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Trace Elements in Human Tissue

3. STRONTIUM AND BARIUM IN NON-SKELETAL TISSUES*

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It has been found previously (Sowden & Stitch, 1957) that barium and strontium were regularly present in human bone in concentrations of 7 and 100 $\mu\text{g./g.}$ of ashed tissue respectively. This work has been extended to the estimation of these trace elements in other human tissues, to determine which organ in the body concentrated the elements to the greatest extent, and to estimate the total body content of barium and strontium. These points are significant in the estimation of the radiation hazard to man from contamination with radioactive forms of these elements. It has been generally assumed, from the pattern of distribution of activity within the body after injection of radioactive isotopes, that strontium accumulates to a greater extent in bone than in soft tissues (Pecher, 1941; Lisco, Finkel & Brues, 1947; Kidman, Tutt & Vaughan, 1950; Comar, Wasserman, Ullberg & Andrews, 1957). Three reports issued by Tipton *et al.* (1957) give extensive details of the barium and strontium content of human organs taken from autopsies of American subjects. Other references to the concentrations of these elements in tissues are isolated. Strontium was detected in human tissues by Sheldon & Ramage (1931), Gehrlach & Muller (1934) and Forbes, Mitchell & Cooper (1956). In a single case of barium chloride poisoning reported by Mancini (1943) 5 mg. of barium was found in the liver and kidneys, with traces in the spleen and adrenals. Spectrographic analysis of

eye tissue from various animals has established that barium is concentrated in the pigmented parts of the eye (Bowness, Morton, Shakir & Stubbs, 1952; Scott & Canaga, 1940; Ramage & Sheldon, 1931; Oksala, 1954). The degree of concentration in cow-, rabbit- and human-eye tissue has been established in this Laboratory by neutron-activation analysis (Sowden & Pirie, 1958).

METHODS

Estimations of strontium and barium concentrations were made by neutron-activation of the tissue in ashed form. Radioactive strontium and barium were chemically separated from the ash for comparison of their activity with that of irradiated standard samples of pure barium and strontium salts. Details of the techniques of tissue collection and preparation, neutron-activation and radioassay are given in a previous paper on bone analysis (Sowden & Stitch, 1957), but the more varied mineral composition of non-skeletal tissue made certain modifications of this method necessary. A more elaborate separation was required to obtain radiochemically pure fractions of strontium and barium. To obtain a sufficient activity in the barium and strontium for radioassay, larger amounts of tissue ash were required and these were subjected to a preliminary concentration of strontium and barium, in order to avoid the high radioactivity induced in gram quantities of ash after neutron-activation.

Reagents

Modifications of the technique used for bone analysis involved the use of certain additional reagents.

* Part 2: Sowden & Stitch (1957).

Carrier solutions. Calcium oxalate soln. in dil. HCl contained 10 mg. of calcium/ml. prepared from 'specpure' calcium carbonate (specially selected for low strontium content by Johnson, Matthey and Co. Ltd.). The strontium content was 3 $\mu\text{g./g.}$ of calcium oxalate; the barium present was $\leq 1 \mu\text{g./g.}$ of calcium oxalate, as determined by activation analysis. Nitrates of rubidium, potassium, copper, manganese, silver, cadmium, lead, nickel, cobalt and zinc in aq. 10% (w/v) soln. for addition after neutron-activation.

Other reagents. Water was redistilled from Pyrex apparatus. HCl, M.A.R. grade (Hopkin and Williams Ltd.), was redistilled, the middle fraction being stored for use in stoppered polythene bottles. Aq. NH_3 soln., A.R. grade, was distilled and collected in redistilled water. Ammonium oxalate, A.R. grade, aq. soln. saturated at room temperature; barium and strontium concentrations were $\leq 1 \mu\text{g./g.}$ Ammonium sulphide solution, A.R. grade, was added after neutron-activation.

Preparation of samples

Tissue samples were prepared as described previously (Sowden & Stitch, 1957) but were subjected to a preliminary concentration of strontium and barium before activation. Samples of tissue ash (500 mg.) were weighed into polythene centrifuge tubes and dissolved in redistilled HCl. Calcium oxalate soln. in dil. HCl (2 ml.) was added as carrier for the strontium and barium, and the mixed oxalates were precipitated with excess of ammonium oxalate at neutrality. The tubes were cooled in ice ($1\frac{1}{2}$ hr.) and centrifuged, and then drained and dried to constant weight under an infrared lamp. The precipitation of strontium and barium in trace quantities in the presence of calcium carrier was investigated by the addition of ^{89}Sr and ^{139}Ba to tissue ash, from which calcium oxalate was precipitated. Under the conditions described it was found that there was an average loss of $3.9 \pm 0.9\%$ of ^{139}Ba on 12 precipitations; no loss of ^{89}Sr was observed. The dried oxalate precipitate was transferred to a polystyrene tube for activation, a correction being made to the final assay for the percentage loss of precipitate on transference.

