Diagnosis of Osteoporosis: Usefulness of Photon Absorptiometry at the Radius

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The photon-absorption method (Cameron–Sorenson) is commonly used in the diagnosis of osteoporosis to measure bone mineral in appendicular bones. Although this method gives accurate and reproducible results when applied to the distal radius and midradius, separation between osteoporotic patients and age-matched normals was less than satisfactory because of a large overlap. By contrast, a radiographic index based on the pattern of trabecular bone at the proximal femur (Singh index) gave a better separation between the two populations. The Singh index discriminates better, probably because osteoporotic patients have a greater proportion of loss of trabecular bone of the axial skeleton than of cortical bone of the appendicular skeleton.

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Osteoporosis is a common disease in the elderly, causing pain and serious disability from fractures of vertebrae, proximal femur, and distal radius. Early diagnosis is of great importance since prevention of bone loss may be possible, while restoring lost bone is difficult (*1*).

Osteoporosis is characterized by an absolute decrease in the amount of bone, and since considerable bone must be lost before spontaneous fractures occur (*2*), a sensitive and accurate method of measuring bone mass should make early diagnosis possible. Moreover, such a method would be useful in assessing the severity of bone loss and in following the effects of therapy. During the last decade a number of useful methods have been devised for measuring bone density in the appendicular skeleton (*2–5*). Of these, the photon-absorption technique developed by Cameron and Sorenson (*6*) is by far the most widely used at present and is one of the few methods commercially available. When applied to the appendicular skeleton (the usual measuring site is the radius), this method is accurate and reproducible (*7*).

For the trabecular bone of the axial skeleton, however, an accurate, quantitative, and noninvasive method of measurement does not currently exist. Nevertheless, the amount of trabecular bone loss in the axial skeleton can be estimated by noting the changes in the trabecular pattern of the proximal femur using the index devised by Singh et al. (*8*). This method is simple and reproducible (*9,10*), requiring only a routine radiograph of the hips.

The primary purpose of this study was to compare the sensitivity of these two methods in separating osteoporotic patients with vertebral crush fractures from older patients without such fractures.

METHOD

Patients. A study was made of 123 women with the diagnosis of primary osteoporosis. Their ages ranged from 48 to 80 years (mean, 65.7 years) and all had a history of back pain and had normal values for serum calcium, phosphorus, and alkaline phosphatase. None of them gave a history of significant trauma to the spinal column or prolonged immobilization. Roentgenograms of the thoracic and lumbar portions of the spinal column showed one vertebral fracture in six patients, two in 11, and more than two in the rest. For the grading of the trabecular pattern, bone-mineral determinations and roentgenograms of the hip were performed within 1 week.

Bone mineral. The bone-mineral content of the

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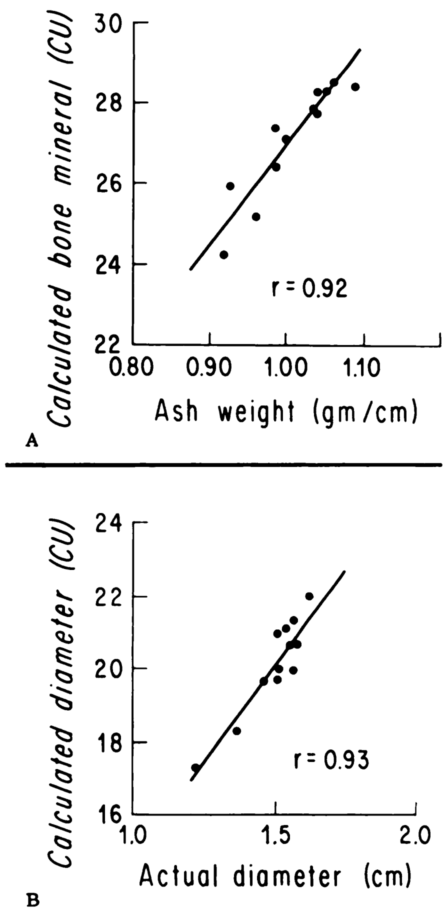

FIG. 1. (A) Ash weight of dried defatted human radius plotted against bone-mineral content as estimated with photon-absorption method. (B) Measured width of radius plotted against width as derived from photon-absorption method. Abscissae are scalyed in arbitrary computer units. In (A) transformation into gm/cm can be performed by the following formula: $y = 1.65 + 25.43x$, where y is the ash weight in gm/cm and x is in arbitrary computer units. The mineral content is obtained from the computer in arbitrary units, which represent the integral of the logarithm of Io^*/I (6), in which Io^* is the intensity of the photon beam after passing through water and soft tissue and I is the intensity after passage through bone, water, and soft tissue. In (B) the width is determined by the computer in arbitrary units from the absorption curve and the scanning speed. Transformation into cm can be performed by the following formula: $y = 3.91 + 10.80x$, where y is width in cm and x is arbitrary computer units (CU).

