From:
Institute of Dentistry,
University of Helsinki,
Helsinki, Finland

STRONTIUM-90 IN DECIDUOUS TEETH COLLECTED IN HELSINKI FROM CHILDREN BORN IN 1956—1963

by
INKERI RYTÖMAA

INTRODUCTION

Deciduous teeth provide useful material for the analysis of the minerals available to the human body during the development of the teeth. It was suggested by *Kalckar* (1958) that this approach should be used to measure the body burden of ^{90}Sr originating from radioactive contamination of the environment due to nuclear explosions.

The first analyses of this kind were made in the St. Louis area, USA, on teeth collected from children born in 1949—1957 (*Reiss*, 1961, *Rosenthal et al.*, 1963). The strontium-90 concentration in deciduous teeth of children born in 1949 was as low as 0.18 pCi/gCa, but as the result of nuclear tests in the 1950s the concentration increased steadily, reaching a value of 2.56 pCi/gCa in children born in 1957. It was further observed by *Rosenthal et al.* (1963) that in breast-fed children the concentration of ^{90}Sr was 25 % lower than in bottle-fed children. The enamel of the incisors contained about 10 % less ^{90}Sr than the dentine. It may be noted here that the results obtained on foetuses indicate that strontium-90 is evenly distributed within the calcifying tissues of bones and teeth (*Reiss*, 1961, *Rosenthal et al.*, 1967).

OR (= observed ratio) is a value which expresses the total discrimination between the dietary intake of ^{90}Sr and the content of this radioisotope in

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bones or teeth, as obtained from the relation pCi/gCa (diet) / pCi/gCa (bone) (UNSCEAR report, 1964). For deciduous teeth the following OR values have been reported (*Rosenthal et al.*, 1964, 1966a): incisors 0.59, cuspids 0.76, first molars 0.69 and second molars 0.77. It may also be noted that intact deciduous teeth contain about 10–15 % less ^{90}Sr than their carious counterparts (*Rosenthal et al.*, 1968).

Analyses on the strontium-90 concentrations in deciduous teeth have been reported from other localities besides the St. Louis area. A summary of the results published is presented in Figure 1. It may be noted that the highest concentrations habe been found in Italy (*D'arca Simonetti et al.*, 1969) and in the Faroe Islands (*Aarkrog*, 1968).

Nuclear tests in 1961 and 1962 resulted in a strong increase in the artificial radioactive contamination of the environment; as a consequence, the strontium-90 concentration in milk rose sharply in Finland also (*Paakkola*, 1966). It is therefore to be expected that in children born during the first half of the 1960s the deciduous teeth would contain more ^{90}Sr than before. The present study is the first attempt to measure strontium-90 concentrations in deciduous teeth in Finnish children.

MATERIAL AND METHODS

The material analysed consisted of deciduous teeth (2 662 teeth in total) collected in the dental clinics of the elementary schools in Helsinki. Clearly identifiable teeth were grouped according to year of birth into incisors, cuspids and molars; non-identifiable heavily carious teeth were excluded from this part of the material.

Caries and fillings were removed from all teeth and the crowns separated from the roots. The analysed material comprised the crowns from the incisors, cuspids and molars and also a heterogeneous group of tooth roots. All samples were then ashed at 600 °C for about two days and the ash was ground to a fine powder. From each sample 6 g of ash was taken for analysis; if more ash was available, replicate samples were prepared. The ash was dissolved in concentrated hydrochloric acid by heating and the carbon particles were removed by filtration. The final sample volume was diluted to about 21 ml with distilled water (25 ml polyethylene vials were used in counting).

