The Prevalence of Dental Caries and Fluorosis in Japanese Communities with Up to 1.4 ppm of Naturally Occurring Fluoride

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Abstract

Objectives: *The purpose of this study was to determine the relationship between the concentration of fluoride in drinking water and the prevalence of dental caries and fluorosis in seven Japanese communities with different concentrations of fluoride occurring naturally in the drinking water.* ***Methods:*** *A total of 1,060 10- to 12-year-old lifetime residents were examined to determine the prevalence of dental caries and fluorosis in communities with trace amounts to 1.4 ppm fluoride in the drinking water in 1987. Systemic fluorides (drops or tablets) have never been available in Japan and the market share of fluoride-containing toothpaste was 12 percent at the time of the study.* ***Results:*** *The prevalence of dental caries was inversely related and the prevalence of fluorosis was directly related to the concentration of fluoride in the drinking water. The mean DMFS in the communities with 0.8 to 1.4 ppm fluoride was 53.9 percent to 62.4 percent lower than that in communities with negligible amounts of fluoride. Multivariate analysis showed that water fluoride level was the strongest factor influencing DMFS scores. The prevalence of fluorosis ranged from 1.7 percent to 15.4 percent, and the increase in fluorosis with increasing fluoride exposure was limited entirely to the milder forms.* ***Conclusions:*** *The findings of this study conducted in 1987 in Japan parallel those reported by Dean et al. in the early 1940s. [J Public Health Dent 2000;60(3):147-53]*

Key Words: dental caries, dental fluorosis, epidemiology, fluoride, drinking water.

Water fluoridation, or the adjustment of the concentration of fluoride naturally occurring in a community's water supply to the best level for preventing dental caries, was first implemented in 1945 in the United States (1). This public health innovation was based on the results of epidemiologic surveys conducted by Dean and colleagues (2,3). Today, water fluoridation is practiced in some 40 countries (1) and the benefits continue to accrue (4). The associations between the prevalence of dental caries (5) or dental fluorosis (6-13) and the concentration of fluoride in drinking water have been confirmed by many studies since Dean's surveys.

Japan is a highly developed country in which municipal water supplies reach 96 percent of the population (14). Community water fluoridation is the most efficient and equitable method for preventing dental caries, and Japan clearly meets the requirements for its use as indicated by the WHO (15). Unfortunately, there is no community water fluoridation in Japan and the caries prevalence among Japanese children is higher than that of most other industrialized countries (16,17).

Three Japanese communities adjusted the concentration of fluoride in their drinking water at one time, but all later discontinued it. These communities and their start and end dates were: Yamashina from 1952 to 1965, Asahi from 1967 to 1971, and Okinawa from 1957 to 1972 (18). In addition to these three, a few communities in Japan have high fluoride concentrations occurring naturally (19). Several epidemiologic studies have been conducted in naturally fluoridated areas in Japan; however, most of them were not systematic surveys to determine the association between the concentration of fluoride in drinking water and the prevalence of dental caries and dental fluorosis (20-23). Thus, the optimal concentration of fluoride in drinking water for use in Japan remains unknown.

The purpose of this study was to determine the relation between the concentration of fluoride in drinking water and the prevalence of dental caries and dental fluorosis in communities with different concentrations of fluoride occurring naturally in the drinking water in Japan.

Methods

Selection of Study Communities. Each prefecture (state) government office maintains a list of the concentration of fluoride in the drinking water for each municipality. Eight prefecture offices in the Kita-kanto region were visited to locate communities with high concentrations of fluoride in the drinking water. The identified municipal offices were then visited to obtain the number of water supply systems, records indicating the concentration of fluoride, history of the water supply systems, population using each water supply, number of children and schools in each water supply service, and a map showing water supply services. Seven municipalities in five prefectures were selected for this study because their concentrations of fluoride were stable, their populations were large enough for the required sample size, and the heads of the municipalities and school principals agreed to participate in our survey.

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The municipalities were located between 36° 00′ and 38° 30′ north latitude and have an annual average air temperature that ranges from 44.6°F to 57.2°F. They were served by 26 water supply systems because some municipalities had two or more water supply systems. Twenty-two primary schools were located in the seven communities. All water supply systems had been established prior to 1976 and no changes had occurred in any of the systems through the time of the dental examinations for this study. As part of this study, water samples were obtained from all sites monthly for 12 consecutive months to observe any seasonal variations. The concentration of fluoride of the water samples was measured using a specific fluoride-sensitive electrode (Orion). The fluoride concentration in the samples was relatively constant, so the mode of these results was used as the fluoride level for each water supply system. The modes ranged from trace amounts to 1.4 ppm (Table 1).

