STRONTIUM-90 CONTENT OF DECIDUOUS TEETH OF CHILDREN

H. L. ROSENTHAL, J. T. BIRD, J. E. GILSTER,
P. V. C. PINTO, AND S. O'NEILL

Reprinted for private circulation from
JOURNAL OF DENTAL RESEARCH
Vol. 45, No. 2, March–April 1966

Strontium-90 Content of Deciduous Teeth of Children

HAROLD L. ROSENTHAL, JOHN T. BIRD, JOHN E. GILSTER, P. V. C. PINTO, and SHEILA O'NEILL

Departments of Physiological Chemistry, Dental Medicine, and Pedodontics, Washington University School of Dentistry, St. Louis, Missouri

SYNOPSIS IN INTERLINGUA

CONTENTO DE STRONTIUM-90 IN DENTES DECIDUE DE JUVENILES.—Le contento de strontium-90 del coronas de dentes decidue de juveniles nate inter 1950 e 1958 es adequatemente describite per le equation $C_T = KC_d$ ubi C_T es le Sr^{90} del corona dental e C_d le Sr^{90} del lacte. Pro incisores e cuspides intacte e prime e secunde molares cariose, le pendentia K es 0,59, 0,76, 0,69, e 0,77, respectivemente. Le equation predice nivellos de inter 12 e 16 pC Sr^{90}/gm Ca in incisores e secunde molares pro juveniles nate durante le anno 1963 quando le concentration medie de Sr^{90} in le lacte attingeva un nivello maximal de 21 pC Sr^{90}/gm Ca in St. Louis, Missouri, U.S.A.

The strontium-90 content of noncarious deciduous incisors increased from 0.18 to 3.65 pC per gram of calcium for children born in St. Louis between 1949 and 1958, a period of increasing Sr^{90} fallout.[1–3] The Sr^{90} content of deciduous incisors of American children also compares favorably with bone values determined during the first year after birth.[4–8] Our studies suggest that the Sr^{90} content of deciduous teeth represents a measure of the total body burden of the nuclide during the time the teeth are formed. In contrast to skeletal bones, which are subject to change due to remodeling, exchange, and turnover, the erupted crown of the tooth is a relatively stable calcified tissue with minimal exchange, remodeling, or turnover. Although secondary dentin is deposited, the amount formed is small in comparison with the total mass of the crown, and the amount of Sr^{90} incorporated in the crown by this process is presumed to be minimal. Kulp and Schulert,[9] however, have voiced a series of objections to the use of deciduous teeth as a measure of Sr^{90} body burden based on the great effort required to obtain enough tooth material for analysis, the complex relationship between calcium deposition in teeth and in bone, and the fact that it is, at best, an indirect method.

This investigation was supported by U.S. Public Health Service Research Grants RH-112 and DE-1922 from the Bureau of State Services and National Institute of Dental Research, National Institutes of Health, Bethesda, Md.

A preliminary report was presented at the 42nd General Meeting, International Association for Dental Research, Los Angeles, Calif., March, 1964.

Received for publication March 1, 1965.

To determine the usefulness of deciduous teeth as a measure of Sr^{90} body burden, a series of studies was undertaken to define the variation in the Sr^{90} content of the various types of deciduous teeth (incisors, cuspids, and first and second molars). It was also of interest to determine the effect of breast feeding versus bottle feeding and the effect of caries on the accumulation of Sr^{90} in teeth. Although many factors remain to be studied and qualified, it was deemed advisable to report the information that is currently available.

Materials and Methods

Deciduous teeth of children born within a radius of 150 miles of St. Louis were collected for the birth years 1947 to 1958. The teeth were classified as to type, the length of time the child was fed by breast or bottle, and whether the teeth were carious or sound. Deciduous teeth with restorations were considered to have been carious. Residual root material was removed from the crown at the cementoenamel junction, and restorations and carious material were removed. Root samples of molars from breast- and bottle-fed children were analyzed separately, but the data were averaged because no significant differences could be found.

