# Radiographic Morphometry and Osteopenia in Spinal Osteoporosis

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***Measurements of bone mineral content and total-body calcium, normalized and expressed as ratios, were compared with radiographic morphometry in 45 women who had spinal osteoporosis. The radiographic indices examined included the femoral score, the femoral trabecular pattern, the biconcavity and metacarpal indices, and the total peripheral score. Both ratios and all the radiographic indices except the femoral trabecular pattern were found to be related to the number of dorsal spine fractures. The relationships observed support the following conclusions: (A) the femoral score and the metacarpal index are related to the degree of osteopenia; (B) the biconcavity index reflects the extraskeletal factors that are pathogenic in spinal osteoporosis; (C) a reduced femoral trabecular pattern index is associated with spinal osteoporosis, although this measurement is not related to the degree of osteopenia; and (D) it may be imprudent to diagnose osteoporosis from the presence of lumbar compression fractures.***

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Spinal osteoporosis may be defined as a syndrome in which reduced bone mass (osteopenia) is associated with structural bone failure in the form of vertebral compression fractures. The bone itself is believed to be "porous" but qualitatively normal. There is simply less normal bone per unit volume. Various forms of therapy for this disorder have been advocated, but they have not produced dramatic results (*1–5*). Treatment might be effective, however, if instituted in the preclinical phase, before progression to structural bone failure.

The measurement of bone mass in the evaluation of osteoporosis depends on one basic assumption, namely, that the level of bone mass (degree of osteopenia) is related to the occurrence of fractures. Is there a threshold value for bone mass below which the risk of structural failure is so great as to warrant therapy?

Since routine radiography is not diagnostic of osteoporosis until over 30% of the skeletal mass is lost, more sensitive technics are needed both to identify osteopenia and to assess the response of skeletal mass to treatment (*6*). Radiographic morphometry has provided a useful tool to study the bone mass of populations (*7,8*). However, with the possible exception of the femoral trabecular pattern index, the radiographic indices are not sufficiently sensitive to identify the preosteoporotic individual (*9*).

Recently, photon absorptiometry has been introduced as a refinement in measuring regional bone mass (*10,11*). Total-body neutron activation analysis (TBNAA) has also been applied to the measurement of bone mineral. Neutron activation analysis is the only technique that directly measures the total-body calcium (TBCa) and thus provides an index of total bone mass (99% of body calcium resides in the skeleton).

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We have previously compared the discriminatory capabilities of TBNAA and photon absorptiometry in the detection of spinal osteoporosis, as well as in the quantitation of changes in skeletal mass with age and in response to treatment (*12–14*). Unfortunately, these techniques are not in widespread clinical use. The present study was designed to determine the relationship of routine radiographic morphometry to the degree of osteopenia as assessed by TBNAA and photon absorptiometry.

## MATERIALS AND METHODS

**Subjects.** Bone mass was estimated in 45 white women who were referred for treatment of spinal osteoporosis. Their mean age was 66 ± 11 (s.d.) years. All patients were ambulatory but complained of disabling back pain. The roentgenographic signs of osteoporosis included all of the following: (A) decreased vertebral density (relative to adjacent soft tissue); (B) increased vertebral end-plate density in comparison to the remainder of the vertebral body; (C) diminished horizontal vertebral trabeculation and accentuated vertical trabeculation; (D) increased vertebral biconcavity; and (E) one or more vertebral compression fractures. The vertebral compression fractures totaled 85 dorsal and 77 lumbar. In six of these patients the vertebral fractures were limited to the lumbar spine. Secondary osteoporosis was excluded by the absence of hepatic, gastrointestinal, or renal disease and by normal values for complete blood count, urinalysis, SMA-12, serum thyroxine, and protein electrophoresis.

