Dental Effects of Exposure to Fluoride-Bearing Dakota Sandstone Waters at Various Ages and for Various Lengths of Time: I. Status of the Permanent Teeth of 339 Children Aged 11 to 15 Years who Used Such Water for Eighteen Months Prior To Eruption of the First Permanent Molars

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J DENT RES 1949 28: 298
DOI: 10.1177/00220345490280031401

The online version of this article can be found at:
http://jdr.sagepub.com/content/28/3/298
DENTAL EFFECTS OF EXPOSURE TO FLUORIDE-BEARING DAKOTA SANDSTONE WATERS AT VARIOUS AGES AND FOR VARIOUS LENGTHS OF TIME

I. STATUS OF THE PERMANENT TEETH OF 339 CHILDREN AGED 11 TO 15 YEARS WHO USED SUCH WATER FOR EIGHTEEN MONTHS PRIOR TO ERUPTION OF THE FIRST PERMANENT MOLARS

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IT IS now generally conceded that children, 12 to 14 years of age, who have been exposed to fluoride-bearing communal waters during their entire lifetimes have a more favorable dental caries experience than individuals of the same age who have always lived in areas where the community water is fluoride-free. This fact, coupled with others elicited through experimental work with animals, led to the working hypothesis that blood-borne fluorides deposited in the enamel of a tooth during its calcification were primarily responsible for the caries-inhibitory effect and that the period of fluoride exposure essential to the inhibition of dental caries was that from birth to the age of 8 years.

More recently, Klein has reported upon two groups of individuals who had migrated into a fluoride area after reaching the age of 8 years. In both instances marked inhibition of dental caries was observed in teeth which had calcified during residence in a fluoride-free area but which had been exposed to a fluoride-bearing water after eruption. The children were resident in the fluoride area at the time of examination.

The present study is the counterpart of those cited in that it deals with children, residents of a low-fluoride area at the time of examination, who had been exposed to a fluoride-bearing water for varying lengths of time, both prior to and subsequent to the eruption of their first permanent molars.

The present report details the status of the permanent teeth of 873 continuous-residence children of a community which accidentally fluorinated its water for a period of eighteen months extending from August 26, 1935, to March 10, 1937, and in particular with the 339 children now 11 to 15 years of age who received this dosage of fluorides prior to the eruption of their first permanent molars.

All of the children described in this report were residents of Mitchell, a community of approximately 11,000 people situated near the center of the so-called "artesian basin" of South Dakota. This basin extends roughly from the Missouri River eastward to within about thirty miles of the state's eastern boundary, north into North Dakota, and south into Nebraska. In this area surface water tends to be scanty or very hard. Both individuals and communities have drilled artesian wells into the Dakota sandstone to obtain a soft and
potable water; in some counties of the basin, as many as 80 per cent of the rural wells are artesian wells. Water from this aquifer is remarkably nonfluctuant in its chemical composition, both from place to place and from time to time. Its outstanding characteristics are a high sulfate content and a fluoride level which rises gradually from about 1.5 p.p.m. at the southern edge of the basin to a value of 4.0 p.p.m. or higher at the northern boundary of the state. In this area no well into a sandstone aquifer has ever been reported as yielding a fluoride-free water. Fluorosis in children of this area was studied by Dean, Elvoe, and Poston in 1938, and examination reports of children of the basin were the raw data for Dean’s first correlation between fluoride exposure and the inhibition of dental caries. Most of the artesian wells within a radius of thirty miles of Mitchell yield water carrying from 2.6 to 3.0 p.p.m. of fluorides.

Prior to August 11, 1930, Mitchell obtained its community water from a number of artesian wells, which were marked as typical Dakota sandstone wells by the high sulfate content of their waters. On that date the city began the use of impounded surface water which has been tested for fluorides periodically since August, 1937; the mean and most constant determination has been 0.2 p.p.m., with comparatively little fluctuation.

In 1935 drought had so depleted this surface supply that “it became necessary . . . to supplement the lake water with well water, and then later it appeared advisable to abandon the lake for water entirely.” On August 26 of that year, water from one of the previously used artesian wells, which had been retained as a stand-by source, was turned into the city mains.

