INCORPORATION OF FALL-OUT STRONTIUM-90 IN DECIDUOUS INCISORS AND FŒTAL BONE

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In a previous article, Rosenthal *et al.*[1] reported that deciduous incisor teeth of children born between 1953 and 1956 who were bottle-fed from birth contained only 25 per cent more strontium-90 than teeth of children who were breast-fed for an average of 25 weeks. On the basis of known ^{90}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-carious 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[1]. 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 samples contained equal amounts (2 g) of tooth crown. 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 fœtuses 7–9 months of age between 1961 and 1963. They were defleshed by boiling in distilled water, and the hard tissues from 3–5 fœtuses were pooled for each analysis.

Because analyses of ^{90}Sr content of milk in the St. Louis milk shed did not begin until 1959, 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 1959. 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 1954–59 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 ^{90}Sr/g Ca of teeth (C_T) was determined by expansion of the basic equation (1) developed by Reiss[2]:

$$C_T = 0·32 \text{ pre-natal } ^{90}\text{Sr/g Ca} + 0·68 \text{ post-natal } ^{90}\text{Sr/g Ca} \quad (1)$$

The factors 0·32 and 0·68 represent the fraction of tooth calcium deposited during the pre- and post-natal periods, respectively[2]. For bottle-fed children, equation (1) becomes:

$$C_T = (0·32)\,(1·2)\,C_d^m\,D_m + 0·68\,C_d^l\,D_I \quad (2)$$

where C_T is tooth ^{90}Sr/g Ca, C_d^m is the mother's dietary intake of ^{90}Sr/g Ca from milk and the total dietary ^{90}Sr/g Ca in the American diet is 1·2 times the amount of ^{90}Sr/g Ca found in milk[3], D_m is the discrimination factor against ^{90}Sr between the mother's dietary intake and her fœtus, C_d^l is the infant's milk intake of ^{90}Sr/g Ca and D_I is the infant's discrimination factor against ^{90}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

	No. of samples	pc. ^{90}Sr/g Ca Found ± *S.E.*	Calc.*
Bottle-fed (> 6 weeks)	21	2·79 ± 0·08	2·53
Breast-fed (< 6 months)	12	2·19 ± 0·35	—
Breast-fed (> 6 months)	8	1·73 ± 0·33	0·52

* Calculated from equations (4) and (8). The milk concentration during 1957 averaged 4·28 pc. ^{90}Sr/g Ca.

In order to solve equation (2), values for D_m and D_I must be experimentally determined. A discrimination factor of 0·13 for D_m appears reasonable as determined from fœtal bone investigations in this report and by Reiss[2]. A value for D_I of 0·8 has been selected as an intermediate value on the basis that children under 60 days of age do not discriminate against ^{90}Sr (ref. 4) and ^{90}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:

$$C_T = 0·05\,C_d^m + 0·54\,C_d^l \quad (3)$$

Because the incisor teeth develop and calcify in less than 1 year, the ^{90}Sr/g Ca in milk (C_d^m and C_d^l) may be averaged for yearly intervals and equation (3) becomes:

$$C_T = 0·59\,C_d \quad (4)$$

The validity of equation (4) is shown in Fig. 1, where the determined values of ^{90}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).

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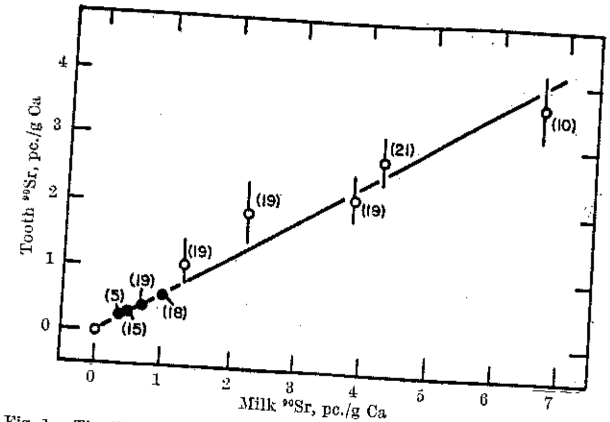

Fig. 1. The ^{90}Sr concentration of deciduous incisor teeth as a function of ^{90}Sr content of commercial milk. The number of samples analysed in parentheses. The vertical bars represent ± 1 *S.D.* The open circles represent values obtained during periods of known milk values between 1954 and 1958. The closed circles represent values obtained for estimated milk values between 1950–53. The line was drawn from equation (4)

The pre-natal contribution from the mother's diet to the fœtal teeth and bone may be defined as:

$$C_T = 1{\cdot}2\ C_d^m\ D_m \qquad (5)$$

and with D_m equal to 0·13:

$$C_T = 0{\cdot}16\ C_d^m \qquad (6)$$

The values for the tooth buds and bone of fœtuses between 1961 and 1963 (Table 2) demonstrate the equilibrium for ^{90}Sr/g Ca in the hard tissues of the developing fœtus, as has been previously shown[3], 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 fœtus. The value for D_m is also in agreement with the value found by Comar[6] in animals but differs from the findings of Kulp[7], who observed that the concentration of strontium-90 in fœtal bone averaged one-twelfth of that in the mother's diet.

