INCORPORATION OF FALL-OUT STRONTIUM-90 IN DECIDUOUS INCisors AND FETAL BONE

By Dr. HAROLD L. ROSENTHAL, SHIRLEY AUSTIN, SHEILA O’NEILL and KUNISUKE TAKEUCHI*
Department of Physiological Chemistry

JOHN T. BIRD
Department of Dental Medicine

AND

JOHN E. GILSTER
Department of Pedodontics, School of Dentistry, Washington University, St. Louis, Missouri

In a previous article, Rosenthal et al.1 reported that deciduous incisor teeth of children born between 1955 and 1956 who were bottle-fed from birth contained only 22 per cent more strontium-90 than teeth of children who were breast-fed for an average of 25 weeks. On the basis of known *Sr/g Ca in the mother’s diet and known discrimination factors, teeth from bottle-fed children were expected to contain considerably more strontium-90 than that found in the teeth from breast-fed children. Because the strontium-90 content of teeth is thought to represent the strontium-90 body burden during the time the teeth are formed, it was desirable to obtain further data on the differences in tooth strontium-90 between breast-fed and bottle-fed children in order to qualify the discrepancies between theoretical considerations and analytical observations.

Samples of non-caries deciduous incisor teeth of children born between 1950 and 1958 within a radius of 150 miles of St. Louis were pooled and analysed for strontium-90 as previously described.2 Samples of teeth from children born during 1957 were divided into 3 groups representing teeth of children who were breast-fed for 6 months or more after birth, teeth of children breast-fed for 6 weeks to 6 months, and teeth of children who were bottle-fed from birth. In the latter group, it was deemed advisable to include samples of teeth from children who were breast-fed for less than 6 weeks because these children were probably, and intermittently, bottle-fed. The 1957 sample contained equal amounts (2 g) of tooth crowns. Although teeth from the first and last six months of the birth year were analysed separately, the data were averaged for the entire yearly interval. Tooth buds and mandibles were obtained from fetuses 7–9 months of age between 1961 and 1963. They were defleshed by boiling in distilled water, and the hard tissues from 3–5 fetuses were pooled for each analysis.

Because analyses of *Sr content of milk in the St. Louis milk shed did not begin until 1958, the values of the Perry, New York, milk shed obtained by the New York Health and Safety Laboratories of the U.S. Atomic Energy Commission were used between 1954 and 1958. A comparison of the Perry, New York, values with the St. Louis values for 1959–63 demonstrates that St. Louis values average 1.14 times greater than Perry, New York, values. This correction has been made although these small differences do not alter the results. The milk values between 1950 and 1953 are not known and have been estimated by extrapolation of the logarithm of the milk concentration from Perry, New York, versus time for the years 1954–56 using average yearly values.

The observed values obtained for the tooth samples are shown in Table 1, and demonstrate that teeth of bottle-fed children contain 19 per cent more strontium-90 than the teeth of children who were partly breast-fed (P < 0.01) and 33 per cent more than the teeth of completely breast-fed children (P < 0.01). The theoretical *Sr/g Ca of teeth (Ct) was determined by expansion of the basic equation (1) developed by Reiss:

\[ C_T = 0.32 \text{ pre-natal } \text{*Sr/g Ca} + 0.68 \text{ post-natal } \text{*Sr/g Ca} \]  

The factors 0.32 and 0.68 represent the fraction of tooth calcium deposited during the pre- and post-natal periods, respectively. For bottle-fed children, equation (1) becomes:

\[ C_T = (0.32) (1.2) C_T' D_m + 0.68 C_T' D_T \]  

where \( C_T \) is tooth *Sr/g Ca, \( C_T' \) is the mother’s dietary intake of *Sr/g Ca from milk and the total dietary *Sr/g Ca in the American diet is 1.2 times the amount of *Sr/g Ca found in milk. \( D_m \) is the discrimination factor against *Sr between the mother’s dietary intake and her fetus, \( C_T' \) is the infant’s milk intake of *Sr/g Ca and \( D_T \) is the infant’s discrimination factor against *Sr between dietary intake and bone.

Table 1. Strontium-90 Content of Deciduous Incisors from Bottle- and Breast-Fed St. Louis Children Born in 1957

<table>
<thead>
<tr>
<th>Type of samples</th>
<th>No. of teeth</th>
<th>Trueness</th>
<th>S.E.</th>
<th>Cals. *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottle-fed (6 weeks)</td>
<td>11</td>
<td>2.37 ± 0.08</td>
<td>258</td>
<td></td>
</tr>
<tr>
<td>Breast-fed (&lt;6 months)</td>
<td>12</td>
<td>2.14 ± 0.52</td>
<td>206</td>
<td></td>
</tr>
<tr>
<td>Breast-fed (6 months)</td>
<td>6</td>
<td>2.27 ± 0.06</td>
<td>122</td>
<td></td>
</tr>
</tbody>
</table>

* Calculated from equation (4) and (6). The milk concentration during 1957 averaged 4.52 µe/g Ca.