Teeth were classified in the "breast-fed" group if the children were breast-fed for 6 weeks or more. The average time of breast feeding was 24 weeks for incisors (40 samples), 27 weeks for first molars (56 samples),

TABLE 1

STRONTIUM-90 CONTENT OF VARIOUS TEETH OF CHILDREN BORN IN ST. LOUIS DURING 1956

Tooth	Tooth Status	Children	Sr^{90}(pC/Gm. Ca. ± s.e.)*
Incisor	Sound	Bottle-fed	2.19±0.08 (19)
		Breast-fed	1.84±0.21 (6)
Cuspid	Sound	Bottle-fed	1.57±0.12 (12)
1st molar	Carious	Bottle-fed	2.20±0.14 (15)
		Breast-fed	1.54±0.10 (6)
2nd molar	Carious	Bottle-fed	2.85±0.26 (13)
		Breast-fed	2.32±0.32 (7)
Tooth average			2.1

* Number of pooled samples analyzed in parentheses.

and 28 weeks for second molars (83 samples). If the children were breast-fed for less than 6 weeks, the teeth were considered to be from bottle-fed children.

For children born between 1947 and 1952, when Sr^{90} fallout was low, sufficient material was pooled to make samples containing 2.5 Gm. of calcium. Thereafter, as the Sr^{90} content increased, the amount of sample material was progressively decreased to yield a minimum of 0.5 Gm. of calcium in 1957 and thereafter. Samples obtained during the first and last 6 months of each year were analyzed separately, but the data were averaged to yield values for yearly intervals. The samples were ashed at 600° C. and analyzed for Sr^{90} and calcium by methods previously described.[1, 3] The Sr^{90} content of commercial milk for the St. Louis area was obtained as previously described.[3] The distribution of enamel and dentin in crowns of first and second molars was calculated from known calcium percentages in dry dentin (26.5 per cent) and dry enamel (35.8 per cent) as reported by Sobel, Rochenmocher, and Kramer.[10]

Results

The accumulation of Sr^{90} in deciduous sound incisors, cuspids, carious first molars, and carious second molars from bottle-fed children is shown (Fig. 1). From 1947, when the Sr^{90} content of all types of teeth averaged about 0.15 pC of Sr^{90} per gram of calcium, the concentration of Sr^{90} continued to increase steadily, reaching a value of 4.7 pC Sr^{90}/Gm. of calcium for carious second molars of children born during 1958.

The data for teeth of children born during 1956 demonstrate the variation of Sr^{90} content for the various kinds of teeth of children who were breast-fed or bottle-fed (Table 1). The largest difference (30 per cent) was between carious first molars of bottle-fed and breast-fed children. The weighted average for all of the teeth of children born in 1956 was 2.1 pC Sr^{90}/Gm. of calcium. This figure is in good agreement

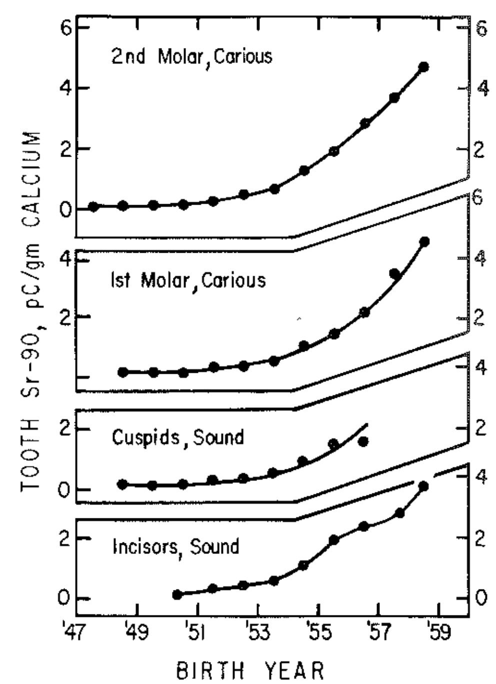

FIG. 1.—The Sr^{90} content of deciduous teeth as a function of the birth year of the child. Each point represents average values obtained for 6 to 21 pooled samples.