**Radiographic indices.** The following radiographic indices were obtained using standard radiographic techniques: the metacarpal index (left and right), the femoral score (left and right), the total peripheral score, the biconcavity index and the femoral trabecular pattern (*15–18*). The metacarpal and femoral indices were obtained by dividing the total cortical thickness (medial and lateral) by the total width of the bone and multiplying by 100. Scores above 43 and 45 were considered normal for the metacarpal and femoral indices, respectively. A total peripheral score (the metacarpal index plus the femoral score) of 88 or greater was considered normal (*15*). The biconcavity index was obtained by dividing the minimum height of the lumbar vertebral body (usually L3) by the maximum height at the anterior aspect of the vertebra and multiplying by 100. A score of 80 or greater was considered normal. The measurements were made with a millimeter ruler to the closest 0.5 mm. The femoral trabecular pattern was graded according to the description of Singh (*9*). No effort was made to obtain the hip x-rays in 15° internal rotation. A femoral trabecular pattern index of 4 or less was considered abnormal.

There was occasional difficulty in determining the femoral score because of unclear definition of the interior cortical margins. The biconcavity index was subject to considerable error if radiographs were obtained with the spine not parallel to the plane of the film. Moreover, if the entire vertebral body was flattened, the biconcavity index would not indicate the true extent of the involvement in the disease process.

**Photon absorptiometry (regional skeletal mass).** Regional skeletal mass was estimated using a commercial bone mineral analyzer.* The site selected for measurement was the distal 8 cm of the nondominant radius. This measurement is usually expressed as bone mineral content (BMC) divided by the bone width (BMC/BW). This technique has a coefficient of variation (% s.d.) of ±2.5% for precision and ±4% for accuracy (*18*). The BMC may be normalized for body size, sex, and age by the BMC ratio ($BMC/BMC_p$), where BMC represents the observed local bone mass and $BMC_p$ represents the predicted bone mass (*20*). Since osteoporotic women are known to lose height, their height was calculated from tibial length (*20*).

**Total-body neutron activation analysis.** The technique of TBNAA employing a portable ($\alpha$,n) neutron source and the Brookhaven whole-body counter has been described previously (*21*). With this technique, the patient is uniformly exposed to a beam of partially moderated fast neutrons, which induce the reaction $^{48}Ca(n,\gamma)^{49}Ca$. The quantity of induced $^{49}Ca$ is measured in the whole-body counter, permitting the calculation of the absolute level of TBCa. The accuracy of this method in a phantom is ±5% and the precision is ±1.1%. Total-body potassium (TBK) is measured in the whole-body counter through its natural isotope, $^{40}K$. The TBCa is normalized for body size, sex, and age by means of the Ca ratio ($TBCa/TBCa_p$), where TBCa represents the measured total-body calcium and $TBCa_p$ represents the total-body calcium predicted from empirically derived formulae (*22*). Height was calculated from tibial length.

## RESULTS

**Regional bone mass (BMC), regional osteopenia (BMC ratio), and the radiographic indices (Table 1).** Figure 1 shows the close correlation observed between the BMC and the TBCa: $r = 0.70$, $p < 0.001$. Significant correlations were observed between the BMC and the Ca ratio, the metacarpal indices (Fig. 2), the femoral scores, and the total peripheral scores. The degree of correlation was not increased by normalizing the BMC measurement for bone