Clinical Examinations. Clinical examinations for dental caries and dental fluorosis were made at the participating schools in October and November 1987. Subjects included all 959 fifth grade children (aged 10 to 11 years) and 1,008 sixth grade children (aged 11 to 12 years) in 22 primary schools. All schoolchildren were examined because these examinations were conducted as one of the scheduled examinations provided by the School Health Law. The concentration of fluoride in home drinking water for each child was confirmed using maps that showed the area of each water supply service and the student's address written on the questionnaire. All students' teeth were brushed by a dental hygienist prior to the clinical examination.

TABLE 1
Number of Subjects for Analysis According to Concentration of Fluoride in Drinking Water and Communities

Community	Subgroup*	F Conc.† (ppm)	Number of Subjects: 5th Grade	6th Grade	Total
A	A1	0.0	31	25	56
	A2	0.5	12	12	24
B	B1	0.0	6	4	10
	B2	1.4	6	4	10
C	C1	0.0	31	40	71
	C2	1.1	56	50	106
D	D1	0.0	42	44	86
	D2	0.3	46	62	108
	D3	0.3	25	25	50
	D4	0.5	11	8	19
	D5	0.5	15	16	31
E	E1	0.0	16	18	34
	E2	0.0	28	47	75
	E3	0.2	5	5	10
	E4	0.4	9	8	17
	E5	0.7	17	13	30
F	F1	0.0	50	30	80
	F2	0.8	11	17	28
	F3	0.8	11	7	18
	F4	0.8	13	17	30
G	G1	0.2	11	17	28
	G2	0.2	5	8	13
	G3	0.4	13	15	28
	G4	0.6	17	23	40
	G5	0.6	6	9	15
	G6	0.6	17	26	43
Total			510	550	1,060

*Water supply system.
†Mode of concentration of fluoride that was measured monthly for 12 consecutive months.

The World Health Organization's (WHO) criteria were used by three dentists to examine for dental caries using plane dental mirrors and explorers (24). Each examiner had two portable lights to maximize visibility by reducing shadows in the oral cavity. Caries experience was expressed using the DMFS index. The examiners were trained to diagnose caries by a dentist proficient in WHO's criteria during three practice sessions prior to the study. The examiners had no knowledge of the concentration of fluoride in the drinking water where they carried out the examinations. Radiographs were not taken.

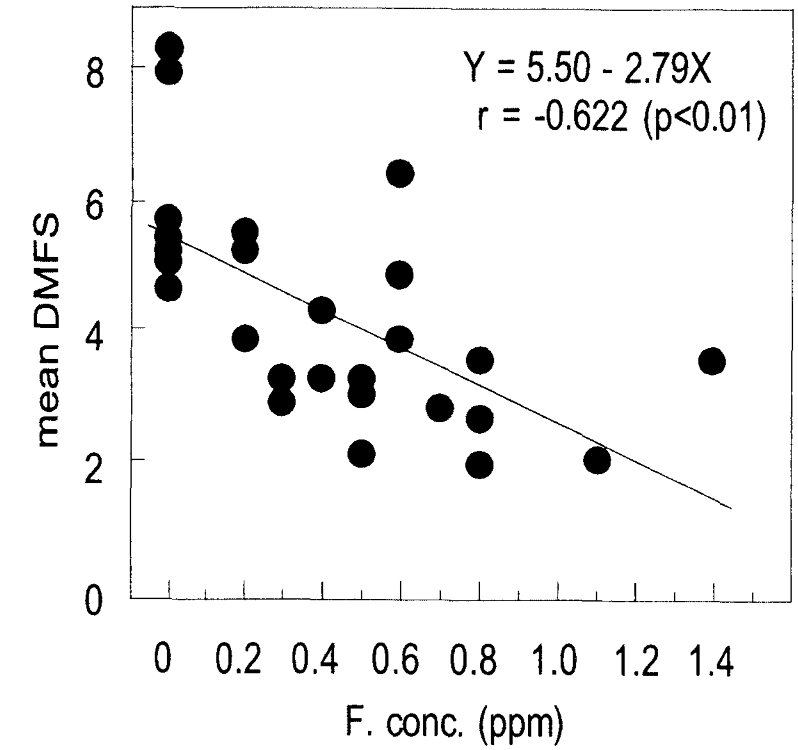
Two other dentists conducted examinations for dental fluorosis using Dean's classification (25). The examiners used criteria described by Russell (26) to distinguish between fluorosis and nonfluoride enamel opacities. They were trained in the use of Dean's classification in communities with different concentrations of fluoride prior to the survey and were thoroughly familiar with the diagnostic criteria. Examinations were carried out in good natural light on sunny days facing a window because artificial light often masks milder fluorosis. If necessary, teeth were wiped with cotton rolls prior to the examination. Buccal or labial surfaces of fully erupted permanent teeth were scored according to Dean's classification. Tooth surfaces that had restorations covering more than 25 percent were excluded. Each child was classified on the basis of the two teeth in the mouth showing the most advanced signs of fluorosis. The Community Fluorosis Index (CFI) also was calculated according to Dean's method (27).

