# Dental Benefits of Limited Exposure to Fluoridated Water in Childhood

B. A. BURT, S. A. EKLUND, and W. J. LOESCHE[1]

*Program in Dental Public Health, School of Public Health, and [1] Department of Oral Biology, School of Dentistry, The University of Michigan, Ann Arbor, Michigan 48109-2029*

*The effect of limited exposure to fluoridated water in childhood is of potential importance in highly-mobile modern society, but the subject has not been well-studied. This longitudinal study assessed caries experience and* S. mutans *proportions from fissure plaque in schoolchildren who lived for at least the three years of the study in a non-fluoridated community (0.2 mg/L). Residence histories permitted division of the cohort into those who had lived all their lives in non-fluoridated communities, and those who had lived for some time previously in a fluoridated community. The children were aged 6-7 years at the beginning of the three-year study. Children with previous residence in the fluoridated communities developed 26.8% less caries in their permanent teeth during the study than did the children who had lived in non-fluoridated communities all their lives ($p = 0.04$), and had 29.8% less caries after three years ($p = 0.02$). Differences between the groups in* S. mutans *proportions from fissure plaque, sampled at six-monthly intervals throughout the study, could not be demonstrated. The dental benefits observed could not be attributed to socio-economic differences between the groups. Despite evidence that the benefits of limited ingestion of fluoridated water are topical in nature, the fact that many of the affected teeth in this study were unerupted at the time of the fluoride exposure means that pre-eruptive benefits cannot be ruled out.*

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## Introduction.

The fluoride concentration in the drinking water is often a major determinant of whether a community is chosen for the epidemiological study of dental caries in humans. In particular, clinical trials of caries-preventive agents are specifically located in fluoridated or non-fluoridated communities, depending on the purposes of the trials (Heifetz *et al.*, 1982; Driscoll *et al.*, 1982). The obvious rationale is that ingestion of fluoridated water will influence results obtained.

Many such studies, however, have assumed an "either/or" approach to ingestion of fluoridated water; they have implicitly assumed that residents of fluoridated communities have been ingesting fluoridated water all their lives, and that residents of non-fluoridated communities have never consumed such water. This assumption discounts the high degree of mobility found in the United States, where many families move in and out of fluoridated areas periodically. The resulting limited and episodic exposure to fluoridated water at different times of life is likely to be an important factor in the epidemiology of dental caries, but its effects on subsequent caries development are poorly understood.

The question that arises may be stated this way: If a child receives fluoridated water for a limited period—say, from two to six years—and then moves to an area where the water is not fluoridated, what is the extent of the benefits received? Driscoll *et al.* (1981) showed that caries-preventive effects were measurable four years after the end of a six-year program of supervised administration of fluoride tablets, during which children chewed and swallowed either one or two tablets containing 1.0 mg F each school day. Benefits were ascribed to both systemic and topical effects of the fluoride. If the ingestion of fluoride tablets in this way mimics the action of fluoridated water, the study suggests that limited exposure to fluoridated water may produce similar retained benefits.

The purpose of this study was to examine the dental benefits resulting from limited exposure to optimally fluoridated water in a group of schoolchildren, and to match the caries incidence with proportions of *Streptococcus mutans* isolated from fissure plaque. The participants had been living in a non-fluoridated area (0.2 ppm) for at least the three years of the study, though some had lived previously in optimally fluoridated areas.

## Materials and methods.

The study was conducted in Coldwater, a town of some 8000 people in lower south-central Michigan where the water supply contains a low fluoride concentration (0.2 ppm). Baseline examinations on 495 children in Grades 1 and 2 (aged 6 and 7 years) were conducted in April-May, 1979.

All permanent and primary teeth were examined for dental caries at baseline, and then annually for three years. The same examiner carried out all examinations. Caries was recorded by the Decayed-Missing-Filled Surfaces index in permanent teeth and by the decayed-filled surfaces index in primary teeth. Caries was diagnosed only when softness or a definite break in the continuity of the enamel surface could be detected with an explorer. Plaque samples, for microbiological assay, were taken from the occlusal surfaces of the lower first permanent molars at six-month intervals. Both sound and carious surfaces were sampled; restored surfaces were not. The numbers of surfaces sampled therefore dropped from one examination cycle to the next as carious teeth were restored.

