

Roentgenographic findings support the conclusion that fluoridation of a municipal water supply results in a substantial reduction in dental caries among children.

Clinical and Roentgenographic Examinations for Dental Caries in Grand Rapids, Mich.

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DENTAL CARIES experience may be estimated by direct clinical observation, by roentgenography, or by a combination of the two methods. Direct observation is most convenient and is therefore most frequently employed, but the demonstration that bite-wing roentgenography is valuable for early detection of caries in the approximal surfaces of the teeth (1-7) has led to its use in several studies (8-14), including some in which it was the only method used. The combined technique, direct observation plus bite-wing roentgenography, consistently yields a higher estimate of caries prevalence than direct observation alone (7, 10-12); therefore, some observers

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have suggested that X-rays are essential for dental surveys designed to determine the efficacy of caries control measures (8, 12, 15).

In Grand Rapids, Mich., a study to evaluate fluoridation of a municipal water supply as a caries control measure has been in progress since 1944. As part of this study, an investigation was undertaken to determine whether or not supplementing direct observation with roentgenographic examination would affect the conclusions based on direct observation alone. Caries experience was estimated separately by direct observation and by bite-wing roentgenography. The data were then combined in such manner that, if the conclusions were affected, it would be evident, and if not, the finding would be unequivocal. Hence, the method selected for combining the data gives the greater weight to the roentgenographic findings and presents the direct observation findings adversely. The roentgenograms were used also to estimate the depth of the carious lesions.

Methods

Each year since the start of fluoridation in Grand Rapids in January 1945, selected samples of school children have received direct observation examinations for dental caries. The

examinations are performed by several dentists, using a mouth mirror, an explorer, and artificial illumination (16, 17).

In 1946, 1947, and 1953 (approximately 21, 33, and 105 months after fluoridation was begun), the annual dental examinations of children in the first, fourth, and eighth grades of four selected schools were supplemented by bite-wing X-rays. The X-ray examinations followed the regular examinations by a period varying from a few days to a month. Left and

right posterior bite-wing radiographs were made for every pupil. For each fourth-grade child (8-10 years of age), one anterior bite-wing X-ray was made to show the central incisor teeth; for each eighth-grade child (12-14 years of age), three anterior bite-wing X-rays were made to show the incisor and cuspid teeth. First-grade pupils (5-7 years of age) did not receive anterior bite-wing X-rays.

Roentgenographic interpretation was limited to the approximal surfaces of the deciduous

Table 1. Mean number of carious teeth per child as estimated by direct observation and by direct observation plus X-ray examination, Grand Rapids, Mich., 1946-47 and 1953

Type of examination	1946-47		1953		Difference	Standard error
	Mean	Standard error	Mean	Standard error		
def ¹ deciduous molars (ages 5-7)						
Direct observation only	4.73	0.27	2.82	0.21	1.91	0.31
Direct observation plus:						
Minimum X-ray findings	5.67	.23	4.06	.23	1.61	.35
Maximum X-ray findings	6.19	.21	4.92	.23	1.27	.33
DMF ² first permanent molars (ages 8-10)						
Direct observation only	2.77	0.16	1.86	0.13	0.91	0.22
Direct observation plus:						
Minimum X-ray findings	2.78	.16	1.93	.12	.85	.21
Maximum X-ray findings	3.04	.14	2.34	.12	.70	.19
DMF ² permanent teeth (ages 12-14)						
Direct observation only	9.66	0.45	5.44	0.36	4.22	0.64
Direct observation plus:						
Minimum X-ray findings	10.96	.46	6.50	.41	4.46	.69
Maximum X-ray findings	13.26	.50	8.73	.52	4.53	.78
DMF ² premolars (ages 12-14)						
Direct observation only	1.51	0.18	0.38	0.09	1.13	0.22
Direct observation plus:						
Minimum X-ray findings	1.90	.20	.73	.11	1.17	.24
Maximum X-ray findings	3.34	.22	2.08	.20	1.26	.31
DMF ² first permanent molars (ages 12-14)						
Direct observation only	3.93	0.04	3.17	0.12	0.76	0.14
Direct observation plus:						
Minimum X-ray findings	3.96	.03	3.30	.11	.66	.13
Maximum X-ray findings	3.98	.02	3.43	.10	.55	.11

¹ Decayed, extraction indicated, or filled.

