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# Bone mineral content of the forearm in healthy Dutch women

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Single energy photon absorptiometry is a reliable technique for assessing the bone mineral content (BMC) of cortical bone in the forearm. It can also be used for BMC measurement in the ultradistal part of the forearm, where there is a considerable proportion of trabecular bone. The results of a BMC survey at both sites in healthy Dutch women, aged 26—75 yr, are reported, and the differences and changes with age are discussed. The technique offers possibilities for a rational screening programme in post-menopausal women, because of its high precision, low radiation dose, speed and low cost. The validity of the ultradistal measurement for the detection of abnormally fast bone mineral loss from trabecular bone in the individual patient has yet to be proven.

(Key words: Bone mineral content, Osteoporosis, Single energy photon absorptiometry, BMC reference values)

## Introduction

Osteoporosis is a matter of great concern in terms of health care and cost. On the basis of the rise in the number of hospital admissions due to osteoporosis or osteoporosis-related fractures in The Netherlands during the period 1972—1982, it is forecast that this figure will triple by the year 2010, taking into account expected population trends [1]. A rational prevention strategy requires the proper identification of women at risk and the availability of preventive measures.

Oestrogen substitution is an effective method of preventing post-menopausal bone loss [2], while adequate calcium intake and appropriate exercise are also recommended. Oestrogens should be prescribed selectively to women at risk for post-menopausal osteoporosis [3]. Risk assessment ultimately relies on the detection of an excessive loss of bone mass or an existing abnormally low bone mass. Several techniques are available for this purpose [4], but only single photon absorptiometry (SPA) is suitable for the screening of bone mineral mass on a

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large scale. The original apparatus did not provide information on the trabecular bone of the skeleton, which is the type primarily affected in post-menopausal osteoporosis. However, recently developed equipment has made it possible to obtain data on bone mineral content (BMC) in the distal forearm, where a fair proportion of trabecular bone is present. Hitherto, only cortical bone at a more proximal site could be measured.

Using this technique, the BMC of the forearm was measured in a group of healthy Dutch women. The aim of this cross-sectional study in a healthy female population was to determine BMC in the forearm in relation to age and to investigate whether differences could be observed between the cortical and the combined cortical plus trabecular measurements.

TABLE I

AGE DISTRIBUTION AND RESULTS FOR THE ENTIRE STUDY POPULATION (MEANS AND STANDARD DEVIATIONS)

| Age | *n* | BMC | | BMC/BW | |
|---|---|---|---|---|---|
| | | Distal | Proximal | Distal | Proximal |
| 21—25 | 2 | 46.0 ($\bar{x}$) | 42.3 | 1.19 | 1.55 |
| | | *1.3* (S.D.) | *3.9* | *0.07* | *0.04* |
| 26—30 | 36 | 41.2 | 40.7 | 1.07 | 1.42 |
| | | *6.6* | *5.6* | *0.16* | *0.14* |
| 31—35 | 65 | 41.6 | 41.8 | 1.08 | 1.43 |
| | | *8.9* | *5.3* | *0.15* | *0.13* |
| 36—40 | 86 | 44.4 | 43.0 | 1.09 | 1.44 |
| | | *6.5* | *5.9* | *0.14* | *0.19* |
| 41—45 | 79 | 46.8 | 44.3 | 1.12 | 1.47 |
| | | *5.3* | *5.0* | *0.12* | *0.13* |
| 46—50 | 109 | 44.3 | 42.8 | 1.10 | 1.45 |
| | | *6.0* | *5.2* | *0.15* | *0.14* |
| 51—55 | 112 | 42.1[a] | 41.2 | 1.05[a] | 1.41 |
| | | *7.4* | *6.4* | *0.17* | *0.17* |
| 56—60 | 82 | 37.7[b] | 38.3[a] | 0.94[b] | 1.32[a] |
| | | *7.7* | *6.6* | *0.17* | *0.20* |
| 61—65 | 67 | 35.0[a] | 35.3[a] | 0.86[a] | 1.19[b] |
| | | *7.0* | *6.3* | *0.17* | *0.20* |
| 66—70 | 33 | 35.1 | 35.6 | 0.35 | 1.16 |
| | | *6.6* | *5.4* | *0.14* | *0.15* |
| 71—75 | 13 | 33.1 | 31.6[a] | 0.79 | 1.05 |
| | | *9.0* | *6.8* | *0.18* | *0.21* |
| 76—80 | 3 | 24.5 | 28.3 | 0.59 | 0.91 |
| | | *4.0* | *0.6* | *0.15* | *0.15* |
| Total | 687 | | | | |

The significance of the difference in relation to the preceding age group is indicated by: [a]$P < 0.01$ and [b]$P < 0.001$.