**TABLE 1. RELATIONSHIP OF RADIOGRAPHIC MORPHOMETRY TO REGIONAL BONE MASS**

| Parameter | n | Mean ± s.d. | BMC (r,P)* (gm/cm) | BMC ratio (r,P) |
|---|---|---|---|---|
| Metacarpal index, left | 44 | 37 ± 11 | 0.625 ± 0.134 (0.63, <0.001) | 0.819 ± 0.143 (0.38, <0.005) |
| Metacarpal index, right | 44 | 38 ± 11 | 0.625 ± 0.134 (0.51, <0.001) | 0.819 ± 0.143 (0.39, <0.005) |
| Femoral score, left | 43 | 47 ± 7 | 0.621 ± 0.135 (0.53, <0.001) | 0.811 ± 0.146 (0.29, <0.05) |
| Femoral score, right | 45 | 48 ± 7 | 0.625 ± 0.134 (0.38, <0.01) | 0.813 ± 0.146 (0.23, NS) |
| Total peripheral score, left | 42 | 84 ± 16 | 0.631 ± 0.136 (0.59, <0.001) | 0.806 ± 0.151 (0.45, <0.002) |
| Total peripheral score, right | 44 | 86 ± 14 | 0.625 ± 0.134 (0.53, <0.001) | 0.815 ± 0.144 (0.43, <0.002) |
| Biconcavity index | 39 | 58 ± 19 | 0.625 ± 0.142 (0.26, NS) | 0.823 ± 0.152 (0.13, NS) |
| Femoral trabecular pattern | 43 | 2.7 ± 0.5 | 0.619 ± 0.132 (0.13, NS) | 0.808 ± 0.142 (0.03, NS) |
| Ca ratio | 45 | 0.809 ± 0.109 | 0.625 ± 0.134 (0.62, <0.001) | 0.813 ± 0.146 (0.39, <0.005) |
| TBCa | 45 | 595 ± 98 | 0.625 ± 0.134 (0.70, <0.001) | 0.813 ± 0.146 (0.32, <0.01) |

* NS indicates not significant.

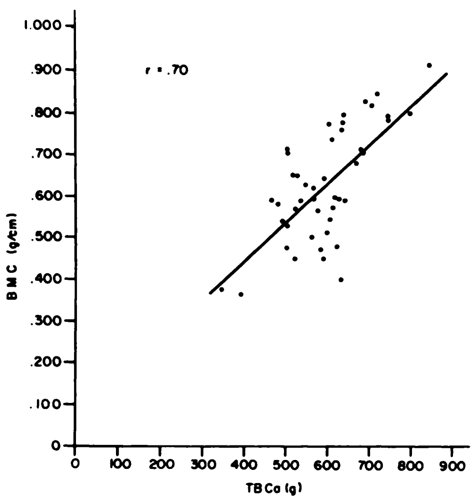


**FIG. 1.** Relationship of regional to total bone mass in spinal osteoporosis.

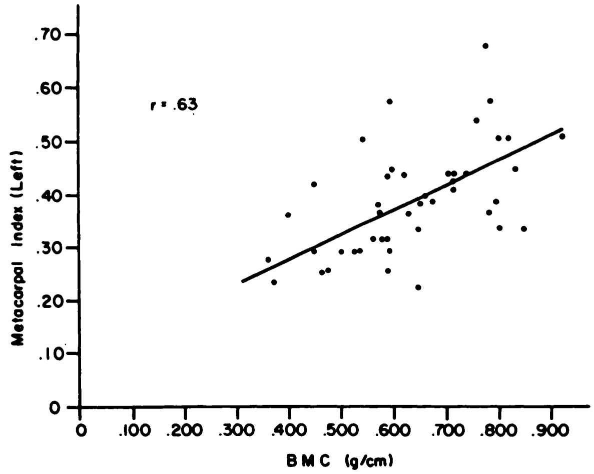


**FIG. 2.** Relationship of metacarpal index to BMC of distal radius.

width (BMC/BW). The BMC ratio was significantly related to the metacarpal indices and the left femoral score. The correlation between the BMC ratio and the total peripheral scores was even better.

**Total bone mass (TBCa), osteopenia (Ca ratio), and the other indices (Table 2).** Significant relationships were noted between the TBCa and the metacarpal and femoral indices (Fig. 3). The correlation was slightly greater for the total peripheral score. Statistically significant relationships were found between the Ca ratio and the left metacarpal index and the left and right femoral scores. The degree of correlation was greater with the total peripheral scores. Significant correlations were also noted between the Ca ratio and the total number of dorsal spine fractures and the BMC ratio. The Ca ratio was not related to the number of compression fractures of the lumbar spine.

**Relationship to fractures of the dorsal spine (Table 3).** All the indices, except for the femoral trabecular pattern index, and both ratios were related to the number of fractures of the dorsal spine. There were no significant correlations among the various radiographic indices.