² Decayed, missing, or filled.

molar teeth of 5- to 7-year-old children, the central incisor and first permanent molar teeth of 8- to 10-year-old children, and the permanent teeth (excluding third molars) of 12- to 14-year-old children. Each set of roentgenograms received two independent readings. Each reading was made without reference to the clinical examination record and was recorded separately from the other.

The first step in recording the caries status of an approximal surface was to score it as

carious or noncarious. An approximal surface was scored as carious if the reader could detect a discontinuity of the enamel surface or any other sign of caries, such as an abnormal radiolucency at the dentino-enamel junction. These surfaces were designated as the maximum number of carious surfaces detectable by X-ray. Each carious surface was then further examined, and a separate notation was made for each one with signs of caries of the dentin. Surfaces with dentinal caries were designated

Table 2. Mean number of carious approximal surfaces per child as estimated by direct observation and by direct observation plus X-ray examination, Grand Rapids, Mich., 1946-47 and 1953

Type of examination	1946-47		1953		Difference	Standard error
	Mean	Standard error	Mean	Standard error		
df ¹ approximal surfaces of deciduous molars (ages 5-7)						
Direct observation only	4.48	0.12	1.92	0.20	2.56	0.43
Direct observation plus:						
Minimum X-ray findings.....	6.11	.12	3.79	.26	2.32	.46
Maximum X-ray findings.....	7.21	.11	5.14	.29	2.07	.47
DF ² approximal surfaces of first permanent molars (ages 8-10)						
Direct observation only	0.56	0.11	0.08	0.02	0.48	0.09
Direct observation plus:						
Minimum X-ray findings.....	.81	.14	.25	.05	.56	.13
Maximum X-ray findings.....	1.55	.16	1.02	.09	.53	.18
DF ² approximal surfaces of permanent teeth (ages 12-14)						
Direct observation only	5.58	0.54	1.90	0.32	3.68	0.68
Direct observation plus:						
Minimum X-ray findings.....	8.60	.68	3.86	.45	4.74	.87
Maximum X-ray findings.....	13.07	.77	7.75	.66	5.32	1.08
DF ² approximal surfaces of premolars (ages 12-14)						
Direct observation only	0.63	0.13	0.09	0.03	0.54	0.14
Direct observation plus:						
Minimum X-ray findings.....	1.38	.22	.53	.11	.85	.25
Maximum X-ray findings.....	3.43	.31	2.33	.26	1.10	.41
DF ² approximal surfaces of first permanent molars (ages 12-14)						
Direct observation only	1.85	0.16	0.75	0.11	1.10	0.21
Direct observation plus:						
Minimum X-ray findings.....	2.45	.18	1.37	.14	1.08	.24
Maximum X-ray findings.....	3.34	.19	2.46	.19	.88	.27

¹ Decayed or filled deciduous teeth.
² Decayed or filled permanent teeth.

Figure 1. Teeth with caries experience, continuous resident children in Grand Rapids, Mich., 1946-47 and 1953.

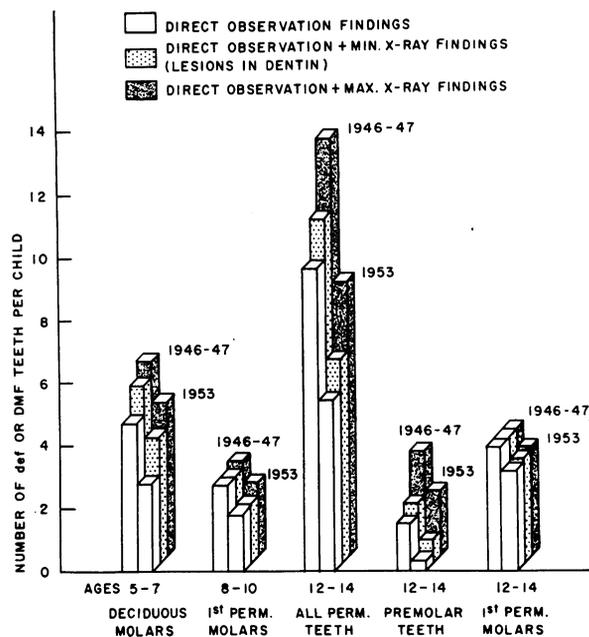
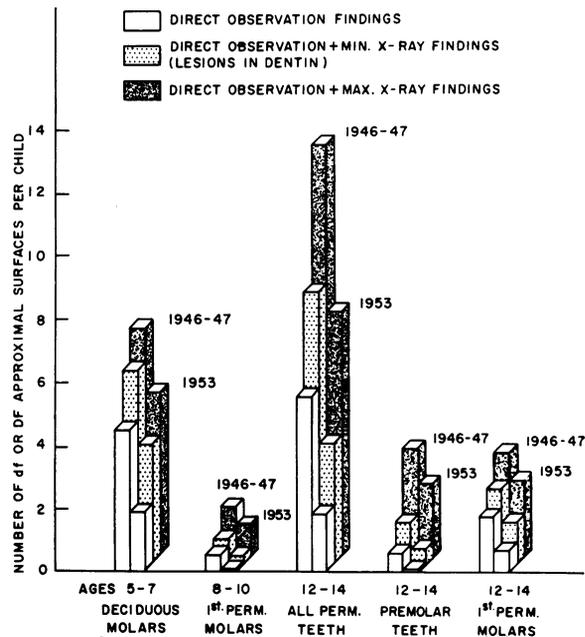


