Anticaries Effect of Various Concentrations of Fluoride in Drinking Water: Evaluation of Empirical Evidence

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THE ADJUSTMENT OF FLUORIDE in drinking water is a widely practiced public health measure in the United States and other countries. The choice of an optimum concentration is based largely on the work of Dean and co-workers (*1,2*), with adjustments for average annual maximum daily temperature suggested by Galagan and Vermillion (*3*). The result is that the optimal concentration is usually considered to be somewhere in the range of 0.7 ppm to 1.2 ppm.

A closely related matter that has received scant attention is the question of what anticaries effect can be expected from various changes in the concentration of fluoride in drinking water. In 1958 Striffler (*4*) pointed out the importance of being able to assess the effect of a change, say, from 0.7 ppmF to 1.0 ppmF. When a community is assessing whether or not to adjust the fluoride content of its drinking water, the benefits to be realized may be expected to vary according to the concentration of fluoride already in the water supply.

We attempted to estimate the shape of the functional relationship between fluoride concentrations of more than 0.1 ppm and mean decayed, missing, and filled teeth (DMFT) among 12- to 14-year-olds. Our sources for this procedure were Dean and associates' data on 21 cities (*1,2*) and data on other cities compiled by Striffler (*4*).

Methods

From the sources cited, we obtained the amount of fluoride in each water supply and the DMFT in 12- to 14-year-old continuous residents in a total of 41 cities. The fluoride values were then modified with a formula derived from the work of Galagan and Vermillion (*3*) to account for the effect of the average annual maximum daily temperature (*5*), as shown in table 1.

Various theoretical curves were tested with respect to these 41 cities by means of the multiple linear regression portion of the Michigan Interactive Data Analysis System (MIDAS) packaged program. This program is supported by the Statistics Research Laboratory of the University of Michigan and is available through the university's Amdahl 470V/7 computer.

Numerous transformations of the data, including reciprocals, logarithms, and polynomials, were assessed. Because of the many possible transformations and linear specifications, literally thousands of curves could have been assessed. To keep the project manageable and to minimize the possibility of matching the sample

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but not the population, only theoretically plausible forms were assessed. In addition, the propriety of mixing the data from the two sources was tested in each of these equations with an indicator variable for the source. In every instance the coefficient for this indicator variable did not approach statistical significance. The lack of statistical significance for this variable supports the use of these data as though they were from a single source.

Two criteria were used to choose the better fitting curves: (*a*) the smallest mean square error (MSE) and (*b*) the subjective fit of the line to the data. Several different lines seemed to fit the data reasonably well, with R^2 values in the range from 0.90 to 0.93 and MSE between 0.37 and 0.53. The equation of the form:

$$\text{DMFT} = a + b(1/\text{ppmF}^{+}),$$

where ppmF^{+} is the modified value of the fluoride concentration that accounts for the average annual maximum daily temperature, fits the data well and was also the simplest. Thus, this equation was chosen as the most useful explanatory one (see chart p. 490).

Discussion

There was no clearcut way to choose which of the "better" lines, from all of those tried, was actually the best. Further, it can be argued that no one "best" line exists, because many other unrecorded factors, such as diet and treatment levels, may influence these lines. What is of most practical importance is that in spite of their different specifications, the "better" lines give remarkably similar expected values for DMFT. Tables 2 and 3 show the predicted reductions in DMFT for an adjustment of the fluoride concentration to ideal levels from various lower initial concentrations. For example, in a community with fluoride levels in the water supply of less than 0.2 ppm and an average annual maximum daily temperature of 60°F, an adjustment to 1.0 ppm could be expected eventually to effect a reduction of approximately 65 percent (5.6 teeth per capita) in the DMFT of 12- to 14-year-old children who had been reared on such water. On the other hand, if that community water supply already contained 0.6 ppm of fluoride, a reduction of approximately 23 percent (0.9 teeth per capita) in the DMFT could be expected.

