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The spatial differences in bone mineral density and hip structure between low-energy femoral neck and trochanteric fractures in elderly Chinese using quantitative computed tomography

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ABSTRACT

The purpose of this study was to investigate the differences in bone mineral density (BMD) and hip structure between femoral neck and trochanteric fractures in elderly Chinese individuals using quantitative computed tomography (QCT). A total of 625 Chinese patients (mean age 75.8 years) who sustained low-energy hip fractures (female: 293 femoral neck, 175 trochanteric; male: 82 femoral neck, 75 trochanteric) were recruited. Each patient underwent a hip QCT scan. The areal BMD (aBMD) of the contralateral normal hip was obtained using a computed tomography X-ray absorptiometry module. Using the bone investigation toolkit (BIT) module, the femoral neck was divided into four quadrants: supero-anterior (SA), infero-anterior (IA), infero-posterior (IP), and supero-posterior (SP). Estimated cortical thickness, cortical BMD, and trabecular BMD were measured in each quadrant. Using the hip structure analysis (HSA) function, several parameters were calculated. Stratified by sex, covariance analyses were applied to compare the femoral neck fractures group with trochanteric fractures group after adjustments for age, height, and weight. In women, trochanteric fractures exhibited lower trabecular BMD and estimated cortical thickness at three quadrants of the femoral neck (IA: $P = 0.02$, $P < 0.01$; IP: $P < 0.01$, $P = 0.01$; SP: $P = 0.01$, $P < 0.01$), and lower aBMD at the trochanter area ($P < 0.01$); femoral neck fractures exhibited lower cortical BMD and estimated cortical thickness at the SA quadrant ($P = 0.04$, $P = 0.01$). Differences in HSA parameters were not statistically significant. Among all parameters, the most valuable ones to discrimination of hip fracture type are estimated cortical thickness of the SA quadrant of femoral neck and the aBMD of the trochanter area. In men, only lower cortical BMD at the SP quadrant and aBMD at the trochanter were found in the trochanteric fractures ($P = 0.02$, $P < 0.01$). QCT outcomes indicate that spatial differences are helpful to explore the pathogenesis of different type of hip fractures. In women, trochanteric fractures are related to severer osteoporosis, whereas cortical fragility in the SA region of the femoral neck predominates in cases of femoral neck fractures. In men, trochanteric fractures are related to more bone loss of trochanter.

1. Introduction

Hip fractures are the most severe consequence of osteoporosis in the elderly population and lead to high rates of mortality and morbidity [1,2]. They are also a major burden to public health care, which is becoming increasingly stressed by rapidly aging societies [3]. The prevention of hip fractures, however, requires a thorough understanding of skeletal characteristics and etiology. Hip fractures are usually classified into femoral neck and trochanteric fractures. Most etiological studies have considered the two types of fractures as a single entity [4–6]. However, treatments and outcomes between these two types of hip fracture frequently differ [7]. Therefore, it is important to explore differences in the patterns of these two hip fracture types.

A review by Mautalen et al. [8] reported that women with trochanteric fractures were older, thinner, and shorter. Race and geographical patterns may also be site specific [9]. Aside from these epidemiological differences, some studies have indicated that patients with trochanteric fractures exhibited more severe osteoporosis [8,10,11].

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Few studies have examined the differences between the two types of hip fracture using hip structure analysis (HSA[1]) parameters, and one report suggested that a diminished femoral neck shaft angle may be a significant contributing factor to trochanteric fractures [12]. These findings suggest that femoral neck and trochanteric fractures may have a different pathogenesis.

Most studies investigating bone mineral density (BMD) and HSA parameters of the hip have involved the use of dual energy X-ray absorptiometry (DXA). However, the two-dimensional nature of DXA may obscure real differences in cortical and trabecular BMD, and cortical thickness. In contrast, quantitative computed tomography (QCT) of the hip can provide three-dimensional (3D) information regarding the distribution of bone mass, structure, and HSA parameters [13,14]. It may also help clarify the pathogenesis of hip fractures further.

As mentioned above, ethnic and geographical differences in hip fractures have been reported [9,15]; however, because subjects in most previous studies have been primarily Caucasian or black, these patterns may not be representative of individuals of Chinese origin. For this reason, it is important to explore the characteristics of hip fractures in elderly Chinese individuals in greater depth. Accordingly, the present study aimed to investigate BMD and hip structure differences using QCT technology in a population of elderly Chinese individuals who sustained femoral neck and trochanteric fractures.

