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What is This?
The Relation Between Caries Prevalence and Strontium Concentrations in Drinking Water, Plaque, and Surface Enamel

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Samples of plaque and surface enamel were collected from 80 boys aged 14 years living in five communities in Ohio (USA). Mean (± SE) strontium concentrations in plaque were 1.43 ± 0.18 μg/g (wet) and 12.34 ± 1.63 μg/g (dry). For surface enamel, the mean concentration was 421 ± 31 μg Sr/g. Concentrations of strontium in both plaque and enamel were significantly related to strontium levels in the drinking water. Caries prevalence as DMFS was inversely related to strontium levels in water, plaque, and enamel.


Introduction.

Studies on caries-free sailors inducted into the U.S. Navy showed a disproportionate number of these men originating from a small, rural area of Ohio (Loese and Adkins, 1969). Subsequent epidemiologic studies in this same geographic area indicated a low level of caries prevalence associated with several trace elements (boron, lithium, molybdenum, and strontium) in the water supplies (Curzon et al., 1970). A further dental survey in an area of Wisconsin again showed that low caries prevalence could be associated with elevated strontium concentrations in drinking water (Curzon et al., 1978).

Schamschula et al. (1978) carried out studies in Papua, New Guinea, and reported significant relationships between dental caries and several trace elements, including lithium and strontium. The major findings were a significant negative relationship between dental caries and the trace element lithium in plaque and enamel and also strontium in enamel. Because of the Schamschula’s report indicating associations of trace elements in plaque and surface enamel with caries, it was appropriate to investigate the levels of strontium in plaque and surface enamel in the low-caries area of Ohio where there was a high concentration of strontium in the drinking water.

Materials and methods.

At the same time as an epidemiologic survey was being conducted on the relationship of strontium in water supplies to dental caries (Curzon, 1983), several plaque and surface enamel samples were collected for analysis. Donors were consenting 14-year-old male life-long residents of five communities in Ohio. Three of these communities had drinking water supplies with elevated strontium levels of 7.26 to 15.3 mg Sr/l and with fluoride concentrations of approximately 1.0 mg/l. Of the two control communities, one used artificially flouridated water at the same level as in the test communities, and the second had low strontium (<0.3 mg/l) and fluoride (<0.1 mg/l) in its drinking water.

At least two hours after the donors had eaten, plaque was collected from all four permanent pre-molars using a sterile, half-circle surgical needle held in an instrument-holder. Plaque was collected from the buccal surface of each tooth, avoiding the gingival margin to prevent contamination with blood or gingival fluid, and pooled to provide one sample per subject. During the collection procedure, cotton wool rolls were used to isolate the area from saliva. Collected plaque was scraped into a prepared, pre-weighed, Teflon boat (after the method of Gilmour et al., 1978), which was weighed as soon as possible on a Cahn Portable Balance. By taking five readings at 30-second intervals and plotting weights, on graph paper, it was possible to extrapolate back to zero time to determine wet weight as collected. After the plaque-filled Teflon boats were weighed, they were placed in coded capsules for transportation.

After plaque collection, the buccal surface of the right maxillary permanent pre-molar was lightly cleaned using a handheld, disposable, battery-operated, prophylaxis head with a rubber cup and a slurry of silicon carbide (600-mesh) in distilled water. The surface was dried with alcohol and re-isolated with a cotton wool roll. To the buccal surface was fixed a double thickness of adhesive electrical tape1 (3M Scotchgard) containing a 3-mm-diameter hole to form a well on the enamel surface. Into the well was placed a 3-mm disc of Millipore pre-filter soaked with 10 μl of 2.5 N HClO4 in a 30% glycerol solution for an enamel biopsy, after the method of Spector and Curzon (1978). The etchant was held on the enamel surface in the pre-filter disc with an amalgam plugger and gently pumped for 15 seconds. The pre-filter disc was then removed and replaced by a second dry disc to dab off excess etchant. Both discs from each etch were dropped into 2 ml of distilled deionized water in a 5 ml Falcon2 tube, sealed, and coded for transportation. The enamel surface was then swabbed with a sodium bicarbonate solution to neutralize any traces of residual acid, which was followed by an application of fluoride gel.

On receipt in our laboratories, the plaque samples, in their Teflon boats, were re-weighed to constant dry weight. Each boat was dropped into a 1.5-ml polypropylene centrifuge tube together with 100 μl of 9M HNO3 and left to digest for 30 minutes. After digestion was complete, the samples were analyzed for strontium by flameless atomic absorption spectrophotometry, using standard methods. Several unused Teflon boats were processed using the nitric acid to provide analytical blanks.

Surface enamel biopsy solutions were analyzed for calcium and strontium using flame atomic absorption spectrophotometry (Perkin-Elmer Model 403). Lanthanum chloride was added to each sample to prevent interference from other ions. Using the results of the calcium analyses, we calculated the weight of enamel removed for each sample and from this deduced the concentration of strontium in each enamel sample (Spector and Curzon, 1978).