Radiochemical purification after neutron-activation

The method of separation employed was similar to that used for bone analysis (Sowden & Stitch, 1957) but was extended to remove the increased amounts of sodium, potassium and trace elements present in soft-tissue ash. The number of carbonate separations was increased to four. After the scavenging with iron hydroxide, mixed sulphides were precipitated with ammonium sulphide in a solution made alkaline with aq. NH_3 soln. and were removed by boiling and filtration (Whatman's no. 1 filter paper). Strontium and barium were recovered from the filtrate by conversion into carbonate on boiling with solid Na_2CO_3 . In

addition to the separations described in the existing method, a separation with fuming HNO_3 was carried out before the final separation of barium and strontium for radioassay.

Reproducibility

Samples of liver and brain ash were analysed repeatedly to determine the reproducibility of the method (Table 1).

RESULTS

Organs from thirty-one individuals were examined for strontium and barium; where insufficient tissue was available from single individuals ash from several specimens was combined for analysis. A comparison of the concentrations of strontium and barium in organs from persons of similar age groups is given in Table 2. No marked accumulation was observed in any of the major organs examined, but lung and aortic tissues were found to have concentrations greater than that of the average for the body.

Analysis of the dissected parts of the eye obtained from adults and still-born infants did not reveal any greater concentration of barium and strontium than in other tissues of the body. Details of the separate tissues examined are given by Sowden & Pirie (1958).

DISCUSSION

Although it is widely believed that barium and strontium are not retained to any appreciable extent in human soft tissues, few quantitative results are available for comparison with these figures. A low concentration was observed in most of the tissues examined by us, the concentration of barium in soft-tissue and skeletal ash being fairly constant throughout the body. This is in marked contrast with strontium where the average concentration in soft-tissue ash was found to be 9 p.p.m., the adult concentration in bone ash being approximately 100 p.p.m. (Sowden & Stitch, 1957). The ash obtained from soft tissues is approximately 1% of the fresh wet weight, whereas an average of 25% of fresh bone remains as ash; although barium and strontium are more concentrated in fresh bone than in non-skeletal tissues, the discrimination is greater for strontium. Comparisons with the values published by Tipton *et al.* (1957) show good agreement on the average level and pattern of distribution in specific organs,

Table 1. *Reproducibility of estimations of barium and strontium in tissue ash*

	Concn. of barium	S.D.	No. of determinations	Concn. of strontium	S.D.	No. of determinations
	($\mu\text{g./g.}$ of ash)			($\mu\text{g./g.}$ of ash)		
Ox liver	18.3	± 2.0	11	4.5	± 0.65	11
Human brain	1.8	± 0.16	6	3.5	± 0.17	11

Table 2. *Average concentrations of barium and strontium in human organs*

Number of specimens analysed is given and the extreme values are given for groups of specimens in which individual samples were analysed.