Examiner consistency was assessed by randomly re-examining 30 children over two examination cycles. Diagnoses were identical on 25 children (83.0%), and the mean DMF score from the re-examinations was 90.3% of that from the initial examinations.

Plaque samples were collected with a no. 26 needle point, broken off from its hub and held in a pair of artery forceps. The needle point was then dropped into a labeled test tube of reduced transport fluid (Syed and Loesche, 1972) for transport back to the laboratory. On each morning during the dental examinations, about 40-50 participants were examined. The resulting 80-100 plaque samples were delivered to the laboratory by early afternoon. After dispersion, serial dilution, and plating, the plaque samples were ready for anaerobic incubation within two to three hours of their arrival in the laboratory. The procedures for preparing the plaque samples and counting the bacterial colonies have been described previously in detail (Loesche and Straffon, 1979; Burt *et al.*, 1983; Loesche *et al.*, 1984; Burt et al., 1985).

Prior to the two-year examinations, a questionnaire on residence history, use of fluoride supplements and topical fluorides, toothbrushing habits, and antibiotic history was distributed to the parents of the 411 children then remaining in the study. Questionnaires were returned from 390, a 94% response rate.

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**TABLE 1**
MEAN DMFS VALUES (PERMANENT TEETH) FOR 319 CHILDREN, AGED 6-7 AT BASELINE, BY PREVIOUS EXPOSURE TO FLUORIDATED WATER (COLDWATER, MI, 1979-82)

| | No F Water (n = 251) | Some F Water (n = 68) | Percent difference | p* |
|---|---|---|---|---|
| Baseline | 0.59 | 0.35 | 40.7 | 0.16 |
| Cumulative incidence: | | | | |
| 12 months | 0.75 | 0.57 | 24.0 | 0.29 |
| 24 months | 1.63 | 1.40 | 14.1 | 0.35 |
| 36 months | 2.35 | 1.72 | 26.8 | 0.04 |
| Final DMFS values** | 2.95 | 2.07 | 29.8 | 0.02 |

*Two-tailed, independent sample *t* test.
**Children aged 9-10 at completion of study.

**TABLE 2**
MEAN dfs VALUES (PRIMARY TEETH) FOR 319 CHILDREN, AGED 6-7 AT BASELINE, BY PREVIOUS EXPOSURE TO FLUORIDATED WATER (COLDWATER, MI, 1979-82)

| | No F Water (n = 251) | Some F Water (n = 68) | Percent difference | p* |
|---|---|---|---|---|
| Baseline | 4.24 | 3.47 | 18.2 | 0.34 |
| 12 months | 4.47 | 3.62 | 19.0 | 0.27 |
| 24 months | 4.13 | 3.35 | 18.9 | 0.26 |
| 36 months** | 2.98 | 2.41 | 19.1 | 0.31 |

*Two-tailed, independent sample *t* test.
**Children aged 9-10 at completion of study.

**TABLE 3**
PROPORTIONS OF *STREPTOCOCCUS MUTANS* IN OCCLUSAL PLAQUE FROM LOWER FIRST MOLARS IN 319 SCHOOLCHILDREN, AGED 6-7 AT BASELINE, BY PREVIOUS EXPOSURE TO FLUORIDATED WATER

| | No F Water (n = 174-218)* | Some F Water (n = 50-62)* |
|---|---|---|
| *Left side* | | |
| Baseline | 12.4 | 12.6** |
| 6 months | 13.2 | 15.1 |
| 12 months | 13.2 | 13.5 |
| 18 months | 13.3 | 9.5 |
| 24 months | 15.7 | 14.7 |
| 30 months | 13.5 | 16.7 |
| 36 months | 12.3 | 13.0 |
| *Right side* | | |
| Baseline | 14.8 | 11.9 |
| 6 months | 16.6 | 13.3 |
| 12 months | 14.5 | 11.7 |
| 18 months | 15.4 | 11.1 |
| 24 months | 17.0 | 16.3 |
| 30 months | 15.8 | 13.7 |
| 36 months | 12.4 | 11.5 |

*Teeth sampled for plaque diminished as fillings were placed throughout the study.
**Two-tailed, independent sample *t* test. None of the differences achieved the 0.05 level of statistical significance.

