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MICROSCOPIC DISTRIBUTION OF ^{239}Pu DEPOSITED IN BONE FROM A HUMAN INJECTION CASE*

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ABSTRACT

The distribution of ^{239}Pu was studied in bone from a woman who received an intravenous injection of 0.3 μCi ^{239}Pu in 1945 at age 18 and who died 17 months later with Cushing's Syndrome. The average depth at which ^{239}Pu was buried by appositional bone growth in trabeculae ranged from 40 to 60 μm in seven bones. The average for all sites of burial studied was 52 μm. Surface and volume concentrations in bone which covered buried surfaces in trabeculae ranged between 0.26 and 0.63 pCi/cm^2 and 56 and 160 pCi/cm^3 respectively in seven bones. The mean values of the data for the seven bones were 0.39 pCi/cm^2 and 94 pCi/cm^3. The volume concentration contributes only about 4% of the total terminal dose rate in a layer of cells 10 μm thick lining the endosteal surfaces of trabeculae in the 6th thoracic vertebra. In other bones the contribution from bone volume would be even less. Concentrations on the periosteal, endosteal and Haversian canal surfaces in the shafts of six long bones ranged between 0.18 and 0.64 pCi/cm^2, 0.14 and 0.31 pCi/cm^2, and 0.13 and 0.59 pCi/cm^2 respectively. These concentrations are considerably less than those observed on buried surfaces at the same sites.

INTRODUCTION

The Center for Human Radiobiology has obtained the remains of one case from the series of human plutonium injections reported by Langham and his colleagues (Langham et al. 1950) and reviewed by Durbin (1972). We report here measurements of the depth at which plutonium is buried by appositional bone growth, and measurements of bone surface and volume concentrations of ^{239}Pu made using autoradiographic methods.

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1000044

THE SUBJECT

The subject, known as HP-4 in the existing literature, is a woman who was injected at age 18 with 0.3 μCi ^{239}Pu in citrate solution and who died 17 months later from the effects of Cushing's Syndrome. She had suffered from Cushing's Syndrome for several years prior to her death and the disease was in an advanced state at the time of injection. Since Cushing's Syndrome affects bone, producing secondary osteoporosis, ^{239}Pu deposition may have been affected by the disease state.

METHODS

Bone pieces from several sites within the skeleton were embedded in methyl methacrylate and cut into sections which had nominal thicknesses of 100 μm. Autoradiographs were made of these sections using the fission track method (Schlenker and Oltman 1973) with Lexan plastic as the detecting medium. Irradiations were made in the Argonne National Laboratory CP-5 reactor.

DEPTH OF SURFACE BURIAL

A typical autoradiograph of trabecular bone is presented in Figure 1. The light gray area represents bone, the dark gray areas represent marrow spaces and the boundary between the light and dark gray represents the bone surface. Arrows point out a band of fission tracks produced by ^{239}Pu deposited on a surface which was buried by appositional bone growth. The average distance between such a band of tracks and the bone surface was determined using the formula

$$D = A/_L$$

where D is the distance, A is the area included between the band and the bone surface, and L is the length of the band between the points at which it intersects the surface. The distance D is the depth of burial for the portion of the buried surface represented by the band.

Table I presents the results of burial depth measurements in bone trabeculae. The minimum values observed in the various bones, 14-31 μm, probably overestimate the true minima, because it is difficult to make an accurate area measurement when the buried band lies near the bone surface. As a result, the average values are probably slight overestimates as well.