Samples of drinking water were obtained at the same time as the plaque and analyzed for trace elements by atomic ab-

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TABLE 1
RESULTS OF WATER, PLAQUE, AND ENAMEL ANALYSES FOR STRONTIUM AND DMFS SCORES

<table>
<thead>
<tr>
<th>Town</th>
<th>Sr</th>
<th>F</th>
<th>Mean Strontium Concentration (± S.E.)</th>
<th>Enamel</th>
<th>DMFS Score mean (± S.E.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(mg/l)*</td>
<td></td>
<td>Dry µg/g</td>
<td>Wet µg/g</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Celina - C</td>
<td>0.22</td>
<td>&lt;0.1</td>
<td>2.96 ± 0.69</td>
<td>0.59 ± 0.13</td>
<td>196 ± 29</td>
</tr>
<tr>
<td>Celina - R</td>
<td>7.62</td>
<td>1.1</td>
<td>29.08 ± 10.03</td>
<td>2.30 ± 0.64</td>
<td>365 ± 36</td>
</tr>
<tr>
<td>Portsmouth</td>
<td>0.22</td>
<td>0.9</td>
<td>1.87 ± 0.61</td>
<td>0.36 ± 0.10</td>
<td>95 ± 15</td>
</tr>
<tr>
<td>Delphos</td>
<td>7.26</td>
<td>1.1</td>
<td>9.27 ± 1.86</td>
<td>1.16 ± 0.44</td>
<td>495 ± 52</td>
</tr>
<tr>
<td>Ft. Recovery</td>
<td>10.2</td>
<td>0.9</td>
<td>18.76 ± 4.91</td>
<td>2.25 ± 0.42</td>
<td>660 ± 67</td>
</tr>
<tr>
<td>Coldwater</td>
<td>15.3</td>
<td>1.2</td>
<td>22.86 ± 3.31</td>
<td>1.98 ± 0.52</td>
<td>509 ± 44</td>
</tr>
</tbody>
</table>

C = Celina, city; R = Celina, rural.
* = determined on samples collected on day of study.

TABLE 2
REGRESSION ANALYSIS OF DMFS WITH STRONTIUM IN PLAQUE AND ENAMEL (µg/g)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>t value</th>
<th>Probability of Parameter = 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>2.949</td>
<td>0.257</td>
<td>11.49</td>
<td>0.0001</td>
</tr>
<tr>
<td>Sr in plaque</td>
<td>−0.2095</td>
<td>0.086</td>
<td>−2.41</td>
<td>0.018</td>
</tr>
<tr>
<td>Sr in enamel</td>
<td>−0.0015</td>
<td>0.0005</td>
<td>−2.86</td>
<td>0.006</td>
</tr>
</tbody>
</table>

Results.

Cooperation was very good, and the percentage of 14-year-old life-long resident males consenting for sampling varied between 62 and 76% of those eligible. In one control community, Celina, it was found that the children attending the school came mainly from the city, which used lake water, but included a small number of children who were brought in each day from an outlying rural village (Montezuma), which used its own well for drinking water. Accordingly, results for Celina included some boys from the city (lake water) and some from the rural areas (well water). Altogether, 80 samples of plaque and enamel were collected in the five communities.

Results for strontium concentrations in plaque, surface enamel, and drinking water supplies are shown in Table 1. The mean depth of etches was 4.2 µm for all samples. The strontium concentrations identified in the plaque samples were in the range <0.1–8.7 µg/g wet weight, with an overall mean of 1.43 µg/g (± 0.18 SE). On a dry weight basis, the mean strontium level in plaque was 12.34 µg/g (± 1.63). The analysis of the surface enamel etches showed mean strontium levels of 421 µg/g (± 31) with a range of ‘‘not detected’’ to 1270 µg/g.

Since an analysis of variance (ANOVA) demonstrated differences between towns for both strontium in plaque (F = 3.83; p = <0.005) and enamel (F = 7.92; p = <0.001), we performed polynomial breakdowns, based on the strontium level of the water supply. The results showed a linear relationship between strontium in water and strontium in both plaque and enamel (p = <0.0001).

Since the DMFS index had been recorded for each boy at the time of sample collection, it was possible to relate drinking water strontium concentrations to individual caries prevalence. The relationship of DMFS to strontium in water supplies is shown in the Fig. and is very similar to that reported previously (Curzon et al., 1978). The results of an analysis of variance showed a significant (F = 6.65; p = <0.001) inverse relationship between dental caries and the water strontium concentration. The analysis also showed that the relationship had a quadratic component, although at a weaker level of significance (p = <0.05). Such a relationship has been demonstrated previously (Curzon et al., 1978).

Discussion.