Organ	Age group (years)	Concn. of barium ($\mu\text{g./g. of ash}$)	Concn. of strontium ($\mu\text{g./g. of ash}$)
Liver	Still-born	4.2 (7)	2.6 (7)
	$\frac{3}{12}$ -12	3.3 (3)	3.2 (3)
		(3.0 $\rightarrow$ 3.6)	(3.0 $\rightarrow$ 3.7)
	30-87	3.5 (15)	4.3 (15)
		(1.0 $\rightarrow$ 15.5)	(1.4 $\rightarrow$ 8.9)
Brain	$\frac{3}{12}$ -12	2.3 (6)	3.1 (6)
		(1.6 $\rightarrow$ 4.0)	(2.2 $\rightarrow$ 4.7)
	30-87	2.6 (12)	3.5 (12)
		(1.0 $\rightarrow$ 11.6)	(2.5 $\rightarrow$ 6.5)
Spleen	$\frac{3}{12}$ -12	3.5 (3)	4.2 (3)
		(2.9 $\rightarrow$ 4.6)	(3.1 $\rightarrow$ 5.7)
	30-87	3.3 (12)	4.8 (12)
		(1.4 $\rightarrow$ 5.9)	(3.4 $\rightarrow$ 9.8)
Heart	Still-born	3.1 (7)	6.1 (7)
	$\frac{3}{12}$ -12	20.3 (9)	4.8 (9)
	30-87	7.4 (11)	6.1 (11)
		(2.0 $\rightarrow$ 35.0)	(2.3 $\rightarrow$ 10.8)
Kidney	0- $\frac{3}{12}$	8.0 (5)	4.7 (5)
	$\frac{3}{12}$ -12	5.0 (3)	4.5 (3)
		(4.4 $\rightarrow$ 5.7)	(4.1 $\rightarrow$ 5.5)
	30-87	9.9 (14)	8.1 (14)
		(2.1 $\rightarrow$ 46.3)	(1.1 $\rightarrow$ 32.9)
Lung	0- $\frac{3}{12}$	21.4 (7)	5.8 (7)
	$\frac{3}{12}$ -12	11.3 (9)	5.6 (9)
	30-87	15.4 (10)	18.2 (10)
		(6.1 $\rightarrow$ 35.4)	(6.9 $\rightarrow$ 47.6)
Pancreas	30-87	8.1 (6)	11.6 (6)
		(3.0 $\rightarrow$ 15.0)	(4.5 $\rightarrow$ 26.0)
Testis	30-87	3.1 (7)	6.1 (7)
Ovary	30-87	1.7 (3)	8.8 (3)
Uterus	0- $\frac{3}{12}$	8.6 (2)	10.0 (2)
	30-87	2.4 (5)	7.0 (5)
Thymus†	0- $\frac{3}{12}$	1.1 (5)	3.0 (5)
	$\frac{3}{12}$ -12	8.0 (7)	8.1 (7)
	30-87	4.2 (2)	17.9 (2)
Bladder	0- $\frac{3}{12}$	6.0 (4)	5.6 (4)
	$\frac{3}{12}$ -12	4.9 (8)	10.3 (8)
	30-87	11.5 (10)	13.1 (10)
Gall bladder	0- $\frac{3}{12}$	3.0 (3)	9.5 (3)
	$\frac{3}{12}$ -12	5.1 (7)	6.6 (7)
	30-87	2.6 (8)	12.9 (8)
Muscle	$\frac{3}{12}$ -12	6.3 (9)	6.3 (9)
	30-87	7.1 (14)	3.4 (14)
Tongue	$\frac{3}{12}$ -12	6.3 (2)	6.3 (2)
	30-87	8.0 (2)	6.0 (2)
Skin	$\frac{3}{12}$ -12	10.3 (7)	9.0 (7)
	30-87	13.3 (14)	8.8 (14)
Lymph gland	30-87	8.5 (4)	20 (4)
Thyroid	$\frac{3}{12}$ -12	1.2 (9)	8.2 (9)
	30-87	23.8 (15)	16.5 (15)
Prostate	$\frac{3}{12}$ -12	6.7 (3)	9.8 (3)
	30-87	5.9 (8)	24.0 (8)
Adrenal	30-87	8.5 (14)	7.4 (14)
Fat	30-87	8.5 (13)	4.4 (13)
Aorta*	10	1000 (1)	60 (1)
	30-87	28 (7)	73 (7)

* Spectrographic analyses of one child and four adult samples in the A.E.R.E. laboratory, Woolwich, estimated reproducibility being $\pm 20\%$.

† Atrophied in adult.

although the range of individual results within the population is greater in the American series. The findings of higher concentrations in lung and aorta have been supported by the results of Tipton *et al.* (1957). There is no relationship between age and concentrations of barium and strontium in the lung, as might be expected if the accumulation of these elements was directly related to dust inhalation. Non-cartilaginous and therefore non-calcified portions of the lung were examined. High concentrations in aortic tissue may have some relation to the degree of calcification. The high concentration of barium in animal-eye tissues has not been observed in human-eye tissue (Sowden & Pirie, 1958). Since no marked accumulation of barium and strontium occurs in the human eye their presence does not appear to constitute a hazard to man of damage to the eye by radiation.

An estimate of the total body content of barium and strontium can be made although it must be stressed that the value of such an estimate is limited by the small number of samples analysed. In calculating the barium and strontium content of each organ, the 'standard-man' specifications were taken for the weights of organs (Recommendations of the International Commission on Radiological Protection, 1955). Values for skeletal concentration were those published by Sowden & Stitch (1957). The total body content of barium, estimated at 23.8 mg., and strontium at 268.4 mg., was comparable to an estimate by Tipton *et al.* (personal communication) of 16 mg. of barium and 133 mg. of strontium. This figure for total body content does not include strontium and barium in the gastrointestinal tract. Harrison, Raymond & Tretheway (1955) estimated a gut reserve of 3 mg. of strontium.

SUMMARY

1. A previously described method of estimating barium and strontium in bone ash by neutron-activation has been modified to include non-skeletal tissues.

2. Soft tissues collected from 31 cadavers have been examined.

3. No marked accumulation of barium and strontium was apparent; lung and aorta were found to have the highest concentrations.

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