TABLE 2

COMPARISON OF STRONTIUM-90 CONTENT OF DECIDUOUS MOLARS FROM ST. LOUIS CHILDREN

Year	Tooth	No. Samples*	Sr^{90} Ratio ± S.E.
Carious; Breast-Fed/Carious; Bottle-Fed			
1948–1957	1st molar	59/76	0.72±0.09 (10)†
1948–1957	2nd molar	71/77	0.81±0.08 (10)
Sound; Bottle-Fed/Carious; Bottle-Fed			
1948–1954	1st molar	55/56	0.66±0.05 (7)
1948–1953	2nd molar	41/42	0.71±0.05 (6)

* Number of samples analyzed for each category.

† Number of yearly averages used to obtain ratio ±S.E. The ratios are significantly different from 1 ($P < 0.01$).

with skeletal bone values of 1.9 pC Sr^{90}/Gm. of calcium, determined in North American children who were newborn to 4 years old in 1958,[5] and 1.7 pC Sr^{90}/Gm. of calcium for children who were between 1 and 2 years old in 1957 (children born during 1956).[6] Although the differences for the various classifications were statistically significant, the determined values were within the range of the weighted average and the analytical error of the Sr^{90} determinations.

A further comparison (Table 2) showed that carious first and second molars from breast-fed children contained 28 per cent and 19 per cent less Sr^{90} than comparable teeth from bottle-fed children, and these differences were consistent for the years thus far analyzed (Fig. 2). Furthermore, sound first and second molars from bottle-fed children consistently contained 34 per cent and 29 per cent less Sr^{90} than comparable carious teeth (Table 2). The correlation for Sr^{90} in the crowns of sound and carious teeth is shown (Fig. 3). The crowns of sound first molar teeth contained proportionately more dentin calcium and less enamel calcium than carious first molars, while the opposite relationship was found for second molars (Table 3).

The roots of first and second carious molars from bottle-fed children, born in 1949, contained proportionately more Sr^{90} than carious crown samples, but the root/crown ratio gradually decreased with time and approximated a value of 1 in 1958 (Fig. 4).

The correlation between the accumula-

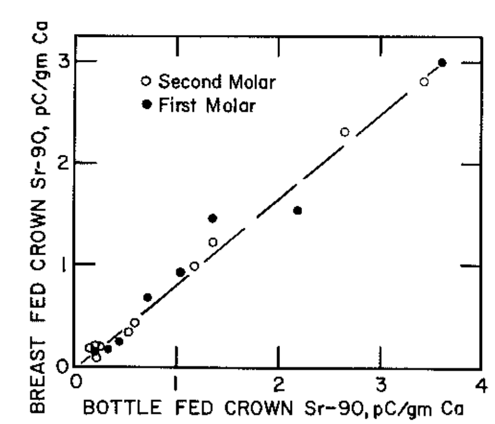

FIG. 2.—Linear correlation for Sr^{90} concentration for crowns of teeth from breast-fed and bottle-fed children.

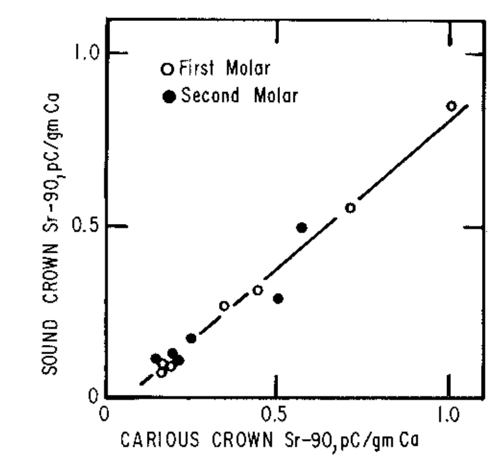

FIG. 3.—Linear correlation for Sr^{90} concentration between crowns for sound and carious teeth.