2. Materials and methods

2.1. Study participants

A total of 1613 consecutive patients with suspected hip fractures, who were admitted to the authors' emergency department of orthopedic trauma between January 2012 and May 2016, were recruited for this study. Informed consent was obtained from each patient. As a routine imaging examination protocol in the hospital for hip injury patients, hip CT using a 16-row detector CT scanner (Toshiba, Tokyo, Japan) is performed for those with suspected or X-ray-proven hip fractures in the emergency service of the radiology department. The CT scanner is equipped with a Mindways QCT calibration phantom (Mindways Software Inc., Austin, TX, USA), which enables the acquisition of hip CT scans according to QCT procedures. Using CT images, the fractures were categorized into femoral neck or trochanteric fractures by an experienced musculoskeletal radiologist (SYB). A one-page questionnaire containing basic information about osteoporosis was completed by the patients or their relatives after the CT examination. Basic information included typical demographic data (age, sex, height, and weight, among others), details of the fall (when, how, where), fracture history, and medical history. The ethics committee of the authors' hospital approved this study.

2.1.1. Eligibility criteria

Individuals who met the following criteria were included: hip fracture resulting from low-energy injury (limited to falls when walking or standing); Chinese Han nationality; underwent QCT scan < 48 h after injury; unilateral hip fracture; female aged ≥ 50 years, or male aged ≥ 55 years.

2.1.2. Exclusion criteria

Individuals who met the following criteria were excluded: previous hip fracture(s); diseases leading to long-term limitation of activity such as paralysis, a poorly healed lower extremity fracture, hip dysplasia, avascular necrosis of the femoral head; painful diseases within the past 3 months such as acute pancreatitis, lumbar fracture; metabolic bone disease (other than senile osteoporosis or postmenopausal osteoporosis); inflammatory arthritis, such as rheumatoid arthritis; indications of bone tumor or tumor-like lesion(s) of the proximal femur, such as bone metastases, chondrosarcoma, or bone island; malignant tumors with the potential to metastasize to bone; treatments that could affect the metabolism of bone tissue; and medications known to affect bone metabolism (e.g., glucocorticoids).

After review of questionnaire responses, medical records, and CT images, 625 cases were considered eligible for further analysis. A flowchart detailing stepwise inclusion and exclusion of the subjects is presented in Fig. 1.

2.2. QCT scanning

Hip QCT was performed as per routine clinical practice. The subjects were scanned in the supine position, with the phantom beneath the hip. Hips were scanned from the top of the acetabulum to a level 3 cm inferior to the lesser trochanter or longer to cover the fractured bone. The QCT scan parameters were 120 kVp, 125 mAs, 1.0 mm slice thickness, with standard reconstruction using a 50 cm field of view.

After clinical evaluation of hip fracture CT data in an multiplanar reformation or 3D manner, the CT images were transferred to a Mindways QCT workstation and analyzed using the computed tomography X-ray absorptiometry function (CTXA, version 4.2.3) and bone investigation toolkit analysis (BIT, version 2.0).

2.3. CTXA

Details of the measurement procedure are described in a previous study [16]. CTXA was used to obtain the area BMD (aBMD) of the contralateral normal proximal femur, given that the aBMD derived from CTXA is equal to DXA [16]. With CTXA, aBMD of the femoral neck, trochanter and intertrochanter regions of interest were acquired.

2.4. BIT analysis

QCT BIT analysis was performed to the contralateral normal hip following instructions in the BIT QCT manual. For cortical separation from the surrounding soft tissue, the threshold for estimation of cortical thickness was set to 450 mg/cm^3.

With BIT, the measurements were separated into two categories: QCT HSA and femoral neck quadrant analysis. Details regarding the former have been described by Khoo et al. [17]. Bone cross-sectional area (CSA), cross-sectional moment of inertia (CSMI), section modulus (Z), femoral neck subperiosteal width (W), femoral neck endosteal width (ESD), averaged cortical thickness (aCT), and buckling ratio (BR) were measured.

Femoral neck quadrant analysis was performed in a fashion similar to a previous study [18]. The software automatically identified the minimum cross-sectional area in the femoral neck perpendicular to the femoral neck axis. Then, defined by a constant perimeter, the femoral neck cross-section was subdivided into 16 sectors. The 16 sectors resulted in four anatomical quadrants (Fig. 2): supero-anterior (SA), infero-anterior (IA), infero-posterior (IP), and supero-posterior (SP). The estimated cortical thickness (Est CTh), cortical volume BMD (CvBMD), and trabecular volume BMD (TvBMD) of each quadrant were measured. Ten further slices were extracted at 1 mm intervals medially. Only the first 6 slices (1–6) were used in the BIT analysis. The interpolated pixel size of extracted cross-sectional images was 0.488 mm.

