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Correlation of Plain Radiographic Indices of the Hip with Quantitative Bone Mineral Density

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Abstract

Objective—Plain hip radiographs are widely used for evaluation of hip pathology in osteoarthritis. A purpose of this study was to determine whether there are relationships between radiographic parameters of bone structure and bone mineral density T-scores, as assessed by Dual Energy X-ray Absorptiometry (DXA).

Methods—Pre-operative radiographs of 32 postmenopausal, osteoarthritic women undergoing hip arthroplasty were evaluated. Radiographic parameters including Singh index, Dorr classification, canal-to-calcar ratio, and cortical thickness indices (CTI) were measured and compared with T-score, serum 25 hydroxyvitamin D levels, Body Mass Index (BMI), and body weight.

Results—The T-score at the femoral neck for type C bone was significantly lower than that of type A ($p = 0.041$). The CTIs were correlated positively with T-scores for anteroposterior radiographs ($r = 0.5814$, $p = 0.0005$), and for lateral radiographs ($r = 0.571$, $p = 0.0006$). A threshold for lateral CTI set at a value of ≤ 0.40 results in sensitivity of 0.85 and specificity of 0.79 to segregate the osteoporotic and non-osteoporotic patients.

Conclusions—Femurs with small radiographic cortical thickness indices had lower T-scores. Finding a radiographic hip Cortical Thickness Index (LAT) with a value of ≤ 0.40 should be an alert for referral for osteoporosis evaluation and bone mineral density testing.

Keywords

bone density; radiographs; cortical thickness; femoral geometry; osteoporosis; osteoarthritis

INTRODUCTION

As the elderly population increases in size, it is expected that there will be increases in the numbers of adults with osteoarthritis and/or osteoporosis. The routine hip radiograph is the principal study used by primary care physicians and orthopedic specialists to support diagnosis, monitor progression, and influence management involving hip disease. The conventional plain radiograph is versatile in that it can visualize localized processes such as osteoarthritis, but can also reflect systemic changes such as osteoporosis [1,2].

Conventional anteroposterior (AP) and lateral (LAT) radiographs of the hip can delineate bone quality of the proximal femur. The Singh index is a method to assess osteoporosis by the radiographic patterns and density of proximal femur trabecular bone [1]. Dorr et al. developed radiographic classifications of bone quality and validated them with histologic parameters [2]. Dual energy x-ray absorptiometry (DXA) estimates two-dimensional bone mineral density and has become a common method to diagnose and to monitor treatment of osteoporosis. DXA testing is not routinely performed during the evaluation of patients with osteoarthritis.

Previously, we described the co-existence of osteoporosis and osteoarthritis of the hip in a series of postmenopausal Caucasian women [3,4]. That finding is in contrast to the belief that osteoarthritis protects against decreased bone mineral density. There is little information about diagnosis of osteoporosis in women with osteoarthritis or about their risk factors for osteoporosis. Having DXA data for a cohort of postmenopausal women with advanced osteoarthritis presents a unique opportunity to test whether pre-operative radiographs give information about bone quality and to determine what features are associated with low bone density in osteoarthritic women. We designed this analysis to test the hypothesis that quantitative bone mineral density (T-score) was correlated with radiographic parameters such as the Singh index, Dorr type, cortical thickness indices, and canal-to-calcar ratios. Moreover, we tested whether age, Body Mass Index (BMI), body weight, or serum level of 25-hydroxyvitamin D differentiated women with and without osteoporosis.