TABLE 3

CALCULATED DISTRIBUTION OF ENAMEL AND DENTIN FOR DECIDUOUS MOLARS

Tooth	Type	No. Samples	Calcium (%)* Enamel	Dentin	E/D Ratio
1st molar	Sound	78	34.36	65.64	0.52
	Carious	168	54.69	45.31	1.21
2nd molar	Sound	58	66.25	33.75	1.96
	Carious	179	52.77	47.23	1.12

* The calcium percentages are based on per cent of the whole crown, as described in "Materials and Methods."

tion of Sr^{90} during prenatal and postnatal tooth development and the diet is shown (Fig. 5). The equations, derived previously for deciduous incisors,[3] are adequately described by the data when modified to account for variation in the time of development of the crown. It has recently been shown[2] that 68 per cent of incisor crown calcium is deposited postnatally, as compared with 94 per cent for cuspids, 83 per cent for deciduous first molars, and 95 per cent for deciduous second molars. The time for postnatal crown development is also well characterized and ranges from about 4 months for incisors to 6 months for first molars, 9 months for cuspids, and 11 months for second molars.[2, 11–13] Because postnatal crown development for all the teeth is less than 1 year, discrimination factors for the infant and his diet ($D_t = 0.8$) were assumed to be the same and discrimination between the mother and fetus in utero ($D_m = 0.13$) is the same as previously described.[3] The slope for the equations ranges between 0.59 for sound incisors and 0.77 for carious second molars.

Discussion

The present data demonstrate the increasing accumulation of Sr^{90} in the deciduous incisor, cuspid, and molar teeth of children born during 1947 to 1958, when the Sr^{90} fallout was increasing. The accumulation is essentially comparable to that described for deciduous incisors during the same period.[1–3]

Different kinds of deciduous teeth vary in nuclide concentration, depending on the time of development in a physiologic environment of changing nuclide concentration. It might be expected that the longer development time of cuspids and deciduous second molars would result in the deposition of substantially more Sr^{90} than in incisors

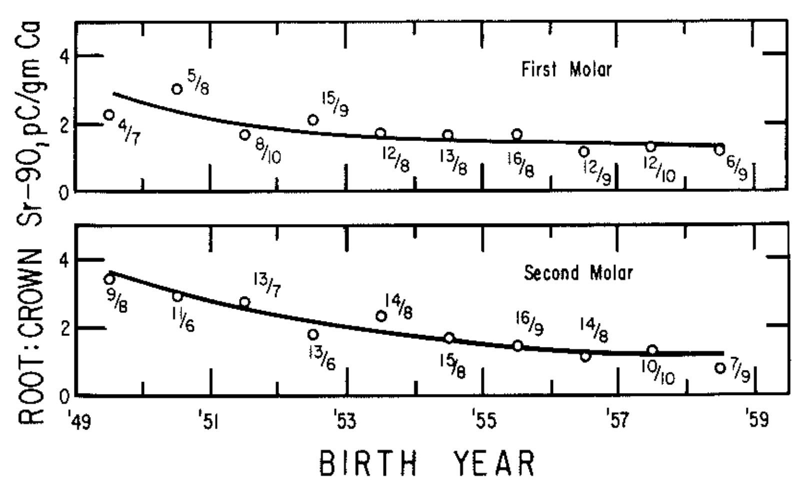

FIG. 4.—The Sr^{90} root/crown ratio as a function of birth year of the child. The numbers for each point represent the number of root and crown samples analyzed.