The radioactivities of the samples were measured in a liquid scintillation counter by making use of the Čerenkov radiation produced by ^{90}Y (*Rytömaa & Paakkola*, 1971). After determination of radioactivity, the calcium content

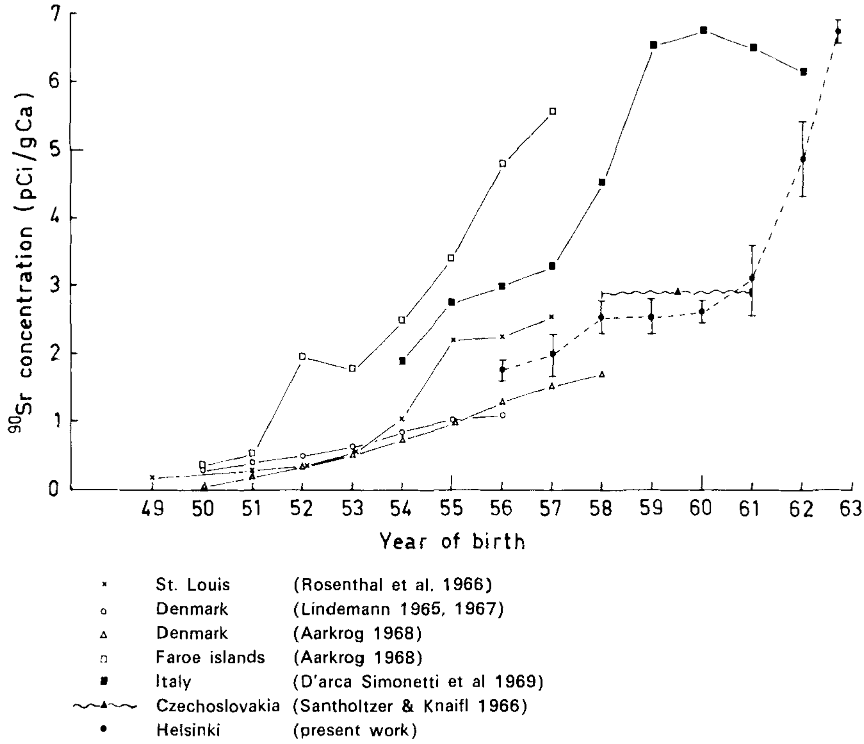

Fig. 1. Mean ^{90}Sr content (pCi/gCa) of deciduous teeth in different localities versus year of birth. Vertical lines given for the values obtained in the present work are standard deviations of the independent samples measured. Note that the value obtained in Czechoslovakia represents the mean ^{90}Sr content of deciduous teeth in children born in 1958—1961.

of the samples was analysed by atomic absorption spectrophotometry. For further details of the techniques used, see *Rytömaa* and *Paakkola* (1971).

The material studied consisted of 73 samples. In addition, six background samples of human teeth collected before 1940 were counted at the same time. All vials (every 12th was a background sample) were counted successively in 18 cycles until a total of 360 minutes was reached for each sample.

The mean background count rate was 11. 8 cpm, with a relative standard error of ± 1.0 %. The variation between the six background samples was a little larger than was to be expected on the basis of the statistical counting error, but this had no significant consequences on the accuracy of the net sample counts observed. The small increase in variation was apparently due to minor differences in sample quenching.

The relative error of the net sample counts was determined from the equation (*Haberer*, 1965)

$$f_r \sqrt{t} = \frac{\sqrt{n_N + 2n_o}}{n_N}$$

where f_r is the relative error, t the counting time (360 minutes), n_N the observed net sample count rate, and n_o the background count rate. According to this equation, the sample with the lowest activity was counted with a relative error of ± 10.0 % and the sample with the highest activity with a relative error of ± 2.6 %. For most samples the relative counting error was about ± 6 %.

In addition to the statistical counting error, the final results (pCi/gCa) are also affected by other errors connected with the procedure. These include determination of the calcium content (pipetting and measurement of the calcium concentration; in this latter case the relative error was ± 1.5 %), and factors such as quenching of the samples. It is apparent that these errors are relatively small and that therefore the over-all error is mainly due to the statistical accuracy of the net sample counts. This was actually confirmed by the standard deviations obtained in 15 cases where 2 to 4 replicate analyses could be made from the same pool of tooth ash. The relative standard deviations within these groups varied from 0.0 to 15.6 %, with an average of about 6 %.