BMC = bone mineral content, BW = bone width.

## Subjects and methods

*Subjects*

An appeal for healthy female volunteers, aged 26—75 yr, was issued in a local newspaper. The first 800 women who came forward were screened as potential participants in the study. An extensive history was taken in each case and those suffering from any disease or taking any medication which could interfere with bone metabolism were excluded. The reasons for exclusion included hyperparathyroidism, hyperthyroidism, hypercorticism, hypogonadism, renal failure, malabsorption, alcoholism, hepatic cirrhosis, osteogenesis imperfecta, rheumatoid arthritis, malignancies, partial or total gastrectomy, bilateral ovariectomy, prolonged immobilization, and treatment with prednisone, heparin, furosemide, anticonvulsants or oestrogens. The number subsequently admitted to the study totalled 687. BMC and bone width (BW) were measured in all participants at the distal and more proximal sites as described below. The age distribution of the participants is shown in Table I. They were considered to be post-menopausal if the last menstruation had occurred 1 yr or more before examination ($n$ = 246). All those who had menstruated regularly during the previous year ($n$ = 377) were classed as pre-menopausal and those in whom the menstrual pattern had been irregular during the previous year were regarded as peri-menopausal ($n$ = 64).

*Bone density scanner*

BMC was determined using an ND 1100A Bone Density Scanner (Nuclear Data). This equipment consists essentially of a radiation source containing $^{125}I$, which emits a narrowly calibrated beam of photons. The source is mechanically coupled to a scintillation detector. The photon counts and the positions at which they are registered are processed on line by a computer system. The forearm is submerged in water and positioned in a rectangular container. A handgrip in the container, which is held by the subject, prevents movement during the procedure. The coupled scanning system operates at a constant speed and is driven by a computer system along a fixed scanning path as illustrated in Fig. 1. The first scan (No.5 in Fig. 1) is effected at the position where the distance between the radius and the ulna is 8 mm. This site is detected automatically by the system. From this reference position scans 5—10 are made 4 mm apart in the proximal direction. The results of these measurements are processed to give the BMC value in the forearm at this position, where the proportion of cortical bone is about 95%. Thereafter, 4 scans are made in the distal direction from the 8 mm reference point at intervals of 2 mm. In this part of the forearm the bone composition is about 60% trabecular and 40% cortical [5]. Measurements are made in both the radius and the ulna. BMC is expressed in arbitrary units. The BW is recorded during each scan to enable the BMC/BW relationship to be determined. The complete procedure takes less than 15 min.