For surface enamel, our finding of 421 µg/g strontium compares with 100.7 µg/g reported by Schamschula et al. (1978) and 67 µg/g by Brudevold et al. (1975). Thus, the levels of strontium in enamel from Ohio were far higher than those reported previously. The findings of Schamschula et al. (1978) were comparable with our results for the low-strontium communities of Celina (city) and Portsmouth. Thus, changes in the amount of strontium available from the water supplies, and presumably also in the food, were reflected in surface enamel.

In the Papua, New Guinea, study (Schamschula et al., 1978), mean strontium concentrations in plaque, on a dry weight basis, were 20.4 µg/g (± 1.01 SE); in samples from Australia (Schamschula et al., 1977), they were 3.58 ± 0.53. The mean plaque strontium value of 12.34 µg/g (± 1.63) in our study therefore fell between the levels reported by Schamschula. The subjects used for the Papua study were habitual chewers of sorption spectrophotometry and ion-specific electrode (Curzon et al., 1978).
betel nut together with lime. The latter would contain strontium as a contaminant, and would be a source for increased strontium uptake by the plaque. For the communities in our study, with low strontium in water supplies, the mean dry plaque concentration of 2.41 µg/g was directly comparable with the level first reported by Schamschula et al. (1977), also for communities with low strontium in their drinking water.

The ratio of strontium in wet plaque to that in dry plaque was 7.9% for rural Celina as compared with 19.9% for Celina city samples. In addition, the Coldwater samples had a ratio of 8.7%. Thus, where the water supplies were hardest, and therefore with considerably more mineral content, the wet/dry ratio was lowest. It is not clear why this should be so, and it would merit further investigation.

The finding of a significant inverse relationship between caries and the level of strontium in surface enamel was surprising in light of the lack of such a finding in a previous study (Spector and Curzon, 1978). In the latter study, no significant relationship was found between individual caries prevalence and strontium in surface enamel in teeth extracted from the donors. The caries levels (as DMFT) used by Spector and Curzon for their analyses were based upon those reported by the dentist who had extracted the teeth for orthodontic purposes. These factors may have led to a bias in the caries levels used for statistical calculations. By contrast, in the present study the subjects formed a representative sample of the population, and the caries (as DMFS) was diagnosed by the author at the time of sampling. The results found here may therefore be considered a more representative finding, although the number of subjects involved is relatively small. Further work is indicated to confirm these findings in larger population groups.

As described previously (Curzon et al., 1984), caries prevalence increased once strontium levels in drinking water were above about 10 mg/l. However, for plaque and enamel, strontium concentrations were essentially linearly related to those in water. So there is an apparent change in caries, depending on the strontium levels. Fluoride concentrations, with the exception of those in Celina city, were virtually the same in each town.

Since the mechanism of action of strontium in reducing caries prevalence is not yet known, it can be speculated that the relationship between strontium in plaque and enamel may be important. Until the present study, no clear relationship between caries and the level of strontium in surface enamel had been found. A significant negative relationship between caries prevalence and strontium has been found only for strontium in whole enamel (Curzon and Losee, 1977; Vrbic and Stupar, 1980), although Little and Barrett (1976) found a significant negative relationship between caries and strontium in “surface” enamel for teeth collected from different geographic areas of the USA. However, in this latter study the surface enamel was some 20 µm deep and not exactly comparable to the present report, where a mean depth of 4.2 µm was used.

It has been suggested that strontium may contribute to remineralization of the subsurface zone of the early caries lesion (Featherstone et al., 1981). If this is so, then it is not surprising that significant relationships between caries and strontium in surface enamel have not been shown. The amount of enamel removed in most surface enamel etches is usually quite large (from 9 to 20 µm), and any surface effect of the strontium may be only in the outermost layers of the enamel, at a depth of <2 µm.

The strontium concentrations in plaque reported here may be as important. A significant relation of strontium in plaque solids to drinking water levels was previously found in the Wisconsin studies (Spector and Curzon, 1977), and the present study confirms such a relationship. Strontium in the plaque would be available for remineralization, but it is not known whether this strontium is present mainly in the plaque solids or fluids. In addition, the number of subjects available in this study was small, and hence the standard errors on some of the data were large. It may be that the high levels of strontium in plaque reported here and previously (Spector and Curzon, 1977) in low-caries communities are related to a possible action of the strontium together with fluoride, in remineralizing early caries.

In this study, the relationship of caries prevalence (as DMFS) to strontium in enamel (or plaque) was difficult to determine, since the strontium concentrations were so obviously related to town of residence (and use of drinking water). We therefore attempted a regression analysis on DMFS, with strontium in plaque and enamel as the independent variables. Due to the nature of the DMFS variable, it was appropriate to use \( \sqrt{\text{DMFS}} + 0.5 \) in the analysis (Steel and Torrie, 1980), the results of which are shown in Table 2. The significant probabilities \(<0.05\) for the plaque and enamel, and their negative signs, imply that as strontium in enamel or plaque increases, so the DMFS tends to decrease. This is, however, a mathematical relationship and does not necessarily imply a cause-and-effect condition.

REFERENCES


