

Effect of Fluoridated Public Water Supplies on Dental Caries Prevalence

By FRANCIS A. ARNOLD, Jr., D.D.S., H. TRENDLEY DEAN, D.D.S.,
PHILIP JAY, D.D.S., and JOHN W. KNUTSON, D.D.S., Dr.P.H.

AS EARLY as 1942, it had been adequately demonstrated that the use of fluoride-bearing drinking waters produces a marked reduction in the incidence of dental caries. It was also known by that time that this beneficial effect occurs in populations using water supplies containing fluoride from natural sources in concentrations below the level established as the threshold for mottled enamel or endemic fluorosis (1).

These epidemiological studies suggested the hypothesis that the addition of fluorides to public water supplies would result in a substantial reduction in dental caries. To test this hypothesis and to evaluate the procedure as a method

of caries control, several studies were begun in 1944-45. One of these studies is the Grand Rapids-Muskegon study, conducted by the Public Health Service with the cooperation of the Michigan Department of Health, the University of Michigan, and the city officials of Grand Rapids and Muskegon, Mich. This paper summarizes some of the findings from 10 years of observation in that study.

General Procedure

As originally planned the Grand Rapids-Muskegon study was designed to continue for a period of 10 to 15 years. This period was selected so that observations would be comparable to those obtained in the basic epidemiological studies on children 12 through 14 years of age with a continuous history of using fluoridated water. The selection of the study areas, the methods and types of examinations, the selection of the annual study groups, and preliminary findings have been reported (2, 3).

Beginning in January 1945, sodium fluoride has been added to the water supply of Grand Rapids, the principal study area. Since that time the fluoride content of the water supply has been maintained at a concentration level of 1 p.p.m. (within the range 0.9 to 1.1 p.p.m.). The water supply at Muskegon, the control area, contained less than 0.2 p.p.m. of fluoride until July 1951. At that time Muskegon began adding fluoride to its water supply to maintain a level similar to that in Grand Rapids. (In this paper, parts per million of fluoride refers to the concentration of the fluoride ion.)

Dr. Arnold is director of the National Institute of Dental Research, National Institutes of Health, Public Health Service; Dr. Dean is secretary of the Council on Dental Research, American Dental Association; Dr. Jay is professor of dentistry at the University of Michigan School of Dentistry; and Dr. Knutson is chief dental officer of the Public Health Service.

The following dental officers of the Public Health Service conduct the annual dental examinations in the Grand Rapids-Muskegon study: Dr. Robert C. Likins, Dr. A. L. Russell, Dr. David B. Scott, Dr. D. E. Singleton, and Dr. Robert M. Stephan. The following dentists, formerly with the Public Health Service, also participated as examiners in the study: Dr. F. S. Loe, Los Angeles, Calif.; Dr. H. B. McCauley, Baltimore, Md.; Dr. S. J. Ruzicka, Cleveland, Ohio; and Dr. Edwin M. Short, Hyattsville, Md.

To establish the caries status of the study population before fluoridation of the waters, complete oral examinations with a mouth mirror and explorer were made of virtually all children enrolled in elementary and secondary schools in Grand Rapids and Muskegon in 1944 and 1945. Each year thereafter, similar examinations have been made of selected samples of children in the two areas. (Bite-wing roentgenographic and bacteriological studies on selected samples of children will be reported in subsequent papers.) To provide an "expectancy curve," complete oral examinations were also made, in 1945 and 1946, of school chil-

dren in Aurora, Ill., where it is known the water supply has contained 1.2 p.p.m. fluoride from natural sources for about 50 years.

The annual samples of the school population of Grand Rapids and Muskegon are taken from schools selected as representative of each city as a whole. The samples consist of all available children in certain grades (or in sections of the grades) in these schools. The grades are selected to yield certain age groups. The number of grades has been expanded each year so that for the 10th year of the study a representative sample of children at each age from 5 through 16 years was obtained. The grades

Table 1. Distribution of continuous resident children examined in Grand Rapids and Muskegon, Mich., according to age, by year of examination

