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AN UNUSUAL CASE OF RADIUM TOXICITY*

H. F. Lucas, Jr., R. E. Rowland, C. E. Miller,** R. B. Holtzman,
R. J. Hasterlik,† and A. J. Finkel**

Abstract

A case history of a patient with radium toxicity is presented. The patient, before death at age 54, was found to have large amounts of Ra^{226} in a femur amputated in the treatment of an osteoblastic osteogenic sarcoma. The total body burden was estimated by several methods. Whole-body counting showed a body burden of about $0.60 \pm 0.06\ \mu C$ of Ra^{226}. Radiochemical analyses of small sections of the amputated femur gave an estimated burden of about $0.4\ \mu C$ and Rn^{222} breath measurements indicated a burden of about $0.17\ \mu C$ Ra^{226}. Autoradiographic studies indicated a total burden of about $2\ \mu C$, an estimate in agreement with that from bone damage observed in Roentgenograms.

It was estimated that the Ra^{226} had been incorporated into the skeleton about 40 years prior to these measurements. While the patient received a series of weekly injections at about this age, there is a lack of direct evidence that they contained radium. The coefficient of excretion, the ratio of RaD to Ra^{226} in bone samples, and Roentgenographic findings are consistent with exposure to Ra^{226} at about 18 years of age.

The route and rate of intake of the original exposure, as deduced from the hot-spot-to-diffuse ratios in the autoradiographs, are consistent with injection over a period of 3 months and correspond to an intravenous dose of about $360\ \mu C$.

The discrepancies in the estimate of the body burden were apparently due to the extensive turnover of large areas of bone which were subsequently seen in the autoradiographs and microradiographs. The whole-body gamma counting and the chemical methods showed only averages of the remaining Ra^{226}, while the autoradiographs, indicating where activity was present, showed the nature of the original deposits. The importance of the initial amount of radium in the body on the carcinogenic process is discussed.

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0016501

Pb^{210} (RaD) IN INHABITANTS OF A CARIBBEAN ISLAND

Richard B. Holtzman

Abstract

The mean concentration of lead-210 in vertebrae of Puerto Ricans was 0.118 pC/g ash. The value in males, 0.133 pC/g ash, was significantly higher than the 0.088 pC/g ash in females. These values are significantly lower than those in similar groups of mid-continent (midwestern U.S.) residents, 0.196 for males and 0.156 for females. These lower values in island dwellers are attributed to the lower atmospheric concentration of Pb^{210} over the oceans with the consequently lower exposure of these people.

Discussion

The distribution of Pb^{210} (RaD) in human populations is of particular interest because this nuclide, along with its daughter Po^{210}, contributes 20% or more of the natural radiation dose to the skeleton.(1) In turn, the dose from natural radiation (cosmic rays, gamma rays, Ra^{226}, etc.) accounts for 90% or more of the total skeletal radiation dose (natural and fallout) exclusive of the uncertain dose received from medical X-ray exposure.(2)

Geographical variations in Pb^{210} concentration are to be expected on the basis of a previously proposed mechanism for the acquisition of the nuclide. In the United States about one half the activity is acquired by intake from food and the rest by inhalation, the contribution from skeletal Ra^{226} being negligible.(1) The concentration of Pb^{210} in air, however, should be lower over the ocean than over the continents because of the known lower concentrations over the ocean of the Pb^{210} precursor, Rn^{222}.(3,4) The atmospheric concentrations of Pb^{210} measured in England(5) and those measured at the 80th meridian air sampling stations are consistent with this concept.(6) Consequently, the Pb^{210} content in populations breathing ocean air should be lower than that in similar populations breathing continental air. This effect may be further enhanced by a lower intake from food, if, by analogy with the uptake of Sr^{90} in plants, a substantial fraction of the Pb^{210} in food is acquired from atmospheric precipitation.(7)

Skeletal concentrations of Pb^{210} have been determined previously in residents of various geographical locations: in England, by Hill and Jaworowski;(8) in the eastern United States, by Hursh;(9) in the midwestern United States, by Holtzman;(1) and in Germany by Groos, Sattler, and Stahlhofen.(10) However, little variation is to be expected among these groups,

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since the subjects are mainly from continental regions with the exception of England. Unfortunately, since only a few samples were reported from England and the concentrations were given in units of activity per gram of wet bone, no accurate comparison is possible (vide infra).[11] To verify the hypothesis of regional variation, the Pb^{210} concentration in bone from residents of a Caribbean island, Puerto Rico, was measured.