radius was measured with a linear scanning device constructed locally according to the principles developed by Cameron and Sorenson (*6*). With this method, the mineral content of bone can be determined from the absorption by bone of a monochromatic well-collimated low-energy photon beam. The results are expressed as the ash weight of dried bone in grams per centimeter of length, and the bone width (cm) at the scanning site. An electronic readout device (*11*) and a commercially available ^{125}I source were used. The instrument was standardized twice daily, using an aluminum reference standard and a bone phantom.

Measurements were made in triplicate at each site and on two successive occasions, 1 or 2 days apart. Bone-mineral content was recorded as the mean of these measurements. Scanning sites were the distal radius (10% of radius length) and the midradius of the nondominant arm.

The reproducibility of the method in our laboratory is 3–4% (coefficient of variation). Table 1 shows estimates of reproducibility for measurements of bone-mineral content and bone width. The tests were performed on 16 normal subjects of different ages and both sexes who were scanned in triplicate on the same day without repositioning (for machine error) and on two different days (for position and machine error) under identical conditions as the study patients. The components of variance are listed. The coefficient of variation (CV) is within generally accepted limits for such measurements (*7*).

$\hat{s}_w^2$, $\hat{s}_p^2$, $\hat{s}_s^2$ are estimates of the components of the total variance associated with machine ($\hat{s}_w^2$), position ($\hat{s}_p^2$), and subjects ($\hat{s}_s^2$), where each is expressed as a variance. Overall variance of a single measurement can be obtained by adding the individual variances. The overall error can then be estimated in terms of s.d. by taking the square root of this overall variance. The CV is obtained by expressing the $\hat{s}_w$, $\hat{s}_p$, and $\hat{s}_s$ as a percentage of the

TABLE 1. BONE-MINERAL MEASUREMENTS. ESTIMATE OF REPRODUCIBILITY

			Components of variance					
			Machine		Positions		Subjects	
Measurements	Mean (n = 10)	s.d.	$\hat{s}_w^2$	CV	$\hat{s}_p^2$	CV	$\hat{s}_s^2$	CV
Bone mineral								
Distal radius	28.51	6.04	0.24	1.73	0.34	2.04	36.31	21.14
Midradius	26.39	4.02	0.25	1.91	0.63	3.01	16.70	15.49
Bone width								
Distal radius	26.09	3.17	0.25	1.92	1.12	4.06	2.81	6.42
Midradius	21.26	2.25	0.27	2.43	0.14	1.79	1.56	5.87

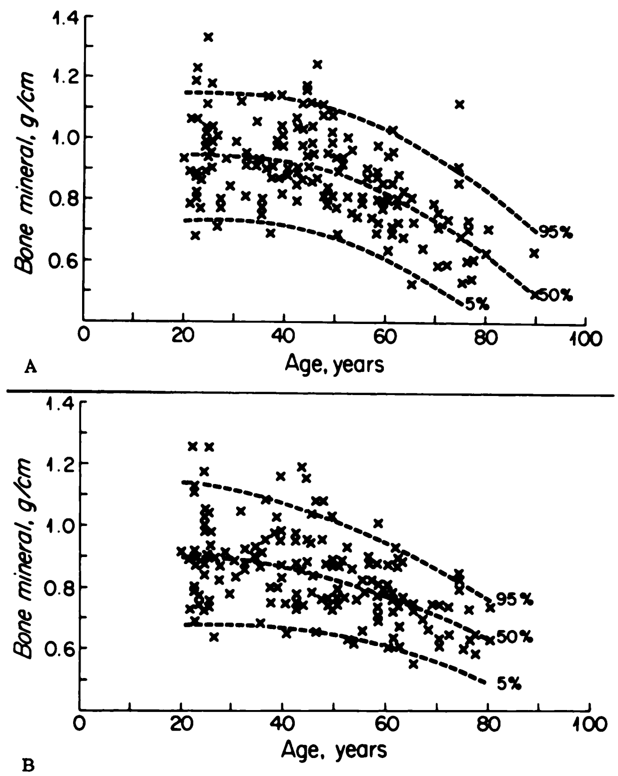

FIG. 2. Normal values obtained from 153 healthy female subjects of different ages. This cross-sectional study shows large spread about mean and significant positive regression of bone-mineral content with age. This was 12% per decade for distal measuring site (A) and 9.0% for midradius (B).

mean. The accuracy was determined by a comparison of the actual mineral mass of a dry defatted human radius with the scan reading, and the coefficient of correlation r was found to be 0.92 (Fig. 1). These data are similar to those reported by others (*12*). The comparability of bone-mineral measurements made with our device and with a commercial unit has been shown (*13*).