**Lumbar spine fractures.** There was no correlation between the number of lumbar spine fractures and any of the indices or ratios. The Ca ratio and BMC ratio were significantly higher in the patients who had only lumbar fractures than in those with fractures of the dorsal spine (Table 4). The radiographic indices were generally higher in the lumbar-fracture group. Comparison of the patients with normal and abnormal radiographic indices failed to reveal any other dependent variables (such as duration of osteoporosis, severity of back pain).

**Sensitivity of the radiographic indices in the detection of osteopenia.** According to the metacarpal index, 20% of the patients were normal on the left

**TABLE 2. RELATIONSHIP OF RADIOGRAPHIC MORPHOMETRY TO TOTAL BONE MASS**

| Parameter | n | Mean ± s.d. | TBCa (r,P) (gm) | Ca ratio (r,P) |
|---|---|---|---|---|
| Metacarpal index, left | 44 | 37 ± 11 | 591 ± 99 (0.45, <0.01) | 0.794 ± 0.100 (0.37, <0.05) |
| Metacarpal index, right | 44 | 38 ± 11 | 591 ± 99 (0.35, <0.05) | 0.790 ± 0.100 (0.29, NS) |
| Femoral score, left | 43 | 47 ± 7 | 592 ± 99 (0.51, <0.001) | 0.789 ± 0.099 (0.46, <0.01) |
| Femoral score, right | 45 | 48 ± 7 | 595 ± 98 (0.43, <0.01) | 0.790 = 0.099 (0.38, <0.05) |
| Total peripheral score, left | 42 | 84 ± 16 | 596 ± 100 (0.53, <0.001) | 0.801 ± 0.099 (0.50, <0.001) |
| Total peripheral score, right | 44 | 86 ± 14 | 591 ± 99 (0.43, <0.002) | 0.798 ± 0.098 (0.46, <0.002) |
| Biconcavity index | 39 | 58 ± 19 | 597 ± 104 (0.30, NS) | 0.795 ± 0.100 (0.33, NS) |
| Femoral trabecular pattern | 43 | 2.7 ± 0.5 | 590 ± 92 (0.17, NS) | 0.789 ± 0.099 (0.14, NS) |

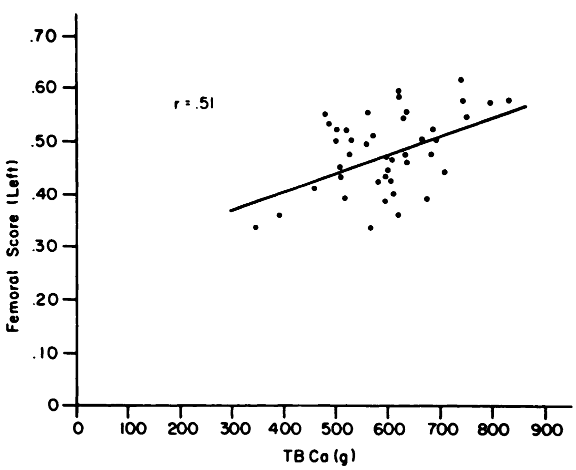


**FIG. 3.** Relationship of femoral score to total bone mass (TBCa).

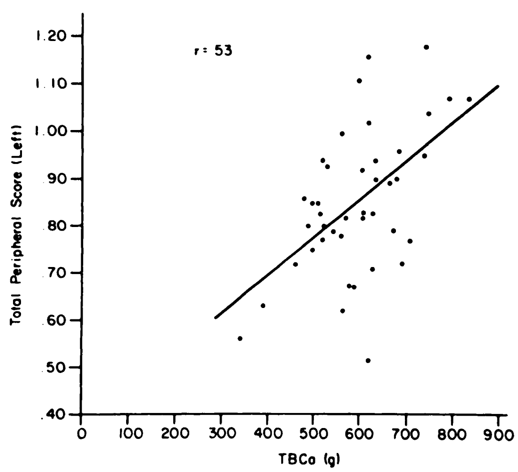


**FIG. 4.** Relationship of total peripheral score to total bone mass (TBCa).

and 42% on the right. Fifty percent of the patients had normal femoral scores. The total peripheral scores were normal on the left in 43% and on the right in 45%. The biconcavity index was reduced in more than 90% of the patients, and the trabecular pattern index was below 4 in all patients.

