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Systemic effect of water fluoridation on dental caries prevalence

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Abstract – *Objectives:* The aim of this study was to evaluate the systemic effect of water fluoridation on dental caries prevalence and experience in Cheongju, South Korea, where water fluoridation ceased 7 years previously. *Methods:* A cross-sectional survey was employed at two schools where water fluoridation had ceased (WF-ceased area) and at two schools where the water had never been fluoridated (non-WF area). The schools in the non-WF area were of a similar population size to the schools in the WF-ceased area. Children of three age groups were examined in both areas: aged 6 (n = 505), 8 (n = 513), and 11 years (n = 467). The differences in the mean number of decayed or filled primary teeth (dft) and the mean number of decayed, missing, or filled permanent teeth (DMFT) scores between areas after adjusting for oral health behaviors and socio-demographic factors were analyzed by a Poisson regression model. *Results:* The regression model showed that the DMFT ratio for children aged 11 years in the WF-ceased area was 0.581 (95% CI 0.450–0.751). In contrast, the dft ratio for age 6 in the WF-ceased area was 1.158 (95% CI 1.004–1.335). Only the DMFT ratio for age 8 (0.924, 95% CI 0.625–1.368) was not significant. *Conclusions:* While 6-year-old children who had not ingested fluoridated water showed higher dft in the WF-ceased area than in the non-WF area, 11-year-old children in the WF-ceased area who had ingested fluoridated water for approximately 4 years after birth showed significantly lower DMFT than those in the non-WF area. This suggests that the systemic effect of fluoride intake through water fluoridation could be important for the prevention of dental caries.

Key words: cessation; dental caries; pre-eruptive effect; systemic effect; water fluoridation

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Dental caries is one of the most prevalent oral diseases (1) and can have negative impacts on quality of life, especially in children (2, 3). As Dean et al. (4) and McKay (5) reported that high fluoride exposure is related to high resistance to dental caries, many countries have endeavored to improve the oral health of their citizens by implementing public health campaigns such as promoting toothbrushing with fluoride toothpaste, rinsing with fluoride solution, and water fluoridation (6–9).

From the 1940s to the 1970s, it was widely believed that fluoride controlled caries via systemic effects, because the first caries-preventive effects were found when fluoride was ingested from 'systemic' sources (10). However, other authors have cast doubt on the importance of systemic effects of fluoride. Bibby et al. (11) demonstrated that an important mechanism of action of fluoride is post-eruptive. In a randomized, double-blind, and longitudinal study, Leverett et al. (12) failed to support the hypothesis that the observed low caries levels are attributable to prenatal fluoride exposure. Several recent reviews have questioned the significance of a systemic effect of fluoride, suggesting that the caries-preventive effect of fluoride was almost exclusively topical (13–15).

However, recently, Singh et al. (16) reported that fluoride exposure during crown completion was important for caries prevention regardless of exposure during enamel maturation and posteruption. Groeneveld et al. (17) also concluded that caries resistance for pit and fissure surfaces of molars and premolars increased if fluoride was taken from birth, although topical effects also play a major role in caries prevention. These findings support the notion that fluoride can prevent dental caries via a systemic mode of action.

These studies suggest that the systemic effects of fluoride may be dependent on the ingestion period. Systemic effects can be measured independently of topical effects in cases where fluoride was ingested when permanent teeth were pre-erupted and still covered by gingiva or bone and was ceased thereafter. There is still uncertainty regarding the significance of systemic effects of fluoride.

It is very difficult to isolate the systemic effects of fluoride without the topical effects caused by water fluoridation, because some topical effects from ingesting fluoridated water cannot be ignored. However, Korea recently ceased water fluoridation, creating a situation where water fluoridation was available to infants in some communities for approximately 4 years after birth, at which point the water was no longer fluoridated. The oral health of these children was then examined at 11 years of age, making it possible to isolate and investigate the systemic effects of water fluoridation.