The normal population studied consisted of 153 healthy white women, 20 to 90 years old, 89 of whom were more than age 45. This latter group forms the basis for comparison. All subjects were present or past employees of the Mayo Clinic with current medical records. Excluded from the group were: subjects with a history of chronic liver disease, renal disease, malignant disease, or other condition known to affect bone metabolism; and subjects on estrogen or steroid medication. The normal bone-mineral contents were determined by using procedures identical to those used for patients with osteoporosis. Normal data are given in Fig. 2.

Proximal femoral trabecular index. Grading of the trabecular pattern of the femoral neck was made as described by Singh et al. (*8–10*). The method is based on the principle that, as trabecular bone loss occurs, those trabeculae that are subject to least mechanical stress are lost first. Grades range from 7 to 1 (Fig. 3) and are based on roentgenograms of the femoral neck with 15° internal rotation. Since all healthy men and women 40 years old or younger were found to fall into grade 7 or 6, these grades are considered normal, and lower grades are considered to indicate trabecular bone loss. Reference radiographs from Singh's original description of the method (*9*) were used as standards. Repeated grading by one observer showed a correlation coefficient of 0.97 between the first and second evaluations. The pooled correlation coefficient was 0.85 for 91 roentgenograms independently graded by three observers. Normal values for women more than 50 years old were taken from a random control group previously described (*10*).

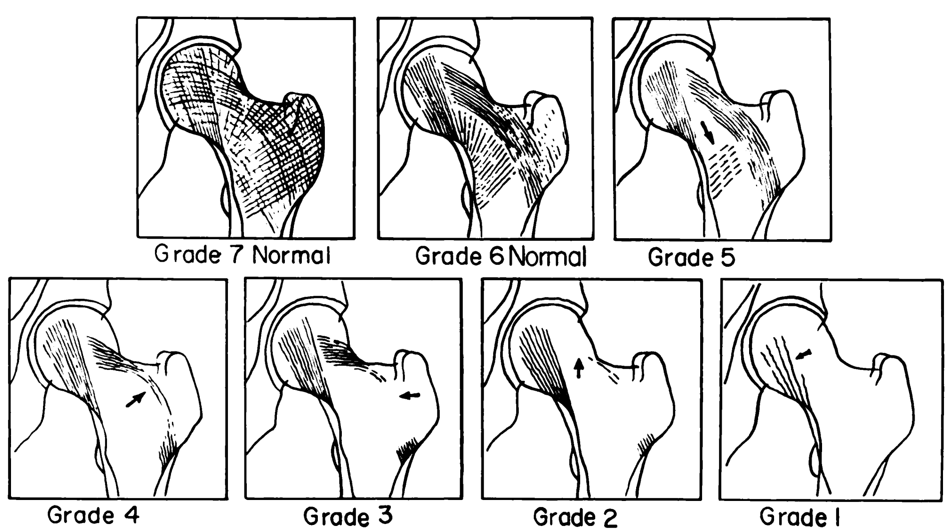

FIG. 3. Trabecular grading pattern in human femoral neck as used for deriving proximal femoral trabecular bone index.

In order to approximate the relative proportion of cortical and trabecular bone at a potentially usable scanning site, ash weight of cortical and trabecular bone was measured in a human radius (normal woman, 47 years old) obtained from the anatomic specimen collection. The bone was defatted, cut into 1-cm pieces along its longitudinal axis, and dried. The cross section of each piece was then photographed. Next, both cortical and trabecular bone were identified visually on enlarged photographs and separated using scissors. Care was taken to eliminate the paper not occupied by trabeculae. The percentage of total bone that was trabecular bone was then determined by weighing the pieces of paper on a precision balance.