## DISCUSSION

Recent refinements in morphometric measurements were not applied in our study: calipers were not used for the measurements, and the x-rays of the hip were not always taken in slight internal rotation. Nonetheless, previous reports indicate that the radiographic indices (with the exception of the femoral trabecular pattern) are unsuitable for detecting osteopenia in the prefracture phase since they do not successfully separate osteoporotic individuals from age-matched normals (*21–24*). This was confirmed in the present study by the high frequency of normal values for the metacarpal index, femoral score, and the total peripheral score. Although the biconcavity index was decreased in almost all the patients, this measurement has been shown to be unreliable in separating osteoporotic from normal individuals (*24*).

The techniques of photon absorptiometry and total-body neutron activation analysis provide precise and accurate approaches to the quantitative measurement of bone mineral. Two factors, however, must be considered concerning the comparability of these methods in the quantitation of osteopenia. First, bone-mineral data must be normalized for age, sex, race, and the size of the skeleton (*27*). Secondly, photon absorptiometry measures regional mineral content, which does not always reflect the state of mineralization of the total skeleton. This is particularly relevant when there are differential changes in cortical and trabecular bone mass, since the most commonly employed site for photon absorptiometry consists almost entirely of cortical bone. Further, various skeletal sites show different rates of bone loss. Thus, Manzke et al. (*28*) noted that the 8-cm site reflects a more rapid mineral loss with age than does the entire skeleton (as measured by TBNAA). The correlation between total-body

**TABLE 3. THE RELATIONSHIP OF THE VARIOUS INDICES TO THE NUMBER OF FRACTURES OF THE DORSAL SPINE**

| Parameter | n | Mean ± s.d. | r | p |
|---|---|---|---|---|
| Ca ratio | 44 | 0.791 ± 0.099 | −0.43 | <0.01 |
| BMC ratio | 45 | 0.813 ± 0.146 | −0.31 | <0.02 |
| Metacarpal index, left | 44 | 37 ± 11 | −0.34 | <0.01 |
| Metacarpal index, right | 44 | 38 ± 11 | −0.27 | <0.05 |
| Femoral score, left | 43 | 47 ± 7 | −0.28 | <0.05 |
| Femoral score, right | 45 | 48 ± 7 | −0.32 | <0.02 |
| Total peripheral score, left | 42 | 84 ± 16 | −0.39 | <0.01 |
| Total peripheral score, right | 44 | 86 ± 14 | −0.38 | <0.01 |
| Biconcavity index | 39 | 58 ± 19 | −0.51 | <0.001 |
| Femoral trabecular pattern | 43 | 2.7 ± 0.5 | 0.003 | NS |

calcium and regional bone mass measured in the appendicular skeleton is closer in normal populations than in patients with osteoporosis (*13*). This may reflect different rates of bone loss in the axial and appendicular skeleton in osteoporosis.

The absence of a more complete correlation between the number of dorsal spine fractures and either the BMC ratio or the Ca ratio may result from the contribution of extraskeletal factors to the development of vertebral compression fractures. These factors may include developmental remodeling of bone, mechanical stress to the skeleton, defective ligamentous support to the spine, and a loss of the protective function of the intervertebral disks (*25,26*). The mass of the axial skeleton in spinal osteoporosis is probably reduced to a greater degree than the mass of the appendicular skeleton or the total skeleton.