Age last birthday ¹	Basic examinations, 1944-45	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954
Grand Rapids, Mich.											
4.....	323	540	300	168	137	75	117	168	116	101	77
5.....	1,633	1,714	831	886	842	777	720	853	1,087	715	529
6.....	1,789	1,186	628	663	736	697	748	750	826	1,010	561
7.....	1,806	149	82	69	55	54	438	423	422	410	751
8.....	1,647	15	216	135	138	155	501	470	444	390	567
9.....	1,639	0	525	465	484	519	520	582	720	623	477
10.....	1,626	0	109	108	111	125	131	141	512	499	515
11.....	1,556	0	17	18	22	140	130	151	246	291	499
12.....	1,685	174	85	38	60	130	200	176	211	316	260
13.....	1,668	953	547	625	600	574	530	497	497	557	224
14.....	1,690	273	173	196	152	153	130	128	119	111	250
15.....	1,511	80	53	80	64	64	58	53	80	99	240
16.....	1,107	4	3	233	245	209	177	198	191	197	198
Total.....	19,680	5,088	3,569	3,684	3,646	3,672	4,400	4,590	5,471	5,319	5,148
Muskegon, Mich. ²											
4.....	20		43	18	26	51	41	63	52	43	40
5.....	402		321	348	422	340	359	351	487	370	381
6.....	462		339	312	305	393	310	294	353	397	386
7.....	408		36	42	36	30	274	223	246	209	292
8.....	376		18	13	10	12	190	275	205	212	244
9.....	357		213	215	199	197	227	277	348	258	275
10.....	359		62	57	52	52	51	62	287	311	226
11.....	293		12	10	14	146	141	139	133	175	208
12.....	328		21	19	11	28	43	48	46	163	183
13.....	377		197	207	208	214	173	225	178	228	243
14.....	369		77	50	79	66	63	59	54	51	121
15.....	292		18	44	41	34	35	21	30	35	139
16.....	248		1	199	205	132	146	155	132	161	185
Total.....	4,291		1,358	1,534	1,608	1,695	2,053	2,192	2,551	2,613	2,923

¹ See reference 1 for information regarding the effect of selection of sample by grades on specific age groups.

² The basic examinations in Muskegon were not done until late spring of 1945; therefore, no examinations were made in the fall of 1945.

selected for the annual examinations are as follows:

Year	Grade
1945	Kindergarten, 1, 8
1946	Kindergarten, 1, 4, 8
1947	Kindergarten, 1, 4, 8, 11
1948	Kindergarten, 1, 4, 8, 11
1949	Kindergarten, 1, 4, 6, 8, 11
1950	Kindergarten, 1, 2, 3, 4, 6, 8, 11
1951	Kindergarten, 1, 2, 3, 4, 6, 8, 11
1952	Kindergarten, 1, 2, 3, 4, 5, 6, 8, 11
1953	Kindergarten, 1, 2, 3, 4, 5, 6, 7, 8, 11
1954	Kindergarten through 11

Each year of the study, all available children in the selected grades (or section thereof) in each school in the study received dental examinations. Only the records of children aged 4-16 years who had used city water supplies continuously since birth are included in this report. Not included are records of children who lived outside their respective communities

for more than 3 months in any one calendar year. The number of continuous resident children and their distribution by age for each year of the study are shown in table 1.

Results

The amount of dental caries observed at each annual examination through 1954 in Grand Rapids and in Muskegon is shown in tables 2 and 3. There has been a striking reduction in the amount of dental caries in both the deciduous and permanent teeth. For example, in 1944 the average 6-year-old child had 6.43 def (decayed, extraction indicated, or filled) deciduous teeth; in 1954 the average child had only 2.95 def teeth. This represents a reduction of about 54 percent. Similar results were observed in the permanent teeth of children born since fluoridation started; that is those 6 to

Table 2. Average number of def¹ deciduous teeth per child² in Grand Rapids and Muskegon, Mich., by year of examination