*Reproducibility*

A possible reproducibility error arises from the automatic search for the

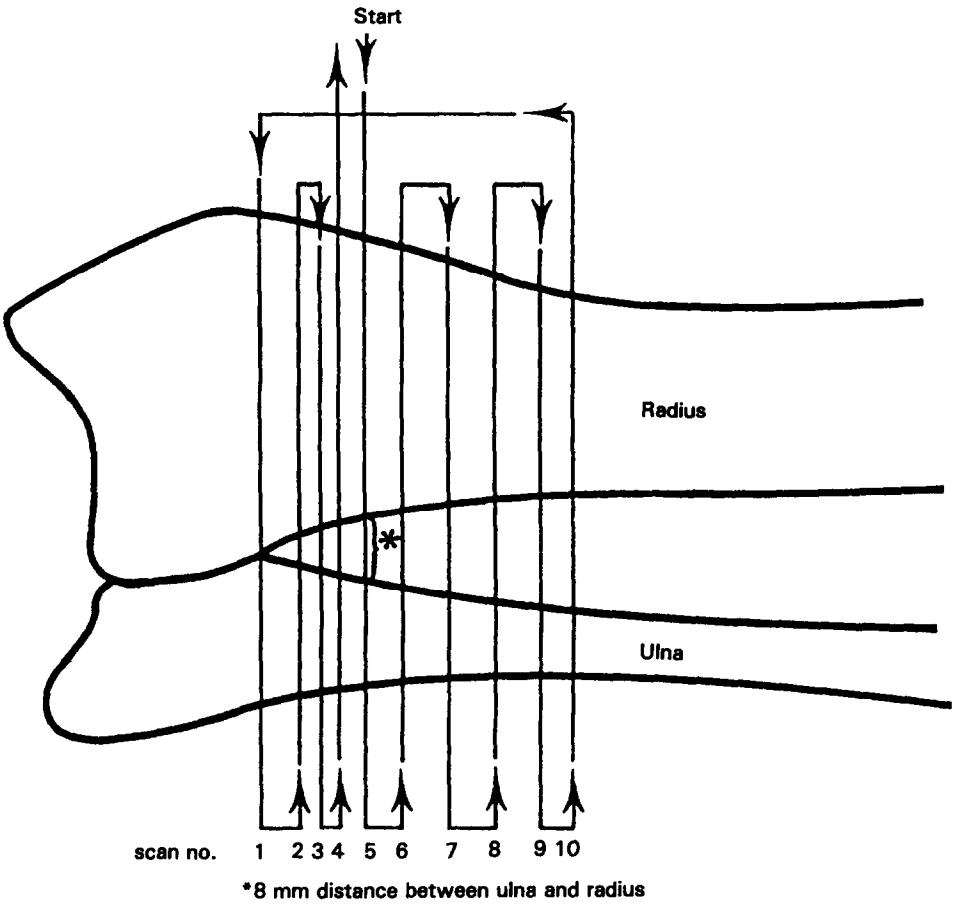


Fig. 1. Pattern of movement of the source-detector assembly of the ND 100A bone density scanner over the distal forearm.

starting point. The system scans the gap between the radius and ulna at 2-mm intervals until a space 8 ± 0.8 mm wide is found. The machine needs a baseline calibration every day and a master calibration based on an aluminium phantom is necessary at least once a week. Correction factors derived from the calibration procedures are applied automatically during calculation of the BMC. Reproducibility was assessed by effecting 6—10 BMC determinations in 3 volunteers within 2 wk. The volunteers were so chosen that their results fell in the low, middle and upper ranges of the values recorded in the study population as a whole. Reproducibility was expressed as the square root of the variance within volunteers obtained by analysis of variance and expressed as a percentage of the general mean to obtain a coefficient of variation.

*Statistics*

The subjects were subdivided into 5-yr age-interval groups and the mean

values were compared. In the 40—60 age groups we checked for differences between pre-menopausal and post-menopausal women by means of a two-tailed *t*-test. Since no significant differences were found, the sample was treated as a uniform whole. A polynomial regression analysis was performed on all the data for both measurement sites to obtain a general picture in relation to age. The simplest polynomial function which described BMC as a function of age with the least residual variance was chosen. The standard error of the estimate was calculated. In the pre-, peri- and post-menopausal women aged 48—64 yr linear and semilogarithmic regression analyses were performed. The regression coefficients obtained for the proximal and distal sites were compared by means of a two-tailed *t*-test. All the values in the pre-menopausal women ($n$ = 377) were pooled and percentiles were calculated to serve as normal reference values.

## Results

The reproducibility error expressed as the coefficient of variation was 1.7% at the ultradistal site and 0.9% at the proximal site (Table II). The BMC data for the ultradistal site in relation to age are shown in Fig. 2 and for the proximal site in Fig. 3. The mean values and standard deviations for 5-yr age groups are presented in Table I. For the calculation of young normal reference values the peri-menopausal women were excluded; these values are presented in Table III. The curves resulting from the polynomial regression analysis and a 95% confidence interval are shown. The regression functions were as follows:

BMC distal

$$= 4.82527 \times A - 0.09369 \times A^2 + 0.0005392 \times A^3 - 31.80 \pm 6.77 \text{ (S.E.E.)}$$

BMC/BW distal

$$= 0.07374 \times A - 0.0013864 \times A^2 + 0.000007257 \times A^3 - 0.0689 \pm 0.153 \text{ (S.E.E.)}$$