Two wells, each approximately 538 feet deep and within a few yards of each other, were used singly or in combination during the following eighteen months. The aquifer is a sandstone which was entered at a depth of 515 feet. In 1946 the wells were reopened for the purpose of obtaining a water sample for fluoride analysis; this sample showed a fluoride inclusion of 2.8 p.p.m., quite consistent with year-by-year analyses of similar wells in the neighborhood. This presumptive evidence that water from these wells contained about that concentration of fluorides during the 1935-1937 pumping period is supported by the observation that about seven per cent of Mitchell teen-age children who used this water during that time now exhibit very mild or mild dental fluorosis.

Pumpage from the wells was intermittent during this period of eighteen months. For the first four months the proportion was about one-third well water to two-thirds lake water. For the following two months well water was used exclusively. During March, April, May, and June of 1936, surface water was used exclusively. Water was then mixed for five months; and for the final three months of this period, well water was again used exclusively. The probable fluoride levels for the period in question, then, were: during the initial four months, about 1.0 p.p.m.; during the following two months, about 2.8 p.p.m.; during the following four months, about 0.2 p.p.m.; during the following five months, slightly above 1.0 p.p.m.; and for the final three months, about 2.8 parts per million. During the entire period 417,702,000 gallons of water (63.54 per cent) were pumped from the low-fluoride surface source, and 239,704,000 gallons
from the wells. Ignoring the variations in mixing the mean fluoride content of Mitchell's tap water for this period was probably in the neighborhood of 1.15 parts per million.

Since March 10, 1937, none of Mitchell's artesian wells has been pumped for more than an hour or two at a time.

In all, 2,140 white children ranging in age from 5 to 22 years were examined, using mouth mirror and explorer. Of this number, 873 were subsequently found to be continuous residents. Among the migrants an additional group of 297 children were found who had been exposed to fluoride-bearing waters somewhere in the South Dakota artesian basin for a period of one year or more before moving to Mitchell.

While the dentists of the area had made extensive use of topical sodium fluoride treatments during the summer before the examinations were begun, it is believed that these treatments were too recent to have made any essential difference in the D.M.F. patterns seen in these children.

**METHOD**

All of the examinations were made by the author, using No. 5 plane mouth mirrors and explorers, and all were recorded by the same assistant. The same portable operating light was used throughout. The residence history of none of the children was known at the time of examination. The examinations were begun in November, 1947, and concluded in March, 1948. Children of all five elementary schools, the junior high school, and both high schools were included; all but 33 of the children enrolled in the entire school systems were examined.

Criteria were the same as those established for the 1933-1934 national survey\(^{11}\) except that "catches" were not considered carious in the absence of other indications of disease. An attempt was made to use criteria comparable to those followed during the Hagerstown studies,\(^{12}\) since comparison with those results was contemplated.

Residence histories for children in the elementary schools were obtained through schedules completed and signed by parents. In the few cases where schedules were not returned, the children were considered to be noncontinuous residents. In the junior and senior high schools the purpose of the survey was explained to the pupils at a preliminary assembly. The importance of an accurate history of residence and water usage was stressed; each child was asked to verify his own history with his parents and to come to the examination room prepared to answer questions in detail. The history was then elicited by interview at the conclusion of each individual examination. The cooperation received was excellent and it is believed that the individual histories so obtained are reasonably accurate and complete. At the outset, random checks were made against original records of Davison County or the State of South Dakota, or individual parents were interviewed for confirmation. Since these checks uniformly supported the history as given by the child this procedure was abandoned after the first 400 children had been examined.
The status of the permanent teeth of the entire group of 2,140 children is outlined in Table I. Their over-all D.M.F. rates are shown graphically in Fig. 1. For purposes of comparison the Hagerstown D.M.F. rate\(^{12}\) is plotted in Fig. 1, together with a base line previously computed here as representative of the D.M.F. prevalence to be expected in any low-fluoride South Dakota community. This base line is a composite of the examination results for 8,330 children of known low-fluoride areas in 1933-1934,\(^{11}\) 2,185 in 1946, and 3,206 in 1947, expressed as a curvilinear trend having the formula \(Y = 8.75 + 42.43X + 3.06X^2\).