[1] 3D: three-dimensional; aBMD: areal bone mineral density; aCT: averaged cortical thickness; BIT: bone investigation toolkit; BMD: bone mineral density; BR: buckling ratio; CSA: bone cross-sectional area; CSMI: cross-sectional moment of inertia; CTXA: computed tomography X-ray absorptiometry; CvBMD: cortical volume BMD; DXA: dual energy X-ray absorptiometry; Est CTh: estimated cortical thickness; ESD: femoral neck endosteal width; FN: femoral neck; HSA: hip structure analysis; IA: infero-anterior; IP: infero-posterior; QCT: quantitative computed tomography; SA: supero-anterior; SP: supero-posterior; SPM: surface-based statistical parametric mapping; TR: trochanter; TvBMD: trabecular volume BMD; VBM: voxel based morphometry; W: femoral neck subperiosteal width; Z: section modulus

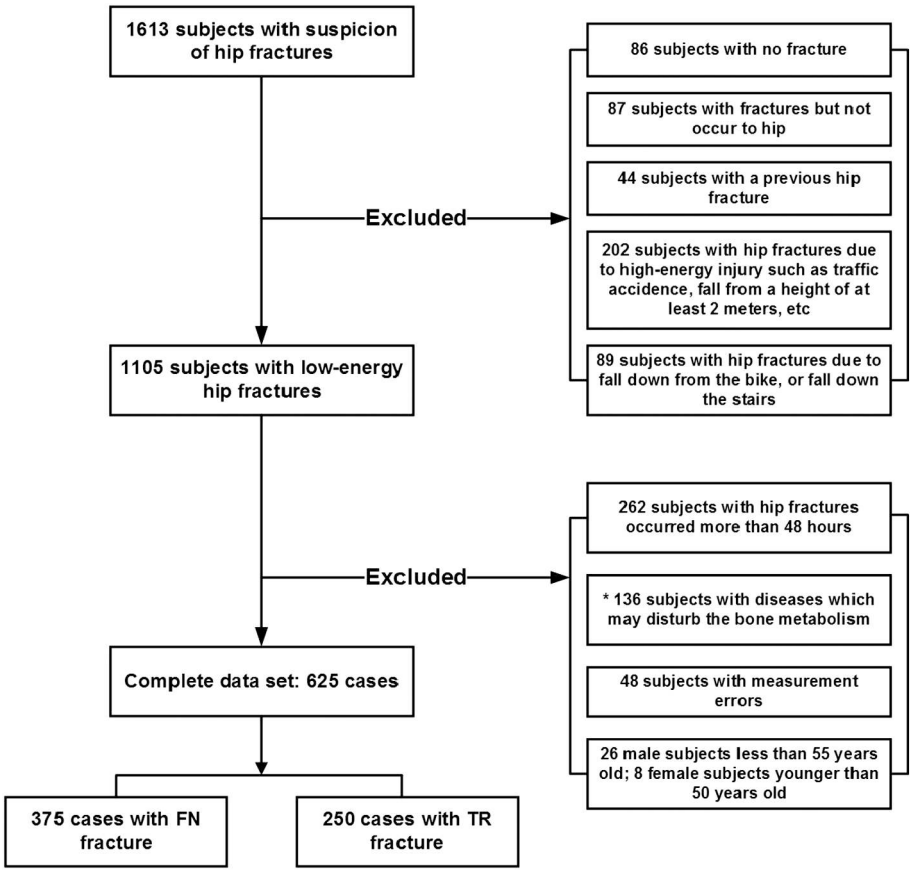

Fig. 1. Schematic flow diagram illustrating the stepwise exclusion of subjects with hip injuries. FN, femoral neck; TR, trochanteric.
*: These subjects were with diseases, which may disturb the bone metabolism, or had received treatments that could affect the metabolism of bone tissue or medications known to affect bone metabolism.