METHODS

The study group comprised 32 Caucasian postmenopausal women with osteoarthritis for whom both hip radiographs and DXA tests were available. Body mass index was calculated for each subject. In addition, these subjects had other specialized tests prior to hip replacement surgery, including measurement of 25-hydroxyvitamin D [3,4]. Hip radiographs were obtained a median of 11 days prior to DXA analysis. Arthroplasty surgery followed bone mineral density testing by a median of 9 days. Bone mineral density had been measured by DXA of the femoral neck, spine, and greater trochanter (QDR2000; Hologic, Bedford, MA) [3]. Osteoporosis was defined as T-score at any site of less than -2.5 [5]. By that criterion, 25% of the group of osteoarthritic women tested had occult osteoporosis [3,4]. For the subset of 32 subjects in this analysis, T-scores (the number of standard deviations that the bone mineral density was above or below the mean values of young normal adults [5]) at the femoral neck were strongly correlated with those at the femoral trochanter (Spearman $r = 0.766$, $p < 0.0001$, $n = 32$) and with values from the spine (Spearman $r = 0.528$, $p = 0.008$, $n = 24$). The presence of osteophytes and/or disc space narrowing in 8 cases made those spine values technically unsuitable for analysis. Thus, analyses with femoral neck values are reported, but results were similar with the other sites. These studies were approved by the prevailing Institutional Review Boards.

Pre-operative radiographs were requested from film libraries. The 32 subjects had anteroposterior (AP) and Lowenstein (modified frog-leg) lateral views of the affected hips with adequate visualization of the femur at least 10 centimeters distal to the lesser trochanter, a feature that is required for measurement of the canal-to-calcar ratio and cortical thickness indices as described by Dorr [2].

The reviewer of radiographs was blinded from whether the patient did or did not have occult osteoporosis. Proximal femurs were classified with the Singh grading system, which uses 6 grades of trabecular patterns to describe degree of osteoporosis.¹ Grade 6 represents normal bone density and Grade 1 reflects severe osteoporosis. Films were reviewed three times with the reviewer blinded from previous results. Intrarater reliability in determining Singh scores was 88%.

The Dorr classification of femoral geometry was assessed by examination of the AP and lateral hip films [2]. Intrarater reliability in the determination of Dorr classification was 92%. Type A bone is defined as having thick cortices with a narrow and funnel shape of the proximal femoral canal. Type B bone shows thin medial and posterior cortices, frequently with irregular endosteal surfaces. Type C bone has dramatically thin medial and posterior cortices with a more cylindrical shape to the femoral canal.

The canal-to-calcar ratio was measured as described by Dorr et al. [2]. A horizontal line at the mid-lesser trochanter was established on the AP hip radiograph (Figure 1). Markers at both medial and lateral aspects of medullary canal were placed at distances 3 cm and 10 cm below that line. Lateral and medial markers were connected and the distance between the intersections of these lines with the mid-lesser trochanteric line was measured as the calcar width (CW). The intramedullary femoral canal width (FW) was measured as the distance between the medial and lateral markers at the 10 cm level. The canal-to-calcar ratio was calculated as the fraction of the isthmus canal width divided by the calcar canal dimension (CC ratio = FW/CW). Thus, the canal-to-calcar ratio is a reflection of the geometric relationship of two points of the proximal femoral canal. A small ratio represents a funnel shape and a larger ratio, approaching 1.0, is a more cylindrical or stovepipe shape.

Cortical thickness indices on both the AP and lateral (LAT) radiographs were measured according to Dorr [2]. Cortex thickness was measured at a point 10 cm distal and parallel to the mid-lesser trochanteric line on both AP and lateral views (Figure 2). Cortical thickness index for each view was calculated as the ratio of the femoral diaphysis width (DW) minus medullary canal width (FW) then divided by DW [Cortical Index = (DWF)/DW]. Thus, the cortical index is a reflection of cortex thickness at that level, with a higher index indicating greater thickness. Intrarater reliability in measuring femoral canal diameter and width on AP and lateral radiographs were 96% and 94%, respectively.

Radiographic data were analyzed for relationships with osteoporosis and T-score. Data were analyzed both with T-score as a continuous variable and also with classification into either osteoporotic or non-osteoporotic groups. Data were tested for normality and, if not normal, were analyzed by non-parametric methods, including Kruskal-Wallis tests and Spearman non-parametric correlation tests. Fisher's exact test (<http://www.unc.edu/~preacher/fisher/fisher.htm>), Student t-test with Welch correction for unequal variances, and ANOVA were performed. All tests used two-tailed comparisons and $p < 0.05$ was considered significant. Analysis of discriminatory power was performed by Elena Losina, Ph.D., BWH Orthopedics and Arthritis Center for Outcomes Research, using SAS software (SAS Inc., Cary, NC). Other tests were done with GraphPad InStat version 3.00 for Windows 95 (GraphPad Software, San Diego CA).