Specimens of vertebra were obtained at autopsy from each of 28 residents, 19 male and 9 female, in the vicinity of the city of San Juan between January and August of 1961. Each specimen was ashed in a muffle furnace at 900°C, dissolved in concentrated hydrochloric acid, and diluted to 0.5 N acid. The Pb^{210} was determined by the previously described method of plating out its daughter Po^{210} onto a silver disk, which was then counted for alpha particles.[1] Although some Po^{210} was probably lost during the ashing process, the interval of one year between ignition and measurement allowed the Po^{210} to reach virtual radioactive equilibrium with the Pb^{210}, a fact confirmed by subsequent re-analysis of the samples.

The loss of Pb^{210} at the 900°C ashing temperature appears to be negligible as shown by tests with samples of human rib, vertebra, and joint, and bovine mandible. Each was homogenized in a mortar; part of each was ashed at 900°C and another part wet-ashed in nitric and perchloric acids.[1] The ratio of Pb^{210} in the dry-ashed to wet-ashed samples was 1.06 ± 0.10 (standard error).

Table 12 presents the data on the Puerto Rican subjects arranged in order of increasing Pb^{210} concentration. The ages range from 21 to 109 years and the concentrations from 0.049 to 0.237 pC/g ash. Little

Table 12

Pb^{210} concentration in the bone of residents of San Juan, Puerto Rico

Sample No.	Age, years	Sex	Pb^{210}, pC/g ash ± E*	Sample No.	Age, years	Sex	Pb^{210}, pC/g ash ± E*
1	34	F	0.049 ± 0.005	15	45	F	0.111 ± 0.009
2	23	F	0.053 ± 0.007	16	29	M	0.113 ± 0.013
3	45	M	0.064 ± 0.006	17	109	F	0.115 ± 0.012
4	66	F	0.064 ± 0.010	18	45	M	0.117 ± 0.012
5	24	M	0.074 ± 0.009	19	51	M	0.125 ± 0.013
6	29	F	0.080 ± 0.004	20	51	F	0.126 ± 0.011
7	61	M	0.083 ± 0.012	21	54	M	0.139 ± 0.008
8	67	M	0.083 ± 0.009	22	66	M	0.165 ± 0.015
9	39	F	0.085 ± 0.007	23	67	M	0.170 ± 0.013
10	85	M	0.093 ± 0.011	24	25	M	0.180 ± 0.012
11	73	M	0.100 ± 0.011	25	68	M	0.187 ± 0.011
12	46	M	0.107 ± 0.007	26	58	M	0.187 ± 0.013
13	26	F	0.107 ± 0.011	27	78	M	0.195 ± 0.014
14	24	M	0.108 ± 0.012	28	44	M	0.237 ± 0.016

*E = 90% confidence limit

correlation between age and concentration is apparent. Table 13 shows, for the entire group and for the males and females separately, the mean concentrations of Pb^{210}, the range of values and the number of samples; similar data are presented for the "trabecular" bone samples (rib, vertebra, iliac crest, and talus) taken from the Midwest study.[1]

Table 13

Mean concentrations of Pb^{210} found in the specimens of bone obtained from residents of Puerto Rico and of the Midwest

Subjects	Region				P**
	Puerto Rico		Midwest		
	Age, years	Pb^{210}, pC/g ash ± E*	Age, years	Pb^{210}, pC/g ash ± E*	
Total	51 ± 21	0.118 ± 0.054	57 ± 13	0.184 ± 0.144	< 0.005
Range	23 - 109	0.049 - 0.237	18 - 90	0.053 - 0.454	
No. of samples		28		67	
Male	53 ± 19	0.133 ± 0.049	60 ± 11	0.196 ± 0.096	< 0.001
Range	24 - 85	0.064 - 0.237	34 - 85	0.059 - 0.453	
No. of samples		19		47	
Female	47 ± 27	0.088 ± 0.028	52 ± 16	0.156 ± 0.108	< 0.005
Range	23 - 109	0.049 - 0.126	18 - 90	0.053 - 0.454	
No. of samples		9		20	

*E is the standard deviation (of a single measurement).

**P is the probability that the mean value for a given Puerto Rican group is essentially identical with that of the analogous Midwest group.