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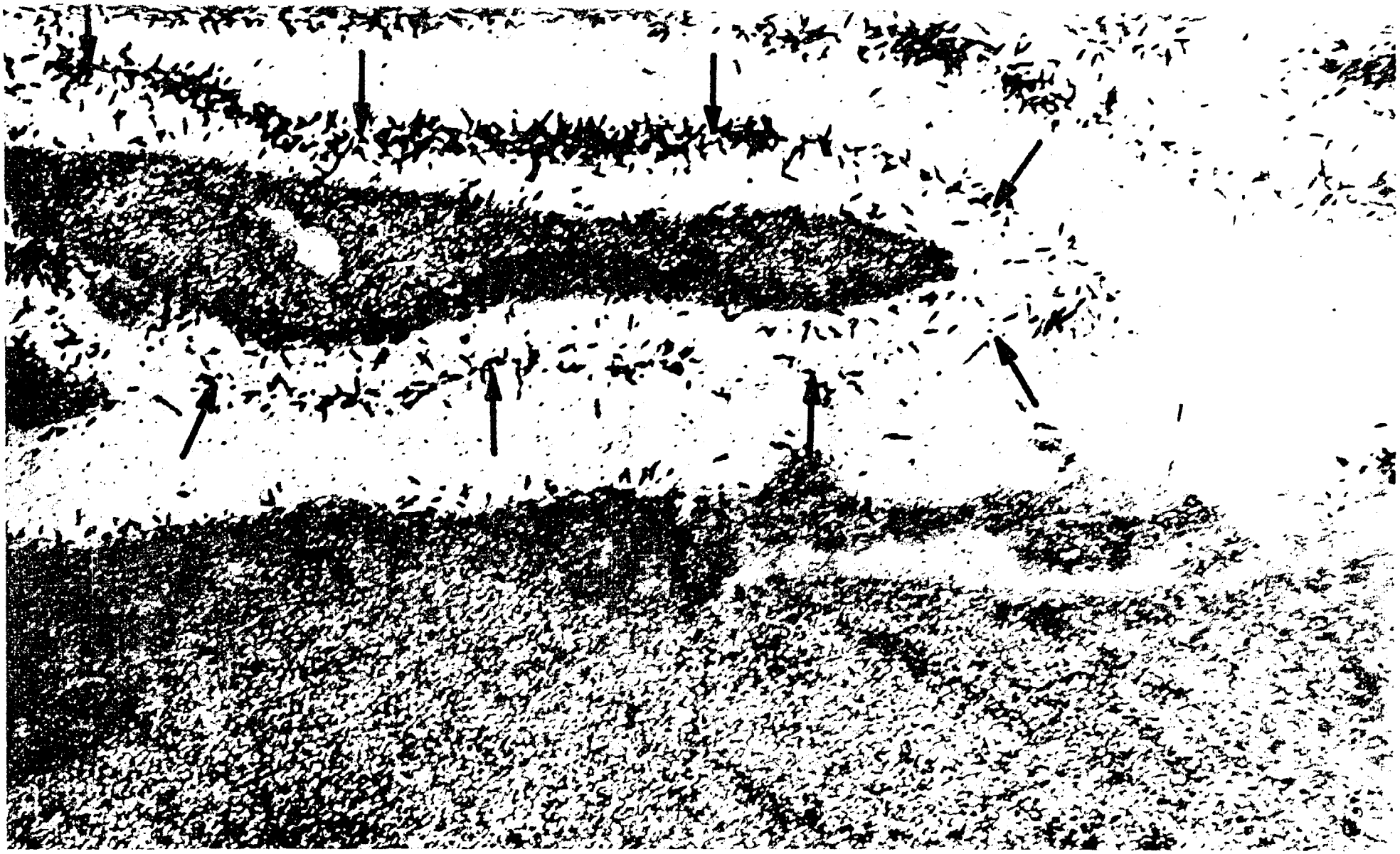

Figure 1. Autoradiograph of trabecular bone from the iliac crest. The light gray area represents bone and the dark gray areas represent marrow spaces. The arrows point to a band of fission tracks produced by ^{239}Pu deposited on a surface which was buried by appositional bone growth.

1000041

Table I. Burial depths of trabecular surfaces covered by appositional bone growth

Bone	Number measured	Depth, μm Range	Average
Cervical vertebra	10	18- 86	54
Lumbar vertebra	14	14-120	57
Thoracic vertebra	18	27- 76	50
Iliac crest	48	31-100	50
Pubis	37	31-160	60
Humerus	9	21- 80	40
Femur	42	15-110	49
Average ± standard error of all measurements			52 ± 2

For comparison with observations, the range of ^{239}Pu alpha particles in bone, computed using Kolenkow's and Manly's (1967) quadratic approximation to the range-energy relationship, is 23 μm. In some bones the minimum depth is less than this but in all bones the average depth is about 1.7 times this. Thus although some buried surfaces, or portions thereof, can irradiate surface cells, most lie deeper than an alpha particle range and produce no surface dose. Thus it appears that irradiation of bone surface cells results principally from deposits on the existing surface and from deposits in the volume between the existing and buried surfaces.