Although these figures should not be interpreted as exact in any specific instance, they give reasonable estimates of the relative magnitude of the benefit to be anticipated when the fluoride level in a water supply is adjusted to ideal levels from a given initial concentration. These expected benefits should then be considered in terms of other location-specific factors, such as the size of the population served by the water supply, the dollar cost of fluoride adjustment, and the likelihood of a prolonged "fluoridation battle." A DMFT reduction of less than 20 percent might not be considered worth the cost for a small community, especially if a bitter political battle would be involved. On the other hand, the same percentage reduction could be well worth the time and effort required for a water supply that serves a large population.

Summary and Conclusions

Previously gathered data on fluoride levels in the water supply and the decayed, missing, and filled teeth (DMFT) for 12- to 14-year-old children were assessed to determine the relation between various fluoride adjustments and DMFT. Several plausible equations were developed, all of which gave remarkably similar expected values for DMFT. The results of the analysis lead to the following conclusions:

- Fluoride level is significantly related to DMFT within the range from approximately 0.1 ppmF to approximately 1.2 ppmF.

- The reduction in DMFT to be expected from the

Table 1. Average number of decayed, missing, and filled teeth (DMFT) per 12- to 14-year-old continuous resident, average annual maximum daily temperature, and fluoride content and modified fluoride content of drinking water of 41 U.S. cities

City and State	*ppmF*	*Average annual daily temperature (°F)*	*Modified ppmF* [1]	*Average DMFT*
Sedalia, MO	0.18	66.0	0.20	9.09
"c," IL	0.20	60.1	0.20	8.72
Mitchell, SD	0.20	56.4	0.19	8.27
Wenatchee, WA	0.20	62.5	0.21	7.83
Zanesville, OH	0.20	63.5	0.21	7.33
Middeltown, OH	0.20	64.0	0.21	7.03
Chillicothe, MO	0.26	64.8	0.28	7.80
Lima, OH	0.30	60.0	0.30	6.52
Jacksonville, IL	0.30	63.9	0.32	6.39
Huron, SD	0.35	56.0	0.32	7.80
Hutchinson, MN	0.35	54.2	0.31	7.79
Marion, OH	0.40	62.0	0.41	5.56
Bismarck, ND	0.45	52.7	0.39	5.11
Jefferson City, MO	0.49	66.0	0.54	4.91
Omaha, NE	0.50	61.8	0.52	4.91
"d," IL	0.50	60.1	0.50	4.53
Elgin, IL	0.50	60.1	0.50	4.44
Kansas City, KS	0.50	66.3	0.56	4.10
Pueblo, CO	0.60	68.7	0.70	4.12
Fort Dodge, IA	0.60	56.6	0.56	3.33
Elgin, IL	0.60	60.1	0.60	3.22
Cherokee, IA	0.70	56.6	0.66	2.02
Charles City, IA	0.80	55.0	0.73	3.33
Fulton and Mexico, MO	0.87	66.0	0.97	2.11
Kewanee, IL	0.90	60.1	0.90	3.43
Denver, CO	0.90	64.6	0.98	3.11
Union Grove, WI	1.00	55.4	0.91	2.90
"e," IL	1.10	60.1	1.10	2.05
East Moline, IL	1.20	60.1	1.20	3.03
Aurora, IL	1.20	60.1	1.20	2.81
Kimberly, WI	1.20	53.6	1.06	2.60
Maywood, IL	1.20	60.1	1.20	2.58
Joliet, IL	1.30	60.1	1.30	3.23
Columbia, MO	1.32	66.0	1.47	2.01
Oconto, WI	1.50	53.6	1.32	2.90
Kaukauna, WI	1.80	53.6	1.59	2.80
Elmhurst, IL	1.80	60.1	1.80	2.52
Galesburg, IL	1.90	61.2	1.94	2.36
DePere, WI	2.00	53.6	1.76	2.60
Green Bay, WI	2.30	53.6	2.03	2.60
Colorado Springs, CO	2.60	62.9	2.74	2.46

[1] Modified according to the formula: $ppmF^{+}=ppmF/[.334/\{.0062(temp) - .038\}]$, developed from the work of Galagan and Vermillion (3).