The data from each study appear to be approximately normally distributed. The mean age and sex classifications are also comparable, the Puerto Rican subjects being slightly, but not significantly, younger than those of the Midwest study. The mean value of Pb^{210} concentration in each Puerto Rican group is about 60% that of its Midwest analog. The differences are significant based on Student's t'-test (t-test modified for the nonidentities of the variances of the groups);[12] for the complete groups and female groups, $P<0.005$; for the male groups, $P<0.001$. The Puerto Rican male group also shows a mean value significantly higher than that of the female ($P<0.005$). It might be noted that the significance of the difference between the mean values of the Midwest male and female groups is questionable ($P<0.1$), possibly because of the greater Midwest population inhomogeneity as indicated by the larger fractional variance and the more extensive geographical areas sampled.

That the mean Pb^{210} concentrations are higher in the male than in the analogous female groups is probably due to the greater metabolic activity of the former. This greater activity implies (and is seen in the "Recommended Daily Dietary Allowances")[13] that, per unit body weight, males consume more food (and air) and consequently more Pb^{210} than females.

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These comparisons are consistent with the hypothesis that, for human skeletons, the atmosphere constitutes a significant source of Pb^{210}, whether absorbed through direct inhalation or precipitation on foodstuffs. The relative contributions of diet and inhalation cannot be determined from the present data.

Additional support for the hypothesis that the atmosphere is a significant source of Pb^{210} could be inferred from Table 14. The average of 0.110 ± 0.037 pC/g ash in cortical bone from Germany is essentially identical to the 0.105 ± 0.100 pC/g ash found in cortical bone from the Midwest study. In England, where one would expect a lower atmospheric concentration of Pb^{210}, the few available measurements[8] indicate an average concentration in vertebrae (assuming an ash-to-wet weight ratio of 0.25[11]) very similar to that of the Puerto Rican samples. The mean values of both groups appear to be significantly lower than the comparable Midwest value for "trabecular" bone ($P<0.005$). The data of Hursh[9] for eastern U.S. are not directly comparable since whole-body rather than skeletal ash was measured.

Table 14

Regional variation of the Pb^{210} content of bone ash*

Bone	Region			
	Midwest, pC/g ash	Puerto Rico, pC/g ash	England, pC/g ash	Germany, pC/g ash
Trabecular	0.184 ± 0.144 (67)	0.118 ± 0.054 (28)	0.103 ± 0.019 (5)	- -
Cortical	0.105 ± 0.100 (61)	- -	- -	0.110 ± 0.037 (20)

*Numbers in parentheses - number of samples in study.

In summary then, skeletal concentrations of Pb^{210} appear to be higher in residents of continental regions than in those of islands. Further information is needed, however, before definite conclusions can be drawn concerning the importance of the atmosphere as a source of this nuclide. The concentration of Pb^{210} should be determined in the diet and in the atmosphere, and a larger sampling of the populations should be taken. Most important, comparison should be made of data from populations which, except for Pb^{210} concentrations in the air, are more nearly similar than those studied here.

I thank Dr. J. Rivera of the U. S. Atomic Energy Commission Health and Safety Laboratory and Dr. C. Galindo of the University of Puerto Rico for supplying the samples.

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0016506

THE KINETICS OF ALKALINE EARTH TRACER METABOLISM*

Richard B. Holtzman

Abstract

In mammals the fractional retention R at time t after a single injection of an alkaline earth tracer has been shown to follow a power function which has only two adjustable constants:

$$R = \left[\frac{t + \gamma}{\gamma}\right]^{-b}.$$

It is suggested here that this equation is theoretically sound; it is derived from a differential equation describing an nth order kinetic reaction, and it is otherwise consistent with the principles of reaction kinetics. It is assumed that 1) the tracer is deposited onto a purely inorganic system of bone crystal (hydroxyapatite) of constant mass and surface area and is bathed in a solution of constant calcium concentration; 2) the fraction of the tracer in solution is negligible; and 3) the specific activity of the calcium deposited with the tracer at $t = 0$ remains constant throughout time, i.e., the traced calcium does not mix with the other calcium in the system. The parameters of the equation are then $b = 1/(n-1)$ and $\gamma = (b/k)c_0^{-1/b}$ where n is the order of the reaction, k the rate constant, and c_0 the ratio of the calcium deposited with the tracer to that present in the system. The proposed mechanism is recrystallization (only the dissolution component is observed). This theory is consistent with the experimental results that R is independent of the amount of tracer injected and that R and the apparent value of b are dependent on the calcium content of the diet.

Application of these equations to the case of a continuous and constant uptake of tracer yields finite values for the predicted retention, rather than the infinite level predicted by the simple power function.

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