Age last birthday	Basic examinations, 1944-45	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954
Grand Rapids, Mich.											
4	4.19	5.40	3.43	3.19	3.02	2.75	2.46	2.13	2.17	2.06	2.12
5	5.37	6.15	5.08	3.89	4.03	3.27	2.50	2.27	2.32	2.29	2.50
6	6.43	6.98	5.73	5.38	4.78	4.59	3.73	2.98	2.93	2.92	2.95
7	6.29	7.66	6.11	5.84	5.20	4.83	5.72	4.03	3.48	3.10	3.26
8	5.78	8.00	5.10	5.07	4.88	4.75	4.91	4.12	3.89	3.48	3.31
9	4.59		4.45	4.11	4.43	4.41	4.23	3.86	3.66	3.35	3.00
10	2.84		2.84	3.16	3.06	2.86	2.36	2.43	2.61	2.38	2.35
11	1.35		2.12	2.78	1.77	1.19	1.16	1.35	1.51	1.90	1.32
12	.47	.28	.13	.11	.25	.35	.25	.30	.34	.44	.44
13	.18	.13	.14	.14	.17	.10	.15	.12	.17	.19	.18
Muskegon, Mich. ³											
4	5.05		3.44	4.67	4.39	4.41	5.32	4.46	4.35	3.41	3.03
5	6.82		5.86	5.05	5.55	5.56	5.65	5.25	5.39	4.42	3.98
6	7.17		6.24	6.18	6.06	5.99	6.02	5.67	5.75	5.71	4.85
7	6.66		6.83	5.95	6.92	6.33	5.83	5.77	5.67	5.46	5.35
8	6.06		4.83	3.85	4.80	6.08	5.06	5.32	5.28	4.95	4.98
9	4.89		4.32	4.34	4.71	4.48	4.09	4.17	4.36	4.29	3.81
10	3.08		3.15	3.67	2.79	2.77	3.49	2.86	2.69	2.96	2.75
11	1.33		1.67	2.90	.64	1.21	1.09	1.46	1.20	1.38	1.42
12	.42		.14	.37	.64	.68	.61	.31	.54	.32	.61
13	.23		.29	.17	.11	.11	.13	.15	.08	.21	.12

¹ Decayed, extraction indicated, or filled deciduous teeth. A decayed and filled tooth is counted only once.

² See table 1 for small numbers involved in some instances.

³ The basic examinations in Muskegon were not done until late spring of 1945; therefore, no examinations were made in the fall of 1945.

Table 3. Average number of DMF¹ permanent teeth per child² in Grand Rapids and Muskegon, Mich., by year of examination

Age last birthday	Basic examinations, 1944-45	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954
Grand Rapids, Mich.											
6-----	0.78	0.56	0.23	0.37	0.26	0.38	0.26	0.26	0.23	0.12	0.19
7-----	1.89	1.72	1.11	1.09	1.04	.76	1.03	.84	.90	.71	.69
8-----	2.95	3.27	2.54	2.62	2.30	2.16	1.77	1.58	1.50	1.41	1.27
9-----	3.90		2.98	3.12	2.67	2.48	2.38	2.04	2.02	1.83	1.97
10-----	4.92		3.70	3.56	3.51	3.56	3.17	2.93	2.71	2.41	2.34
11-----	6.41		4.24	3.56	4.32	4.69	4.36	3.67	3.49	3.12	2.98
12-----	8.07	9.53	7.62	7.03	8.32	7.02	7.10	5.89	5.04	4.76	3.87
13-----	9.73	10.76	8.92	8.47	8.34	8.11	7.21	6.60	5.87	5.12	5.05
14-----	10.95	11.90	9.41	9.50	9.41	8.90	8.55	8.21	7.23	5.92	6.78
15-----	12.48	12.68	11.26	11.94	10.61	11.80	10.12	8.91	9.04	9.75	8.07
16-----	13.50	13.00	9.33	12.47	13.50	11.83	11.35	11.06	10.14	9.53	9.95
Muskegon, Mich. ³											
6-----	0.81		0.48	0.66	0.79	0.63	0.75	0.80	0.52	0.35	0.45
7-----	1.99		1.33	1.05	2.19	1.43	2.01	1.88	1.66	1.24	1.14
8-----	2.81		2.83	2.15	3.50	2.58	2.96	2.63	2.49	2.66	2.18
9-----	3.81		3.29	3.54	3.58	3.88	3.89	3.52	3.05	3.22	3.16
10-----	4.91		4.27	3.60	4.87	4.44	4.53	4.32	3.90	3.64	3.72
11-----	6.32		4.25	4.70	4.71	5.93	5.67	5.34	5.04	4.70	4.58
12-----	8.66		8.43	6.79	7.82	7.21	6.88	7.71	7.00	6.53	6.12
13-----	9.98		9.02	9.23	10.52	9.52	9.58	9.36	8.71	8.20	7.98
14-----	12.00		11.09	12.00	12.27	11.08	12.11	11.36	10.06	10.35	10.74
15-----	12.86		11.17	12.89	12.66	10.32	10.94	12.38	11.57	11.69	11.19
16-----	14.07		19.00	12.77	14.31	12.51	13.91	13.16	12.36	11.48	12.55

¹ Decayed, missing, or filled permanent teeth. A decayed and filled tooth is counted only once.