**TABLE 4**
TWO INDICATORS OF SOCIO-ECONOMIC STATUS RELATED TO PREVIOUS EXPOSURE TO FLUORIDATED WATER*

| | No F Water (n = 290) | Some F Water (n = 86) | p** |
|---|---|---|---|
| Brush 2× or more daily | 38.0% | 47.7% | 0.11 |
| Have taken F supplements | 20.7% | 33.7% | 0.01 |

*n = 376, children with data on all three variables.
**One-way ANOVA.

Twelve residence histories were too vague to be used, and not all questions were answered by all respondents, so results in the Tables are based on various numbers of children. The 1975 Fluoridation Census (US Public Health Service, 1977) was used to determine the fluoridation status of the communities given in the residence history.

## Results.

Although all children had resided in the Coldwater schools district for the three years of the study, parents reported that only 66% of the children had lived in the area for their whole lives. Another 13% were reported to have lived in other non-fluoridated areas for some period, meaning that 79% of this cohort had lived their whole lives in non-fluoridated areas. The remaining 21% (children were aged 8-9 at the time the questionnaires were completed) reported that they had lived in fluoridated areas for periods ranging from less than one year to six years at various times of their lives. This group (n = 86) was not big enough to permit division into groups of varied exposure, so those who reported any residence of six months or more in fluoridated areas were grouped together for purposes of this analysis. Data presented therefore compare children with no history of fluoridated water against those who reported some, though varied, exposure.

Table 1 shows the caries experience in permanent teeth for the 319 children for whom information on all variables was available. The difference between the groups at baseline was 40.7%, and this relative difference became smaller over the next three years. The differences between the two groups in terms of both the three-year caries increment and the DMFS scores at the end of the study are statistically significant. Table 2 shows the caries experience in primary teeth at each examination cycle. While no differences at any one examination cycle were statistically significant, all favored the group which had received some fluoride exposure and thus are consistent with the results in Table 1.

Table 3 shows the proportions of *S. mutans* in plaque from left and right first molars according to fluoridation history. Patterns here are not consistent. On the right side, the proportions of *S. mutans* were higher in all seven examinations among the non-fluoridated group. But the pattern was more varied on the left side, where the *S. mutans* proportions were higher, in all but two readings, among those children with some exposure to fluoridated water. P-values in this Table do not approach the 0.05 level, even when there is a two-fold difference in proportions, primarily because the variances in microbiological data are so large.

It could be hypothesized that socio-economic (SES) differences might account for the differences seen in Tables 1 and 2, if children with a fluoride history were in some way different from those who had lived in Coldwater all their lives. Two variables likely to be correlated with SES were collected in the questionnaire; these were (a) reported frequency of toothbrushing, and (b) use of dietary fluoride supplements. Table 4, in which these indicators are matched against residence history, suggests that those with a fluoride-residence history may well be of higher SES. Therefore, to assess the possibility that the lower DMFS scores in those with some history of fluoridated water (Table 1) might really reflect lower caries experience in children of higher SES, rather than a residual effect of consumption of fluoridated water, we used multiple regression to assess the relative effects of these variables on DMFS scores. Results are shown in Table 5. The first row of data in that Table shows that the average difference between the two residence-history groups was −0.94 DMFS when the only explanatory variable in the model was residence history. The second line shows that, after addition of the explanatory variable of brushing frequency to the model, the estimate of the average difference between the groups remains essentially unchanged at −0.90 DMFS. The third line demonstrates that inclusion of fluoride supplement history also results in virtually no change in the average effect on DMFS as associated with residence history.

Because of the skewed distribution of DMFS values in this age group, a logistic regression model was also tried, in which DMFS was expressed as a two-level variable. Results are not tabulated, but again the fluoride-residence variable was highly significant and unaffected by the subsequent inclusion of the two SES indicators. These regression models therefore suggest that factors related to possible SES differences are unlikely to be the source of the observed difference in DMFS experience between the groups.

## Discussion.

The results of this analysis showed that the children who had received some limited exposure to fluoridated water in their early childhood experienced less caries than did those who had lived in a non-fluoridated community all their lives. In attempting to determine the mechanism by which this benefit was received, we can discount several possibilities: There was no difference between the groups in use of fluoridated toothpaste; over 88% in each group reported using a fluoridated toothpaste. Similarly, there was no difference between the groups in use of fluoridated rinses (very few reported using the over-the-counter rinses), nor in reported frequency of professionally-applied fluorides. If the data in Table 4 are accurate, then those with a fluoride-residence history might be using fluoridated toothpaste more frequently and might have gained some extra benefit from fluoride supplements, but the regression analysis suggests that such effects, as well as any other effects related to SES, were minor. While there is always the possibility that other unidentified factors might have influenced the results, the probability that the observed differences are attributable to the limited exposure to fluoridated water seems the most likely explanation. It is worth considering how this fluoride exposure might have exerted its benefits.