TABLE II

REPRODUCIBILITY OF THE BONE MINERAL CONTENT (BMC) AND BONE MINERAL CONTENT IN RELATION TO BONE WIDTH (BMC/BW) DETERMINATIONS IN THE FOREARM (EXPRESSED AS THE PERCENTAGE COEFFICIENT OF VARIATION (CV))

| $n$ | BMC (distal) | | BMC (proximal) | | BMC/BW (distal) | | BMC/BW (proximal) | |
|---|---|---|---|---|---|---|---|---|
| | $\bar{x}$ | S.D. | $\bar{x}$ | S.D. | $\bar{x}$ | S.D. | $\bar{x}$ | S.D. |
| 6 | 63.7 | 0.4 | 64.2 | 0.7 | 1.39 | 0.06 | 1.79 | 0.02 |
| 8 | 55.9 | 1.1 | 57.9 | 0.5 | 1.24 | 0.02 | 1.70 | 0.02 |
| 10 | 40.8 | 0.3 | 40.2 | 0.2 | 1.07 | 0.02 | 1.31 | 0.02 |
| CV | 1.7% | | 0.9% | | 3.0% | | 1.4% | |

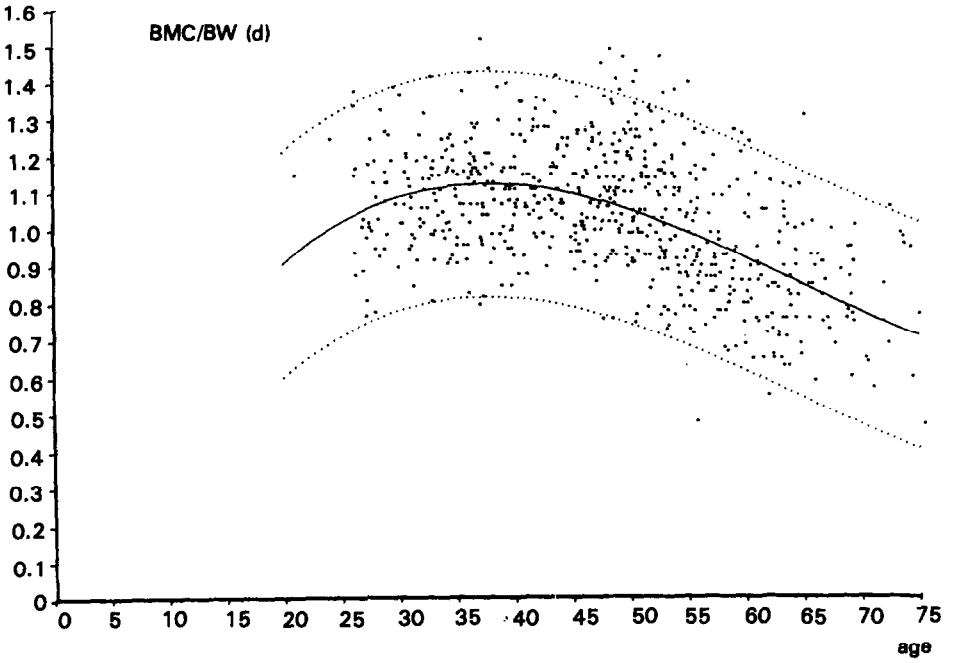


Fig. 2. Bone mineral content in relation to bone width of radius and ulna (BMC/BW) at the ultradistal (d) site ($n$ = 687).