² See table 1 for small numbers involved in some instances.

³ The basic examinations in Muskegon were not done until the late spring of 1945; therefore, no examinations were done in the fall of 1945.

10 years old. It should be noted also that some beneficial effect was obtained by the older children. For example, the 16-year-old children had an average of 13.50 DMF (decayed, missing, or filled) permanent teeth in 1944 and 9.95 in 1954. They were between 6 and 7 years of age when fluoridation started.

A breakdown of the dental caries experience rates for 1954 in the two cities is shown in table 4. For comparison with these results, table 5 offers the findings in 1945 among Aurora, Ill., children, who had used a naturally fluoridated water since birth. The caries experience observed among them is similar to that reported for other areas with fluorides of that concentration (1).

Prior to the decision to add fluoride to the water supply at Grand Rapids, it was concluded that the procedure would not produce an un-

desirable cosmetic effect, that is, mottled enamel. However, it was recognized that an increase in the milder, nonobjectionable forms of dental fluorosis was likely. In order to evaluate this factor fully, it is necessary to wait for observations on all permanent teeth (excluding third molars) which are calcified on fluoridated water. The observations to date give evidence of only a slight increase (0.24 percent in 1944; 0.36 percent in 1954) in the number of children with the milder forms of fluorosis, which are not objectionable from an esthetic or cosmetic standpoint.

Discussion

From the results obtained in Grand Rapids after 10 years of water fluoridation, it is quite clear that this procedure is remarkably effec-

tive in reducing the incidence of dental caries. These observations are in accord with the results of similar studies conducted under separate auspices (4-6). The scientific evidence is conclusive, therefore, that water fluoridation is an effective public health procedure for producing a substantial reduction in the incidence of dental caries.

According to this study, the beneficial effects of fluoridated water are not confined to persons drinking the water since birth. The results suggest that some benefit was obtained by per-

sons whose teeth had already formed or erupted when they started drinking fluoridated water. The effects on the teeth of adults in these cities have not as yet been ascertained. However, the fact that a reduction in caries was observed for teeth which had already been calcified when fluoridation was started indicates that some beneficial effect may be gained by older age groups.

The possibility of an increase in dental fluorosis in a community after fluoridation has received considerable discussion. After 10 years

Table 4. Dental caries in deciduous and permanent teeth of continuous resident children of Grand Rapids and Muskegon, Mich., as observed in the 1954 examination

Age last birthday	Number of teeth per child						Percent of caries-free children ⁴
	Deciduous teeth		Permanent teeth				
	Filled	Total def ¹	Decayed	Missing ²	Filled	Total DMF ³	
Grand Rapids, Mich.							
4	0.68	2.12					
5	1.14	2.50	0.01		0.01	0.02	99.4
6	1.30	2.95	.11		.09	.19	89.3
7	1.45	3.26	.36		.35	.69	66.8
8	1.42	3.31	.52	0.02	.77	1.27	49.4
9	1.30	3.00	.74	.04	1.26	1.97	33.1
10	.98	2.35	.73	.07	1.63	2.34	26.6
11	.63	1.32	.78	.10	2.19	2.98	16.8
12	.12	.44	1.14	.26	2.55	3.87	13.5
13	.04	.18	1.56	.44	3.23	5.05	10.7
14			2.13	.52	4.36	6.78	5.6
15			2.08	1.02	5.23	8.07	1.2
16			1.96	1.35	6.90	9.95	2.0
Muskegon, Mich. ⁵							
4	1.18	3.03					
5	.98	3.98	0.03			0.03	98.4
6	1.64	4.85	.33	0.00	0.13	.45	79.8
7	1.96	5.35	.74	0	.41	1.14	49.7
8	2.03	4.98	1.23	.06	.95	2.18	27.5
9	1.60	3.81	1.29	.14	1.80	3.16	14.5
10	1.14	2.75	1.44	.23	2.20	3.72	5.7
11	.44	1.42	1.79	.32	2.67	4.58	4.3
12	.14	.61	2.05	.42	3.85	6.12	4.4
13	.06	.12	2.47	.72	4.97	7.98	1.6
14			4.31	1.39	5.31	10.74	0
15			3.55	1.42	6.51	11.19	1.4
16			2.78	1.42	8.77	12.55	1.1

