Prediction of Osteoporosis through Radiographic Assessment of Proximal Femoral Morphology and Texture in Elderly; is it Valid and Reliable?

Yaşlılarda Proksimal Femur Morfoloji ve Dokusunun Radyografik Değerlendirilmesi Yoluyla Osteoporozun Tahmini, Geçerli ve Güvenilir midir?

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Summary

Objective: The purpose of this study was to determine the best predictive radiographic measurement method to identify the presence of osteoporosis and test the inter-observer and intra-observer reliability and validity of these methods in postmenopausal women.

Materials and Methods: Ninety-two elderly female patients who presented with hip pain were included. Hip radiographs were used to determine the values of Singh index (SI), canal-to-calcar ratio (CCR), and cortical thickness index (CTI). All measurements were performed by two independent observers on two separate occasions, at least 4 weeks apart. Bone mineral density (BMD) was assessed by DEXA. In the first part of the analysis, reliability of the all measurement methods was tested. In the second part, correlation coefficient (Pearson r) was used to determine the relationship between the measurement methods and BMD. Finally ROC curve analysis was performed to determine the sensitivity, specificity, and threshold values for each radiographic measurement method.

Results: Intra-observer reliability analysis of SI revealed kappa coefficient of 0.359 for observer A, and 0.224 for observer B. Inter-observer reliability analysis of SI revealed kappa coefficient of 0.070 for observer A and 0.051 for observer B. The intra-observer and inter-observer reliability was good and excellent for CTI and CCR for both observers (ICC: 0.920 and ICC: 0.936). There was no correlation between SI and BMD (p=0.818). On the other hand, there was a significant correlation between CTI and CCR and BMD (p=0.001). All measured indices were significantly different (p<0.05) between osteoporotic and non-osteoporotic patients. CTI value less than 0.3 or CCR value less than 0.47 reflects the presence of osteoporosis with 100% sensitivity and 98% specificity.

Conclusion: SI is not reliable and do not correlate with BMD. However, both CTI and CCR showed good and excellent reliability, and each index correlated well with the real BMD values. (Türk Osteoporoz Dergisi 2015;21: 46-52)

Key words: Osteoporosis, pelvis radiography, bone mineral density, Singh index, Cortical thickness index, calcar to canal ratio

Conflicts of Interest: The authors reported no conflict of interest related to this article.

Özet

Amaç: Bu çalışmanın amacı, postmenepozal kadınlarda osteoporoz varlığını kalça grafilerinden belirleyecek en iyi radyografik ölçüm metodunu belirlemek ve bu yöntemlerin geçerlilik ve güvenilirliğini araştırmaktır.

Gereç ve Yöntem: Kalça ağrısıyla hastaneye başvuran 92 postmenepozal kadın hasta çalışmaya alındı. Kalça radyografileri değerlendirilerek Singh indeks (Sİ), kanal kalkar oranı (KKO) ve Kortikal kalınlık indeksi (KKİ) ölçüldü. Tüm ölçümler en az 4 hafta arayla iki bağımsız gözlemci tarafından iki kez gerçekleştirildi. Hastaların kemik mineral yoğunluğu (KMY) DEXA ile değerlendirildi. Analizin ilk kısmında tüm ölçüm yöntemlerinin güvenilirliği test edildi. İkinci kısımda KMY ile ölçüm yöntemleri arasındaki ilgileşim analiz edildi, ilgileşim katsayısı (Pearson r) kullanıldı. En sonunda her bir radyografik ölçüm metotlarının sensivite, spesifitesini ve eşik değerini belirlemek için ROC eğri analizi yapıldı.