Table 2. STRONTIUM-90 CONTENT OF FŒTAL TOOTH BUDS AND MANDIBULAR BONE*

Year	No. of samples	Tooth	Bone	Tooth; bone	Tooth and bone average	Calc. †	Deviation %
1961	6	1·82 ± 0·17	1·62 ± 0·17	1·12	1·72	1·44	−16
1962	7	1·51 ± 0·14	1·66 ± 0·22	0·91	1·58	1·76	+10
1963	17	3·39 ± 0·40	3·68 ± 0·43	0·92	3·54	3·36	−5
			Weighted average	0·96			−4

* Values expressed as pc. ^{90}Sr/g Ca ± *S.E.*
† Calculated from equation (6). Average pc. ^{90}Sr/g Ca for St. Louis milk was 9, 11 and 21 for 1961, 1962 and 1963, respectively.

For children who were completely breast-fed until after the incisor teeth were completely formed, the post-natal portion of equation (2) must be modified to include discrimination of ^{90}Sr between the mother's diet and her milk, which is approximately the same as the discrimination between the mother's diet and her fœtus, and equation (2) becomes:

$$C_T = (0{\cdot}32)\ (1{\cdot}2)\ C_d^m\ D_m + (0{\cdot}68)\ (1{\cdot}2)\ C_d^I\ D_m\ D_I \qquad (7)$$

When C_d^m and C_d^I are the same, equation (7) becomes:

$$C_T = 0{\cdot}135\ C_d \qquad (8)$$

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

The deviation between the theoretical and determined values for the ^{90}Sr/g Ca in the teeth of completely breast-fed children may be explained on the basis of skeletal turnover time in growing infants. Recently, Bryant[5] reported a turn-over rate for bone of about 100 per cent during the first year after birth and, at birth, the average American infant contains 28 g of calcium in its skeleton. In 1957, the fœtus would have had a skeletal burden of 0·69 pc. ^{90}Sr/g Ca (equation (6)) or a total content of 19 pc. ^{90}Sr in the hard tissues. During the first year of growth, approximately 2 g of tooth calcium are formed in all the deciduous teeth, and if no additional ^{90}Sr is obtained from the diet, a skeletal turnover of only 20 per cent would supply sufficient ^{90}Sr from the infant's own skeletal stores to account for the determined values. In addition, it is possible that the diet of completely breast-fed children was supplemented with exogenous food because the information supplied by the parents, which depends on memory, is probably inaccurate. In all probability, both factors tend to increase the tooth values of breast-fed children over that expected from equation (8). For bottle-fed children, the dietary intake of ^{90}Sr/g Ca during the post-natal period is 8 times greater than that of breast-fed children (equations (2) and (7)), and the contribution of ^{90}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 (4).

The peak milk concentration of ^{90}Sr occurred in June 1963, when the St. Louis milk values reached 38 pc./g calcium with a yearly average of 21 pc./g calcium. For children born during 1963, application of equation (4) yields an estimated strontium-90 burden of 12·4 pc./g of incisor calcium. The validity of this estimate must wait until 1968–70 when these teeth are shed and become available for examination.

The data presented in this report demonstrate the value of the ^{90}Sr concentration of deciduous incisor teeth as a measure of ^{90}Sr body burden and the relationship of the body burden to the dietary milk concentration for bottle-fed children at the time the teeth are formed. The difference between the values obtained for bottle-fed and breast-fed children, although statistically significant, is within the analytical errors of the estimates and does not seriously interfere with the usefulness of tooth ^{90}Sr as an index of ^{90}Sr body burden. The parameter relating the tooth ^{90}Sr to the infant's skeletal ^{90}Sr burden accumulated during the pre-natal development and the skeletal turnover during post-natal development needs to be resolved and further investigation of these phenomena is in progress.

The fœtus material was kindly supplied by Prof. Mildred Trotter, Washington University School of Medicine and the St. Louis Anatomical Board. We thank Sylvia Raymond, Sophia Goodman and Yvonne Logan for the collection of baby teeth and the Greater St. Louis Citizens' Committee for Nuclear Information for operation of the Baby Tooth Survey. The ^{90}Sr milk values for St. Louis were made available by C. M. Copley, jun., Deputy Health Commissioner of St. Louis, Mo.

This work was supported by grant *RH*–112 from the Bureau of State Services, U.S. Public Health Service.

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