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BONE MINERAL CONTENT IN THE FOREARM OF HEALTHY ADULTS

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Bone mineral content (BMC) in the forearm was measured in 256 healthy adult persons (114 men and 142 women) by the ^{241}Am gramma ray attenuation method. The BMC decreased with increasing age after reaching a maximum, and was greater in men than in women.

The amount of calcium hydroxyapatite in human bone is a very important parameter (1). A reliable *in vivo* measurement of this mineral could serve to diagnose various demineralising diseases accompanied with changes in BMC like osteoporosis, osteomalacia, rheumatoid arthritis and diabetes mellitus, and to follow their treatment (1, 2). It could also be used to observe the effects of lack of stress on bones such as result from prolonged bed rest or weightless flight in space. The effects of certain drugs, such as fluorides, steroides and cortison-like drugs (3, 4) as well as the effects of diet, pregnancy and lactation can be examined by these measurements. The determination of bone mineral content is of interest to scientists in the animal sciences for similar reasons.

Roentgenographic procedures are also used to estimate BMC. However, they do not give quantitative information if changes in mineral content are less than 30—60% (5). Since in 1963 *Cameron and Sørenson* (16) reported a new method based on gamma-ray attenuation for the determination of bone mineral content, general modifications of it have been introduced. The method is suitable for rapid, easy and non-invasive measurement of local bone calcium with a radiation dose received during measurements lower than 10 mr (7). Early identification of persons with a high risk of osteoporosis requires a sensitive and highly reproducible measuring procedure (7). We need a non-invasive method of bone quantification that has good reproducibility to which all patients can be subjected repeatedly with negligible risk (8, 9). Photon absorptiometry of the appendicular bones is widely used for the non-invasive assessment of skeletal status (9, 10). The Cameron photon absorption technique of bone mineral analysis (11, 12) should make it possible to develop a clinically useful measurement of total body calcium, since the results can be expressed quantitatively and accepted in physical terms. This simple technique of measuring the BMC in loco can be extrapolated to yield information concerning human total body calcium (13).

The purpose of this investigation was to find out normal values of bone mineral content in healthy adult persons of different age which could serve as reference values in investigation of skeletal system of healthy adults and persons suffering from various bone diseases.

SUBJECTS AND METHOD

Two hundred and fifty-six subjects participated in this study: 142 women and 114 men. They were randomly selected among the staff of the Institute for Medical Research and Occupational Health in Zagreb, members of their families, friends and visitors as volunteers. We chose healthy subjects, who had not been operated upon previously, were using neither drugs nor contraceptives, and had no previous fractures. Their ages ranged from 20 to 90 years.

The method of *Cameron and Sørenson* (6) modified by *Nilsson* (9) was applied. A Gamma absorptiometer (Gambro, Sweden) equipped with a scintillation detector (NaI (TI) 2"x2"), a single-channel analyzer and a Wang 600 calculator was used. This equipment makes possible a direct read-out of BMC and bone width (BW) and is commercially available (12). The coefficient of variation (%) reflecting reproducibility and precision of the method was 4—6% for distal (BMC_1) measurements, and 3—5% for proximal (BMC_6) measurements (8). Our instrument is equipped with an ^{241}Am isotope source and operates as a low dose instrument (8, 11). It was originally developed at Lund, Sweden (12). The bone mineral content of the trabecular bone was measured on the right forearm in supine position at a distance of 1 cm (distal densitometry), and that of the cortical bone at a distance of 6 cm (proximal densitometry) from the styloid process of the ulna. Each value at 1 or 6 cm represents the average BMC value of the radius and ulna measurements. For more details see *Harmut and co-workers* (8).

RESULTS

Individual measurements are presented in Figure 1. Bone mineral content values are plotted against age (years). The ten years means (Table 1) and their standard deviations are plotted as well. Although some authors present these results by a third-degree regression curve (21), we think that a second-degree regression and a shape of our parabola (10) is much simpler of calculate and fairly adequate for our distribution.

