9

Table 3. Caries experience in 15-year-old children

City	Water F conc. (mg/L)	*N*	DMFT	Standard deviation	DMFT=0 %
Rancagua	0.07	150	5.06	3.94	15.3
Santiago	0.21	203	4.12	3.29	18.8
La Serena	0.55	158	3.55	2.94	19.1
San Felipe	0.93	155	3.33	2.91	15.5
Iquique	1.10	132	2.60	2.65	31.8

tage of subjects who had caries-free primary and permanent dentition. It can be seen that the dmft index of 7-year-old children and the DMFT indices of 12- and 15-year-olds show a decreasing trend with the increase in the fluoride concentration in tap water ($P<0.001$, for the three age groups). The proportion of caries-free subjects increased with increasing fluoride concentration in water ($\chi^2>15.9$; $P<0.003$, for the three age groups). The DMFT indices of 12-year-old children residing in the three communities with 0.55, 0.93 and 1.1 mg/L F in water do not differ significantly ($P=0.36$), while the prevalence of dental fluorosis among 12-year-old children at La Serena was significantly lower than the corresponding values of San Felipe and Iquique ($\chi^2=36.3$; $P<0.001$).

Table 4 presents data on enamel fluorosis in the permanent dentition for all age groups according to the fluoride concentration in their tap water. The prevalence of dental fluorosis for each age group and community, expressed as a percentage, is shown in the last column of Table 4. These values were calculated without taking into account the "questionable" category of Dean's scoring system. The proportion of subjects presenting with enamel fluorosis increased within each age group with increasing fluoride concentration ($\chi^2>148.5$; $P<0.001$, for the three age groups). Dental fluorosis severity for each age group and community is presented in Table 4 as CFI values. These latter values are lowest in Rancagua (0.07 mg/L F in water) and highest in Iquique (1.1 mg/L F in water) ($P<0.001$).

When the 12-year-old children group is considered, the relationship between DMFT indices for the five communities under study and fluoride concentration in tap water is best fitted by the logarithmic function DMFT=1.26–0.69 ln (mg/L F); $r^2=0.98$, while the dependence of CFI on water fluoride concentration is linear: CFI=0.062+0.734 (mg/L F); $r^2=0.983$. The prevalence of enamel fluorosis is also linearly dependent on the fluoride concentration of drinking water: fluorosis prevalence (%)=−2.75+50.3 (mg/L F); $r^2=0.98$. The relations of mean DMFT indices and CFI values to fluoride water concentration are shown in Fig. 1. Visual inspection reveals that the range of fluoride concentration in drinking water corresponding to minimal values for DMFT together with minimal CFI values lies in the range 0.5–0.6 mg/L F. The same result is obtained if the prevalence of fluorosis (%) and the mean DMFT indices are plotted as a function of fluoride concentration of drinking water (graph not shown).

Table 4. Enamel fluorosis in permanent dentition

Age (years)	Water F conc. (mg/L)	*N*	CFI	Prevalence %
7	0.07	158	0.15	6.0
7	0.21	205	0.22	5.5
7	0.55	162	0.32	14.5
7	0.93	129	0.87	13.5
7	1.10	158	0.93	46.3
12	0.07	155	0.16	3.0
12	0.21	197	0.19	6.7
12	0.55	160	0.41	21.4
12	0.93	152	0.78	47.7
12	1.10	157	0.87	51.3
15	0.07	150	0.14	6.7
15	0.21	203	0.16	7.4
15	0.55	158	0.36	16.5
15	0.93	155	0.37	25.3
15	1.10	132	1.01	56.8

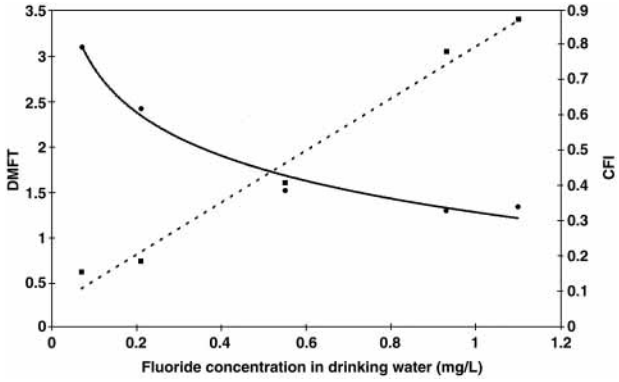

Fig. 1. Relation of average number of decayed, missing and filled teeth (DMFT) (●—) of 12-year-old children and CFI values (■ - - -) to fluoride content of drinking water.

Taking the average AMMT value (20°C) of the five communities under study, application of equation 2 (see previous section) yields an optimal fluoride concentration in potable water of 0.51 mg/L.

Discussion

Clinical data for 15- and 7-year-old children were collected in the present study in order to expand the very small database that is at present available in Chile. In addition, data recorded in the 7-year-old children were primarily intended for a companion case-control fluorosis study. Thus, our discussion will mainly consider results obtained among 12-year-old children since this is the age group most frequently used for comparative purposes, bearing in mind that results obtained in the 15-year-old subjects show a similar pattern.