Bulgular: Sİ'nin gözlemciler içi güvenilirlik analizi gözlemci A için kappa katsayısını 0,359, gözlemci B için 0,224 olarak bulundu. Sİ, gözlemciler arası güvenilirlik analizi gözlemci A için kappa katsayısını 0,070, gözlemci B için 0,051 olarak bulundu. Gözlemciler içi ve gözlemciler arası

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güvenilirlik KKO ve KKİ için iyi ve mükemmeldi (ICC: 0,920 ve ICC: 0,936). Sİ ve KMY ölçümleri arasında ilgileşim bulunamadı (p=0,818). Diğer yandan KKO, KKİ ve KMY ölçümleri arasında anlamlı bir ilgileşim saptandı (p=0,001). Osteoporotik ve nonosteopotik hastalar arasında ölçülmüş tüm indeksler anlamlı derecede farklıydı (p<0,05). KKİ değeri 0,3 den az ve KKO değeri 0,47 den az osteoporoz varlığını %100 sensivite ve %98 spesifite ile gösterdiği saptandı.
Sonuç: Sİ osteoporozu saptamada güvenilir değildir ve KMY ile ilgileşim göstermemektedir. Ancak hem KKO hem de KKİ güvenilirdir ve gerçek KMY değerleriyle anlamlı şekilde ilgileşim göstermektedir. (Turkish Journal of Osteoporosis 2015;21: 46-52)
Anahtar kelimeler: Osteoporoz, pelvis radyografisi, kemik mineral yoğunluğu, Singh indeks, Kortikal kalınlık indeksi, kalkar kanal oranı

Çıkar Çatışması: Yazarlar bu makale ile ilgili olarak herhangi bir çıkar çatışması bildirmemiştir.

Introduction

Osteoporosis (OP) has become a world-wide public health problem as the number of aging populations rise (1). One of the most common complications of osteoporosis is hip fractures due to increased fragility of the bones. Hip fractures can be treated with various surgical treatment methods and implants such as fixed angle plates, dynamic hip screws, proximal femoral nails and prosthetic replacement either hemiarthroplasty or total hip arthroplasty (2-4). During decision making orthopedic surgeons consider several factors to contemplate the best treatment option for a particular patient. In patients who had unstable fracture pattern particularly associated with marked osteoporosis, failure of fixation may occur that results with secondary operations. Several studies have shown that osteoporosis is a major risk factor for failure of fixation in these patients (5). Therefore orthopedic surgeons dealing with treatment of hip fractures in elderly should asses the presence of osteoporosis. In other words preoperative identification and quantification of osteoporosis is useful information for surgeons to contemplate a proper treatment method (6,7).

Currently, bone densitometry has been accepted as the gold standard to assess and quantify the severity of osteoporosis (8). Diagnosis and follow-up of patients with OP should be done with bone densitometry. However, additional cost of the examination and difficulties in obtaining bone densitometry in a patient with hip fracture is the major disadvantages of this examination. Furthermore, bone densitometry equipment may not be readily available in many healthcare centers. On the other hand, direct radiographic examination is always obtained in a patient with hip fracture and it can be utilized to predict the severity of osteoporosis in these patients (9). Although radiographic examination cannot be used as a single method to diagnose the osteoporosis and monitor the treatment, it may provide valuable information for the physicians. Singh index (SI) is one of the traditional techniques used to determine the extent of osteoporosis which is based on radiological appearance of the trabecular bone structure of the proximal femur on a plain antero-posterior hip x-ray (10). These patterns categorized into six different scales or grades corresponding to the degree of bone loss starting from grade 6, in which all major trabecular systems are visible (normal), to grade 1 in which only the primary compressive trabeculae can be seen (severe osteoporosis).

Other than SI, Dorr et al. described two other indices, namely cortical thickness index (CTI) and calcar to canal ratio (CCR),

which define the proximal femoral morphology. Although, these indices were originally developed to select the proper prosthesis design (cemented versus cementless femoral stem) in patients undergoing hip arthroplasty, they reflect the morphological changes associated with osteoporosis (11-13).

In relevant literature, there are controversial findings whether these methods can predict the degree of osteoporosis. Moreover, reliability and validity of these methods has not been comprehensively studied. The purpose of this study is twofold, first we aimed to determine the best predictive measurement method on radiographs to identify the presence of osteoporosis and test the inter-observer and intra-observer reliability and validity of these methods in postmenopausal women.