The second-degree regression curves ($y = a + bx + cx^2$) of the measured bone mineral content (y) i.e. BMC_1 and BMC_6 distributions in relation to age in years (x) are given as:

$BMC_1 = 480.78 + 4.31\,x - 0.05\,x^2$

$BMC_6 = 751.44 + 1.14\,x - 0.03\,x^2$ for men and as

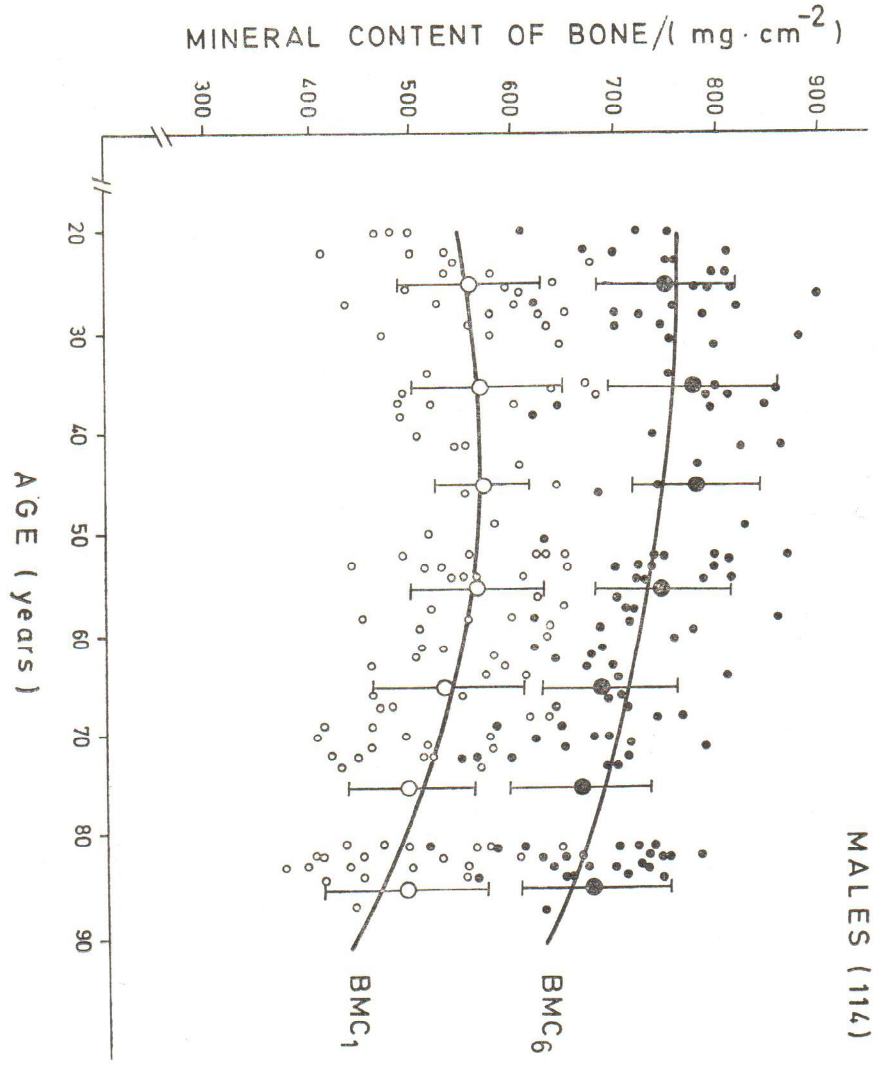

Fig. 1. *The mineral content of normal human forearm. The means (± 1 S. D.) of the bone mineral content (BMC) in different decades of age. The second--degree regression curves of the distributions, for men.*

$BMC_1 = 491.68 + 0.34\ x - 0.02\ x^2$

$BMC_6 = 647.96 + 3.54\ x - 0.07\ x^2$ for women.

The extreme values on the second-degree regression curves are in accordance with the extreme points seen on the curves in Figs. 1 and 2.