RESULTS

Adequate pre-operative hip radiographs were available for evaluation for 32 postmenopausal Caucasian osteoarthritic women for whom DXA data were available. The average age of the 32 subjects at time of surgery was 67 years (range 47 to 90). The subjects were divided into osteoporotic ($n=13$) and non-osteoporotic ($n=19$) groups, on the basis of T-score at any site being ≤ -2.5 for classification as osteoporosis (Table 1). Accordingly, the mean T-score at the femoral neck for the osteoporotic group (-2.71 ± 0.56) was significantly lower than that for the non-osteoporotic group (-0.45 ± 1.02 , $p < 0.0001$). The mean age of the osteoporotic group was 71.4 ± 10.8 and of the non-osteoporotic group was 64.7 ± 9.4 ($p = 0.016$). There was an inverse correlation between T-score and age (Spearman $r = -0.358$, $p = 0.044$).

A primary aim of this study was to assess the relationship between the Singh classification and bone mineral density as measured by DXA. The mean Singh scores of the osteoporotic (4.2 ± 1.0) and non-osteoporotic (3.9 ± 0.8) groups were not different ($p=0.406$) (Table 1). Further, there was no correlation between the Singh grade and T-score at the femoral neck ($p = 0.726$).

Another primary aim of this study was to assess the relationship between Dorr's classifications and measurements and bone mineral density as measured by DXA. According to Dorr's criteria, the proximal femoral geometry of the 32 hips sorted into 13 type A, 14 type B, and 5 type C patterns. Dorr type A bone has a narrow funnel-shaped canal with greater cortical thickness indices and with a smaller canal-to-calcar ratio (Figure 3A). In contrast, type C bone has a wide stovepipe-shaped canal with lesser cortical thickness indices and with a larger canal-to-calcar ratio (Figure 3B); type B bone lies between these two classifications. Type A bone was found in 57.8% (11 of 19) of the non-osteoporotic subjects, compared with 15.3% (only 2 of 13) of the osteoporotic subjects, $p = 0.028$, Fisher's exact test (Table 1). There was only one subject classified as type C in the non-osteoporotic group, compared with 4 in the osteoporotic group.

As expected, there were significant differences among the three Dorr types by objective radiographic measurements including cortical indices, both AP ($p<0.0001$) and LAT ($p<0.0001$), and in canal-to-calcar ratio ($p = 0.038$), as assessed with the Tukey-Kramer multiple comparison method (data not shown). Subsequently, these radiographic parameters were analyzed as continuous variables for their relationship with bone mineral density as measured by DXA (Figure 4). Positive correlations were statistically significant between cortical thickness index AP and T-score at the femoral neck (Spearman $r = 0.478$, $p = 0.003$) and between cortical thickness index LAT and T-score (Spearman $r = 0.459$, $p = 0.004$). There was no correlation, however, between the canal-to-calcar ratio and T-score ($p = 0.576$). The means of the cortical thickness indices were significantly lower in the group of osteoporotic subjects than in the non-osteoporotic group (Table 1).

The T-scores at the femoral neck were correlated with Dorr bone type (Figure 5). The median T-scores were -0.530 for type A, -1.935 for type B, and -3.303 for type C. The mean T-scores were -0.538 ± 1.346 for type A, -1.817 ± 1.193 for type B, and -2.244 ± 1.276 for type C. The mean T-score for type C bone was 1.714 standard deviations lower than that for type A ($p = 0.041$).

Analysis of discriminatory power to identify osteoporotic subjects showed better sensitivity and specificity with the Cortical Thickness Index (LAT) than with Cortical Thickness Index (AP) or Dorr Classification (Table 2). With the numbers available, a threshold for Cortical Thickness Index (LAT) set at a value of ≤ 0.40 has suitable discriminatory power, with a 4.0 positive likelihood ratio, to alert the surgeon to recommend referral for osteoporosis evaluation and bone mineral density test.