To determine intra- and interexaminer reliability in diagnosing dental caries and dental fluorosis, repeated examinations were conducted in community D (0.5 ppm F) and in community C (1.1 ppm F). Levels of agreement between examiners were tested using the kappa statistic (28).

Questionnaire. A questionnaire designed to be completed by parents was sent home with each participating student. The questionnaire determined the child's residence history and lifetime sources of drinking water. Oral health practices at home including toothbrushing frequency, mother's attitude about the need to reduce her child's frequency of consumption of sweets, use of fluoride mouthrinse, and history of other topical fluoride applications were determined. The use of fluoride-containing toothpaste was not determined because the share was only 12 percent (29) and thus not commonly used by children at that time.

Statistical Analysis. Statistical analyses were carried out using a personal computer with StatView J4.5. The differences between groups were analyzed using a *T*-test and ANOVA with a multiple comparison test (Bonferroni/Dunn) (30). The associations between the prevalence of dental caries or fluorosis and the concentration of fluoride in the drinking water were assessed using simple linear regression analysis. Multiple linear regression was used to model the association between DMFS score and water fluoride concentration, school grade, toothbrushing frequency, and mother's attitude about the need for children to reduce the frequency of sweets. Toothbrushing frequency was categorized and coded as follows: less than once a day=0, once a day=1, twice a day=2, 3 times a day=3, 4 times or more a day=4. Mother's attitude about the need for children to reduce the frequency of sweets was categorized and coded as follows: indicating an intention to reduce the frequency of sweets=1, no intention to reduce the frequency of sweets=0.

FIGURE 1
Relation Between DMFS of 26 Subgroups and Concentration of Fluoride in Drinking Water



Results

Subjects for Analysis. Only children who had been using the municipal water supply and who were lifelong residents of each community were included in this study. If the home and school were located in different water supply areas, the difference in fluoride level could be no more than 0.2 ppm. Those children (n=886) who did not meet these requirements were excluded from the study. Another 18 children whose questionnaires were incomplete and three children who had received periodic applications of topical fluoride also were excluded. No children had used fluoride mouthrinses. As a result, a total of 510 fifth grade children and 550 sixth grade children were selected for the analysis. Participants were divided into 26 subgroups according to their water supply systems (Table 1).

Intra- and Interexaminer Reliability. Kappa values for diagnosing dental caries for all tooth surfaces ranged from 0.97 to 0.99 and from 0.90 to 0.96 for intraexaminer and interexaminer agreement, respectively. These values represented strengths of agreement being "almost perfect" according to Landis and Koch (28). Kappa values

TABLE 2
Caries Prevalence of Permanent Teeth According to Water Fluoride Level

F Conc. (ppm)	No. Subjects	DMFS	SE	% of Difference	ANOVA* Significance					
0.0–0.2	412	6.06	0.27	Control	‡	‡	†	‡	‡	
0.2–0.4	209	3.61	0.24	40.5						
0.4–0.6	119	3.21	0.25	47.0						
0.6–0.8	128	4.31	0.37	28.8						†
0.8–1.0	76	2.79	0.25	53.9						
1.0–1.4	116	2.28	0.29	62.4						

*ANOVA with a multiple comparison test (Bonferroni/Dunn).] Difference with significance: †P<.01, ‡P<.001.

for diagnosing dental fluorosis for all teeth were 0.78 and 0.78 for intraexaminer agreement, and 0.58 for interexaminer agreement. The respective strengths of agreement for these values were judged to be "substantial" and "moderate."