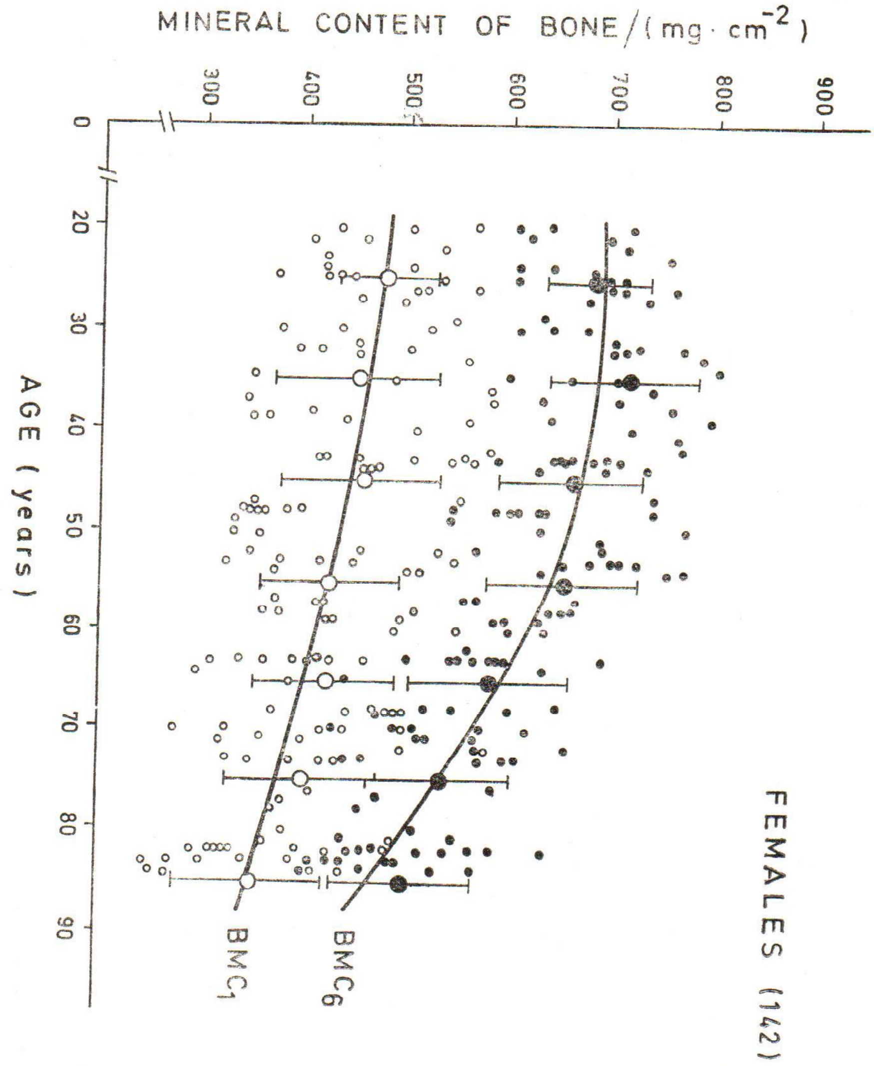

Fig. 2. *The mineral content of normal human forearm. The means (± 1 S. D.) of the bone mineral content (BMC) in different decades of age. The second-degree regression curves of the distributions, for women.*

Table 1

The means, standard errors and standard deviations (in parentheses) of the bone mineral content (BMC) in healthy persons of different age

Decade	Sex	N	BMC_1/(mg cm^{-2})	BMC_6/(mg cm^{-2})
20 — 29	F	21	476 ± 12 (56)	683 ± 11 (50)
	M	22	558 ± 15 (72)	750 ± 14 (67)
30 — 39	F	20	450 ± 18 (81)	711 ± 15 (69)
	M	12	566 ± 23 (79)	778 ± 23 (80)
40 — 49	F	22	456 ± 16 (77)	663 ± 14 (67)
	M	7	570 ± 17 (45)	779 ± 24 (63)
50 — 59	F	22	423 ± 14 (68)	655 ± 15 (71)
	M	22	565 ± 14 (65)	744 ± 14 (64)
60 — 69	F	19	422 ± 16 (68)	583 ± 18 (76)
	M	17	533 ± 17 (70)	689 ± 14 (57)
70 — 79	F	18	400 ± 17 (74)	537 ± 16 (68)
	M	12	497 ± 17 (59)	644 ± 19 (66)
80 — 89	F	20	352 ± 17 (74)	497 ± 14 (64)
	M	22	492 ± 16 (77)	678 ± 15 (70)