RESULTS

Bone-mineral determinations. Figure 4 plots the mineral content of bone scanned at the mid (A) and distal (B) radius in 123 osteoporotic women with crush fractures. These individual points are compared with data from 89 normal women more than 45 years of age. At the midradius measuring site, no significant difference was found between the normal women and those with osteoporosis. A difference between the means of the two populations, however, was noted at the distal scanning site ($p < 0.01$). Here 81% of the osteoporosis population fell below the 50th percentile and 24% below the 10th percentile of the normal bone-mineral distribution. Three patients with crush fractures were in the 95th percentile of the normal range. When the two populations were compared, a significant difference existed between the mean for the normal group and that for the osteoporosis group in the distal-radius measuring site. The overlap between the two populations, however, limited the usefulness of this procedure for predicting a tendency toward crush fractures in the individual subjects. The ratio of mineral content in the distal radius to that at midradius was calculated and plotted; also a correction for bone diameter was evaluated. Neither significantly improved the discrimination between the two groups. This finding agrees with observations made by other investigators (*14–16*). Our results differ somewhat from the data of Smith et al. (*17*), who found that mean density values were significantly different at both scanning sites; however, a large overlap was noted between individual values for normal persons and osteoporotic patients.

Trabecular bone in the radius was approximately 27% of the total bone weight at the distal measuring site and approximately 9.8% at midradius. The general distribution of trabecular bone in the radius is shown in Fig. 5.

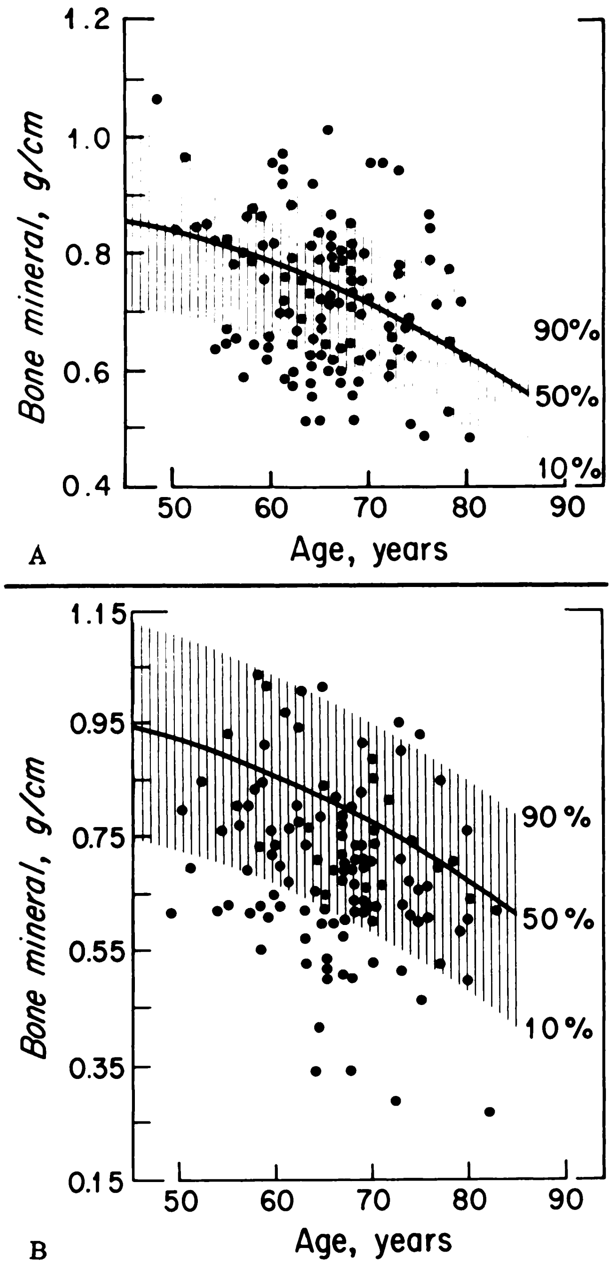

FIG. 4. Changes in bone mineral (g/cm) with age, measured by 28-keV absorption; (A) midradius site; (B) in the distal 10% of the radius's length. Shaded area represents normal range (10th–90th percentile) 89 women over 45 years old; solid line plots 50th percentile. Dots give data for 123 women with compression fractures of vertebrae.

Proximal femoral trabecular index. Separation between normal and osteoporosis populations was better when the proximal femoral trabecular index was used than when separation was based on bone-mineral measurements (Fig. 6). Of all patients with osteoporosis as defined in this study, 89% were below the 50th percentile and 61% were below the 10th percentile of the normal range.

Eighty-two percent of all normal subjects more than 50 years old had index values of 5 or above. In

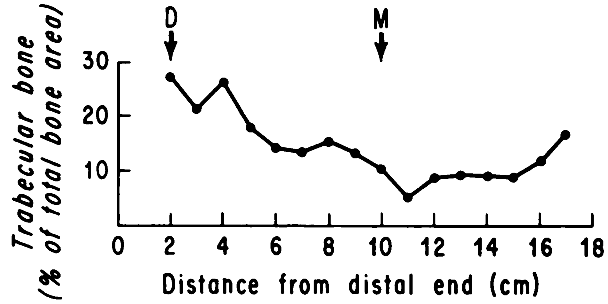

FIG. 5. Distribution of trabecular bone to total bone in different parts of normal human radius. Scanning sites: (D) Distal radius; (M) midradius.

contrast, 96% of all women more than 50 years old with crush fractures had index values of 4 or below (Fig. 6).