Water fluoridation was first implemented in Jinhae, South Korea, in 1981 and increased until 2003, when approximately 13% of the national population was supplied with fluoridated water. However, by 2007, only 6.3% of the population was receiving fluorinated water. (18, 19). Antifluoridation activities resulted in the cessation of water fluoridation in regions such as Cheongju, where water fluoridation began in 1982 but ceased in late December, 2003, because of antifluoridation protest movements. This situation allows for what is termed 'opportunistic epidemiology' (20). The aim of this study was to use a cross-sectional survey to evaluate the systemic effects of water fluoridation on dental caries prevalence.

Materials and methods

The study was conducted by the Ministry of Health and Welfare (21) in 2011 to assess the effectiveness of community water fluoridation at improving dental health in school-aged children in South Korea. Written informed consent was obtained from the parents of all subjects.

Cheongju ceased water fluoridation in December 2003, and water fluoridation was never introduced to Seongnam. A cross-sectional survey was employed at two schools in Cheongju (WF-ceased area) and at two schools in Seongnam (non-WF area). Two schools in each area were selected using convenience sampling based on regional socioeconomic status. In previous studies, Seongnam was used as a control because Cheongju and Seongnam have a similar economic status and population size in the previous studies (22).

The appropriate sample size for this study was calculated using the power and sample size calculation program (23). In this program, an output was modeled to estimate the sample size sufficient to detect a difference in the mean number of decayed, missing, or filled permanent teeth (DMFT) between the WF-ceased area and the non-WF area. A type I error probability (α) associated with this test of the null hypothesis was 0.05, and the power (1-β) associated with correctly rejecting the null hypothesis was 0.8. Based on the 2010 Korea National Oral Health Survey (24), the standard deviation was set at 2.8 (the estimated standard deviation for age 11), and the effect size of water fluoridation on DMFT was set at 1.0. Finally, at least 123 subjects in each group were calculated to be needed in this study.

In the WF-ceased area, there were 7026 children in the 6-year-old age group, 7343 children in the 8-year-old age group, and 9382 children in the 11-year-old age group. In the non-WF area, there were 9275, 10 345, and 12 168 children in the 6-year-old, 8-year-old, and 11-year-old age groups, respectively. The intended numbers of schoolchildren in the target schools were 247 6-year-old children, 244 8-year-old children, and 277 11-year-old children in the WF-ceased area and 281 6-year-olds, 308 8-year-olds, and 257 11-year-olds in the non-WF area. The examined sample size was 238, 230, and 260 for children ages six, eight, and 11, respectively, in the WF-ceased area and 267, 283, and 207 for children ages six, eight, and 11, respectively, in the non-WF-ceased area. The examined sample included all subjects who were examined and consented to participate in this study (Fig. 1). No subjects declined consent. However, some students could not be examined because of absence from school on the day of examination. Information about entrance year and oral health behaviors was