and deciduous first molars, which develop in a shorter time. However, the fluctuation of Sr^{90} in the diet and the dynamic equilibrium established between diet and bone over a relatively short period of approximately a year for all of the teeth results in only minor differences for the Sr^{90} content of the various teeth. The variation of Sr^{90} content between the various kinds of teeth is similar to the variations found between various kinds of skeletal bone in man[8] and other animals.[14]

The finding that the nuclide concentration in first and second molars is lower in breast-fed children than in bottle-fed children is in accord with our previous findings for deciduous incisors,[1, 3] and further discussion of this point seems unnecessary. The similarity between the various kinds of teeth, whether the children were breast- or bottle-fed and whether the teeth are carious or sound, suggests that pooled samples of mixed teeth may adequately serve as a general index for the estimation of the Sr^{90} concentration in deciduous teeth as a measure of Sr^{90} body burden.

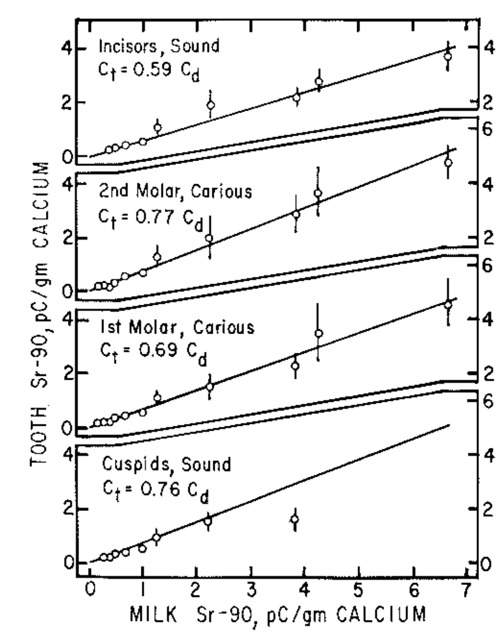

FIG. 5.—The Sr^{90} content of deciduous teeth as a function of the Sr^{90} content in milk. The open circles represent average values ± s.d. for five to 21 pooled samples obtained during periods of known milk values between 1954 and 1958. The closed circles represent values obtained for estimated milk values between 1950 and 1953. The lines were drawn from the equations shown for each type of tooth where C_t and C_d represent pC Sr^{90}/Gm. Ca for teeth (C_t) and commercial milk (C_d), respectively.

The good correlation between the Sr^{90} concentration in deciduous teeth and bone of children during the first year of life, shown in this and other reports,[3, 6, 9] and the correlation between deciduous incisors, cuspids, first molars, and second molars and the diet[3] is in contrast to the data obtained by Bryant, Henderson, and Holgate[15] for bicuspids of patients 9 to 15 years old and third molars of patients 17 to 23 years old. They indicated difficulty in obtaining direct correlation between teeth and bones due to the different growth patterns of tooth development over a period of about 8 years for bicuspids and 10 years for third molars. Furthermore, they analyzed teeth containing both root and crown.

In a more recent report, Starkey, Bryant, and Henderson[16] found the Sr^{90} content of bicuspid crowns to be comparable to our data when related to the years of calcification. Thus, the objections voiced by Bryant, Henderson and Holgate[15] are probably not valid for the crowns of deciduous teeth developing over the relatively short period of less than a year. A more valid objection to the use of deciduous teeth involves the uncertainty of the Sr^{90} accumulation during prenatal tooth development and the influence of placental discrimination on tooth Sr^{90} concentration. This objection does not appear to be a serious one, because the factor can be experimentally determined and was previously reported in detail for deciduous incisors.[3]