DISCUSSION

When the ability to distinguish between osteoporotic patients with vertebral crush fractures and age-matched normals was explored, bone-mineral measurements at the midradius showed poor discrimination, those made at the distal radius showed moderate discrimination, and the proximal femoral trabecular index showed the best discrimination. It is of interest that the midradius scanning site measures only cortical bone, the distal radius site measures about 75% cortical bone and 25% trabecular bone, while the proximal femoral trabecular index is based entirely on changes in trabecular bone. This supports the suggestion of Nordin (*18*) that persons with vertebral crush fractures caused by osteoporosis have undergone a proportionately greater loss of trabecular bone than of cortical bone. If this is correct, it is not surprising that the proximal femoral trabecular index showed high discrimination because trabecular bone is found chiefly in the axial skeleton, and 90% of the bone found in the vertebrae is trabecular.

Dequeker et al. (*19*) found that the femoral trabecular index completely differentiated patients who had undergone hip fractures from age-matched normals. The separation of patients with vertebral crush fractures, however, was less striking than that reported previously by Singh et al. (*9*) and that which we are reporting here. The reason for this discrepancy is not clear: it could be related in part to their use of a much smaller control group and their failure to make age-matched comparisons on a decade-to-decade basis, as we have done. This may also represent a difference in the populations being studied. As a result of living in a more northerly latitude, persons living in Northern Europe have been reported to have a lower nutritional status of vitamin D as assessed by lower serum 25-hydroxyvitamin D concentrations (*20*).

The femoral trabecular index is a simple and useful test for separating patients with osteoporosis and vertebral crush fractures from age-matched normals. Although photon-absorption densitometry at the ra-

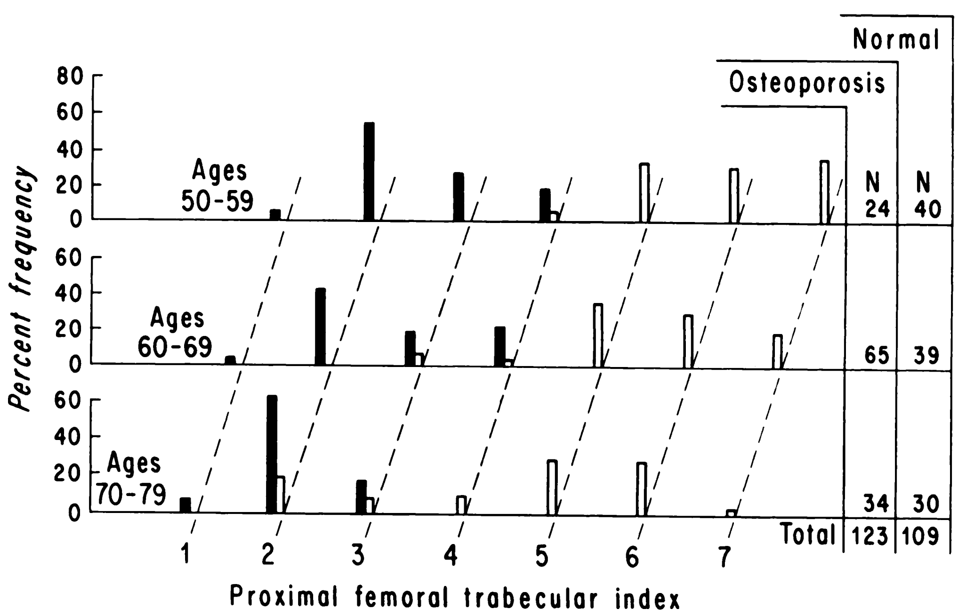

FIG. 6. Proximal femoral trabecular indices of 109 normal women aged 50 years or older compared with indices of 123 women with osteoporosis and crush fractures. Latter group was studied with photon absorptiometry. Black bars represent patients with osteoporosis; white bars, normal patients. Note clustering of patients with osteoporosis at lower index numbers, where only few normal patients are found.

dius was less useful, it is quantitative and accurate, and it should be valuable in assessing the effect of therapy on bone loss in osteoporotic patients. Nevertheless, an instrument capable of quantitative measurements of trabecular bone in the axial skeleton would be desirable.

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