SOURCES: references 3–5.

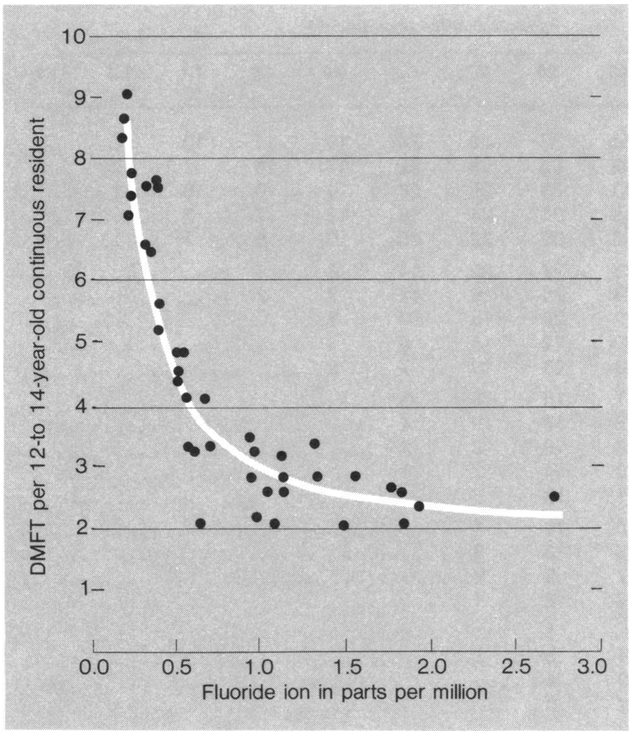
Table 2. Expected percentage reduction in DMFT in 12- to 14-year-olds, given various endemic fluoride concentrations, average annual maximum daily temperatures, and an adjustment to ideal fluoride levels

Average annual maximum daily temperature (°F)	*Endemic fluoride level (ppmF)*											
	0.2	*0.3*	*0.4*	*0.5*	*0.6*	*0.7*	*0.8*	*0.9*	*1.0*	*1.1*	*1.2*	*1.3*
46	73	62	52	44	37	30	24	19	14	10	5	2
48	71	60	51	42	35	28	22	17	12	7	3	
50	70	59	49	40	33	26	20	14	10	5	1	
52	69	57	47	38	31	24	18	12	7	3		
54	68	56	46	37	29	22	16	10	5	1		
56	67	55	44	35	27	20	14	8	4			
58	66	53	42	33	25	18	12	7	2			
60	65	52	41	32	23	16	10	5				
62	64	50	39	30	22	15	9	3				
64	63	49	38	28	20	13	7	2				
66	62	48	37	27	19	12	5					
68	61	47	35	25	17	10	4					
70	60	45	34	24	16	9	2					
72	59	44	32	23	14	7	1					
74	58	43	31	21	13	6						
76	57	42	30	20	12	4						
78	56	41	29	19	10	3						
80	55	40	27	17	9	2						
82	54	39	26	16	8	1						
84	53	38	25	15	7							
86	52	37	24	14	5							
88	51	35	23	13	4							
90	50	34	22	12	3							

Table 3. Expected per capita reduction in DMFT in 12- to 14-year-olds, given various endemic fluoride concentrations, average annual maximum daily temperatures, and an adjustment to ideal fluoride levels