¹ Decayed, extractions indicated, or filled deciduous teeth.

² Includes teeth listed as "remaining roots" and teeth destroyed beyond any possible repair.

³ Decayed, missing, or filled permanent teeth; each tooth is counted only once for this total. A tooth that has both a filled and a carious surface is included in both the "Decayed" and the "Filled" columns.

⁴ Permanent teeth only.

⁵ These children had already received the beneficial effects of 3 years of water fluoridation (see text).

Table 5. Dental caries in deciduous and permanent teeth of continuous resident children of Aurora, Ill., as observed in the 1945-46 examination period

Age last birthday	Number children examined	Deciduous teeth		Permanent teeth				Percent of caries-free children ⁴
		Filled	Total def ¹	Decayed	Missing ²	Filled	Total DMF ³	
Number of teeth per child								
4	30	0.10	2.07				0.06	97.3
5	407	.25	2.79	0.06			.28	84.8
6	473	.38	3.36	.27	0.00	0.02	.71	66.1
7	516	.44	3.51	.68	.01	.04	1.04	55.2
8	469	.54	3.60	.95	.01	.11	1.52	44.8
9	368	.49	2.98	1.27	.06	.27	2.02	33.5
10	397	.27	2.28	1.55	.09	.51	2.67	27.7
11	383	.15	1.18	2.03	.23	.69	2.95	26.9
12	401	.05	.43	2.06	.22	.96	3.09	26.7
13	401	.01	.13	2.10	.24	1.20	3.64	21.7
14	433			2.05	.31	1.58	4.54	16.9
15	467			2.37	.50	2.05	5.19	14.6
16	371			2.32	.53	2.71		

¹ Decayed, extraction indicated, or filled deciduous teeth.

² Includes teeth listed as "remaining roots" and teeth destroyed beyond any possible repair.

³ Decayed, missing, or filled permanent teeth; each tooth is counted only once for this total. A tooth that has both a filled and a carious surface is included under both the "Decayed" and the "Filled" columns. (Note that this table differs from table 2, reference 2.)

⁴ Permanent teeth only.

of fluoridation in Grand Rapids, the percentage of children classed as having fluorosis has increased, but, as anticipated, this increase is confined to the milder forms. As pointed out previously (7), the signs of the milder forms of fluorosis caused by ingestion of water containing 1 p.p.m. fluoride as a rule do not appear on the anterior teeth. It is the plan of this study to continue the observations to evaluate this factor fully. Thus far, however, the ingestion of the Grand Rapids water supply has not produced any undesirable cosmetic effect in the form of objectionable dental fluorosis on the anterior teeth.

Summary

The results of the Grand Rapids-Muskegon study after 10 years of observation indicate that the adjustment of the fluoride content of a communal water to an optimal level (approximately 1 p.p.m. fluoride) will produce the following effects:

1. A striking reduction in the prevalence of dental caries in the deciduous teeth. At the

peak of prevalence, namely 6 years of age, the caries rate for the deciduous teeth was reduced by about 54 percent.

2. A marked reduction in the prevalence of dental caries in the permanent teeth. In children born since fluoridation was put into effect, the caries rate for the permanent teeth was reduced on the average by about 60 percent.