The possible role of additional error factors (such as presence of radionuclides other than $^{90}Sr-^{90}Y$ in the teeth) has been discussed in detail in an earlier paper (*Rytömaa & Paakkola* 1971).

RESULTS

The average calcium content was 36.5 % of the ash weight in all tooth groups.

In the heterogeneous group of tooth roots the net sample counts varied relatively strongly, mainly because of a quenching effect caused by the samples themselves (coloured solutions). Consequently, the results obtained were not fully reliable and the whole group was neglected.

The results obtained for incisors, cuspids and molars are presented in Table I and Fig. 1. It is seen that in children born in 1956 the strontium-90 content was about 1.8 pCi/gCa in Helsinki. During the next two years the ^{90}Sr content of deciduous teeth rose slightly, reaching a value of about 2.6 pCi/gCa in 1958. No further increase occurred during 1959 and 1960, but in 1961 a small increase may already have occurred. Thereafter a strong increase began, which reached a value of about 6.8 pCi/gCa for the age group born in 1963.

When the strontium-90 content of the incisors is compared with the activities found in the cuspids and molars (see Table I), it appears that the incisors contained somewhat less ^{90}Sr.

DISCUSSION

Most of the strontium-90 present in deciduous teeth is deposited during the first year of life, because the crowns of these teeth develop and calcify in less than one year (*Orban*, 1962). Depending on the type of tooth, only 5–32 % of the crown is formed before birth (*Reiss*, 1961) and, in addition, the ^{90}Sr content in the tooth germ is relatively low, especially because of the strong discrimination factor between the mother's dietary intake and her foetus. On the other hand, the child's own discrimination against strontium-90 is at its lowest during the first year of life (UNSCEAR report, 1969). As a consequence, the strontium-90 content in deciduous teeth is a good measure of the strontium-90 body burden during that time. It is also easy to obtain large numbers of deciduous teeth for analyses as compared to bone. Furthermore, the mechanism for deposition of calcium is less complex in teeth than in bone, because turn-over, exchange, and remodelling are absent in the crowns of teeth once they are formed.

Deciduous teeth develop in the order incisors, first molars, cuspids, and second molars (*Orban*, 1962). It may therefore be expected, owing to the longer time of development of cuspids and second molars, that incisors would contain less ^{90}Sr than cuspids and molars. This has in fact been observed by *Rosenthal et al.* (1966a) and *Aarkrog* (1968). In the present study a similar trend was also observed.

It has been suggested by *Rosenthal et al.* (1966a) that »pooled samples of mixed teeth may adequately serve as a general index for estimation of the ^{90}Sr concentration in deciduous teeth as a measure of ^{90}Sr body burden». Nuclear tests in 1952–1958 resulted in a strong increase in deposited artificial radioactivity; no further nuclear devices were exploded above ground before 1961 (UNSCEAR report, 1964). The subsequent artificial radioactivity contamination of the environment is well reflected in the ^{90}Sr content in deciduous teeth in Helsinki children born in 1956–1963. The mean strontium-90 content in the age group born in 1956 was 1.8 pCi/gCa; it increased to a value of 2.6 pCi/gCa in 1958 and remained at the same level for the next

Table 1.