The mean serum level of 25-hydroxyvitamin D [25(OH)D] was 23.8 ± 11.1 ng/mL, with a range of 7.6 to 61.6 and median of 21.9. With the numbers available, there was no difference in the mean values of the osteoporotic and non-osteoporotic groups ($p = 0.797$). There was no correlation between serum level of 25(OH)D and the Singh grade ($p = 0.659$). Although there were differences in the mean serum levels of 25(OH)D in type A (25.6 ± 15.3), type B (23.4 ± 7.6) and type C (20.5 ± 6.4), those differences were not statistically significant (ANOVA). Only 6 of these subjects had 25(OH)D ≤ 15 ng/ml; thus there were insufficient numbers to assess the effect of extreme vitamin D deficiency on radiographic parameters.

Subjects were further evaluated for risk factors for having poor bone quality as measured by both DXA and the Dorr radiographic parameters. There was a wide range of Body Mass Indices (BMI) for this group of osteoarthritic women, 17.3 to 31.5. The group of non-osteoporotic

subjects, for 18 of whom height and weight data were available, had a mean BMI of 26.2 ± 3.7 ; whereas the 13 osteoporotic subjects had a significantly lower mean of 23.5 ± 3.4 ($p = 0.0433$, Table 1). Accordingly, the mean weight for the osteoporotic subjects (60.2 ± 5.9 , Table 1) was 83% that of the non-osteoporotic subjects (72.2 ± 11.0 kg, $p=0.0006$). T-score also demonstrated a significant and positive correlation with BMI (Spearman $r=0.4132$, $p=0.0209$).

Multivariate analysis of the most robust radiographic parameter, cortical thickness index (AP), showed a correlation with BMI (Pearson $r=0.3990$, $p=0.026$) and body weight (Pearson $r=0.6370$, $p=0.0001$) and an inverse correlation with age ($r=-0.5881$, $p=0.0004$), but there was no relationship with height ($p=0.421$), as expected. In sum, osteoarthritic subjects with lower weight, lower BMI, or greater age had poorer quality of bone by both radiographic and DXA measures.

CONCLUSIONS

This analysis showed that radiographic measures of femur cortical thickness and Dorr type were correlated with occult osteoporosis in postmenopausal women with osteoarthritis. Dual Energy X-ray Absorptiometry is not often performed for osteoarthritic women. Radiographs of the hip are a common diagnostic tool, but are not used as tests for osteoporosis. Both proximal femoral canal geometry and bone structure are important features obtainable from plain radiographs and are routinely used for surgical planning. These radiographic features have been postulated to be determinants of fracture risk and prosthesis longevity [6,7]. Early awareness of occult osteoporosis by plain radiographs may result in early intervention for populations not regularly believed to be at risk, such as women with osteoarthritis. The importance of screening tools is evident because there are more than 2 million osteoporotic fractures expected annually in the US, totaling nearly 17 billion dollars in medical costs [8].

The main purpose of this study was to assess radiographic parameters for a group of osteoarthritic women for whom DXA was performed as part of a previous study [3,4]. The Singh index is a method of assessing osteoporosis as reflected by the trabecular pattern of the proximal femur and a progression of trabecular thinning [1]. Patients with Grade 4 or less by Singh classification are considered to have an abnormal degree of bone loss and a higher risk of osteoporosis [1]. Some subsequent studies showed that the Singh index provides a reliable estimate of osteoporosis and mechanical bone quality [9,10]. For example, in three patients who sustained femoral neck fractures with normal histological grades, radiographs of the femur revealed Singh's osteoporotic patterns [1]. Likewise, Cooper performed a study of the weight and volume of excised femoral heads compared with radiographic indices of bone quality and reported that both Singh grading of the proximal femur and calcar width were correlated with bone mass of the proximal femur [11].