Figure 2. Approximal surfaces with caries experience, continuous resident children in Grand Rapids, Mich., 1946-47 and 1953.



as the minimum number of carious surfaces demonstrable by X-ray. Radiolucencies contiguous to restorations were not recorded, but restorations were considered caries of both the enamel and the dentin.

After the completion of all X-ray interpretations, a master record of the roentgenographic findings was made for each child. This record, which contained the notations from each of the independent readings, was used in combining the radiographic and clinical findings. To give greater weight to the radiographic findings, an approximal surface was given a roentgenographic diagnosis of caries if it was scored as carious at either reading.

Two more records were then made for each

child: one for direct observation findings plus minimum X-ray findings; the other for direct observation findings plus maximum X-ray findings. Surfaces negative for caries according to direct observation but positive according to X-ray examination were added to the direct observation findings. Surfaces positive according to direct observation were considered carious at both levels of penetration, regardless of the X-ray findings.

Only children designated "continuous residents," that is, those who had consumed water from the Grand Rapids supply continually since birth and who had not been absent from that community longer than 3 months in any calendar year, were included in the study, although

Table 3. Number of continuous resident children examined with bite-wing X-rays and mean age of children in each age group, Grand Rapids, Mich., 1946-47 and 1953

Age group (years)	1946-47				1953			
	Boys	Girls	Total	Mean age	Boys	Girls	Total	Mean age
5-7	58	50	108	6.2	70	71	141	6.4
8-10	50	41	91	9.1	89	79	168	9.4
12-14	59	54	113	13.3	55	60	115	13.3

Table 4. Mean number of teeth per child subject to the risk of caries, Grand Rapids, Mich., 1946-47 and 1953

Type of teeth and age group	1946-47	1953
Deciduous molars: 5-7.....	7.63	7.77
Permanent teeth:		
8-10.....	14.03	13.76
12-14.....	26.80	26.56
Premolars: 12-14.....	7.60	7.48

others were examined. Of those who received X-ray examination in addition to the regular examination, 736 (312 in 1946 and 1947, and 424 in 1953) met the residence requirements. As there was no essential difference in the caries experience of the 167 radiographed in 1946 and the 145 in 1947, the data for these 2 years were combined.

The representativeness of the X-ray sample was determined by comparing the caries experience of the children in this sample, as deter-

mined by direct observation of the teeth, with that of their age peers in the entire sample of children examined in 1946-47 and 1953 (18). Between 1946-47 and 1953 both samples displayed substantial decreases in the number of def (decayed, indicated for extraction, or filled) deciduous teeth and in the number of DMF (decayed, missing, or filled) permanent teeth. Both samples yielded essentially the same results.

Support for Clinical Findings

Supplementation of the dental examinations with bite-wing X-rays did not change the basic observation that decreases in dental caries occurred among the Grand Rapids children between 1946-47 and 1953. The mean numbers of carious teeth were smaller in 1953 than in 1947 whether estimated by direct observation alone or by direct observation plus X-ray examination (table 1 and fig. 1). The same was

Table 5. Caries of approximal surfaces, by depth of lesion as determined by X-rays, Grand Rapids, Mich., 1946-47 and 1953