^{90}Sr content (pCi/gCa) of deciduous teeth collected in Helsinki from children born in 1956—1963

Tooth	Year of birth							
	1956	1957	1958	1959	1960	1961	1962	1963
Incisors				2.85	2.47	2.91[2]	4.17[1]	6.63
							4.80[1]	
							4.71	
Cuspids and Molars	1.79	2.47[1]	2.80[1]	2.12	2.76[1]	2.89	5.80	6.89
	1.64	1.95	2.37	2.57	2.55	2.37	4.90[1]	
	1.92[1]	1.92	2.75	(1.78)*	2.46	4.00		
		1.68[3]	2.31[3]	2.77	2.57	3.30[1]		
				2.40[1]	2.88	3.16[1]		
				2.66[1]	2.48			
					2.50[3]			
					2.93			
$\bar{x}$ S.D.	1.78±0.14	2.00±0.33	2.56±0.25	2.56±0.27	2.62+0.18	3.12±0.54	4.88±0.59	6.76±0.18

[1] Mean of two samples prepared from the same pool of tooth ash

[2] Mean of three samples prepared from the same pool of tooth ash

[3] Mean of four samples prepared from the same pool of tooth ash

* Sample causing strong quenching effect when counted.

two or three years. After the new injections of nuclear debris into the atmosphere in 1961 and 1962, the strontium-90 content of deciduous teeth rose sharply: it reached a mean value of 6.8 pCi/gCa in children born in 1963. It is apparent from these results that the ^{90}Sr concentration in deciduous teeth is a good measure of the ^{90}Sr body burden.

When the ^{90}Sr concentrations in deciduous teeth in Helsinki are compared with the values reported from other localities, it is seen that in children born in 1956—1958 the values were higher in Italy (*D'arca Simonetti et al.*, 1969) and in the St. Louis area, USA, (*Rosenthal et al.*, 1966a) than in Helsinki, but that they were lower in California (*Rosenthal et al.*, 1966b) and in Denmark (*Aarkrog*, 1968). The lower values obtained in Denmark than in Helsinki are apparently due to differences in the consumption of cow's milk and other sources of ^{90}Sr and Ca. The strontium-90 content in the deciduous teeth of children born in 1959—1960 was about the same in Czechoslovakia (*Santholzer & Knaifl*, 1966) as in Helsinki, but was 2.5 times as high in Italy (*D'arca Simonetti et al.*, 1969). Concentrations of ^{90}Sr in teeth of children born in 1963 and thereafter have not yet been reported in the literature.

The values for the concentrations of strontium-90 in bone in Finland (*Salo et al.*, 1964, *Salo & Uotila*, 1969) showed a sharp increase in children born in 1961, 1962 and 1963. Thus these results are in full accord with the values obtained for deciduous teeth in the present study. A strong increase in ^{90}Sr concentration in milk was also obvious in Finland in 1962 and 1963 (*Paakkola*, 1966).

Considering that the values of ^{90}Sr activity were lower in human than in cow's teeth, the use of direct measurement of the Čerenkov radiation can be further compared to the conventional method utilizing a low-background beta counter (see *Rytömaa & Paakkola*, 1971). The results obtained with these two techniques, i.e. radiochemical separation of ^{90}Sr and β-counting, vs. direct measurement of Čerenkov radiation, were identical (*Rytömaa & Paakkola*, 1971), provided that the counting time was adequate with respect to the sample activity. The major disadvantage in the measurement of the Čerenkov radiation by means of an ordinary liquid scintillation counter is the relatively large counting error due to the high background count rate. However, tooth samples with net count rates from about 4 cpm to 16—17 cpm are usually easy to obtain and thus the relative counting error becomes reasonable with counting times of only a few hours. For instance, a sample with a net count rate of 10 cpm (and a background count rate of 12 cpm) can be measured with a relative error of $\pm 5\ \%$ in 2.3 hours. The minimum counting time required for a sample with a net count rate of only 1 cpm to detect activity different from zero would be about 1.5 hours, as estimated from the equation

$$n_{min} = 2\sigma_n = \sqrt{\frac{8\, n_o}{t}}, \quad (\textit{Gibbs}, 1962).$$

An idea of the sensitivity of the counting technique used in the present study may also be obtained from the following figures. A sample consisting of 6 g of tooth ash (equivalent to about 2.2 g of calcium) is counted for 10 hours with a background of 12 cpm. The minimum statistically significant count rate different from zero is then 0.4 cpm (see above) (*Gibbs*, 1962) and this would be equivalent to a ^{90}Sr concentration of about 0.2 pCi/gCa. In this case the relative counting error (one σ equivalent) would, of course, be as high as ± 50 %.