The finding that the roots of deciduous molar teeth contained higher concentrations of Sr^{90} than comparable crowns between 1949 and 1955 probably reflects the time element of formation of various calcified tissues and the diet. The crown of the deciduous tooth is developed over a relatively short period of less than 1 year and, once calcified, is no longer subject to major changes of remodeling, exchange, or turnover. Although carious teeth may deposit secondary or sclerotic dentin (or both) that may augment or inhibit ionic exchange between more distal dentin and the circulatory system, as reported by Rowland,[17] we assume this factor to be small with respect to the amount of mineral matter originally deposited in the tooth crown. The crown, therefore, primarily represents the accumulation of Sr^{90} available during the time of its formation. In contrast to the stability of the crown, the roots undergo continual and varying degrees of resorption, remodeling, exchange, and turnover. During a period of increasing Sr^{90} fallout, the roots reflect the availability of greater amounts of the nuclide during root metabolism. Conversely, when root formation occurs during a time when the availability of Sr^{90} is lower than that occurring when the crown is formed, roots contain less Sr^{90} than tooth crown. The fact that roots and crowns approached equal concentrations of Sr^{90} between 1956 and 1958 may be fortuitous, but suggests that the availability of Sr^{90} was essentially similar during the time of crown and root formation.

It is interesting to speculate on the lower Sr^{90} content for the crowns of sound teeth as compared with carious teeth. The simplest explanation would be that the carious tooth crown represents a larger proportion of dentin (which would contain more Sr^{90} due to later development in a higher Sr^{90} environment) than does a sound tooth crown. This explanation appears not to be acceptable because the sound crowns of both first and second molars contain less Sr^{90} than carious crowns, and the distribution of dentin in carious first molars is diametrically opposite to the distribution in second molar crowns. Furthermore, it is known that dentinal calcium contains only about 10 per cent more Sr^{90} than enamel calcium.[1] It is more probable that intrinsic differences in either crystal structure or chemical composition of carious enamel and dentin may be associated with increased Sr^{90} accumulation. Unfortunately, sufficient sound first and second molars are not as yet available for testing this hypothesis by analytical measurements of separated dentin and enamel.

The good correlation between the Sr^{90} content of tooth crown and the Sr^{90} content of milk and the minor degree of variation found between various kinds of teeth between 1949 to 1958 make it possible to use the tooth content of Sr^{90} as a measure of the dietary Sr^{90} intake during the time of tooth formation. It is also apparent that the objections voiced by Kulp and Schulert[9] are not valid: (1) The collection of large numbers of deciduous tooth crowns can be obtained with relative ease and does not involve any more effort than the obtaining of bone samples at either biopsy or necropsy. (2) The mechanism for calcium deposition in teeth is less complex than that in bone, because the factors of turnover, exchange, and remodeling are essentially absent in the crowns of teeth once they are formed. Deciduous tooth crowns are formed over a relatively short period and appear to accurately reflect the Sr^{90} content of the diet during the time of tooth formation. (3) The criticism that the Sr^{90} content of tooth crown is an indirect measure of body burden can not be refuted; however, this indirect measure appears to be of value when direct analyses of the diet are not readily available. A more valid criticism is the fact that the Sr^{90} content of deciduous teeth reflects the Sr^{90} accumulation some 5 to 10 years previously for incisors and second molars, respectively. The correlation between the Sr^{90} content of tooth crown and the diet, however, makes it possible to estimate the dietary Sr^{90} content prior to 1955—before milk and diet levels were known. The Sr^{90} content of teeth, therefore, furnishes a permanent record of the Sr^{90} body burden at the time the teeth are formed.

Summary

The Sr^{90} content of deciduous tooth crowns increased from 0.15 to 4.7 pC Sr^{90}/Gm. of Ca between 1947 and 1958, respectively, for children born in the St. Louis area and who were bottle-fed from birth. The variation of Sr^{90} content in deciduous incisors, cuspids, and first and second molars, between carious and sound teeth or between teeth from children who were breast-fed or bottle-fed during the time of tooth formation, was less than 30 per cent. This small variation suggests that pooled samples of tooth crown, without regard to these classifications, may adequately serve as a measure of Sr^{90} body burden during the time of tooth formation.