Year(s)	Number of approximal surfaces present	Number of carious surfaces			Number of caries-free surfaces	Number of carious surfaces per 100 surfaces present		
		Total	Caries of dentin	Caries of enamel only		Caries of dentin	Caries of enamel only	Caries free
Deciduous molars (ages 5-7)								
1946-47.....	1,648	756	622	134	892	37.7	8.1	54.1
1953.....	2,190	705	503	202	1,485	23.0	9.2	67.8
First permanent molars (ages 8-10)								
1946-47.....	712	131	63	68	581	8.8	9.6	81.6
1953.....	1,344	171	38	133	1,173	2.8	9.9	87.3
Premolars (ages 12-14)								
1946-47.....	1,700	382	144	238	1,318	8.5	14.0	77.5
1953.....	1,692	266	59	207	1,426	3.5	12.2	84.3
First permanent molars (ages 12-14)								
1946-47.....	696	355	240	115	341	34.5	16.5	49.0
1953.....	838	270	146	124	568	17.4	14.8	67.8

true for carious approximal surfaces (table 2 and fig. 2). Inasmuch as the changes in caries experience for children in this study as determined by direct observation alone were essentially the same as those for all the children in their age groups, it is likely that the rest of the first-, fourth-, and eighth-grade children would provide similar X-ray findings.

The reduction in caries between 1946-47 and 1953 was statistically significant, as can be seen by an inspection of the standard error terms (last column in tables 1 and 2). The reduction cannot be explained by differences in the age or sex distribution (table 3) or by variations in the number of teeth at risk (table 4) since these

were all essentially the same for the two periods. The between-method variation in the magnitude of the differences between the 1946-47 and 1953 caries rates might be attributed to chance.

The findings suggest, both numerically and proportionally, that there was little variation in the effectiveness of the clinical examinations between 1946-47 and 1953. The maximum X-ray increments for 12- to 14-year-old children were 3.60 DMF teeth per child in 1946-47 and 3.29 in 1953. If the mean number of teeth in eruption (table 4) is used as the denominator, X-rays revealed the first evidence of caries for 13 percent of the teeth in eruption in 1946-47

Table 6. Approximal surfaces with dentinal caries, by individual and by combined roentgenographic readings, Grand Rapids, Mich., 1946-47 and 1953

Criteria for acceptance of lesions	1946-47		1953		Change in caries experience: ¹ Surfaces per 100 surfaces present
	Number of carious surfaces	Number of carious surfaces per 100 surfaces present	Number of carious surfaces	Number of carious surfaces per 100 surfaces present	
Deciduous molars (ages 5-7)					
Either reading.....	622	37.7	503	23.0	-14.7
Reading 1 only.....	595	36.1	479	21.8	-14.3
Reading 2 only.....	600	36.4	479	21.9	-14.5
Both readings.....	573	34.8	452	20.6	-14.2
First permanent molars (ages 8-10)					
Either reading.....	63	8.8	38	2.8	-6.0
Reading 1 only.....	56	7.9	34	2.5	-5.4
Reading 2 only.....	61	8.6	32	2.4	-6.2
Both readings.....	54	7.6	28	2.1	-5.5
Premolars (ages 12-14)					
Either reading.....	144	8.5	59	3.5	-5.0
Reading 1 only.....	125	7.4	49	2.9	-4.5
Reading 2 only.....	135	7.9	53	3.1	-3.8
Both readings.....	116	6.8	43	2.5	-4.3
First permanent molars (ages 12-14)					
Either reading.....	240	34.5	146	17.4	-17.1
Reading 1 only.....	227	32.6	136	16.2	-16.4
Reading 2 only.....	226	32.5	137	16.4	-16.1
Both readings.....	213	30.6	127	15.2	-15.4

¹ Minus indicates a decrease in 1953.

and for 12 percent in 1953. Selection of the denominator for these and other proportions is based on Hill's advice concerning numerators, denominators, and proper use of the risk factor (19).

New Information From X-Rays

The X-ray data revealed that most of the decrease in caries of the approximal surfaces occurred among the deeper lesions (those involving dentin) and that there was little or no change in the number of shallow lesions (those limited to the enamel). These findings are shown in table 5, where depth of lesion as de-

termined by X-ray is related to the number of approximal surfaces present. The denominators are the numbers of surfaces at risk; they are thus corrected for the slight variation in the number of teeth in eruption but not for any possible variation in time of eruption. Extracted teeth were excluded since there was no way of determining the caries experience of their approximal surfaces.