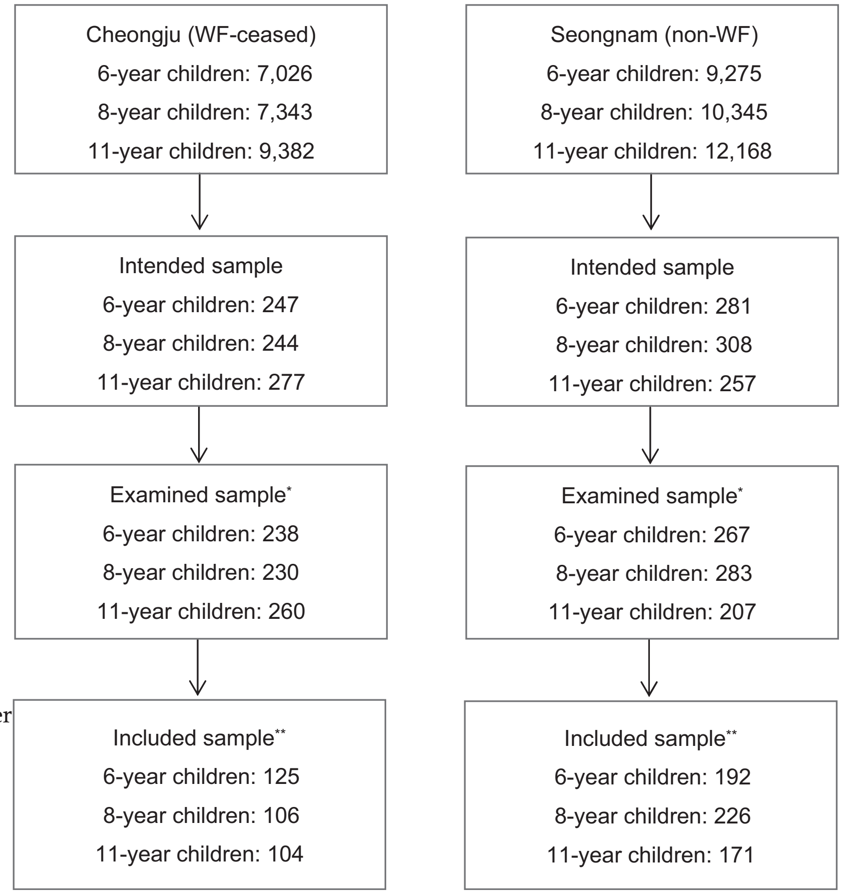

Fig. 1. CONSORT recruitment flowchart for study participants. *Number of subjects who were examined and gave consent to participate in the study. **Number of subjects included in the analysis. Subjects with missing data were excluded in both areas. In Cheongju, only those who had lived there since birth were included (to account for exposure to water fluoridation).

collected by questionnaire. Entrance year was examined by a question of 'Since when has your child lived here'. Cheongju ceased water fluoridation in December 2003, and this survey was performed in July 2011, so 11-year-old children who had lived there since birth only had access to fluoridated water for 4 years on average, while 8-year-old children who had lived there since birth (2002 or early 2003) had access to fluoridated water for about 1 year. Therefore, 'entrance year' was a very important question when excluding children who had not lived in Cheongju since birth. As this study used a multiple logistic regression, and some variables had missing values, the examined sample size was smaller than the included sample size (Fig. 1). There was a greater difference between the examined sample size and the included sample size in Cheongju than in Seongnam, because only those who had lived in Cheongju since birth were included in the study, while this exclusion was not necessary in Seongnam. In Seongnam, the included sample sizes were 125, 106, and 104 for children ages six, eight, and eleven, respectively, in the WF-ceased area and 192, 226, and 271 for children ages six, eight and eleven, respectively, in the non-WF-ceased area.

In the WF-ceased area, one school carried out a fluoride mouth-rinsing program (0.2% fluoride solution, once a week) from March 2008 to date of this study, while another school in the same area carried out the same program from March 2009 to date of this study. Generally, fluoride mouth-rinsing program was conducted in class once a week for 35–40 weeks per year (due to vacations and examinations). The fluoride mouth-rinsing program was not carried out in either school in the non-WF area.

All schools agreed to participate in a cross-sectional survey composed of an oral examination and a questionnaire. Oral examinations were performed on every child present that day.

Prior to the dental examination, parents provided written informed consent and completed questionnaires about the child's socio-demographic characteristics (i.e., child sex, age, monthly income of the family, and entrance year) and oral health behaviors. Parents were asked how many times their child ingested cariogenic foods or beverages daily (none, one, two or three, four or more, or unknown). Cariogenic foods and beverages were defined as those containing sugar which means only sucrose. Parents were also asked how many times their children brushed their teeth per day. We did not ask whether they use fluoride toothpaste or nonfluoride toothpaste as fluoridated toothpastes have about 97% toothpaste market share in Korea (25).

The survey was performed by four trained dentists, with kappa values for agreement ranging from 0.941 to 0.984 for caries experience at tooth level according to World Health Organization (WHO) criteria (26). This kappa value was determined based on annual calibration training held by an oral health epidemiologic committee for all dentists participating in the Korean National Oral Health Examination Survey. The state of dental caries in each child was examined using a dental mirror under natural light and fluorescent light in the classroom according to the standard proposed by the WHO (26).