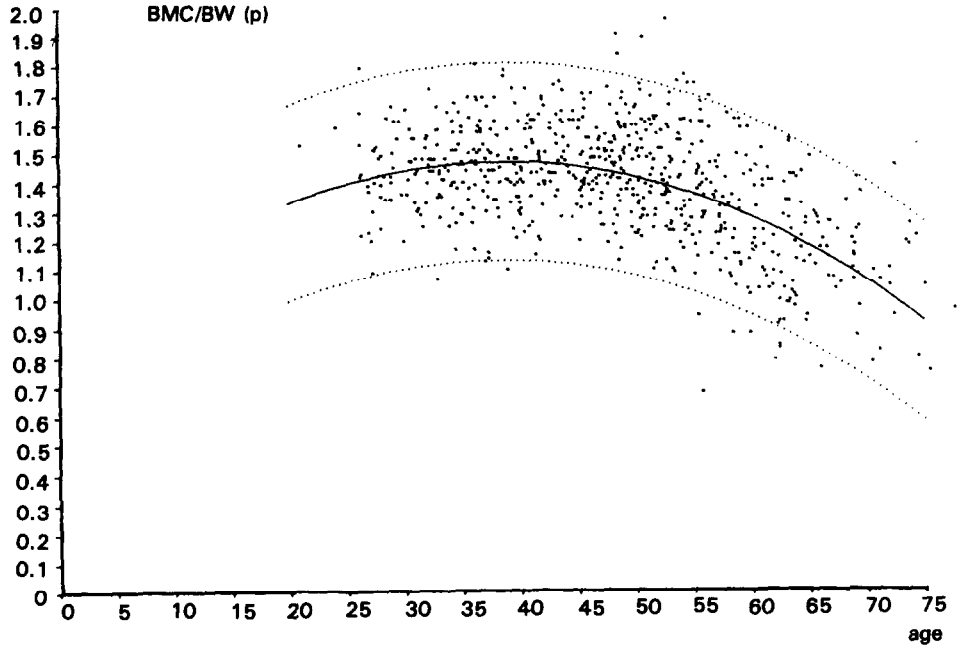


Fig. 3. Bone mineral content in relation to bone width of radius and ulna (BMC/BW) at the proximal (p) site ($n$ = 687).

TABLE III

BMC REFERENCE VALUES IN PRE-MENOPAUSAL WOMEN ($n$ = 377)

| Percentile | BMC (distal) | BMC/BW (distal) | BMC (proximal) | BMC/BW (proximal) |
|---|---|---|---|---|
| 2.5 | 32.4 | 0.84 | 32.7 | 1.16 |
| 5 | 34.0 | 0.89 | 33.8 | 1.21 |
| 10 | 36.7 | 0.93 | 35.5 | 1.28 |
| 50 | 44.3 | 1.09 | 42.1 | 1.44 |
| 95 | 55.2 | 1.34 | 51.7 | 1.68 |
| 97.5 | 57.5 | 1.39 | 53.4 | 1.71 |
| Mean | 44.3 | 1.09 | 42.5 | 1.44 |
| Standard deviation | 6.2 | 0.14 | 5.3 | 0.15 |
| Actual range | 29.1—60.0 | 0.76—1.51 | 30.9—60.0 | 1.14—1.79 |

BMC = bone mineral content, BW = bone width.

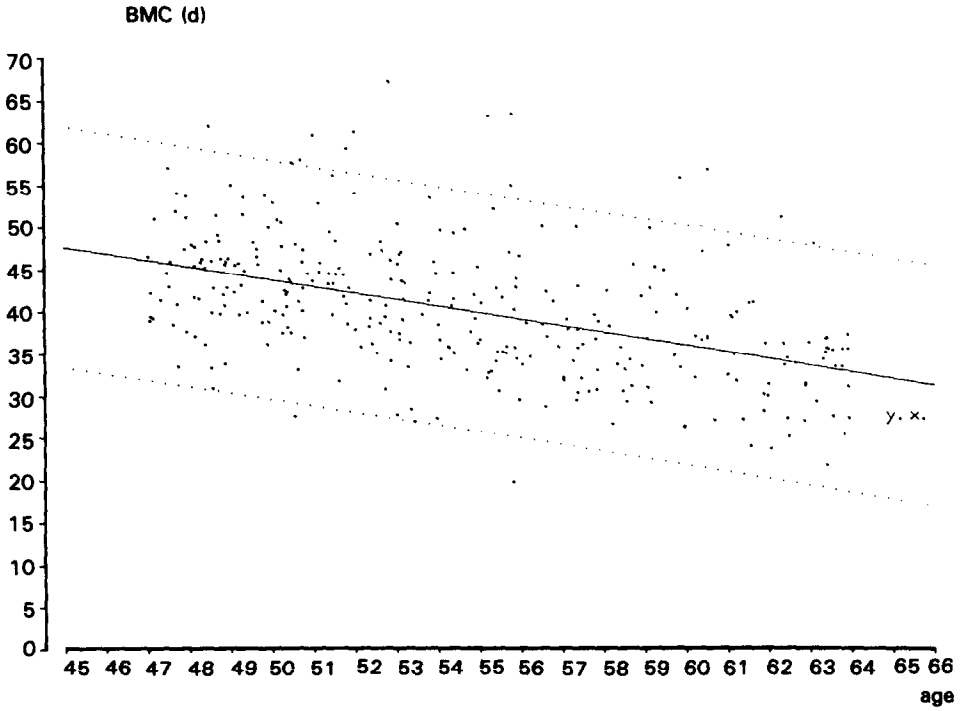


Fig. 4. Linear regression of BMC in the forearm at the ultradistal (d) site in women aged 48—68 yr. (For regression equation see text.)