Caries Prevalence. Figure 1 shows the relationship between the mean DMFS of the 26 subgroups and the concentration of fluoride in the drinking water. The mean DMFS decreased with an increase in the level of fluoride in the drinking water. The negative correlation between the two variables was statistically significant (r=0.622, P<.01). The group with a fluoride level of less than 0.2 ppm was regarded as the control; the mean DMFS for this group was 6.06 (DS=1.49, MS=0.00 and FS=4.57) (Table 2). The mean DMFS of each of the other groups was significantly lower than that of the control group. The mean DMFS scores for the groups with a fluoride level of 0.8–1.0 ppm and 1.0–1.4 ppm were 54 percent and 62 percent lower than that of the control group, respectively. The mean DMFS of the group with a fluoride level of 1.0–1.4 ppm was significantly lower than that of the group with a fluoride level of 0.6–0.8 ppm.

Table 3 presents the results of multiple regression analysis for DMFS. In this table, the partial regression coefficient of –3.389 indicates that increasing water fluoride level (in ppm F) was significantly associated with lower DMFS scores, and that was the strongest factor influencing the DMFS score. Being female and in the sixth grade were associated with higher DMFS scores; increasing toothbrushing frequency was associated with lower DMFS score. Mother's attitude about the need for children to reduce the frequency of sweets was not associ-

TABLE 3
Linear Regression Model of DMFS (R^2=0.077)

Variables	Partial Regression Coefficient	SE	Standard Partial Regression Coefficient	F-value
F concentration	–3.389	0.418	–0.240	65.643
Sex (female)	1.156	0.321	0.109	13.003
Grade (6th)	0.968	0.314	0.091	9.503
Toothbrushing frequency	–0.450	0.194	–0.070	5.405
Constant	5.047	0.375	5.074	183.387

FIGURE 2
Relation Between Prevalence of Dental Fluorosis of 26 Subgroups and Concentration of Fluoride in Drinking Water

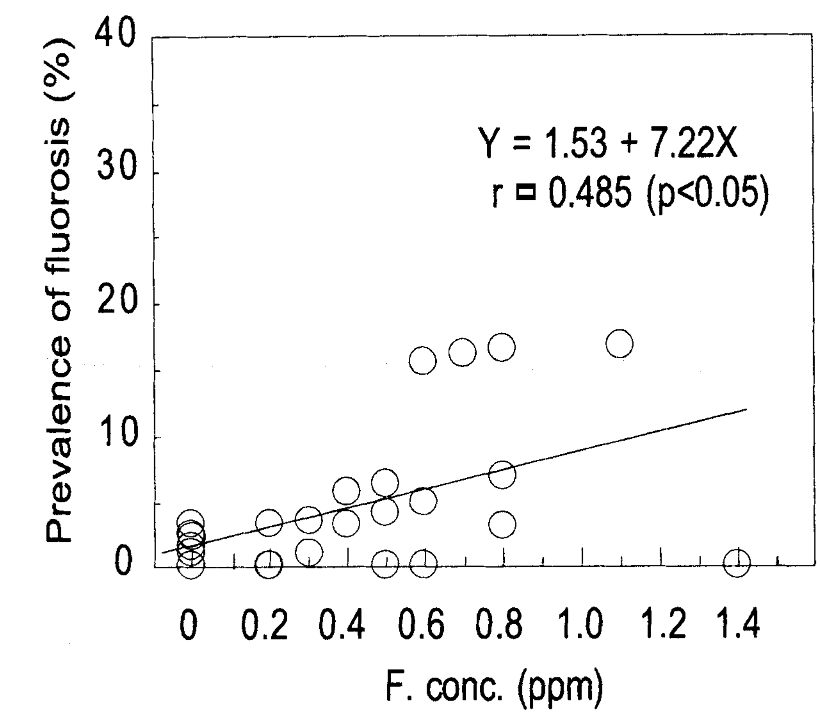


TABLE 4
Percent Distribution of Children with Dean's Classification and CFI According to Water Fluoride Level

F Conc. (ppm)	No. Subjects	Normal	Questionable	Very Mild	Mild	Moderate/ Severe	Fluorosis Prevalence (%)	CFI	SE
0.0–0.2	412	94.7	3.6	1.4	0.2	0	1.7	0.04	0.01
0.2–0.4	209	88.7	9.4	1.4	0.5	0	1.9	0.07	0.02
0.4–0.6	119	84.4	11.5	4.1	0.0	0	4.1	0.10	0.02
0.6–0.8	128	77.4	12.0	8.3	2.3	0	10.6	0.19	0.04
0.8–1.0	76	68.8	23.4	6.5	1.3	0	7.8	0.21	0.04
1.1–1.4	116	58.9	25.6	13.7	1.7	0	15.4	0.30	0.04

ated with DMFS score in this model. The multiple regression coefficient was 0.278 (P<.001).