The results of the oral examinations and questionnaires were analyzed using SPSS software version 19.0 (SPSS, Chicago, IL, USA). Significance was determined at $\alpha = 0.05$ for all tests. The difference between WF-ceased area and non-WF areas for each variable, including the mean number of decayed or filled primary teeth (dft) for age 6 and the mean number of decayed, missing, or filled permanent teeth (DMFT) for ages 8 and 11, was analyzed by a chi-square test for noncontinuous variables and an independent samples *t*-test for continuous variables. The differences in the dft and DMFT values between the areas after adjusting for oral health behaviors and socio-demographic factors were analyzed using a Poisson regression model because dft and DMFT scores were not normally distributed. There were no significant two-way interactions between variables, so that subgroup analysis was not performed in this study. All variables were included in the multivariable model.

Results

Socio-demographic factors by school age and fluoridation area were shown in Table 1. There were a total of 465 boys (50.3%) in the study sample. There were no significant differences in terms of sex or frequency of consumption of cariogenic beverages between the WF-ceased area and non-WF area for all age groups. However, significant differences were observed between the areas in terms of frequency of toothbrushing for all age groups. Monthly income of the family was significantly different according to area for 8-year-olds and 11-year-olds, and frequency of consumption of cariogenic food was significantly different according to area for 6-year-olds.

The mean number of decayed or filled primary teeth (dft) and the mean number of decayed, missing, or filled permanent teeth (DMFT) in the WF-ceased and non-WF areas are shown in Table 2. The proportion of 6-year-olds who had decayed or filled primary teeth (df rate) was 69.6% in the WF-ceased area and 62.5% in the non-WF area. The proportion of 8-year-olds who had decayed, missing, or filled permanent teeth (DMF rate) was 21.7% in the WF-ceased area and 19.9% in the non-WF area, and the DMF rate for 11-year-olds was 40.4% in WF-ceased area and 52.0% in non-WF area. Although dft for 6-year-olds in the WF-ceased area was higher than in the non-WF area, it was not a statistically significant difference. DMFT for 8-year-olds in the WF-ceased area was not significantly lower than in the non-WF area, either. However, there were significant differences between areas in the mean number of decayed, missing, or filled permanent teeth surfaces (DMFS), DMFT, and mean number of filled permanent teeth (FT) for 11-year-olds.

Table 3 showed the effect of the cessation of WF on caries experience based on the Poisson regression model adjusted for sex, monthly family income, number of cariogenic foods per day, number of cariogenic beverages per day, and number of toothbrushings per day. The regression model showed that the DMFT ratio of the mean DMFT score for 11-year-olds in the WF-ceased area versus non-WF area was 0.581 (95% CI 0.450–0.751). Conversely, the dft ratio for 6-year-olds in the WF-ceased area versus non-WF area was 1.158 (95% CI 1.004–1.335). This showed that the adjusted mean DMFT in the WF-ceased area was 16% greater for 6-year-olds and 42% lower for 11-year-olds than in the non-WF area. The DMFT ratio for 8-year-olds (0.924, 95% CI 0.625–1.368) was not statistically significant.

Discussion

This cross-sectional study assessed the effects of cessation of water fluoridation. The study was unique in that 11-year-old children in the WF-ceased area had ingested fluoridated water for approximately 4 years after birth, after which fluoridated water was no longer available. As a result, the systemic effect of water fluoridation could be

Table 1. Comparison of socio-demographic factors and oral health behavior of children in the WF-ceased and non-WF areas