Materials and Methods

Patients over 60 years of age who were admitted to our outpatient orthopedic clinic with hip pain were included in this prospective study. This study was carried out in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. All patients gave informed consent prior to their inclusion in the study and institutional review board (Bozok University Faculty of Medicine) approved the study protocol. Patients with previous hip surgery, congenital deformity of the proximal femur, patients with metabolic bone disease, such as Paget's disease, were excluded from the study. All patients underwent direct radiographic examination and bone mineral density (BMD) measurement of the affected hip within the same week. Antero-posterior hip radiographs had been taken with the x-ray beam directed toward the femoral head while the patient is supine with the foot internally rotated 15° to obtain best views of the femoral neck. X-ray tube was positioned 100 cm from focal plane of film cassette to yield an image at 20% magnification. All radiographs were taken with the same digital x-ray machine (Silhouette VR x-ray System, GE Healthcare, USA) at 70 kVp and 25 mAs. Bone mineral density was measured by DXA of the same femoral neck (Explorer QDR series, Hologic Inc, USA). A T-score of -2.5 or lower was defined as osteoporosis in accordance with World Health Organization. All referred patients filled a questionnaire to obtain demographic information and duration of menopause. Body weight of the subjects was measured with a digital scale and recorded in kilograms, and height of the patients were measured during standing in front of a wall height scale and recorded in meters. Body mass index (BMI) was calculated using standard formula

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(body mass divided by square of the height) and recorded in units of kg/m^2.

Two consultant orthopedic surgeons took part in the reliability analysis as observers. Before initiation of the study, the participants received a briefing about the radiological assessment of proximal femoral morphology and interpretation of SI in order to standardize the assessments. All radiographs were anonymous and presented to the observers in random order. The measurements were performed using a translucent ruler and a pencil. All radiologic assessments were performed in random order by each observer on two separate occasions, at least 4 weeks apart. Observers repeated their readings without knowledge of both their previous measurements and BMD. The order of the x-rays was randomized using a sequential random number generator to prevent possible recall. Determination of SI was made according to the principles presented in the original article by Singh et al. Observers assigned a Singh grading between 6 and 1 to each radiograph. Descriptions of SI are given in Table 1. CTI was calculated as the ratio of cortical thickness to bone diameter at a location 10 cm distal to the lesser trochanter (Figure 1). CCR was calculated as the ratio of the isthmus canal width divided by the calcar canal dimension (Figure 2).

Statistical Analysis

In the first part of the statistical analysis we have evaluated the reliability of the measurement methods. For SI, kappa statistics were used to establish a relative level of agreement between observers for the two readings and between separate readings by the same observer. Interpretation of the data was performed according to Landis and Koch (14). An agreement is graded as slight (kappa=0-0.2), fair (kappa=0.21-0.40), moderate (kappa=0.41-0.60), substantial (kappa=0.61-0.80) and almost perfect (kappa=0.81-1). To test the reliability of radiographic indices, the degree of agreement between the observers was calculated by the interclass correlation coefficient (ICC) in 95% confidence interval. Cicche provides commonly-cited cutoffs for qualitative ratings of agreement based on ICC values, with IRR being poor for ICC values less than 0.40, fair for values between 0.41 and 0.59, good for values between 0.60 and 0.74, and excellent for values between 0.75 and 1.0. In the second part of the analysis, we have analyzed the correlation between each radiographic measurement method and BMD, T score and Z score. Correlation coefficient (Pearson r) was used to determine the relationship between the variables. The mean value of the radiographic measurements performed by two observers in two occasions was used as the resultant value for analysis in continuous variables. Finally ROC curve analysis was performed