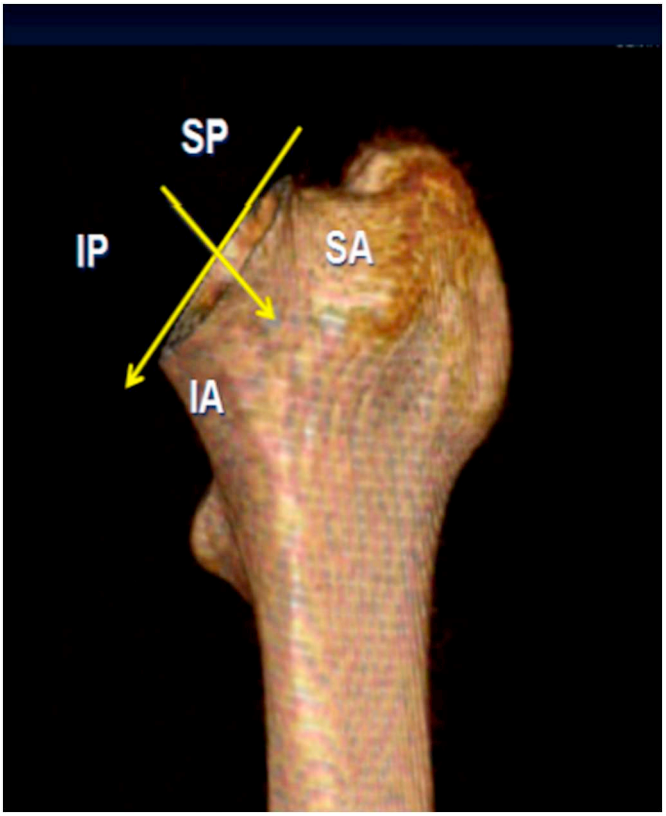

Fig. 2. The cross-sectional area of the femoral neck was subdivided into four anatomical quadrants. IA, infero-anterior; IP, infero-posterior; SA, supero-anterior; SP, supero-posterior.

2.5. Statistical analysis

Statistical analysis was performed using SPSS version 17 (IBM Corporation, Chicago, IL, USA) for Windows (Microsoft Corporation, Redmond, WA, USA). Demographic differences between the two groups were evaluated using the Student's *t*-test. Comparisons of each parameter, measured using CTXA, HSA, and femoral neck quadrant analysis, between femoral neck and trochanteric fractures were performed using covariance analysis after adjustments for age, height, and weight. Non-normally distributed data was analyzed using the Mann-Whitney *U* test. Based on the results of comparisons, the odds ratios (OR) of variables with $P < 0.01$ for hip fracture types were calculated, adjusted for height, weight and age. Based on results of OR, receiver operating characteristic curve (ROC) analysis of parameters with $P < 0.01$ was carried out after adjustments for age, height and weight. $P < 0.05$ was considered statistically significant.

3. Results

3.1. Characteristics of the study groups

A total of 625 hip fracture subjects were eligible for further analysis (Fig. 1). There were 375 femoral neck fractures (293 female, 82 male), and 250 trochanteric fractures (175 female, 75 male). Relevant demographic data of the two groups stratified by sex were summarized in Table 1. In women, the average age of the trochanteric fractures group was 5.9 years older than the femoral neck group ($P < 0.01$). No statistical difference of height or weight was found. In men, no statistical difference of age, height or weight was found between femoral neck fractures and trochanteric fractures (the values are very similar in each group).

Table 1
Characteristics of subjects who sustained femoral neck or trochanteric fractures.

Characteristic	Female		Male	
	FN (293)	TR (175)	FN (82)	TR (75)
Age (year)	73.3 (0.6)**	79.2 (0.6)**	76.5 (1.0)	76.3 (1.1)
Weight (kg)	58.2 (0.5)	58.7 (0.8)	66.8 (1.2)	66.3 (1.3)
Height (cm)	159 (0.6)	157 (0.4)	171 (0.6)	170 (0.6)

Data are presented as mean with standard error in parentheses.
FN: femoral neck fracture group; TR: trochanteric fracture group
**: $P < 0.01$. Statistically differences were compared between FN and TR, stratified by sex.

3.2. CTXA, HSA, and femoral neck quadrant analysis using QCT

Stratified by sex, the results of CTXA, HSA, and femoral neck quadrant analysis were compared between the two groups after age, height and weight had been adjusted.