The biconcavity index was related to the number of dorsal spine fractures but not to the degree of osteopenia. This suggests that this index reflects largely the extraskeletal factors involved in the pathogenesis of vertebral compression. Direct measurement of vertebral mineral content is consistent with this observation (*29*). Biconcavity results from a series of microfractures of the internal trabecular structure, reducing the support for the transverse end plates. Stress causes a uniform pressure of the adjoining disk cartilage upon the end plates, which therefore bend inward, giving the roentgenographic picture of biconcavity. In patients who do not experience stress to the spine (e.g., adults with neurologic disorders that preclude weight-bearing), the vertebral bodies are taller, the disk spaces are more narrow, and the vertebral end plates may actually be convex (*30*).

Manzke et al. (*28*) previously reported a weak correlation between the TBCa and the cortical area in 14 osteoporotic patients. In the present study, the morphometry of cortical bone (metacarpal index, femoral score, total peripheral score) was observed to correlate with both regional and total osteopenia as well as with the number of fractures of the dorsal spine.

In the current study the lack of correlation between the trabecular pattern index and the Ca ratio or the BMC ratio is not altogether surprising, since to a large extent trabecular pattern index reflects the effects of stress rather than the degree of osteopenia. The femoral head migrates laterally with aging, altering the stress patterns in the femoral neck and thus changing the trabecular pattern. Kramendink et al. (*31*) found that the trabecular pattern index does not correlate with measurements made by photon absorptiometry, which also agrees with the findings in the current study. These authors also pointed out that an intrinsic limitation in grading the trabecular pattern is poor resolution. The resolution in our patients was only 40%, which may be partly responsible for the lack of correlation between this index and the degree of osteopenia. On the other hand, Wahner et al. (*32*) reported a better separation between normal and osteoporotic populations

**TABLE 4. COMPARISON OF INDICES IN OSTEOPOROTIC WOMEN WITH DORSAL OR LUMBAR SPINE FRACTURES**

| | Age (years) | Ca ratio | BMC ratio | Metacarpal index | | Femoral score | | Total peripheral score | | Biconcavity index | Femoral trabecular pattern |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Left | Right | Left | Right | Left | Right | | |
| Osteoporotic women with dorsal spine fractures | 67.6 ± 10.7 | 0.772 ± 0.083 | 0.603 ± 0.128 | 37 ± 11 | 38 ± 11 | 46 ± 9 | 46 ± 9 | 84 ± 14 | 86 ± 12 | 57 ± 19 | 2.7 ± 0.5 |
| Women with fractures of only lumbar spine | 59 ± 9 | 0.938 ± 0.109 | 0.901 ± 0.142 | 42 ± 12 | 42 ± 12 | 50 ± 7 | 49 ± 7 | 94 ± 17 | 92 ± 21 | 75 ± 5 | 2.4 ± 0.3 |
| p* | <0.05 | <0.001 | <0.001 | NS | NS | NS | NS | NS | NS | <0.025 | NS |

* t-test for unpaired data.

with the femoral trabecular pattern index than with photon absorptiometry. The current study provides no information concerning this point, since our osteoporotic patients were not compared with nonosteoporotic individuals. The femoral trabecular pattern may reflect trabecular bone mass of the spine more closely than does the BMC ratio and the Ca ratio, but the lack of correlation of this index with the number of fractures of the dorsal spine suggests that this is unlikely.

The finding that neither the Ca ratio nor the BMC ratio was correlated with the number of fractures of the lumbar spine is consistent with the clinical impression that lumbar spine fractures frequently represent the effects of mechanical stress to the spine rather than the degree of osteopenia. It would seem imprudent to accept lumbar fractures as diagnostic of osteoporosis.

The question of whether there are differences in bone mineral in the dominant versus the nondominant extremity has been discussed previously (*28*). The nondominant extremity may more nearly reflect the state of the entire skeleton and the trabecular bone mass because it is not subjected to greater mechanical stress than the entire skeleton. This supposition is supported in the current study by the following findings: (A) the left metacarpal index correlated more closely with bone mass and with the number of dorsal spine fractures than the right; and (B) the frequency of normal metacarpal indices in this group of right-handed individuals was twice as great for the right hand than for the left.

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FOOTNOTE

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