The difference between the 1946-47 and 1953 caries patterns with regard to depth of lesion is consistent with the hypothesis that fluoride retards the development of dental caries. A reasonable explanation for the data is that some enamel lesions did not progress to dentinal

Table 7. Approximal surfaces with caries limited to the enamel, by individual and by combined roentgenographic readings, Grand Rapids, Mich., 1946-47 and 1953

Criteria for acceptance of lesions	1946-47		1953		Change in caries experience: ¹ Surfaces per 100 surfaces present
	Number of carious surfaces	Number of carious surfaces per 100 surfaces present	Number of carious surfaces	Number of carious surfaces per 100 surfaces present	
Deciduous molars (ages 5-7)					
Either reading.....	134	8.1	202	9.2	+1.1
Reading 1 only.....	116	7.0	181	8.3	+1.3
Reading 2 only.....	125	7.6	200	9.1	+1.5
Both readings.....	106	6.4	178	8.1	+1.7
First permanent molars (ages 8-10)					
Either reading.....	68	9.6	133	9.9	+0.3
Reading 1 only.....	66	9.3	125	9.3	0
Reading 2 only.....	63	8.8	118	8.8	0
Both readings.....	61	8.6	110	8.2	-.4
Premolars (ages 12-14)					
Either reading.....	238	14.0	207	12.2	-1.8
Reading 1 only.....	231	13.6	184	10.9	-2.7
Reading 2 only.....	204	12.0	196	11.6	-.4
Both readings.....	198	11.6	173	10.2	-1.4
First permanent molars (ages 12-14)					
Either reading.....	115	16.5	124	14.8	-1.7
Reading 1 only.....	115	16.5	114	13.6	-2.9
Reading 2 only.....	101	14.5	118	14.1	-.4
Both readings.....	101	14.5	108	12.9	-1.6

¹ Minus indicates a decrease in 1953; plus, an increase.

lesions and that many enamel lesions did not occur or at least did not develop to a size detectable by practical methods. (Some enamel lesions might have been replaced by microscopic lesions of the type described by Burket (20); this study did not investigate these lesions). The nonappearance of the shallow lesions is also consistent with the hypothesis that fluoride actually prevents the inception of caries. The alternative hypothesis that fluoride selectively prevents caries of the dentin is not supported by these data, as this hypothesis would require decreases in dentinal caries to be balanced by increases in enamel caries.

Effect on DMF Studies

Bite-wing roentgenography produced less change in estimates of caries experience of teeth (DMF or def) than that of approximal surfaces (DF or df). This can be seen by comparing parallel radiographic increments of these scores in figures 1 and 2. The lower sensitivity of DMF estimates is related to the high susceptibility of children's teeth to occlusal caries (21), the relative ease of detecting occlusal lesions by direct observation (2), and the fact that a tooth is counted only once in arriving at a DMF score. Only radiographic evidence of caries in a tooth deemed to be free of caries on direct observation would add to a DMF score.

The methods selected for combining the direct observation and roentgenographic data did, in fact, present the direct observation findings adversely, as can be seen in figures 1 and 2. As shown in tables 6 and 7, different methods of using the two independent X-ray readings would have led to the same conclusions: that there was a substantial decrease in dental caries experience and that this decrease occurred primarily among the deeper lesions. The essential conclusion—that there was a substantial decrease in dental caries experience—was reached without the X-rays.

Summary

Bite-wing roentgenography was used to supplement the regular dental examinations of 736 continuous resident children of Grand Rapids,

Mich., in 1946–47 and 1953. Findings from direct observation indicated that the children in the X-ray sample were representative of their age peers in the entire sample of children examined in those years.

The roentgenograms were read for radiolucencies of dentin and for discontinuities of the enamel surface. For the primary purpose of testing the effect of X-ray findings on conclusions reached by direct observation alone, the X-rays were read twice and any surface scored as carious at either reading was added to the directly observed estimate of caries.

There were wide but consistent variations in total caries experience according to the three methods of estimation, but all estimates demonstrated a significant decrease in total caries experience between 1946–47 and 1953. The decrease in caries appeared to be greater for deeper lesions than for shallow lesions. This was demonstrated by analysis of roentgenographic data without reference to the regular dental examinations and was independent of the method used to combine the two X-ray readings. The decrease in the deeper lesions without a balancing increase in the shallow lesions suggests that fluoride retards the development of caries and that it also prevents the inception of caries.

From this study, we draw the following conclusions:

1. Roentgenographic findings support the clinical finding that fluoridation of a municipal water supply is an effective caries control measure.
2. Estimates of dental caries experience expressed as the number of decayed, missing, or filled teeth are less sensitive to modification by roentgenographic findings than are estimates of caries expressed as the number of decayed or filled approximal surfaces.

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