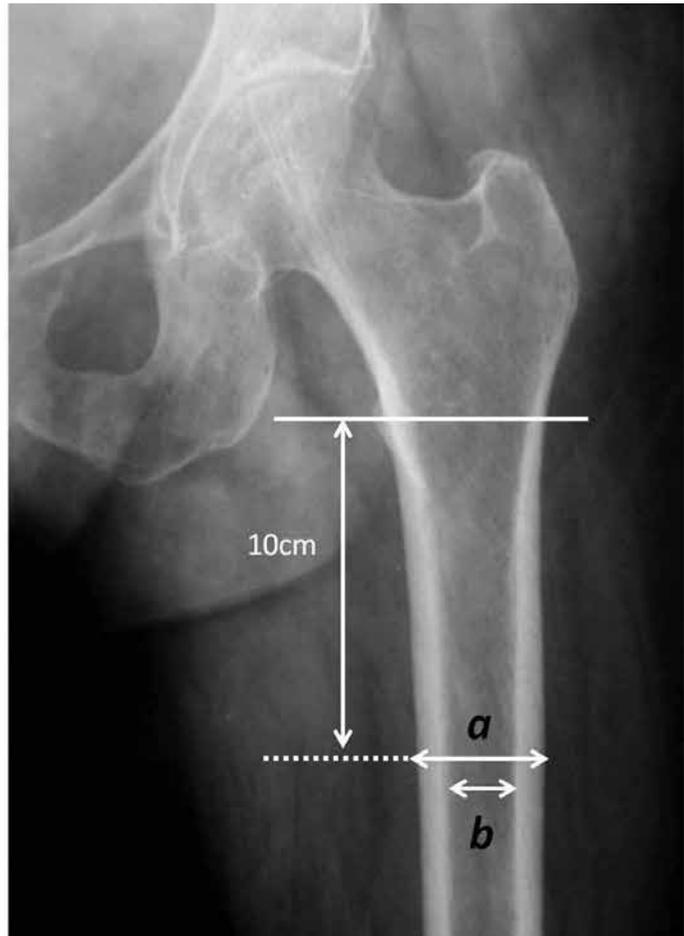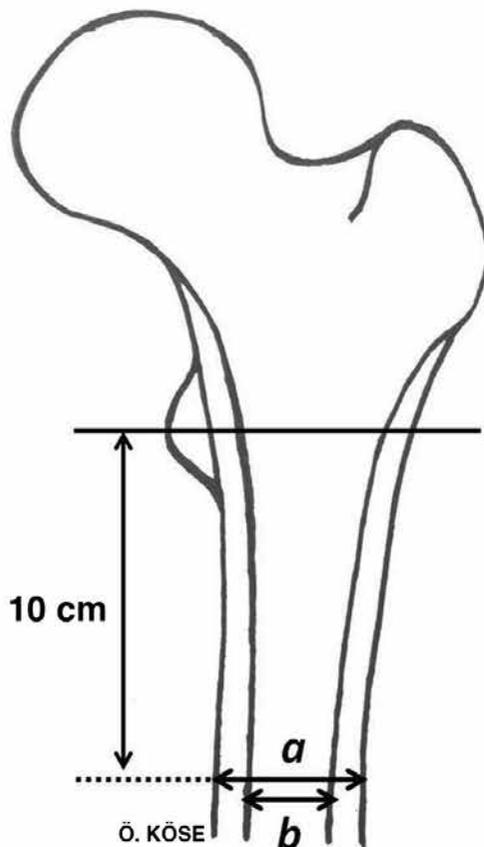**Figure 1.** Cortical thickness index

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to determine the threshold values, sensitivity and specificity for each radiographic measurement method.

Results

There were 92 patients (all female) with a mean age of 72.0±8.9 (range, 60-93). Of these patients, 35 had below -2.5 T score and constitute the osteoporosis patients. Demographic and clinical characteristics of patients are presented in Table 2. Intra-observer reliability analysis of SI revealed kappa coefficient of 0.359 for observer A, and 0.224 for observer B (fair agreement for both observers). Inter-observer reliability analysis of SI revealed kappa coefficient of 0.070 for observer A and 0.051 for observer B (slight agreement for both observers). The intra-observer and inter-observer reliability was good and excellent for CTI and CCR for both observers (Table 3). There was no correlation between SI interpretation of each observer on each occasion and DXA measurements (BMD, T score and Z score). On the other hand, there was significant correlation between CTI and CCR and DXA measurements (BMD, T score and Z score) (Table 4). All measured indices were significantly different (p<0.05) between osteoporotic and non-osteoporotic patients (Table 5). CTI value less than 0.3 or CCR value less than 0.47 reflects

the presence of osteoporosis with 100% sensitivity and 98% specificity (Table 6).