Fig. 1.—D.M.F. rates of 2,094 white elementary and high school children of Mitchell, South Dakota, 1947-1948, together with D.M.F. rates of Hagerstown, Maryland, children and a base line representing age-specific D.M.F. rates expected in South Dakota children who are residents of a low-fluoride community.

It will be seen that, on the whole, the caries experience of Mitchell children is slightly better than either the Hagerstown or the expected experience at all ages, and particularly in children 14 years of age or older; that it tends to follow the pattern of the Hagerstown and basic South Dakota rates, particularly at the younger ages; and that, up through the age of 16, about the same conclusion will be reached regardless of whether a specific Hagerstown rate or a South Dakota base-line rate is used as a basis for comparison.

**Continuous-Residence Children.**—The term "continuous resident," used for convenience throughout this study, is applied only to Mitchell children who have used Mitchell’s community water continuously since birth; certain residents of the city who had used water from other sources during a part of their lives have been excluded from this category. Included in this group are 437 boys.
and 436 girls, a total of 873. The group is further subdivided; there were 216 boys and 209 girls, aged 5 to 10 years, whose fluoride exposure had been negligible, and 165 boys and 174 girls, aged 11 to 15 years, who had been exposed to the accidentally fluorinated water some time after birth and prior to the eruption of the first permanent molars.

The status of the permanent teeth of these children is summarized in Table II and their D.M.F. rates through the age of 15 years are shown graphically in Fig. 2. Continuous-residence children aged 16 years or older are not considered in this report, since their 1935-1937 fluoride exposure came after the eruption of their first permanent molars, and because some of them had previously been exposed to Mitchell’s original high-fluoride, artesian-well community water supply.

It will be seen, in Fig. 2, that the rates for these children are somewhat higher than those which were seen in Hagerstown children, or which would have been predicted from the South Dakota base line. Had there been any marked caries-inhibitory effect following the eighteen months of fluoride exposure undergone by the 11- to 15-year age groups, their D.M.F. curve should have broken sharply downward through these age points. This is not the case.

Controls.—Since the expected inhibition of dental caries is absent or negligible, the matter of controls becomes of more than usual importance in this study. There are two standards by which the observed experience of these 11- to 15-year-old children may be judged: their expected caries rates as estimated from the experience of children aged 5 to 10 years now living in the same community, or the actual experience of similar children in other places or at other times.
### Table II

**Status of the Permanent Teeth of 873 White Elementary and High School Children, All Continuous Residents of Mitchell, South Dakota, 1947-1948**