For the teeth of children who were bottle-fed, a relationship between the Sr^{90} content of tooth crown (C_t) and the diet (C_d) is adequately described by the equation $C_t = XC_d$, where the slope (X) must be determined experimentally. The value of X was 0.59 for sound incisors, 0.69 for carious first

molars, 0.76 for sound cuspids, and 0.77 for carious second molars. This relationship makes it possible to estimate the dietary Sr^{90} content from tooth values for years prior to the initiation of dietary Sr^{90} estimations.

We thank Sylvia Raymond, Sophia Goodman, and Yvonne Logan for the collection of deciduous teeth; Inez Terry for laboratory assistance, and the Greater St. Louis Citizens' Committee for Nuclear Information for operation of the Baby Tooth Survey.

References

1. Rosenthal, H. L., Gilster, J. E., and Bird, J. T. Strontium-90 Content of Deciduous Human Incisors, *Science*, **140**:176–77, 1963.
2. Reiss, L. Z. Strontium-90 Absorption by Deciduous Teeth, *Science*, **134**:1669–73, 1961.
3. Rosenthal, H. L., Austin, S., O'Neill, S., Takeuchi, K., Bird, J. T., and Gilster, J. E. Incorporation of Fallout Strontium-90 in Deciduous Incisors and Foetal Bone, *Nature (London)*, **203**:615–16, 1964.
4. Libby, W. F. Radioactive Strontium Fallout, *Proc. nat. Acad. Sci. (Washington)*, **42**:365–90, 1956.
5. Kulp, J. L., Schulert, A. R., and Hodges, E. J. Strontium-90 in Man. IV, *Science*, **132**:448–54, 1960.
6. Kulp, J. L. Strontium-90 in Man. Presented at the Symposion über Radiostrontium. Bundesminister für Atomkirenergie and Wasserwirtshaft, Bad Kreuznach, Germany, 1959. Gersbach and Sohn Verlag, Munich, 1961 (Reprinted in Kulp and Schulert,[9] p. 161–73).
7. Eckelman, W. R., Kulp, J. L., and Schulert, A. R. Strontium-90 in Man. II, *Science*, **127**:266–74, 1958.
8. Schulert, A. R., Hodges, E. J., Lenhoff, E. S., and Kulp, J. L. Strontium-90 Distribution in the Human Skeleton, *Health Phys.*, **2**:62–68, 1959.
9. Kulp, J. L., and Schulert, A. R. Strontium-90 in Man and His Environment, Report NYO-9934, Vol. 1. U.S. Atomic Energy Commission, 1962, p. 301–02.
10. Sobel, A. E., Rochenmocher, M., and Kramer, B. Microestimation of the Inorganic Constituents of Bone, *J. biol. Chem.*, **152**:255–66, 1944.
11. Gilster, J. E., Smith, F. H., and Wallace, G. K. Calcification of Mandibular Second Primary Molars in Relation to Age, *J. Dent. Child.*, **31**:284–88, 1964.
12. Schour, I. and Massler, M. The Development of the Human Dentition, *J. Amer. dent. Ass.*, **28**:1153–60, 1941.
13. Kraus, B. S. Calcification of the Human Deciduous Teeth, *J. Amer. dent. Ass.*, **59**:1128–36, 1959.
14. Rosenthal, H. L., and Harbor, N. C. The Absorption, Retention and Distribution of Strontium-90 from Naturally Contaminated Food by Female Rabbits, *J. dent. Res.*, **44**:935–39, 1965.
15. Bryant, F. J., Henderson, E. H., and Holgate, W. Strontium-90 in Human Teeth, *Brit. dent. J.*, **108**:291–94, 1960.
16. Starkey, W. E., Bryant, F. J., and Henderson, E. H. The Accumulation and Retention of Strontium-90 in Permanent Human Teeth in the United Kingdom, *Int. dent. J.*, **14**:206–25, 1964.
17. Rowland, R. E. Radium in Human Teeth, *Arch. oral Biol.*, **8**:13–21, 1963.