Discussion

In this study, relationship between radiographic measurements that specify the proximal femoral morphology and texture and BMD measurements were investigated. Furthermore reliability analysis of these measurements was tested. According to our findings, SI had very low (lower than acceptable limits) inter and intra-observer agreement between observers and between the separate assessments of the same observer. Moreover, these assessments did not correlate with the BMD values. On the other hand, both CTI and CCR showed good and excellent reliability, and each index correlated well with the real BMD values. CTI value less than 0.3 or CCR value less than 0.47 reflects the presence of osteoporosis with 100% sensitivity and 98% specificity.

Since SI has been published in 1970, several other authors studied the reliability and validity of this measurement method. There are controversial findings in relevant literature on both reliability and validity of SI in prediction of osteoporosis. In a study by Koot et al., 72 consecutive patients were assessed by six observers using Singh index, and only three
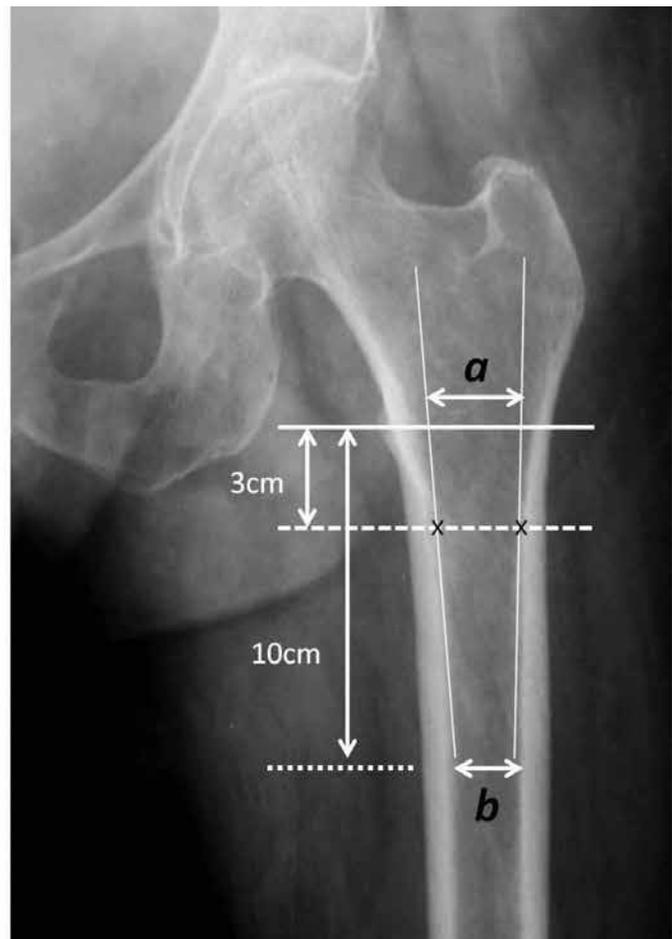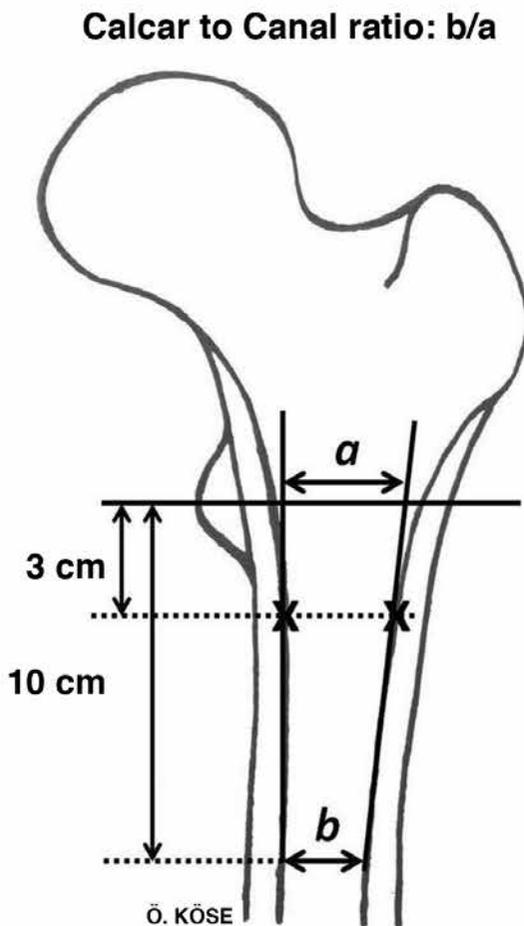