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Number of Children</th>
<th>Mean Number of Teeth in Eruption</th>
<th>Per Cent Children with D.M.F. Teeth</th>
<th>Number of D.M.F. Teeth</th>
<th>D.M.F. Rate</th>
<th>Missing Teeth per 100 Children</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>73</td>
<td>1.47</td>
<td>0.0</td>
<td>0</td>
<td>0.0</td>
<td>—</td>
</tr>
<tr>
<td>6</td>
<td>68</td>
<td>5.94</td>
<td>13.2</td>
<td>16</td>
<td>17</td>
<td>23.5</td>
</tr>
<tr>
<td>7</td>
<td>76</td>
<td>8.58</td>
<td>30.3</td>
<td>40</td>
<td>42</td>
<td>52.6</td>
</tr>
<tr>
<td>8</td>
<td>74</td>
<td>12.14</td>
<td>55.4</td>
<td>94</td>
<td>114</td>
<td>127.0</td>
</tr>
<tr>
<td>9</td>
<td>79</td>
<td>13.84</td>
<td>67.1</td>
<td>151</td>
<td>198</td>
<td>191.1</td>
</tr>
<tr>
<td>10</td>
<td>55</td>
<td>18.58</td>
<td>85.5</td>
<td>147</td>
<td>213</td>
<td>267.3</td>
</tr>
<tr>
<td>11</td>
<td>75</td>
<td>22.01</td>
<td>84.0</td>
<td>246</td>
<td>381</td>
<td>328.0</td>
</tr>
<tr>
<td>12</td>
<td>79</td>
<td>25.35</td>
<td>91.1</td>
<td>307</td>
<td>510</td>
<td>388.6</td>
</tr>
<tr>
<td>13</td>
<td>61</td>
<td>27.05</td>
<td>88.5</td>
<td>318</td>
<td>546</td>
<td>521.3</td>
</tr>
<tr>
<td>14</td>
<td>64</td>
<td>27.59</td>
<td>89.1</td>
<td>353</td>
<td>585</td>
<td>551.6</td>
</tr>
<tr>
<td>15</td>
<td>60</td>
<td>27.95</td>
<td>95.0</td>
<td>457</td>
<td>792</td>
<td>761.7</td>
</tr>
<tr>
<td>16</td>
<td>47</td>
<td>28.15</td>
<td>85.1</td>
<td>313</td>
<td>570</td>
<td>666.0</td>
</tr>
<tr>
<td>17</td>
<td>58</td>
<td>28.32</td>
<td>94.6</td>
<td>428</td>
<td>756</td>
<td>764.3</td>
</tr>
<tr>
<td>18</td>
<td>4</td>
<td>28.75</td>
<td>100.0</td>
<td>32</td>
<td>64</td>
<td>800.0</td>
</tr>
<tr>
<td>19</td>
<td>1</td>
<td>28.00</td>
<td>100.0</td>
<td>2</td>
<td>2</td>
<td>200.0</td>
</tr>
<tr>
<td>22</td>
<td>1</td>
<td>30.00</td>
<td>100.0</td>
<td>8</td>
<td>24</td>
<td>800.0</td>
</tr>
<tr>
<td>Total</td>
<td>873</td>
<td>65.9</td>
<td>2,912</td>
<td>4,814</td>
<td>16.6</td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 2.—D.M.F. rates of 764 white continuous-residence children of Mitchell, South Dakota, 1947-1948, together with D.M.F. rates of Hagerstown, Maryland, children and a base line representing age-specific D.M.F. rates expected in South Dakota children who are residents of a low-fluoride community.**

Knutson has demonstrated a rough correlation between the percentages of children with D.M.F. experience at any age and the D.M.F. rate for that age group; he has suggested a mass survey method in which the percentage of children with one or more D.M.F. teeth is obtained for the ages of 7, 9, and 11, from which a straight-line trend is computed and extrapolated as a basis for the...
estimation of D.M.F. rates for the older age groups. Had this technic been used at Mitchell, a total of 1,495 D.M.F. teeth would have been estimated for the 339 children aged 11 to 15 years. The total obtained by mouth-mirror examination is 1,680. The Knutson technic, then, would have underestimated the actual number of D.M.F. teeth by 185, an underestimation of 11.0 per cent.

However, with South Dakota data at least, this method invariably underestimates the D.M.F. rates of teen-age children. It presumes that the D.M.F. rate rises with age in a straight line, whereas the actual pattern is usually a pronounced curve. As a matter of fact, age-specific D.M.F. rates for school-age children of either sex plot as a rather complex but typical curve with periods of acceleration and lag which follow periods of tooth eruption and intervals when eruption is at a minimum. When data for school-age groups including both boys and girls are plotted, the peaks and valleys in the sex-specific curves tend to offset each other, the resultant appearing as a fairly smooth parabolic curve with a definite upward acceleration from the age of about 11 years through the teens. This is true of all of the D.M.F. data which have so far come to the author's attention.

![Graph](https://example.com/graph.png)

**Fig. 3.**—Total number of decayed, missing, and filled permanent teeth found in 339 continuous-residence Mitchell, South Dakota, white children, aged 11 to 15 years, and numbers which would have been estimated by various public health technics.

In field practice, then, this division estimates the D.M.F. experience of older children by plotting a parabolic curve which, while still an over-simplification, permits a more accurate prediction of the actual D.M.F. pattern than one based upon a straight-line trend. The percentages of children at all ages up through 11 years are obtained, translated into D.M.F. rates through Knutson's formula, and analyzed as a curvilinear least-squares trend which is then extrapolated into the higher age ranges. Had this method of estimation been used at Mitchell, the total number of D.M.F. teeth in the 11- to 15-year groups would have been computed at 1,790, an overestimation of 110 or 6.58 per cent. In fact, the actual number of D.M.F. teeth would have been underestimated by only 153, or 9.1 per cent by a calculation from the South Dakota base line, even though none of the children at Mitchell had been examined.