The results obtained in this study are not unexpected from a qualitative standpoint. Numerous previous reports point out an inverse relationship between caries experience and fluoride concentration of community drinking water. Dean's classic studies were among the first to reach this conclusion, together with the finding that enamel fluorosis prevalence and severity increased with increasing fluoride concentration (19, 26, 27). As discussed by Ismail (28), data from these latter studies were used to recommend 1.0 mg/L fluoride as the optimal F concentration in drinking water. Results presented in Fig. 1 for 12-year-olds strongly suggest that, under current Chilean conditions, the optimal range of fluoride concentration in potable water should be 0.5–0.6 mg/L. We reached this conclusion because no significant differences were found for DMFT index in 12-year-old children residing in La Serena (F concentration=0.55 mg/L) compared with San Felipe and Iquique, with F water concentrations of 0.93 and 1.10 mg/L, respectively, while the corresponding CFI values are significantly higher for the two latter cities than the CFI value for La Serena. This data analysis does not follow exactly the same epidemiological criteria that Hodge (29) used when analysing previous data of Dean's studies (26, 27), establishing the so-called optimal water fluoride concentration for the mid-western states in the United States, since we used actual (not logarithmic) fluoride concentration on the x-axis of Fig. 1.

Hodge presented his graphical analysis using a logarithmic scale for fluoride concentrations, suggesting a ''threshold'' value for enamel fluorosis (29), but this procedure was criticised by several authors (28, 30). Thus, Fejerskov et al. (30) have shown that a dose-response relationship exists between either CFI values or fluorosis prevalence and the daily dose of fluoride from drinking water which, in turn, is proportional to the fluoride concentration in water. This dose-response relationship predicts that even at very low fluoride concentration in tap water a certain degree of fluorosis prevalence will be apparent (30). Results of the present study also show a linear relationship between CFI values of 12-year-old children and fluoride concentration in water (Fig. 1; r^2=0.983). It is interesting to note that even in Rancagua, a community with a water fluoride concentration value as low as 0.07 mg/L, CFI values of approximately 0.15 were recorded. Current conditions in Chile suggest that other sources of fluoride exposure in addition to water are available to pre-school children, e.g. fluoridated toothpastes, tea ingestion (25). Thus, a likely explanation for this situation might be that these other sources of available fluoride are the origin of the significant albeit low prevalence of enamel fluorosis in communities such as Rancagua or Santiago. Estimation of current total fluoride ingestion through urinary fluoride excretion among Chilean pre-schoolers has been carried out and will be published elsewhere.

There are several previous reports (31–35) showing that in hot climate areas the WHO recommendation of 1.5 mg/L as an upper limit for fluoride concentrations in drinking water (36) is not suitable, and upper limits of 0.6 mg/L fluoride were suggested for Senegal and Hong Kong (31, 34). The results obtained in the present study constitute an example of communities with a temperate climate where low caries indices together with an ''acceptable'' prevalence and severity of enamel fluorosis can be achieved with fluoride concentrations in tap water in the range 0.5–0.6 mg/L.

The communities under study in this work all have a temperate climate (AMMT in the range 18–22°C). Thus, the relatively high fluorosis prevalence found in cities with fluoride concentration in their drinking water in the range 0.5–1.1 mg/L might seem unusual. The use of powdered milk after weaning and extending during the first 8–10 years of life is a common dietary habit in Chile. Recent results obtained in a national epidemiological study show that approximately 90% of Chilean pre-school children ingest milk prepared from powdered products and tap water (25).

Galagan & Vermillion (23) proposed an equation to allow for the effect of temperature on the optimum fluoride levels in domestic waters of the United States (equation 1 of *Material and methods* section). Their formula was broadly used for estimating the daily water ingestion of young children, but this relationship was derived from a study of US children who consumed about 44% of their daily fluid intake as fresh cow's milk, which has a very low fluoride concentration (24). Assuming that under similar AMMT children drink approximately the same amount of fluid per body weight in all populations, Galagan & Vermillion's formula should be corrected when it is applied to the Chilean population, where fresh milk consumption accounts for only a minute amount of the total fluid intake, and almost all fluid consumption comes directly or indirectly from tap water. When equation 2 (see *Material and methods* section), which is the corrected form of equation 1 for Chilean condi-

tions, is applied to the communities under study a value of 0.51 mg/L fluoride is obtained as the optimal fluoride concentration in drinking water. This value is consistent with the conclusion obtained when analysing the results shown in Fig. 1. The present results are remarkably similar to those found in an oral epidemiological study carried out in Chile 37 years ago (10). Witkop and colleagues showed that for the five northern cities surveyed in 1960 the average DMFT index was as low as 1.81 for children aged 12–14 years, while the corresponding CFI average value was 0.58 (10). The average naturally occurring fluoride concentration in drinking water for these five communities was 0.45 mg/L (range: 0.26–0.59 mg/L). The authors attributed these findings to a higher water intake by Chilean children compared to US children, due to the use of powdered milk prepared with tap water (10). It seems unfortunate that Chilean health authorities appeared to be unaware of the results obtained by Witkop et al. (10) when they established 0.95 mg/L F as the target concentration of fluoride in drinking water for the Chilean Fifth Region in 1985.

The data obtained in the present study strongly suggest that under current conditions in Chile a concentration of 0.6 mg/L of fluoride in drinking water appears to be an appropriate upper limit. Additionally, our results show that no common guidelines on ''optimal'' water fluoride concentration can be followed without a previous thorough analysis of all other fluoride sources available to each community.

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