Variable	6-year-old children			8-year-old children			11-year-old children		
	WF-ceased (n = 125)	Non-WF (n = 192)	P-value[a]	WF-ceased (n = 106)	Non-WF (n = 226)	P-value[a]	WF-ceased (n = 104)	Non-WF (n = 171)	P-value[a]
Sex, n (%)									
Boy	64 (51.2)	93 (48.4)	0.631	57 (53.8)	114 (50.4)	0.571	54 (51.9)	83 (48.5)	0.586
Girl	61 (48.8)	99 (51.6)		49 (46.2)	112 (49.6)		50 (48.1)	88 (51.5)	
Monthly family income, n (%)									
Low	49 (39.2)	98 (51.0)	0.072	26 (24.5)	114 (50.4)	<0.001	27 (26.0)	97 (56.7)	<0.001
Middle	65 (52.0)	85 (44.3)		59 (55.7)	93 (41.2)		55 (52.9)	56 (32.7)	
High	11 (8.8)	9 (4.7)		21 (19.8)	19 (8.4)		22 (21.2)	18 (10.5)	
Frequency of cariogenic food intake per day, n (%)									
Once or none	74 (59.2)	88 (45.8)	0.020	58 (54.7)	123 (54.4)	0.960	63 (60.6)	89 (52.0)	0.168
Two or more	51 (40.8)	104 (54.2)		48 (45.3)	103 (45.6)		41 (39.4)	82 (48.0)	
Frequency of cariogenic beverage intake per day, n (%)									
None	68 (54.4)	86 (44.8)	0.094	54 (50.9)	103 (45.6)	0.361	34 (32.7)	67 (39.2)	0.279
One or more	57 (45.6)	106 (55.2)		52 (49.1)	123 (54.4)		70 (67.3)	104 (60.8)	
Number of toothbrushings per day, n (%)									
Once or none	6 (4.8)	17 (8.9)	<0.001	5 (4.7)	24 (10.6)	<0.001	9 (8.7)	20 (11.7)	<0.001
Two	51 (40.8)	133 (69.3)		59 (55.7)	160 (70.8)		40 (38.5)	123 (71.9)	
Three or more	68 (54.4)	42 (21.9)		42 (39.6)	42 (18.6)		55 (52.9)	28 (16.4)	

[a]Analyzed by a chi-square test.

distinguished from the topical effect of water fluoridation. Orally ingested fluoride can act topically on teeth by increasing the concentration of fluoride in saliva and plasma. Pre-eruptive teeth that are covered by gingiva or bone and not exposed to the oral environment are not influenced by the topical action of ingested fluoride. In this study, 11-year-old children in the WF-ceased area had ingested fluoridated water from birth to approximately 4 years of age, at which point water fluoridation ceased. As their permanent teeth had been in a pre-eruptive state during this time, their teeth were not exposed to a fluoridated oral environment. Therefore, their teeth were not influenced by the topical action of orally ingested fluoride. Moreover, the 8-year-old children had ingested fluoridated water for 1 year after birth on average, because they were born 2002 to 2003 February. A Poisson regression model was used to adjust for the confounding effects of sex, monthly family income, frequency of consumption of cariogenic foods and beverages, and number of toothbrushings per day.

Moorrees et al. (27) reported that, on average, permanent molars completed crown formation in the first 27 months after birth for girls and 26 months for boys. Lyaruu et al. (28) suggested that administration of fluoride in high doses during the pre-eruptive stages of enamel formation leads to the incorporation of fluoride into the dentin and enamel. Therefore, even 4 years of fluoridated water after birth could have had a significant preventive effect on dental caries in the 11-year-old children in the WF-ceased area. This is similar to a previous study where the resistance of teeth to acid dissolution increased due to fluoride intake from fluoridated water until 4 years of age during the development of permanent teeth (29). However, some previous studies reported that posteruptive fluoride had a major role in caries prevention compared with pre-eruptive fluoride. Bibby et al. (11) compared the efficacy of coated fluoride pills that were swallowed immediately with fluoride lozenges intended to be sucked and then swallowed in five- to 14-year-old children. The results showed that, in the group using lozenges that were sucked and then swallowed, fewer carious lesions developed compared with the group using pills that were swallowed. In a study by Leverett et al. (12), pregnant women were encouraged to take 1-mg fluoride tablets daily during the last 6 months of pregnancy, whereas a control group received a placebo. For ethical reasons, postnatal supplements were distributed to both the intervention and placebo group. Leverett et al. (12) assessed caries experience when the children were three to 5 years old, and there were no statistically significant differences between groups. Although the results of the present study support the concept of systemic effects of water fluoridation, it remains a controversial issue to be elucidated in future studies.