DISCUSSION

Studies with photon absorptiometry show that the patients with proved osteoporosis are separated from age matched controls only by one standard deviation (7, 16). Therefore all known parameters so far enable only a modest degree of discrimination between normal and osteoporotic individuals. Bones even in healthy persons of the same age and sex differ highly from one individual to another. In general, early detection of osteoporosis is not possible on the basis of a single measurement. Much more reliable is a time series of multiple measurements in which the patient serves as his own control. It is accepted that after the age of 40 a bone loss of approximately 1% per year for women and 0.5% for men might be considered as normal, whereas a bone loss in excess of 2% for women and 1% for men might lead to skeletal problems (7). Figure 1 clearly shows that between the ages 40 and 80 our healthy persons lose bone at a rate of 2 mg cm^{-2}/year (men) and 4.5 mg cm^{-2}/year (women). The loss in women is much quicker after the menopause. In the same age interval women lose about 27% of the bone, whereas men 11% only, if proximal BMC_6 measurements are taken into account. According to distal BMC_1 measurements the bone loss for women makes 33% and for men 14%. In the first case women lose about 0.66% and men 0.28% of the bone per year in the age interval of 40—80 years. In the second case the respective fractions are 0.83 for women and 0.35 for men. Our results are in accordance with the other investigations reporting the bone loss values of about 1% per year for women and 0.5% for men. Our results are in accordance with the other investigators reporting the bone loss values of about 1% per year for women and 0.5% for men (5, 7).

Trabecular bone is claimed to show changes in mineralization faster than cortical bone. At the distal end of the radius the bone cross section changes rapidly in the axial direction. Area changes of the order of 5% per millimeter of axial distance are common (7). For that reason our BMC_1 values are much more scattered than the BMC_6 values measured at the proximal measuring sites. Measurements on the radius and ulna shafts are highly correlated ($r = 0.85$) with the BMC of the femoral neck, but only moderately correlated ($r = 0.6 — 0.7$) with the BMC of the spine (14). The reason for this may be that the BMC of the radius contains predominantly cortical bone, while the BMC of the vertebra is based primarily on spongy bone. Since the mineral content of the bone is the chief determinant of its strength and resistance to fracture, it is evident that the peripheral BMC is a satisfactory indication of femoral neck strength but not of spinal strength.

The precision of bone mineral measurements in clinical work is typically 3 — 5% (7). Precision may be poorer if care is not taken with repositioning or if measurements are done on highly irregular bones such as the distal radius. The high inherent precision of the technique and the low dose (11) make serial measurements useful.

Our capacity to evaluate treatment regiments systematically and objectively depends to a large extent on the application of newer methods of non-invasive bone measurements. The methods of radiographic morphometry and photodensitometry are the first to be used in the objective assessment of dynamic changes in bone mass (14). The development of monoenergetic radiation densitometry, or photon absorptiometry allows estimation of appendicular bone mass with an accuracy of 1—3% and a precision of 2—4% (14). In his review of the various methods of non-invasive bone measurement Mazess also evaluates newer and less available methods including neutron activation of calcium, radionuclide uptake, Compton scattering, and computed tomography scanning (15). The latter method may in the future provide means for direct evaluation of trabecular bone in less accessible parts of the skeleton such as the vertebra. Once these methods are perfected, we shall be able to measure precisely the impact of therapeutic agents on the entire skeleton (13—20).

CONCLUSIONS

From the results of this work we can conclude that:

— the BMC is higher in men than in women;

— the BMC is a function of age in both sexes. It approaches a maximum between 30 and 40 years of age for both sexes and falls thereafter following a parabola;

— the loss of bone with age is more pronounced in women than in men. After the age of 40 the loss is 1% in women and 0.5% in men of the same age;

— the BMC at the distal sites is lower than at the proximal sites;
— the BMC at the proximal sites is much better reproducible than at the distal sites because of a higher scatter of the results due to the irregularities at these measuring sites;
— the radiation dose received during measurements (scanning) is negligible.

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Sažetak

SADRŽAJ MINERALA U KOSTI PODLAKTICE U ZDRAVIH ODRASLIH OSOBA

Sadržaj minerala u kosti podlaktice mjeren je metodom atenuacije (gašenja) gama-zraka ^{241}Am u 256 zdravih osoba (114 muškaraca i 142 žene). Sadržaj opada s dobi nakon što postigne maksimum u dobi između 30 i 40 godina a viši je u muškaraca negoli u žena. Rezultati ovih istraživanja primjenjivat će se u ispitivanjima bolesti i faktora koji utječu na sadržaj minerala u kostima populacije u Hrvatskoj.

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