In this study, trabecular patterns of the osteoporotic group were not found by Singh grading to be significantly different from the non-osteoporotic group. Moreover, the Singh classification was not correlated with T-scores at the femoral neck. Because the Singh scores of all but one of these subjects fell in the range of 3 to 5, there was not the range required for comprehensive testing of the hypothesis. Other studies indicate that the Singh classification may not be as reliable or accurate as originally proposed [8,12–14]. Alternatively, it is possible that osteoarthritic changes masked the expected trabecular thinning in the osteoporotic group. Cooper et al. reported distorted Singh values of proximal femurs that showed radiographic evidence of osteoarthritis [15].

Bone architecture has been shown to be a major determinant of overall bone strength [16]. Geometric changes of the proximal femoral canal have been reported to occur with age, especially in women, and result in a loss of strength and a possible predisposition for fracture

[17,18]. The correlation that we found between the Dorr subjective classification (A, B, and C) and its objective measurement of femur type supports the robustness of Dorr's geometric classification, as expected.

We found the Dorr classification and cortical thickness index to be related to T-scores. First, subjects with type C bone had lower T-scores than those who had type A. These data support the view that type A femurs have greater bone density. This distinction has implications in fracture healing, hip prosthesis implantation, and need for osteoporosis intervention. Thus, the correlation of proximal femoral canal shape with bone mineral density suggests that plain radiographs can provide useful information for screening for osteoporosis and fracture risk. These results support the suggestion that clinicians plan further testing for patients who do not have type A femurs. Validation would require large numbers of samples for assessment of reproducibility, sensitivity, specificity, and generalizability.

The canal-to-calcar ratio did not prove to be correlated significantly with T-score. This apparent discrepancy between subjective and objective evaluation of canal shape may be due to the fact that the numerical ratio does not compensate for differences in patient femoral length. The heights of these subject ranged from 142 to 178 cm. The determination of intramedullary width at the fixed point 10 cm below the mid-lesser trochanteric line can represent different portions of the femur depending on patient height. In contrast, the cortical thickness indices are normalized measurements of cortical width in relation to overall width.

Second, diaphyseal cortical thickness indices were correlated with T-score. Although traditional emphasis has been on BMD of the proximal femur, these findings suggest that the femoral diaphysis may reflect overall bone integrity based on both geometry and structure. Radiographic examination of femoral canal geometry and mid-femur cortices is widely available, but may be an underappreciated screen for overall bone strength.

These results support the suggestion that clinicians plan further testing for patients with small cortical thickness indices. This analysis indicates that a threshold for Cortical Thickness Index (LAT) set at a value of ≤ 0.40 has suitable discriminatory power, with a 4.0 positive likelihood ratio, to alert the surgeon to recommend referral for osteoporosis evaluation and bone mineral density test. Prospective studies with larger groups of subjects would be useful to optimize thresholds, develop composite indices, and validate predictive values for general use.

Vitamin D deficiency is associated with osteomalacia, fractures, and bone pain [3,4,21–22]. With chronic vitamin D-deficiency, impaired mineralization leads to overall decreased bone density, and secondary hyperparathyroidism results in increased bone resorption. Although a trend was observed in this series for lower 25(OH)D levels with Dorr's ranking of width of intramedullary canal, that finding was not statistically significant, with the numbers available. There was severe vitamin D-deficiency in only 6 of the 32 subjects whose radiographs were evaluated in this study. Thus, a limitation of the study is that it was not powered to test whether vitamin D-deficiency was correlated with the radiographic indices. This relationship does warrant further testing in larger, prospective studies. Hypovitaminosis D is a public health problem that is relatively simple and inexpensive to address [22].

Currently there is widespread attention being paid to the need for continuing care of patients who sustain an osteoporotic fracture [23,24]. These new findings call attention to risks of osteoporosis in non-fracture osteoarthritic women and to the potential utility of plain radiographs to indicate referral for DXA. In our initial study, 25% of a population of osteoarthritic women was found by DXA to have occult osteoporosis. Because osteoarthritic patients commonly undergo routine radiographic studies, it would seem prudent to examine the hip radiographs carefully to identify osteoarthritic patients also at risk for osteoporosis [4]. This analysis shows that osteoarthritic women with lower weight and lower BMI had lower

bone density. Advanced age was also correlated with low bone mineral density. These findings support the suggestion that osteoarthritic women with low weight, low BMI, or advanced age be evaluated for osteoporosis risk.