The relative magnitude of these totals is shown in Fig. 3.
The first two results pictured are well within the limits of chance fluctuation. The South Dakota base line is not strictly comparable, since it reflects the combined experience of continuous residents and migrants. In the typical South Dakota community a significant percentage of migrant children will have been exposed to a fluoride-bearing water at some time during their lives, and their more favorable caries experience tends to lower the D.M.F. rates for the entire group.

It is clear, then, that eighteen months of fluoride exposure prior to eruption of the first permanent molars either resulted in no inhibition of dental caries in these children, or in one so small that it cannot be demonstrated on the basis of younger but otherwise similar children in the same community, or by comparison with theoretical rates previously computed to be representative of the D.M.F. experience of all present-day children living in low-fluoride communities of South Dakota.

![Diagram showing D.M.F. rates for children in different age groups]

Fig. 4.—Numbers of decayed, missing, and filled permanent teeth per 100 children in Sioux Falls, South Dakota, 1933-1934 (Bulletin 226), and in continuous residents of Mitchell, South Dakota, 1947-1948.

D.M.F. rates for South Dakota children examined in 1933-1934 have been reconstructed from Public Health Bulletin 226 by the method used by Dean in his original correlation of South Dakota fluorosis and dental caries data. In general, where no water-supply changes has occurred, these rates approximate very closely those found in South Dakota children of the same communities today. Mitchell children were not examined in 1933-1934, but Bulletin 226 includes data on 1,293 girls and 1,298 boys aged 6 to 14 years who were residents of Sioux Falls, a city 75 miles east of Mitchell and outside the artesian basin, with a kelly-well community water carrying 0.2 p.p.m. of fluorides, the same concentration as that in the present Mitchell water supply.

The data in Bulletin 226 are presented for children in age groups of 6 to 8, 9 to 11, and 12 to 14 years. Similarly grouped data from Table II yield D.M.F. rates for continuous-residence Mitchell children which are compared with those seen in Sioux Falls in 1933-1934 in Table III and in Fig. 4. Inspection of Fig. 4
Fig. 5.—D.M.F. rates for individual maxillary tooth types in 339 Mitchell, South Dakota, continuous-residence children, aged 11 to 15 years, and for 3,038 Hagerstown, Maryland, children, aged 11 to 15 years.

Fig. 6.—D.M.F. rates for individual mandibular tooth types in 339 Mitchell, South Dakota, continuous-residence children, aged 11 to 15 years, and in 3,038 Hagerstown, Maryland, children, aged 11 to 15 years.
shows that the experience of these two groups of children is substantially the same. The discrepancy in the 6- to 8-year group is probably due to the inclusion of "catches" as caries in the 1933-1934 examination.

**Table III**

**D.M.F. Rates at Grouped Ages for Continuous-Residence White Children of Mitchell, South Dakota, 1947-1948, with Similar Rates for Groups of Sioux Falls, South Dakota Children, 1933-1934**

<table>
<thead>
<tr>
<th>AGE GROUP</th>
<th>MITCHELL</th>
<th>SIoux FALLS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NUMBER OF CHILDREN</td>
<td>NUMBER OF D.M.F.</td>
</tr>
<tr>
<td>6 to 8</td>
<td>218</td>
<td>150</td>
</tr>
<tr>
<td>9 to 11</td>
<td>200</td>
<td>544</td>
</tr>
<tr>
<td>12 to 14</td>
<td>204</td>
<td>978</td>
</tr>
<tr>
<td>Total</td>
<td>631</td>
<td>1,672</td>
</tr>
</tbody>
</table>

It has been suggested that the caries-inhibitory effect of fluoride exposure is more marked in those morphological tooth types which are normally the more resistant to caries.\(^6\) D.M.F. rates for individual tooth types are available in the Hagerstown data.\(^15\) With the possibility in mind that certain individual tooth types in these Mitchell children might show an inhibition of caries which had been overshadowed in the total rates, the D.M.F. rate was calculated for each morphological tooth type in Mitchell children aged 11 to 15 years, and for Hagerstown children in the same age range. These rates are summarized in Table IV and compared graphically in Figs. 5 and 6.