TRABECULAR SURFACE AND VOLUME CONCENTRATIONS

In order to estimate the relative contributions of volume deposits and of existing surface deposits to the terminal dose rates, we have measured their concentrations. Our surface measurements have been limited to bone which covers buried surface deposits. In our autoradiographs such bone appears to carry no more intense a surface label than bone which does not cover a surface deposit.

Concentration data and dose rates are presented in Table II. The concentrations have a fractional standard deviation of about 25%. The dose rates are averages throughout a 10 μm thick cell layer assumed to lie adjacent to the ^{239}Pu deposit. They are computed using the mean concentration values for seven bones given in Table II and the equations of Mays and Sears (1962).

1000048

Table II. Average ^{239}Pu concentrations on the surface and in the volume of bone which covers buried surfaces in trabeculae.

Bone	Number burial sites measured	Surface concentration, pCi/cm^2	Volume concentration, pCi/cm^3
Cervical vertebra	10	0.47	160
Lumbar vertebra	14	0.32	89
Thoracic vertebra	18	0.26	120
Iliac crest	48	0.33	56
Pubis	37	0.63	100
Proximal humerus	9	0.29	67
Proximal femur	29	0.41	64
Mean for seven bones		0.39	94
Average dose rate in 10 μm thick cell layer, mrad/day		33	5

If all cells were irradiated by both surface and volume ^{239}Pu deposits, they would receive about 33 mrad/day from the surface and 5 mrad/day from the volume. However, volume deposits occur only where appositional growth has buried a labeled surface so that much of the existing surface has no volume deposit adjacent to it. Thus the dose rate in a 10 μm thick layer would be 33 + 5 f mrad/day where f is the fraction of the existing surface which has a volume deposit adjacent to it. Measurements in the 6th thoracic vertebra indicate that about 30% of the existing surface has an adjacent volume deposit. Thus the data here would predict a total dose rate of 33 + 5 x 0.3 = 34.5 mrad/day. The volume deposits thus contribute only 1.5/34.5 or about 4% of the total dose. The vertebrae appear to have experienced more remodeling than other bones so that the contribution of volume deposits to the total dose in other bones would be even less than in the vertebrae. Thus little error would result in any dosimetric computations if the dose contribution from volume deposition were ignored altogether.

HAVERSIAN CANAL, ENDOSTEAL SURFACE, AND PERIOSTEAL SURFACE CONCENTRATIONS

Monomeric plutonium is known to be deposited in highest concentration on endosteal surfaces in the midshaft regions of mouse long bones a few days after injection (Rosenthal and Lindenbaum 1969). The next

1000049

highest concentrations are observed on Haversian canal surfaces and the lowest concentrations are found on periosteal surfaces. In order to determine whether or not such a gradation in terminal surface concentrations occurred in this case, we measured Haversian canal, endosteal surface and periosteal surface concentrations in the midshafts of the radius, ulna, humerus, femur, tibia, and fibula. Data are presented in Table III. The concentration values have fractional standard deviations of about 25%, but the relative concentrations between the different types of surface within each bone are accurate to 10%.

Table III. ^{239}Pu surface concentrations in long bone midshafts.

Bone	Concentration, pCi/cm^2 Periosteal	Haversian canal	Endosteal
Humerus	0.30	0.31	0.59
Radius	0.38	0.25	0.32
Ulna	0.28	0.22	0.13
Femur	0.64	0.26	0.23
Tibia	0.18	0.23	0.17
Fibula	0.27	0.14	0.16

There is no tendency for preferential deposition on any one of the bone surface types in this case, in contrast to the observations in mouse. There is, however, a preferential deposition of ^{239}Pu in buried endosteal surfaces. Figure 2 illustrates this graphically with plots of the distributions of concentrations on the Haversian canal, periosteal, existing endosteal and buried endosteal surfaces in the tibia midshaft. The average concentration observed on the buried surfaces is 12 times the average observed on the existing surfaces. A simple explanation of these sites is that they were forming at the time of injection and preferentially concentrated the ^{239}Pu producing high concentrations similar to those produced in growing bone following injection of alkaline earth elements.