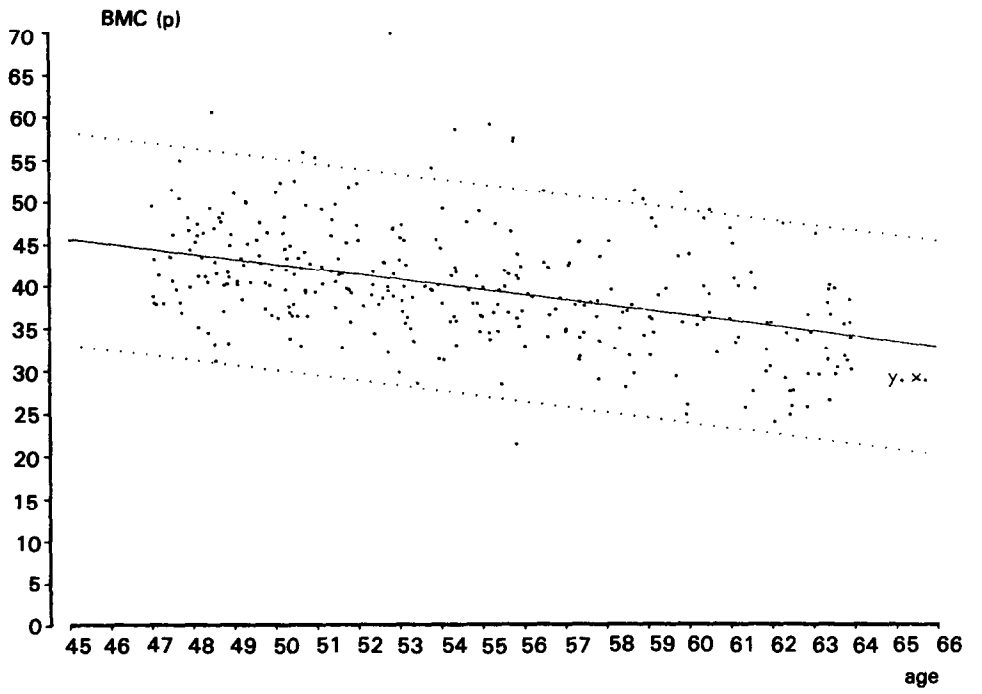


Fig. 5. Linear regression of BMC in the forearm at the proximal (p) site in women aged 48—68 yr. (For regression equation see text.)

BMC proximal

$$= 2.991416 \times A - 0.05557 \times A^2 + 0.0002945 \times A^3 - 5.85 \pm 5.90 \text{ (S.E.E.)}$$

BMC/BW proximal

$$= 0.03125 \times A - 0.0004077 \times A^2 + 0.8643 \pm 0.168 \quad \text{(S.E.E.)}$$

where $A$ signifies age in yr and S.E.E. the standard error of the estimate.

The linear regression functions in women aged 48—64 were as follows:

BMC distal

$$= -0.686 \text{ (S.E. } 0.073) \times A + 77.88 \text{ (S.E. } 4.08) \pm 7.10 \text{ (S.E.E.)}$$

$$(r = -0.464;\ P < 0.0001;\ n = 365)$$

BMC proximal

$$= -0.551 \text{ (S.E. } 0.064) \times A + 69.95 \text{ (S.E. } 3.63) \pm 8.32 \text{ (S.E.E.)}$$

$$(r = -0.427;\ P < 0.0001;\ n = 363).$$

Comparison of the regression coefficients using a two-tailed $t$-test gave $t = 1.398$ and $0.05 < P < 0.10$. These data are presented in Figs. 4 and 5. While the linearity of the relationship in this age group was obvious, the decline in BMC with age at both sites was not significantly different.