**Table IV**

**D.M.F. Rates for Individual Teeth of 339 White Children Aged 11 to 15 Years With Continuous Residence in Mitchell, South Dakota (1947-1948) and of 3,038 White Children Aged 11 to 15 Years of Hagerstown, Maryland**

<table>
<thead>
<tr>
<th>TOOTH</th>
<th>MAXILLARY D.M.F. RATES</th>
<th>MANDIBULAR D.M.F. RATES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MITCHELL</td>
<td>HAGERSTOWN</td>
</tr>
<tr>
<td>Second molar</td>
<td>27.1</td>
<td>29.9</td>
</tr>
<tr>
<td>First molar</td>
<td>124.8</td>
<td>119.1</td>
</tr>
<tr>
<td>Second bicuspid</td>
<td>17.4</td>
<td>16.6</td>
</tr>
<tr>
<td>First bicuspid</td>
<td>15.9</td>
<td>16.3</td>
</tr>
<tr>
<td>Cuspid</td>
<td>5.6</td>
<td>2.5</td>
</tr>
<tr>
<td>Lateral incisor</td>
<td>32.7</td>
<td>29.9</td>
</tr>
<tr>
<td>Central incisor</td>
<td>34.8</td>
<td>31.0</td>
</tr>
<tr>
<td>All teeth</td>
<td>258.4</td>
<td>245.2</td>
</tr>
</tbody>
</table>

It will be seen by reference to these figures that the two D.M.F. patterns are strikingly similar. Chi square estimation indicates that the only significant differences occur in the upper cuspid and in the lower central incisor. In each case the fluoride-exposed Mitchell children show a substantially higher D.M.F. rate than did the Hagerstown children.

**Prevalence of Fluorosis.**—One hundred eighty-eight cases of dental fluorosis were discovered in the 2,140 children examined. One hundred fifty-six of these cases occurred in migrant children, appearing as early as the age of 6 and running the entire range of severity. The remaining 32 cases, all very mild or mild in degree, were found in continuous-residence children. Thirty-one
were in children 11 years of age or older, with 26 in the 11- to 15-year group with no known fluoride exposure except that in 1935-1937. The over-all prevalence for these ages was 7.67 per cent. Eight cases were found in 165 boys, a prevalence of 4.85 per cent, and 18 in 174 girls, a prevalence of 10.34 per cent. This variation verges upon statistical significance; the difference is $5.49 \pm 2.34$, establishing odds against chance of approximately 14 to 1.

**SUMMARY AND CONCLUSIONS**

1. The community water of Mitchell, South Dakota, was accidentally fluorinated to a mean level of 1.15 p.p.m. for the eighteen months subsequent to August 26, 1936. The normal fluoride content of Mitchell's community water is 0.2 part per million.

2. Of 339 Mitchell children now 11 to 15 years of age who underwent this fluoride exposure prior to the eruption of their first permanent molars, about 10 per cent of the girls and about five per cent of the boys show very mild or mild dental fluorosis.

3. No inhibition of dental caries can be demonstrated in this group on the basis of the caries prevalence in younger children in the same community.

4. No dental caries inhibition can be demonstrated in this group by comparison with a base line calculated from the D.M.F. rates of contemporary children in other South Dakota communities.

5. No caries inhibition can be demonstrated in this group by comparison with the D.M.F. rates of similar children in a comparable South Dakota community in 1933-1934.

6. No inhibition of dental caries can be demonstrated in this group by comparison with over-all D.M.F. rates of Hagerstown children of the same ages, nor by comparison of the D.M.F. rates for individual tooth types between this group and Hagerstown children of the same ages.

7. These findings tend to weaken the hypothesis that the mechanism whereby dental caries is inhibited through exposure to fluoride-bearing drinking waters depends essentially upon the deposition of fluorine in dental enamel during the period of calcification.

The sincere thanks of the author are due to Superintendent of Schools Lloyd Uecker, Sister M. Martha, City Engineer J. C. Scallin, and in particular to School Nurse Helene Tobin Baker for their unfailing courtesy and their essential assistance during the fourteen weeks this survey was in progress in the Mitchell schools.

**REFERENCES**