Figure 2. Calcar to canal ratio

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Table 1. Singh index	
Grade	**Description**
1	Even the principal compressive trabeculae are markedly reduced in number and are no longer prominent.
2	Only the principal compressive trabeculae stand out prominently, the others have been more or less completely resorbed.
3	There is a break in the continuity of the principal tensile trabeculae.
4	Principal tensile trabeculae are markedly reduced in number but can still be traced from the lateral cortex to the upper part of the femoral neck.
5	The structure of principal tensile and principal compressive trabeculae is accentuated. Ward's triangle appears prominent.
6	All the normal trabecular groups are visible and the upper end of the femur seems completely occupied by cancellous bone.

Table 2. Demographic and clinical characteristics of patients	
Variable	**Value**
Number of patients	92
Age (mean ± SD years)	72.0±8.9
BMD (mean ± SD)	0.722±0.165
T Score	-1.71±1.46
Z Score	-1.79±1.23
Body mass index (mean ± SD kg/m^2)	31.6±7.7
Duration of menopause (mean ± SD years)	24.7±9.3
Presence of osteoporosis (Yes/No)	35/57
BMD: Bone mineral density	

Table 3. Inter and intra-observer reliability analysis of indices and Singh index used to assess the proximal femoral geometry.				
Variable	**Reliability Analysis**		**ICC (95% CI) Kappa (95% CI)***	**Interpretation**
Calcar to Canal Ratio	Intra-observer reliability			
	Observer A t1	Observer A t2	0.920 (0.879-0.947)	Excellent
	Observer B t1	Observer B t2	0.921 (0.880-0.947)	Excellent
	Inter-observer reliability			
	Observer A t1	Observer B t1	0.846 (0.768-0.898)	Excellent
	Observer A t2	Observer B t2	0.750 (0.622-0.835)	Excellent
Cortical Thickness Index	Intra-observer reliability			
	Observer A t1	Observer A t2	0.745 (0.615-0.832)	Excellent
	Observer B t1	Observer B t2	0.936 (0.903-0.958)	Excellent
	Inter-observer reliability			
	Observer A t1	Observer B t1	0.822 (0.731-0.883)	Excellent
	Observer A t2	Observer B t2	0.624 (0.431-0.751)	Good
Singh Index	Intra-observer reliability			
	Observer A t1	Observer A t2	0.359 (0.213-0.504)*	Fair
	Observer B t1	Observer B t2	0.224 (0.092-0.355)*	Fair
	Inter-observer reliability			
	Observer A t1	Observer A t2	0.070 (0.053-0.193)*	Slight
	Observer B t1	Observer B t2	0.051 (0.050-0.156)*	Slight
(*) values are kappa statistics. ICC: interclass correlation coefficient				

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of 72 radiographs were given the same classification by all six observers. Moreover, they found no correlation between SI and BMD (14). Sah et al. studied whether there is a correlation between SI and T score in 32 postmenopausal women. Hip radiographs were rated by three observers to assign the Singh grade. Although they reported acceptable inter-rater reliability (kappa 0.88), SI was not significantly different between osteoporotic and non-osteoporotic patients, and no significant correlation was found between SI and T score (15). Im et al. investigated the association between SI and BMD in 140 Korean adults. They reported excellent inter-observer reliability of SI (ICC=0.85), however SI was not associated with BMD (16). Salamat et al. reported a large inter-observer variation (mean kappa 0.05) between three orthopedic surgeons, and could not determine any correlation the SI and BMD (17). In contrast to these findings, there are also studies which reported acceptable inter and intra-observer reliability, and significant correlation between SI ad BMD. Bes et al. investigated the reliability of SI, and its relationship with real BMD values in patients with rheumatoid arthritis (18). They found substantial intra- and inter-observer agreements with a mean kappa of 0.71 (range, 0.69 to 0.72). Furthermore, they reported good correlation between SI and BMD and high sensitivity for the diagnosis of osteopenia at the proximal femur (91%). D'Amelio et al.

assessed the predictive value of SI to estimate the BMD and mechanical properties of bone (strength and elastic modulus). They suggested that SI is highly predictive both for BMD and mechanical properties (19). It is clear that, there is still no consensus on the use of SI regarding reliability and validity. Our findings were consistent with the previous reports that claimed SI is neither reliable nor valid, and we believe that SI should not be used for prediction of osteoporosis in clinical practice. SI is a semi-quantitative method and in order to assess the trabecular texture, standard and good quality radiographs are required. Moreover, SI is not an easy classification to memorize and it is subject to inter and intra-observer variation. SI should be refined to improve its objectivity.