In order to solve equation (2), values for \( D_m \) and \( D_T \) must be experimentally determined. A discrimination factor of 0.13 for \( D_m \) appears reasonable as determined from fetal bone investigations in this report and by Reiss.4 A value for \( D_T \) of 0.6 has been selected as an intermediate value on the basis that children under 60 days of age do not discriminate against *Sr (ref. 4) and *Sr discrimination in children under 1 year of age is probably less than 0.5 (ref. 5). Using these estimates, equation (2) may be solved to yield:

\[ C_T = 0.05 C_T' + 0.64 C_T' \]  

Because the incisor teeth develop and calcify in less than 1 year, the *Sr/g Ca in milk (\( C_T' \) and \( C_T' \)) may be averaged for yearly intervals and equation (3) becomes:

\[ C_T = 0.59 C_T' \]  

The validity of equation (4) is shown in Fig. 1, where the determined values of *Sr/g Ca in the incisor teeth of bottle-fed children born during 1950–58 are plotted against the milk nuclide concentration. The determined values compare favourably with the line drawn from equation (4).
The prenatal contribution from the mother's diet to the fetal teeth and bone may be defined as:

\[ C_T = 1.32 C_B D_m \]

and with \( D_m \) equal to 0.13:

\[ C_T = 0.16 C_B \]

The values for the tooth buds and bone of fetuses between 1961 and 1963 (Table 2) demonstrate the equilibrium fraction \( \text{Sr/g Ca} \) in the hard tissues of the developing fetus, as has been previously shown, and the agreement between equation (6) and the determined values is satisfactory. This agreement also lends validity to the value of 0.13 for \( D_m \), which indicates a discrimination factor of 8 against strontium-90 relative to calcium between the mother's diet and her fetus. The value for \( D_m \) is also in agreement with the values found by Conant in animals but differs from the findings of Kulp, who observed that the concentration of strontium-90 in fetal bone averaged one-twelfth of that in the mother's diet.

### Table 2. Strontium-90 Content of Fetal Tooth Buds and Mandible Bone

<table>
<thead>
<tr>
<th>Year</th>
<th>No. of Tooth</th>
<th>Bone ( D_m )</th>
<th>Bone ( C_B )</th>
<th>Bone Bone Calc. Average Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1961</td>
<td>13</td>
<td>1.32 ± 0.17</td>
<td>1.22 ± 0.17</td>
<td>1.22 ± 0.17</td>
</tr>
<tr>
<td>1962</td>
<td>3</td>
<td>1.32 ± 0.14</td>
<td>1.22 ± 0.22</td>
<td>1.22 ± 0.22</td>
</tr>
<tr>
<td>1963</td>
<td>3</td>
<td>0.93 ± 0.24</td>
<td>0.93 ± 0.24</td>
<td>0.93 ± 0.24</td>
</tr>
</tbody>
</table>

Wetted average 0.66

* Values expressed as \( \text{Sr/g Ca} \)

\[ C_T = 0.032 (1.2) C_B D_m + 0.068 (1.2) C_B D_m C_T \]  

When \( C_T \) and \( C_B \) are the same, equation (7) becomes:

\[ C_T = 0.135 C_B \]

Solution of equations (4) and (8) for completely breastfed and completely bottlefed children born in 1957 in St. Louis, as compared with the determined values, are shown in Table 1. The tooth of children who were breastfed for less than 6 months the intermediate between completely breast-fed and completely bottle-fed children although equation (4) appears to be satisfactory for breast-fed children, the determined values for breast-fed are three-fold higher than expected when calculated from equation (8).

The difference between the theoretical and determined values for the \( \text{Sr/g Ca} \) in the teeth of completely breastfed children may be explained on the basis of turnover time in growing infants. Recently, Beu reported a turn-over rate for bone of about 100 p during the first year after birth, and, at birth, the 

\[ 0.69 \text{ po. } \text{Sr/g Ca} \]  

or a total of 19.6 po. \( \text{Sr/g Ca} \) in the hard tissues. During the first year of growth, approximately 2 po. of calcium from the diet is in the deciduous teeth, and if no additional \( \text{Sr} \) is obtained from the diet, a skeletal turnover of approximately 17 po. per cent would supply sufficient \( \text{Sr} \) from the infant's skeletal stores to account for the determined values in teeth. In addition, it is possible that the diet of completely breast-fed children was supplemented with oxgenous because the information supplied by the parents depends on memory, is probably inaccurate. In probability, both factors tend to increase the tooth \( \text{Sr/g Ca} \) in breast-fed children over that expected from equation (8). For bottle-fed children, the intake of \( \text{Sr} \) during the post-natal period is 8 times greater than the breast-fed children (equations (2) and (7)), and the contribution of \( \text{Sr} \) from the bottle-fed infant's skeletal stores becomes negligible within experimental error, resulting in little or no effect on the validity of equation (8).

The peak milk concentration of \( \text{Sr} \) occurred in 1963, when the St. Louis milk values reached 38 p. calcium with a yearly average of 21 p. Ca. Children born during 1963 application of equation (6) yields an estimated strontium-90 burden of 14.4 po.  

The validity of these estimates must not be taken until 1968-70 when these teeth are shed and become available for examination.

The data presented in this report demonstrate the usefulness of the \( \text{Sr/g Ca} \) of deciduous incisor teeth as a measure of \( \text{Sr} \) body burden and the relationship of body burden to the dietary \( \text{Sr/g Ca} \) concentration for breastfed children at the time the teeth are formed. This is illustrated by the values obtained for bottle-fed and breastfed children, although statistically significant, is with the analytical errors of the estimates and does not interfere with the usefulness of tooth \( \text{Sr/g Ca} \) as an index of \( \text{Sr} \) body burden. The parameter relating the  

The tooth \( \text{Sr} \) to the infant's skeletal \( \text{Sr} \) burden is calculated during the pre-natal development and the skeletal turnover during post-natal development needs to be resolved and further investigation of these phenomena in progress.

The furus material was kindly supplied by Mrs. M. Trotter, Washington University School of Medicine and the St. Louis Anatomical Board. We thank Sylvia Raymond, Sophy, and Pozzoni for the collection of teeth and the Greater St. Louis Citizens' Committee for Nuclear Information for operation of the Baby Tooth Survey. The \( \text{Sr/g Ca} \) milk values for St. Louis were made available by S. C. Copley, J. W. Health Commissioner of St. Louis, Mo.

This work was supported by grant R1 - 121 from the Bureau of State Services, U.S. Public Health Service.