In a study where large changes in the body burden of ^{90}Sr with time are followed, it is acceptable to allow a high relative counting error for samples with a very low activity. If allowing a 20 % counting error for these samples and adopting 10 hours as the maximum practical counting time, then the minimum sample activity for the present assay system may be estimated from the equation

$f_r \sqrt{t} = \frac{\sqrt{n_N + 2\, n_o}}{n_n}$ (*Haberer*, 1965). In the case of very low sample activity $n_N << 2\, n_o$ and therefore the equation can be reduced to $f_r \sqrt{t} = \frac{\sqrt{2\, n_o}}{n_N}$. From this equation, with the following values, $f_r = 0.2$, $n_o = 12$ cpm and $t = 600$ min, it is obtained $n_N = 1.0$ cpm. On the basis of the present results, the maximum amount of tooth ash from which a clear and colourless solution with a volume of 25 ml can easily be prepared is of the order of 8 g, corresponding to about 2.9 g of calcium. Since in the counting system adopted 1.0 cpm is equivalent to 1.16 pCi ^{90}Sr, the »sensitivity limit» of the assay system becomes 1.16/2.9 = 0.40 pCi/gCa.

Sample activities below this level can, of course, be measured by means of Čerenkov radiation if a larger counting error is sanctioned, if the sample size is increased, or if the background count rate is reduced. In practice, however, it may be easier to measure such low activities with the more conventional method, utilizing radiochemical separation on ^{90}Sr and a low background beta counter.

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SUMMARY

Strontium-90 concentrations were measured by means of Čerenkov radiation in deciduous teeth collected in Helsinki from children born in 1956—1963.

The mean ^{90}Sr content in those born in 1956 was 1.8 pCi/gCa; it increased to a value of 2.6 pCi/gCa in 1958 and remained at the same level for the next 2—3 years. Thereafter a sharp increase occurred, reaching a value of 6.8 pCi/gCa in children born in 1963.

RÉSUMÉ

STRONTIUM-90 DANS LES DENTS TEMPORAIRES D'ENFANTS NÉS EN 1956—1963 RECUEILLIES À HELSINKI

Les concentrations en Strontium-90 ont été mesurées grâce aux rayons Čerenkov dans des dents temporaires recueillies à Helsinki et provenant d'enfants nés en 1956—1963.

La teneur moyenne on ^{90}Sr chez les enfants nés en 1956 était de 1,8 pCi/gCa; elle augmentait jusqu'à la valeur de 2,6 pCi/gCa en 1958 et restait au même niveau pendant les 2—3 années suivantes. Il se produisait ensuite une brusque augmentation, atteignant la valeur de 6,8 pCi/gCa chez les enfants nés en 1963.

ZUSAMMENFASSUNG

STRONTIUM-90 IN MILCHZÄHNEN GESAMMELT IN HELSINKI UNTER KINDERN, DIE ZWISCHEN 1956—1963 GEBOREN WURDEN

Strontium-90 in den Milchzähnen von Kindern, die zwischen den Jahren 1956 und 1963 geboren waren, wurde mittels Čerenkov-strahlung gemessen. Die mittlere ^{90}Sr-Gehalt in den im Jahre 1956 geborenen Altersgruppen war 1,8 pCi/gCa; ^{90}Sr nahm im Jahre 1958 ab und blieb während der folgenden 2—3 Jahren in demselben Niveau, 2,6 pCi/g Ca. Nach dieser Zeit wurde eine scharfe Zunahme notiert und ein Maximum von 6,8 pCi/g Ca fuer die Kinder, die im Jahre 1963 geboren waren, wurde erreicht.

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Address:
Institute of Dentistry,
University of Helsinki,
Fabianinkatu 24,
Helsinki 10, Finland