We tested the possibility that there might have been differences in *S. mutans* proportions between the groups, which could be attributed to earlier fluoride exposure. But the microbiological data in Table 3 do not permit the conclusion that *S. mutans* proportions are lower in the fluoride-residence group.

**TABLE 5**
REGRESSION ANALYSIS OF FLUORIDE RESIDENCE HISTORY (0 = NONE, 1 = SOME) ON DMFS SCORES AT COMPLETION OF STUDY*

| Coefficient for Fluoride-residence History** (0 = none, 1 = some) | Significance | Covariables |
|---|---|---|
| −0.94 | 0.008 | None |
| −0.90 | 0.011 | Brushing |
| −0.89 | 0.013 | Brushing + F Supps. |

*n = 335 children, those with data on all four variables.
**See text for explanation.

Differences between proportions or counts of bacteria from one group to another are difficult to demonstrate because of the large variances which characterize such data; even large differences between mean values often do not reach statistical significance because of the very large variances. These problems were discussed by Socransky *et al.* (1983), and by ourselves in a previous paper (Burt *et al.*, 1985), where the problems were compounded by the longitudinal nature of the study. Ellen *et al.* (1985) encountered similar difficulties in a longitudinal study of root caries. Further research is needed to determine an acceptable method of analyzing microbiological data statistically.

Our results support other studies which did not find a bactericidal role for low-concentration fluorides, whether in drinking water (Kilian *et al.*, 1979) or in a varnish (Zickert and Emilson, 1982). Animal experiments with an intra-oral fluoride-releasing device have suggested that the regular infusion of a low-concentration fluoride into the oral cavity is a highly effective method of caries prevention (Adderly *et al.*, 1981; Mirth *et al.*, 1982, 1983), but the maintenance of a low level of fluoride in the oral cavity did not affect the levels of cariogenic bacteria recovered.

The fact that there were no detectable differences in the proportions of *S. mutans* in our two populations does not mean that the *S. mutans* cells in each population were metabolically identical. Recent isolates of *S. mutans* from children in a fluoridated community were unable to initiate growth at pH 6.0 in the presence of 20 μg/mL of fluoride (Bowden *et al.*, 1982). Also, fluoride-resistant strains of *S. mutans* were not as cariogenic as their parent strains when inoculated into germ-free rats (Rosen *et al.*, 1978). These findings suggest that if similar fluoride-resistant strains were present in children having the fluoride exposure, they may not be as cariogenic as *S. mutans* strains in the non-fluoridated population. Bactericidal action from fluoride only seems to occur with high-concentration fluorides (Loesche, 1977, 1982; Schaeken *et al.*, 1986); the principal benefit of frequent introduction of low-concentration fluoride into the oral cavity is generally accepted to be in promotion of remineralization (Larson *et al.*, 1976; Birkeland *et al.*, 1977; Ericsson, 1977; Ingram and Nash, 1980; Fejerskov *et al.*, 1981; Wefel, 1982).

If the differences between the groups can be attributed to the previous ingestion of fluoridated water, the benefit may have been systemic or topical. Fluoridated water does provide benefits through topical action (Hardwick *et al.*, 1982), presumably through remineralization, and this mechanism would have been exerted in those children whose first molars were erupted during the time they were ingesting the fluoridated water. But some children in the group did not have erupted first molars during the time they were ingesting the fluoridated water, so if they benefited, the effect must have been pre-eruptive. It was stated earlier that the numbers were too small to permit the categorization of the children with fluoride-residence history into sub-groups by varying time of exposure; even more so, they could not be further split by time of exposure as related to the developmental status of first permanent molars (in which nearly all observed caries occurred).

This analysis therefore indicates that limited exposure to fluoridated water in childhood does lead to measurable prevention of dental caries, and that such benefits do not result from reduction of *S. mutans* proportions. Available evidence favors the argument that benefits from limited exposure to fluoridated water come from topical action, but the fact that many of the affected teeth in this study were unerupted during the period of fluoride exposure means that the possibility of some pre-eruptive benefit cannot be ruled out.

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