Dental Fluorosis. Figure 2 presents the prevalence of dental fluorosis by the concentration of fluoride in the drinking water. As the concentration of fluoride increased from trace amounts to 1.4 ppm, the prevalence of fluorosis increased significantly (r=0.485, P<.05). Table 4 shows the percent distribution of children according to Dean's classification and the CFI by water fluoride concentration. The prevalence of fluorosis ranged from 1.7 percent in the 0.0–0.2 ppm fluoride group to 15.4 percent in the 1.1–1.4 ppm fluoride group. The CFI ranged from 0.04 to 0.30. Overall, the increase in fluorosis was limited entirely to its milder forms and neither moderate nor severe categories were detected among children in this study. Each fluoride group had a CFI below 0.4, indicating that the prevalence of fluorosis would not be considered a public health problem by Dean (27).

Discussion

In 1942 Dean and his colleagues in the United States demonstrated that the prevalence of dental caries decreased and the prevalence of dental fluorosis increased as the water fluoride level increased. They concluded that one part per million of fluoride in the drinking water was the optimal level that showed maximal caries protection without adverse dental fluorosis (3).

The results of our study conducted in 1987 show that the mean DMFT of the control group, which had less than 0.2 ppm of fluoride in its drinking water, was 4.14 per person (mean DMFS=6.06). This prevalence was slightly higher than the Japanese average of 3.59 in this same year (31). The caries prevalence decreased with an increase in the concentration of fluoride in the drinking water from trace amounts to 1.4 ppm (Figure 1), which is similar to results reported by Dean et al. (2,3). The present study also demonstrated that the prevalence of dental fluorosis was directly associated with the concentration of fluoride in the drinking water (Figure 2). However, fluorosis was limited entirely to its milder forms, and the CFI, which increased from 0.04 to 0.30 (Table 4) with increasing fluoride levels, suggests there is no public health concern about dental fluorosis in the areas we investigated. This finding and conclusion are in agreement with the findings reported by Dean et al. in communities with trace amounts to 1.3 ppm of fluoride in the drinking water (2, 3).

Several epidemiologic studies in Japan have been conducted in naturally or artificially fluoridated areas. In Kita-tsugaru, which is located in the north (40° 45′ north latitude) of the main island and has a mean annual temperature of 49°F, drinking water was supplied by 37 deep wells containing fluoride concentrations varying from negligible to 3.2 ppm. Tazawa et al. reported in 1979 that the mean DMFT for 6- to 11-year-old children who lived in areas with 0.90 to 1.06 ppm of fluoride was 50.0 percent to 64.3 percent lower than that of the control group with negligible concentrations of fluoride (22). In 1987 Iijima et al. showed that the prevalence of fluorosis for 6- to 9-year-old children who lived in the area with 0.95 ppm of fluoride was approximately 18 percent. They found no moderate or severe fluorosis and the CFI was 0.33 (23).

In Yamashina district, which is next to the old Japanese capital of Kyoto, water fluoridation was carried out from 1952 to 1965 (20). The fluoride concentration was maintained at 0.6 ppm. Minoguchi (20) conducted a survey in 1963 and found that the mean DMFT for 7- to 15-year-old schoolchildren was 38 percent lower than that of the control group. The prevalence of dental fluorosis was 8.0 percent and the CFI was 0.23 for children 10 years of age. Water fluoridation was initiated in Okinawa in 1957, but stopped in 1972 when Okinawa was returned to Japan by the United States. The Okinawa islands are the most southern part of Japan and the mean annual temperature is 72.3°F. Water fluoridation was carried out using a concentration of 0.7 ppm and 0.8 ppm of fluoride for summer and winter, respectively. In a 1977 study by Ueda (21), the mean DMFT in the fluoridated group of children aged 12–13 years was 3.64 per person and the difference between this value and the group with negligible fluoride was 50.2 percent. The prevalence of dental fluorosis for 9- to 13-year-old children in the fluoridated area was 7.9 percent and the CFI was 0.19. In 1967, water fluoridation also was implemented in Asahi, Mie prefecture, at 0.6 ppm of fluoride, but discontinued 3 years and 9 months later (32). The length of time that the community was fluoridated was too short to assess its effectiveness.