Apart from SI, other evaluation methods used to predict the quality of bone at proximal femur has been described such as CTI and CCR. These parameters were first intended to determine the type of femoral stem (cemented versus cementless) in patients undergoing hip arthroplasty (13). In our study, both CCR and CTI measurement methods were found to reliable. Inter-observer and intra-observer reliability analysis showed good and excellent agreement between observers. Furthermore, both CTI and CCR correlated with BMD. CTI and CCR are simple measurement methods which can be easily performed on direct hip radiographs and can

Table 4. Correlation analysis of Singh index, Calcar to canal ratio and Cortical thickness index with DXA measurements

		Observer A t1	Observer A t2	Observer B t1	Observer B t2	Mean CCR	Mean CTI
BMD	Pearson Correlation	0.180	-0.024	-0.035	0.076	-0.303	0.591
	Sig. (2-tailed)	0.086	0.818	0.740	0.471	0.003*	0.0001*
T Score	Pearson Correlation	0.156	-0.065	-0.057	0.058	-0.327	0.588
	Sig. (2-tailed)	0.137	0.537	0.587	0.583	0.001*	0.0001*
Z Score	Pearson Correlation	0.165	-0.043	0.050	0.155	-0.208	0.475
	Sig. (2-tailed)	0.115	0.687	0.638	0.140	0.047*	0.0001*

BMD: Bone mineral density, CCR: Calcar to canal ratio, CTI: Cortical thickness index, t1: First assessment, t2: Second assessment of the observers

Table 5. Comparison of Cortical thickness index and Calcar to canal ratio in osteoporotic and non-osteoporotic patients

	Osteoporosis	n	Mean ± SD	p value
Mean CTI	No Osteoporosis	57	0.51±0.07	0.0001
	Osteoporosis	35	0.43±0.06	
Mean CCR	No Osteoporosis	57	0.68±0.10	0.0001
	Osteoporosis	35	0.74±0.08	

CCR: Calcar to canal ratio, CTI: Cortical thickness index

Table 6. ROC analysis

Variable	Area under curve (AUC)	Cut-off value	Sensitivity (%)	Specificity (%)
CCR	0.671	0.47	100	98
CTI	0.185	0.30	100	98

CCR: Calcar to canal ratio, CTI: Cortical thickness index

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predict the degree of osteoporosis correctly (13). Our results are consistent with several previous studies however threshold values were different in studies performed in different ethnic populations. Sah et al. reported that a CTI ratio less than 0.50 indicate osteoporosis in American population (15). Yun et al. reported that a CTI value less than 0.57 indicates osteoporosis in Korean population (20). On the other hand, we found the threshold value for CTI as 0.30. Similar discrepancies are also present for CCR. Yueng et al. reported a CCR ratio less than 0.57 indicate osteoporosis in Chinese population (21). However, we found a CCR ratio of 0.47 as threshold value for osteoporosis. Femoral geometry is subject to changes between different ethnic groups. These changes may result from congenital traits and also from nutritional habits and the geographical differences.

There are some strengths and limitations of this study. Relatively small number of patients is included in this study and all patients were female. Therefore, we cannot generalize our findings to both genders. However, our study design is sufficient for explaining our hypothesis. Furthermore, not only validity but also the reliability of all measures was performed.

In conclusion, proximal femoral morphology can provide valuable information about the degree of osteoporosis in postmenopausal women. SI is an unreliable and invalid method to assess the degree of osteoporosis, however CCR and CTI are objective indices that can used in clinical practice, and may provide information about the presence of osteoporosis. However, ethnic differences should be kept in mind during decision making.

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