In the present study, the mean dft of 6-year-old children was 16% higher in the WF-ceased area than

Table 2. Comparison of dental caries status between the WF-ceased and non-WF areas

Variable	WF-ceased (*N* = 335) Mean ± SD	Non-WF (*N* = 589) Mean ± SD	*P*-value[a]
6-year-old children	*N* = 125	*N* = 192	
df rate (%)	69.6	62.5	0.228
dfs	7.15 ± 9.44	7.30 ± 9.72	0.896
dft	3.04 ± 3.15	2.66 ± 2.98	0.281
dt	0.77 ± 1.50	0.56 ± 1.29	0.196
ft	2.27 ± 2.54	2.10 ± 2.52	0.552
8-year-old children	*N* = 106	*N* = 226	
DMF rate (%)	21.7	19.9	0.771
DMFS	0.58 ± 1.33	0.65 ± 1.63	0.736
DMFT	0.40 ± 0.85	0.42 ± 0.99	0.860
DT	0.01 ± 0.10	0.02 ± 0.17	0.486
MT	0.00 ± 0.00	0.00 ± 0.00	–
FT	0.39 ± 0.85	0.39 ± 0.98	0.949
11-year-old children	*N* = 104	*N* = 171	
DMF rate (%)	40.4	52.0	0.063
DMFS	1.54 ± 2.73	2.87 ± 5.04	0.014
DMFT	0.94 ± 1.50	1.63 ± 2.34	0.008
DT	0.05 ± 0.40	0.21 ± 1.28	0.210
MT	0.00 ± 0.00	0.00 ± 0.00	–
FT	0.89 ± 1.47	1.42 ± 2.06	0.024

df rate, the proportion of those who had decayed or filled primary teeth; dfs, mean number of decayed or filled primary teeth surfaces; dft, mean number of decayed or filled primary teeth; dt, mean number of decayed primary teeth; ft, mean number of filled primary teeth; DMF rate, the proportion of those who had decayed, missing, or filled permanent teeth; DMFS, mean number of decayed, missing, or filled permanent teeth surfaces; DMFT, mean number of decayed, missing, or filled permanent teeth; DT, mean number of decayed permanent teeth; MT, mean number of missing permanent teeth; FT, mean number of filled permanent teeth.

[a]Analyzed by a chi-square test for df and DMF rates and independent samples t-test for other variables.

in the non-WF area. This suggests that the oral health of children in the non-WF area might be better than in the WF-ceased area. However, there was no significant difference in the mean DMFT of 8-year-old children between the WF-ceased and non-WF areas. This could be explained by the fact that the 8-year-old children were exposed to fluoride for approximately 1 year during tooth development. This reversal of caries experience between areas suggests that fluoride intake from water improved poor oral health in the WF-ceased compared with non-WF area, but only if exposure to fluoridated water occurred for longer than the first year after birth.

This finding corresponds to results by Lemke et al. (30) and Kunzel (31) which state that caries prevalence becomes higher after cessation of water fluoridation compared with before the cessation. These previous studies were conducted when people generally used toothpaste without fluoride, and thus, these previous studies had higher DMFT scores than the present study.

Since the late 1990s, however, several studies have shown that the prevalence of dental caries is maintained or decreases after cessation of water fluoridation (20, 32–34). Kunzel et al. (33) reported that there was a significant caries decrease down to a DMFT score of 2.0 between 1987 and 1995 after the cessation of water fluoridation in Chemnitz, Germany. Another study by Kunzel et al. (34) in Zittau and Spremberg, Germany, in 1996 found that caries prevalence continued to decline even after cessation of water fluoridation (CWF). Burt et al. (20) did not observe any change in caries prevalence from 1990 to 1995 after an 11-month unintentional break in fluoridation in Durham, North Carolina, US. Maupome et al. (32) studied the difference in caries prevalence between 1993 and 1996 after CWF in British Columbia, Canada, and did not find a significant difference in caries prevalence between the fluoridation cessation and fluoridated communities. All of these studies suggest that oral health behaviors have improved and that the widespread use of fluoride in addition to water fluoridation contributes to the decline in caries prevalence.

