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APPLICATION OF XRF TO MEASURE STRONTIUM IN HUMAN BONE IN VIVO *

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INTRODUCTION

Strontium appears in the earth's crust at a concentration of about 400 ppm and in sea water about 8.1 ppm. Consequently, all living forms have evolved in the presence of this alkaline earth and have incorporated it in their tissues. The exact role of Sr in the human body remains ambiguous (1), even though Sr has been extensively studied with reference to the radiation hazard from ^{90}Sr (2).

Metabolic behavior of Sr, in some aspects, is similar to that of Ca (3), but substantial dissimilarities between these two are also well recognized (1,4). It has been suggested that Sr stimulates the formation of bone matrix. At higher concentrations, however, it interferes with calcification mechanism of the bone matrix (5).

Strontium has occasionally been put to therapeutic use. Therapeutic effects of Sr have been reported in an adult case of the Fanconi Syndrome (6), and Sr lactate appears to have some value in the treatment of osteoporosis (7). There is also some evidence that Sr can harden bone and teeth, and hence is considered to be an anticariogenic agent in man (8).

As a basis for better understanding the role that Sr fulfills in human body, it is desirable to measure directly the main Sr store in human body. Although strontium is omnipresent in human tissues, 99% is stored in the mineral portion of the bone (9). In the present study x-ray fluorescence (XRF) was applied to measure the strontium content of the tibial shaft in vivo. The feasibility studies showed

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that normal levels of stable strontium in the bone can be measured successfully.

METHOD

X-ray fluorescence spectroscopy was utilized for the measurement. In the present study either ^{125}I (Te x-rays) or ^{109}Cd (Ag x-rays) was used to stimulate 14.1 keV Sr K x-rays. The emitted x-rays were detected by a Si(Li) detector and processed by standard nuclear spectroscopy electronics.

Because of the low energy of the characteristic Sr x-rays, only superficial bones could be considered for the measurement of Sr. In the present work, the tibial shaft was selected as the measurement site. The geometrical configuration of the source, the detector and subject's leg is shown in Fig. 1.

The radiation dose delivered to the skin surface (approximately 1 cm^2) is one rem, and the dose delivered to the bone marrow subjacent to the exposed surface of the tibia is about 50 mrem..

Fig. 1. Schematic diagram of the source, tibia, and detector configuration.

RESULTS

A typical spectrum acquired from a dry human tibial shaft is shown in Fig. 2. The Sr photopeak is clearly visible above the background. Two lead peaks are also visible, as well as Zn (in trace levels) (10) and Ca, the main constituent of the bone. The spectrum from the measurement of a small area of the tibia in an intact leg from a cadaver is shown in the upper part of Fig. 3. A Sr peak is clearly visible. To confirm that the measured Sr was located in the bone, a second measurement was taken from the mid-calf tissue of the same cadaver, see lower part of Fig. 3. It is apparent that the Sr level in the skin and in the soft tissue is considerably below the detection limit of the present system. The Fe and Cu peaks originated in the collimator materials.

The results of all the measurements are summarized in Table 1. Listed are the source used to induce Sr x-rays, the net number of counts in the Sr peak together with the error of the measurement, and how well the Sr peak is defined above the background. The net number of counts were normalized to an exposure dose of 1 rem.

Quantitative calibration of the Sr measurement was performed by assaying bone specimen, from the measurement site, by atomic absorption. The calibration for the post mortem measurements only, is shown in Fig. 4. It should be noted that the value of the point 64 in Table 1 is corrected in Fig. 4 for increased attenuation corresponding to 1mm of overlying tissue. The corrected value is 1533 instead of 1224. The calibration line in Fig. 4 represents,

Fig. 2. L x-ray spectrum taken from a dry bone, induced by ¹²⁵I source. The peaks above channel 500 are backscattered peaks.

therefore, the slope of the Sr signal for an exposure of 1 rem and overlying tissue thickness of 2.5 ± 0.5 mm. The lower detection limit of Sr (defined as three standard deviation above the background) is about 15 μg Sr/g wet bone, and the reproducibility of the system is about 5%.

Fig. 3. L x-ray spectrum measured on intact cadaver leg irradiated by ^{125}I source. 1 rem skin dose.

TABLE 1

STRONTIUM MEASUREMENTS ON INTACT TIBIAL SHAFTS, EXPOSURE 1 REM

Sample	Source	Net counts* $\pm$ SD	σ 's** Above Bkg.
(1)			
P.M.			
59	I-125	1481 $\pm$ 128	17.1
60	"	1895 $\pm$ 133	21.3
61	"	1124 $\pm$ 175	12.1
64	"	1274 $\pm$ 170	14.4
65	"	1497 $\pm$ 139	15.3
67	Cd-109	2986 $\pm$ 151	29.7
(2)			
A.L.			
1610	Cd-109	1004 $\pm$ 155	9.0
1610	I-125	1363 $\pm$ 175	11.3
2109	Cd-109	888 $\pm$ 193	6.7
3188	"	1363 $\pm$ 202	9.7
4442	"	2363 $\pm$ 191	19.3
(3)			
N.			
H.S.	"	1784 $\pm$ 179	13.5
M.S.	"	840 $\pm$ 176	6.4
S.M.	"	607 $\pm$ 170	5.1
K.E.	"	2089 $\pm$ 180	16.8
S.H.C.	"	1497 $\pm$ 170	12.7
R.S.	"	1609 $\pm$ 187	13.1
D.V.	"	1660 $\pm$ 170	13.3

(1) P.M. - Postmortem measurement

(2) A.L. - Amputated legs measurement from diabetic patients

(3) N - Normal volunteers

* Uncorrected for overlying tissue thickness

** σ = $\sqrt{\text{Background}}$

DISCUSSION

The preliminary results demonstrate the feasibility of measuring normal levels of Sr in the human body in vivo. Although the method is limited to superficial bones, the intensity of the measured Sr signal is satisfactory. The present set-up is also used to measure lead in the bone in vivo (11,12). The chief limitation of the method is the attenuation of the signal due to overlying tissue. It is important, therefore, in particular, for epidemiological studies, that the measured Sr signal be normalized per unit of overlying tissue thickness. In the present study, the thickness of the

Fig. 4.

Strontium calibration.
XRF net count/rem at 2.5 mm
overlying tissue thickness
versus Sr concentration in
the bone determined by
atomic absorption.

overlying tissue in cadaver legs has been determined directly by excision of the tissue. In vivo, the overlying tissue thickness can be determined ultrasonically with an accuracy of 0.3 mm with the use of a 7 MHz ultrasound transducer (12). Alternatively, the measured signal can be normalized with respect to coherently and incoherently scattered radiation (13). An improved response to the Sr signal can be attained by using polarized radiation to excite the Sr characteristic radiation (12). ^{125}I and ^{109}Cd were found to be equally effective sources for the Sr excitation.

Since most of the work reported in the literature deals with Sr transport and balance in human body, a noninvasive method to measure the steady state condition of Sr in the bone facilitate a new insight into the role of Sr in metabolic bone diseases, and epidemiological studies of lower levels of caries prevalent in populations with higher levels of Sr in drinking water.

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