## Discussion

Bone loss, which can lead to osteoporosis and its associated fractures, is preventable [6,7]. A rational prevention programme requires the identification of the individuals at risk for fractures. Femoral neck fractures constitute the most hazardous complication of osteoporosis because of the high morbidity and mortality rates. Vertebral fractures may also lead to considerable morbidity. Direct measurement of bone mineral mass at these locations would be preferable, but this is not possible on a large scale because of the time and cost involved. While osteoporosis is a generalized phenomenon which strikes at all parts of the skeleton, two types can be distinguished: type I, or post-menopausal osteoporosis, and type II, or senile osteoporosis. While type I osteoporosis is characterized by vertebral fractures and loss of trabecular bone (e.g. in the vertebrae or the intertrochanteric region), in type II osteoporosis the femoral neck fracture is more common and cortical bone is lost. Type I osteoporosis can be detected by measuring trabecular BMC. For population screening of trabecular BMC the ultradistal measurement might be useful.

There is some confusion as regards the nomenclature of the BMC site measurement. Earlier investigations were based on measurements at 1/10, 1/3 or 1/2 of the length from the distal end of the radius and/or ulna. The 1/10 location has been referred to as the 'distal site', but with the technique used in our study, this is comparable to the 'proximal site', another difference being that our equipment measures the BMC of the radius and ulna together. This means that a larger bone sample is scanned and higher BMC values are obtained than with equipment measuring one bone only. We prefer to term the most distal site measured by our equipment as the 'ultradistal site'. Reproducibility with our method is very similar to that reported for dual photon absorptiometry (DEPA) of the spine [8]. Many authors have reported a poor correlation between peripheral and axial bone mass, but their measurements were of cortical bone at the midshaft site of the radius. Nilas et al. [9] have reported a good correlation between SPA readings at the ultradistal site in the forearm and DPA results in the lumbar spine. In a population study comparing SPA measurements at the 3 cm and 8 cm sites (both containing predominantly cortical bone) and DPA readings in the spine, a very significant correlation was found between both sets of SPA results and the lumbar BMC data [10]. The correlation coefficient was highest in post-menopausal women. It remains to be proven whether this relationship is strong enough to allow prediction of lumbar BMC in the individual patient from ultradistal BMC. Proximal SPA values for the forearm seem to be a reasonably good indicator of non-spinal fractures, whereas the ultradistal measurements are better predictors of vertebral fractures [10]. The applicability of this relationship to individual patients will be very hard to validate.

Bone mineral mass was also considered in relation to bone width. This eliminates some of the inter-individual differences, which depend on skeletal size. However, reproducibility is much less precise because of a rather large rounding-

off error in the recording of bone width. For the longitudinal follow-up of individuals the simple BMC value should be used. The results of our simple reproducibility study were comparable to those reported in the literature for the same apparatus [9]. The shapes of our curves are in agreement with the generally accepted model for age-related bone loss: there is an increase in bone mass up to the age of about 30 yr, no change between the ages of 30 and 40, and a minimal decrease up to 45—50. Thereafter, a large loss occurs over more than a decade, followed by a slowing of the rate of loss [11—12]. While some authors describe the bone loss after the menopause by means of an exponentially declining function, we prefer to use the simple linear model. A model with a physiological meaning should be based on longitudinal observations. In this cross-sectional study we could not demonstrate a significant difference in the regression of BMC at the two measurement sites in relation to age at, around and after the menopause (48—64 yr). Since the relationship in this age group was fairly linear it was possible to test the difference for statistical significance. The expectation would be for the ultradistal bone loss/year to be greater than the proximal loss, since such peri-menopausal or post-menopausal women may be expected to lose predominantly trabecular bone. We feel, however, that a longitudinal study is needed to demonstrate the superiority of the ultradistal measurement for the detection of exaggerated post-menopausal bone loss.

The assessment of the bone status of an individual patient should be based on reference values obtained in a healthy population of menstruating women. The 50th percentile at age 70 corresponds to the 5th percentile at age 30—40. We propose to use this value as the lower limit of normal. The introduction of the new generation of single photon absorptiometry scanning techniques offers promising prospects for the screening of populations at risk for osteoporosis. This study has presented new reference values and examined the possibilities and limitations of these techniques.

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