However, these studies had several limitations. First, most studies were performed during the few years immediately after cessation of water fluoridation. The study by Burt et al. (20) included only an 11-month break in fluoridation, the study by Maupome et al. (32) examined differences in caries prevalence after only 3 years of CWF, and the studies by Kunzel et al. (33, 34) examined changes

Table 3. Multivariable associations between the cessation of water fluoridation and the mean number of decayed or filled primary teeth (dft) or the mean number of decayed, missing, or filled permanent teeth (DMFT) by Poisson regression model

	6-year dft		8-year DMFT		11-year DMFT	
Explanatory variable	dft ratio[a] (95% CI)	*P*-value[c]	DMFT ratio[b] (95% CI)	*P*-value[c]	DMFT ratio[b] (95% CI)	*P*-value[c]
Area						
WF-ceased	1.158 (1.004–1.335)	0.044	0.924 (0.625–1.368)	0.694	0.581 (0.450–0.751)	<0.001
Non-WF	1.0	–	1.0	–	1.0	–

CI, confidence interval.
[a]dft ratio is presented as the mean dft score for age 6.
[b]DMFT ratio is presented as the mean DMFT score for ages 8 and 11.
[c]Adjusted for sex, monthly family income, frequency of cariogenic foods intake per day, frequency of cariogenic beverages intake per day, and number of toothbrushings per day.

after only 4 years of CWF. Therefore, the previous studies could not evaluate the systemic effect of water fluoridation due to relatively short periods of CWF. Also, these studies had historical control groups for comparison, with the exception of one study by Kunzel et al. (33). Moreover, they were concentrated in European and North American regions, which make extrapolation difficult because European and North American countries have a low prevalence of dental caries. Korean caries prevalence has decreased since 2006, and the mean DMFT score in 2010 was 2.1 for 12-year-old children (35). This caries index was higher than other European or North American countries. The present study was able to assess the systemic effect of water fluoridation because the oral health of 11-year-old children was examined 7 years after cessation of WF. Hence, the results of the present study support statements by Groeneveld et al. (17) and Singh et al. (16) that pre-eruptive fluoride could be important for caries prevention. Another study by Singh et al. (36) concluded that pre-eruption exposure was important for preventive effects on caries, as posteruption exposure alone could not significantly lower caries levels.

The first limitation of this study is that the fluoride mouth-rinsing (FMR) program had been carried out for 2 or 3 years prior to this survey in the WF-ceased area. Thus, the topical effect from the FMR program could be mixed with the systemic effect of water fluoridation. The caries-preventive fraction of the FMR program was reported to be approximately 20–50% (37–40). However, the effect of the FMR program seems to be much less than the systemic effect of water fluoridation in the present study, for two reasons. First, the DMFT ratio for 8-year-olds was only 0.924 (Table 1) even though both 8-year-olds and 11-year-olds were exposed to the FMR program. The second reason that the effect of the FMR program in the WF-ceased area may be lower than expected is that the fluoride mouth-rinsing was only performed once a week and was occasionally suspended due to school vacations. In addition, the FMR program was not conducted well in Korea because many children and teachers were not compliant with the program (41).

The second limitation of this study is that it has a cross-sectional design, preventing the determination of cause and effect. In addition, there might have been a selection bias, as the convenience sampling method was used in this study. Hence, we analyzed data without sampling weights. However, the authors tried to select schools with similar economic levels and adjusted monthly family income and other confounders to reduce potential bias. Thirdly, as this study was conducted in only one part of Korea, the external validity of this result may be limited. Further prospective and well-designed studies on the systemic effects of water fluoridation are needed.

Water fluoridation is recognized as one of ten great public health achievements of the 20th century by the United States Centers for Disease Control and Prevention (42). In conclusion, this study suggests that the systemic effect of fluoride intake through water fluoridation could be important for the prevention of dental caries.

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