3. Some benefit among persons whose teeth having already formed or erupted when fluoridation is begun.

4. No undesirable cosmetic effect from dental fluorosis.

REFERENCES

- (1) American Association for the Advancement of Science: Dental caries and fluorine, edited by F. R. Moulton. Lancaster, Pa., Science Press, 1946.
- (2) Dean, H. T., Arnold, F. A., Jr., Jay, P., and Knutson, J. W.: Studies on mass control of dental caries through fluoridation of the public water supply. Pub. Health Rep. 65: 1403-1408, Oct. 27, 1950.
- (3) Arnold, F. A., Jr., Dean, H. T., and Knutson, J. W.: Effect of fluoridated public water supplies on

- dental caries prevalence. Seventh year of the Grand Rapids-Muskegon Study. Pub. Health Rep. 68: 141-148, February 1953.
- (4) Ast, D. B., Smith, D. J., Wachs, B., and Cantwell, K. T.: Newburgh-Kingston caries-fluorine study. XIV. Combined clinical and roentgenographic dental findings after ten years of fluoride experience. J. Am. Dent. A. 52: 314-325, March 1956.
- (5) Hutton, W. L., Linscott, B. W., and Williams, D. B.: Final report of local studies on water fluoridation in Brantford. Canadian J. Pub. Health 47: 89-92, March 1956.
- (6) Hill, I. N., Blayney, J. R., and Wolf, W.: The Evanston dental caries study. XI. The caries experience rates of 12-, 13-, and 14-year-old children after exposure to fluoridated water for fifty-nine to seventy months. J. Dent. Res. 34: 77-88, February 1955.
- (7) Dean, H. T., Jay, P., Arnold, F. A., Jr., and Elvove, E.: Domestic water and dental caries. II. A study of 2,832 white children, aged 12-14 years, of 8 suburban Chicago communities, including *Lactobacillus acidophilus* studies of 1,761 children. Pub. Health Rep. 56: 761-792, April 11, 1941.

PHS films

The Public Health Aspects of Migrant Workers

16 mm. Film, black and white, sound, 16 minutes, 1955.

Audience: Public health workers, medical societies.

Available: Loan—Public Health Service, Communicable Disease Center, 50 7th St. NE., Atlanta 23, Ga. Purchase—United World Films, Inc., 1445 Park Avenue, New York 29, N. Y.

Instruction in the detection and control of communicable diseases in migrant laborers is provided through this film. National problems in controlling diseases associated with this



Truck showing mode of travel of migrant laborers. Two families of 10 or 12 people traveled 1,000 miles in one of these to get to summer work.

shifting group are elucidated. These problems have, for many years, been growing.

Since migrant laborers are transients, they do not ordinarily enjoy the rights of citizenship. Any attempt to solve such problems must, therefore, transcend legal obligations to protect the health of citizens.

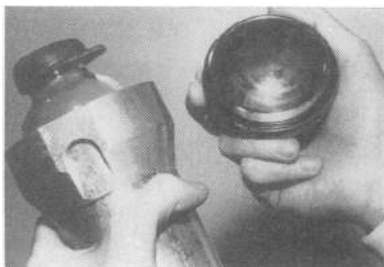
Infectious Hazards of Bacteriological Techniques Series: Part VI, The Centrifuge

35 mm. Filmstrip, color, sound, 12 minutes, 86 frames, 1955.

Audience: Laboratory or institutional personnel using or teaching the use of the centrifuge in handling infectious organisms.

Available: Loan—Public Health Service, Communicable Disease Center, 50 7th St., NE., Atlanta 23, Ga. Purchase—United World Films, Inc., 1445 Park Avenue, New York 29, N. Y.

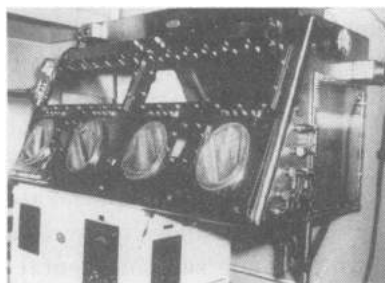
This is one of a series of filmstrips relating to studies of infec-



Safety cup used to prevent dissemination of aerosols from tubes broken in centrifuge.



Air samplers placed to determine aerosol contamination at various distances from centrifuge.



Ventilated cabinet developed at Fort Detrick to house refrigerated centrifuge.

tious aerosols produced by common laboratory operations.

Based on data gathered by the Army's Chemical Corps Biological Laboratories, Fort Detrick, this particular part deals specifically with the centrifuge. It points out some of the hazards of using this apparatus and suggests safe operating procedures.