Average annual maximum daily temperature (°F)	*Endemic fluoride levels (ppmF)*											
	0.2	*0.3*	*0.4*	*0.5*	*0.6*	*0.7*	*0.8*	*0.9*	*1.0*	*1.1*	*1.2*	*1.3*
46	8.1	4.9	3.3	2.4	1.8	1.3	1.0	0.7	0.5	0.3	0.2	0.1
48	7.6	4.6	3.1	2.2	1.6	1.2	0.9	0.6	0.4	0.2	0.1	
50	7.2	4.3	2.9	2.0	1.5	1.1	0.7	0.5	0.3	0.2		
52	6.8	4.1	2.7	1.9	1.3	1.0	0.7	0.4	0.2			
54	6.5	3.9	2.5	1.8	1.2	0.9	0.6	0.4	0.2			
56	6.2	3.6	2.4	1.6	1.1	0.8	0.5	0.3	0.1			
58	5.9	3.5	2.2	1.5	1.0	0.7	0.4	0.2	0.1			
60	5.6	3.3	2.1	1.4	0.9	0.6	0.4	0.2				
62	5.4	3.1	2.0	1.3	0.9	0.5	0.3	0.1				
64	5.1	2.9	1.9	1.2	0.8	0.5	0.2					
66	4.9	2.8	1.8	1.1	0.7	0.4	0.2					
68	4.7	2.7	1.6	1.0	0.6	0.3	0.1					
70	4.5	2.5	1.6	1.0	0.6	0.3	0.1					
72	4.3	2.4	1.5	0.9	0.5	0.2						
74	4.2	2.3	1.4	0.8	0.5	0.2						
76	4.0	2.2	1.3	0.8	0.4	0.1						
78	3.9	2.1	1.2	0.7	0.3	0.1						
80	3.7	2.0	1.1	0.6	0.3	0.1						
82	3.6	1.9	1.1	0.6	0.2							
84	3.4	1.8	1.0	0.5	0.2							
86	3.3	1.7	1.0	0.5	0.1							
88	3.2	1.7	0.9	0.4	0.1							
90	3.1	1.6	0.8	0.4	0.1							

Relation[1] of average number of decayed, missing, and filled teeth (DMFT) per 12- to 14-year-old continuous resident to fluoride content of drinking water of 41 U.S. cities



[1] Line of the form: $DMFT = 1.64 + 1.40\ (1/ppmF^{+})$

t values (8.7) (18.5)

Mean square error = .51; R^2 = .90

NOTE: F^{+} is the modified value of the fluoride concentration which accounts for the average annual maximum daily temperature (reference 5), according to the formula developed from the work of Galagan and Vermillion (reference 3).

adjustment of fluoride to ideal levels from various endemic concentrations should be considered by communities that are contemplating fluoridation of their water supplies.

• Since there is no single "best fit" line to predict the effects of a fluoride adjustment to ideal levels from various endemic levels, those lines that appear to be most plausible provide remarkably similar expected values, and the data from such a line, as presented in tables 2 and 3, may be useful for planning purposes.

References

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3. Galagan, D. J., and Vermillion, J. R.: Determining optimum fluoride concentrations. Public Health Rep 72: 491–493, June 1957.
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SYNOPSIS

EKLUND, STEPHEN A. (University of Michigan School of Public Health) and STRIFFLER, DAVID F.: *Anticaries effect of various concentrations of fluoride in drinking water: evaluation of empirical evidence. Public Health Reports, Vol. 95, September–October 1980, pp. 486–490.*

The benefits to be expected from the adjustment of fluoride levels in drinking water have been studied in great depth, but for the most part only with respect to changes from negligible concentrations to approximately 1.0 ppm.

This study makes use of previously gathered data on fluoride concentration in domestic water supplies, the average decayed, missing, and filled teeth (DMFT) scores of the 12- to 14-year-old children, and temperature data in conjunction with linear mathematical models to estimate the effect on DMFT of changes in fluoride concentrations from levels above 0.1 ppm to ideal levels.

The results of the analyses indicate that the endemic levels of fluoride in a community water supply play a major role in determining the relative benefit of adjusting that water supply to an ideal level of fluoride. If a rational policy decision is to be made with respect to fluoridation for a given community, the endemic fluoride levels must be considered in conjunction with such factors as population size and the anticipated cost to initiate and maintain the program.