THE EFFECT OF CUSHING'S SYNDROME

Cushing's Syndrome is believed to depress the amount of appositional bone growth below normal and to increase the amount of bone resorption above normal (Jowsey et al. 1965). The imbalance between removal and replacement thus created produces osteoporosis. If alteration in the bone

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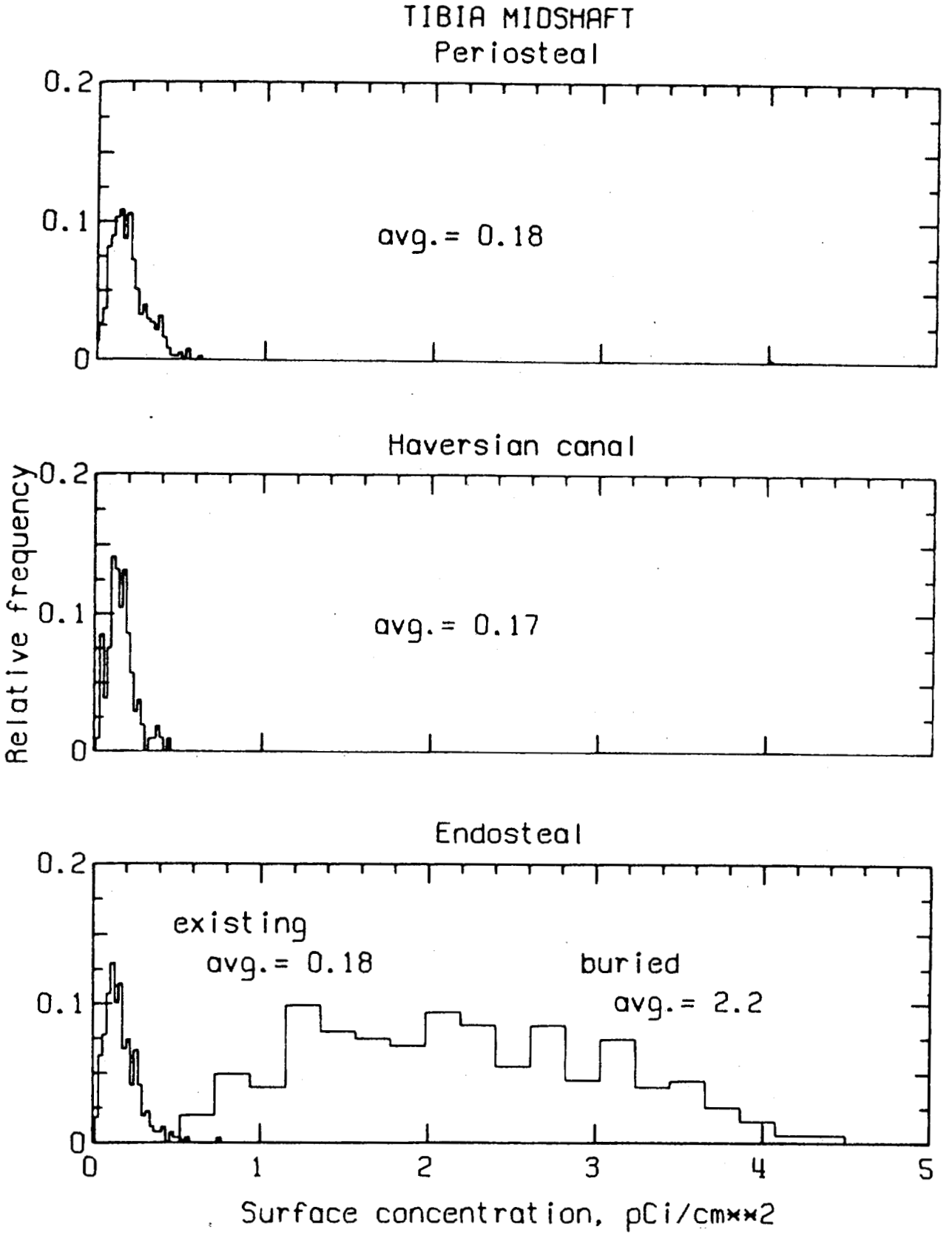

Figure 2. Relative frequency distribution of ^{239}Pu concentration on periosteal, Haversian canal and endosteal surfaces in the tibia midshaft.

1000051

remodeling rates is the sole effect of Cushing's Syndrome, then one would expect bone from a normal person of the same age as this case to show higher mean surface concentrations due to lower resorption rates and to show more burial of ^{239}Pu due to more frequent appositional bone growth.

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1000052