The percent reduction for caries in the present study was similar to the results of the other Japanese studies, with the exception of the Yamashina study. Water fluoridation in Yamashina was done as a pilot study. Although the optimal concentration of fluoride needed in the drinking water in Yamashina was estimated to be 0.76 ppm based on Minoguchi's formula (33), which was supposed to suit Japan according to Galagan's formula (34), the water was fluoridated at 0.6 ppm. In practice, this level of fluoride probably was not enough for caries prevention (20). For the same reason, the prevalence of dental fluorosis in the Yamashina study was lower than in the present or other studies. Overall, there was no public health concern about fluorosis in Yamashina, which is consistent with the results of our study.

The effectiveness of water fluoridation has been reported in many places since it was initiated in Grand Rapids, MI, in 1945. Naylor and Murray (35) reviewed 95 fluoridation studies done in 20 countries between 1945 and 1978 and found that the reduction in the prevalence of dental caries in permanent teeth was 50–60 percent. Seven years later, Newbrun (36) reviewed the US studies of fluoridation from 1979 to 1989. Differences in caries prevalence for permanent teeth ranged from 15 to 35 percent. Lewis and Banting (37) reviewed studies of 1984 or later and reported that effectiveness of fluoridation ranged from 8 to 56 percent, and that seven of the 13 comparisons had reductions of less than 20 percent. Although it appears that the effectiveness of water fluoridation has declined, it has not. Horowitz (1) surmises that two factors explain the apparent decline in the observed benefits from drinking fluoridated water—the diffusion effects of fluoridated drinking water, and the dilution effects from other sources of fluoride on measurement of the effectiveness of community water fluoridation. The reductions of caries prevalence in the 0.8–1.0 ppm and 1.0–1.4 ppm fluoride groups compared to controls in the present study were similar to the 50–60 percent reduction reported by Naylor and Murray (35) and higher than those reported by Newbrun (36), and Lewis and Banting (37). At the time of this study, there were no diffusion effects from water fluoridation and little dilution effects because neither water fluoridation nor dietary fluoride supplements were available. Further, the few naturally fluoridated drinking water supplies serve small towns with no industries, and the share of fluoride-containing toothpaste was only 12 percent at the time of this study. Other topical fluoride vehicles were used very little, thus Japanese children were exposed to few sources of fluoride (38). Therefore, the prevalence of dental fluorosis in the areas with both negligible concentrations of fluoride and 0.8 to 1.4 ppm of fluoride was still lower than found in recent studies (39,40) in North America.

It is well known that dental caries is a multifactorial disease. Multiple regression analysis was used to assess the strength of factors potentially influencing DMFS scores and to control for confounders in the fluoride caries relationship. This regression model explained only a small portion of the variance in caries prevalence. Dental caries also is a cumulative disease. Factors that might influence caries prevalence were obtained for this study using a cross-sectional design. This design and the factors themselves might be insufficient to explain enough of the variance in caries. The results, however, confirmed that water fluoride concentration was consistently and strongly associated with caries prevalence. Sex, school grade, and toothbrushing frequency were only moderately associated with DMFS scores, and mother's attitude about sweets was not associated with DMFS scores. The water fluoride level–caries prevalence association was stronger than any of the other covariates. Szpunar and Burt (41), Stockwell et al. (42), Riordan (43), and Heller et al. (44) have shown that the use of fluoridated water, the length of residency in a fluoridated area, and water fluoride concentration were inversely associated with the prevalence of dental caries in multivariate analyses.

The findings of this study conducted in 1987 in Japan corroborate earlier studies that the concentration of fluoride in drinking water is inversely associated with the prevalence of dental caries and that it is positively associated with the prevalence of dental fluorosis. The prevalence of dental caries in geographic areas with 0.8 to 1.4 ppm of fluoride was 50 percent to 60 percent less than that found in negligible fluoride areas. We also found that there was no public health concern about dental fluorosis. The results of this study will help determine the optimal concentration of fluoride in drinking water for use in Japan. In addition, studies about intake of fluoride from other sources such as fluoride-containing toothpaste, infant formulae, baby foods, and methods of food preparation are required to determine this concentration.

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