Traditionally, radiographs have been considered less valuable in the assessment of bone mineral density because it is believed that 30–50% bone loss must be present to be detected on plain film. Whereas DXA may not be available or economical for routine use, plain films are obtained in most cases of hip pathology and for all osteoarthritic patients. Clinicians who evaluate hip radiographs of osteoarthritic patients may consider using these simple radiographic parameters to assess bone quality. Finding a radiographic hip Cortical Thickness Index (LAT) with a value of ≤ 0.40 should be an alert to recommend referral for osteoporosis evaluation and bone mineral density testing. Although radiographs are not a test for osteoporosis, radiographic parameters, especially cortical thickness and canal type, provide information that makes the routine hip radiograph a useful tool for referral for osteoporosis management, and possibly, for identifying patients who have a higher risk for fracture.

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Figure 1.
Measurement of canal-to-calcar ratio by FW/CW on anteroposterior radiograph of the hip.

Figure 2. Cortical thickness index measurement on both AP and lateral radiographs of the hip. Cortical index is equal to femoral diaphysis width minus intramedullary width divided by diaphysis width ($CI = [DW - FW] / DW$).

Figure 3.

A: Anteroposterior hip radiograph of patient with Dorr type A bone. Funnel-shaped geometry of the proximal femoral canal with thick diaphyseal cortices is characteristic. Dual energy x-ray absorptiometry revealed this as one of the highest T-scores in the study group (+1.62).

B: Anteroposterior hip radiograph of patient with Dorr type C bone. The proximal femoral canal is cylindrical, giving the bone a "stovepipe" appearance. Diaphyseal cortices are characteristically thin. Dual energy x-ray absorptiometry revealed this as one of the lowest T-scores in the study group (−3.13).

Figure 4.

Relationships between T-score at the femoral neck and cortical thickness index (Lateral), cortical thickness index (AP), and canal-to-calcar ratio. Individual symbols signify the Dorr classification (Type A, B, or C) and show the clustering of values in those groups. Lines represent significant Spearman correlations for all types combined.

Figure 5.

Relationships between T-score at the femoral neck and Dorr classification. Medians are represented by the horizontal lines with boxes indicating 25th and 75th percentiles and with whiskers indicating 5th and 95th percentiles. Lines to the right of the boxes show the means $\pm$ S.E.M. Symbols indicate individual values and the numbers in parentheses are the N for each group.

Table 1

Characteristics of Osteoporotic and Non-Osteoporotic Groups of Osteoarthritic Subjects

	Osteoporotic (13)	Non-Osteoporotic (19)	p
T-score (FN)	-2.71 ± 0.56	-0.45 ± 1.02	<0.0001
Singh Index	4.2 ± 1.0	3.9 ± 0.8	NS
% Dorr A	15%	58%	0.028 ^a
CTI (AP)	0.46 ± 0.09	0.55 ± 0.08	0.008
CTI (LAT)	0.34 ± 0.09	0.45 ± 0.09	0.001
Age (years)	71.4 ± 10.8	64.7 ± 9.4	0.016
BMI	23.5 ± 3.4	26.2 ± 3.7^b	0.043
Body wt (kg)	60.2 ± 5.9	72.2 ± 11.0^b	<0.001

Numbers in parentheses are numbers of subjects in each group.

FN: Femoral neck

CTI: Cortical thickness index (Dorr)

AP: Anteroposterior

LAT: Lateral

^aFisher's exact test; all others were by Mann-Whitney t-test.

^bBMI and body weight data were available for 18 non-osteoporotic subjects.

Table 2Discriminatory Power of Radiographic Parameters to Identify Osteoporosis as Defined by T-score -2.5

Parameter	Cutoff	Sensitivity	Specificity	Likelihood Ratio (+)
CTI (LAT)	≤ 0.40	0.85	0.79	4.0
CTI (AP)	≤ 0.50	0.62	0.84	3.9
Dorr	B or C	0.85	0.58	2.0

CTI: Cortical thickness index (Dorr)

AP: Anteroposterior

LAT: Lateral