In women, trochanteric fractures exhibited lower aBMD in the entire area of the proximal femur, especially in the trochanter and intertrochanteric areas by using CTXA. Femoral neck quadrant analysis provided more details. Except for the SA quadrant of femoral neck, the other three quadrants (IA, IP, and SP) exhibited nearly the same differences: the trochanteric fracture cases were with lower trabecular BMD and thinner estimated cortical thickness (IA: $P = 0.02$, $P < 0.01$; IP: $P < 0.01$, $P = 0.01$; SP: $P = 0.01$, $P < 0.01$). However, femoral neck fractures exhibited lower cortical volume BMD and thinner estimated cortical thickness at the SA quadrant ($P = 0.04$, $P = 0.01$). There was no significant difference in each of the HSA parameters between the two fracture types. Details were summarized in Table 2. Based on Table 2, the OR for hip fracture types of variables with $P < 0.01$ were calculated, adjusted for height, weight and age (Table 3). From Table 3, variables with $P < 0.01$ were identified, including intertrochanter (IT) aBMD, trochanter (TR) aBMD, IA Est CTh of femoral neck (FN), IP TvBMD of FN and SA Est CTh of FN. Among these, the most meaningful parameter was TR aBMD. ROC analysis of the data of these five parameters with $P < 0.01$ (from Table 3) was carried out after adjustments for age, height and weight (Fig. 3). The results of the area under the curve (AUC) from Fig. 3A indicated that IT aBMD, IA Est CTh of FN, IP TvBMD of FN were highly correlated to TR aBMD. The AUC of TR aBMD was 0.76. However, from Fig. 3B, TR aBMD and SA Est CTh were identified as two independent parameters. Combination with TR aBMD and SA Est CTh improved the AUC to 0.80.

In men, only lower cortical BMD at the SP quadrant of femoral neck and aBMD at the trochanter were found in the trochanteric fractures ($P = 0.02$, $P < 0.01$). No statistical difference was found in any of the other parameters between the two fracture types. (Table 4).

Table 2
Measurements of CTXA, HSA, and femoral neck quadrant analysis using QCT of female patients (468 cases).

Parameter	Fracture group		P^a
	Femoral neck (293 cases)	Trochanter (175 cases)	
CTXA			
TH aBMD (g/cm^2)	0.60 (0.01)	0.52 (0.01)	< 0.01*
FN aBMD (g/cm^2)	0.48 (0.01)	0.47 (0.01)	0.02*
IT aBMD (g/cm^2)	0.70 (0.01)	0.65 (0.01)	< 0.01*
TR aBMD (g/cm^2)	0.38 (0.00)	0.33 (0.01)	< 0.01*
HSA			
NSA (°)	130.4 (0.3)	130.1 (0.4)	0.52
CSA (cm^2)	1.50 (0.02)	1.46 (0.02)	0.14
CSMI (cm^4)	1.27 (0.04)	1.26 (0.05)	0.89
Z (cm^3)	0.73 (0.02)	0.75 (0.02)	0.47
W (cm)	2.62 (0.02)	2.58 (0.02)	0.15
ESW (cm)	2.39 (0.02)	2.35 (0.02)	0.19
aCt (cm)	0.12 (0.00)	0.12 (0.00)	0.81
BR	15.78 (0.24)	15.56 (0.32)	0.60
Femoral neck quadrant analysis			
Quadrant SA			
Est CTh (mm)	0.17 (0.39)	0.22 (0.42)	0.01*
CvBMD (mg/cm^3)	492 (5)	509 (6)	0.04
TvBMD (mg/cm^3)	65.5 (1.4)	63.4(1.9)	0.38
Quadrant IA			
Est CTh (mm)	1.52 (0.03)	1.35 (0.04)	< 0.01*
CvBMD (mg/cm^3)	694 (3.5)	690(4.6)	0.44
TvBMD (mg/cm^3)	84.7 (1.8)	77.4 (2.4)	0.02*
Quadrant IP			
Est CTh (mm)	2.79 (0.04)	2.61 (0.05)	0.01*
CvBMD (mg/cm^3)	770 (4)	776 (5)	0.34
TvBMD (mg/cm^3)	80.3 (1.7)	71.9 (2.2)	< 0.01*
Quadrant SP			
Est CTh (mm)	0.22 (0.37)	0.12 (0.27)	< 0.01*
CvBMD (mg/cm^3)	507 (4.6)	499 (6.1)	0.28
TvBMD (mg/cm^3)	66.5 (1.5)	59.8 (2.0)	0.01*

Data are presented as mean with standard error of the mean values in parentheses unless otherwise indicated.
CTXA: computed tomography X-ray absorptiometry; TH: total hip; FN: femoral neck area; IT: intertrochanter area; TR: trochanter area; aBMD: areal bone mineral density; HSA: hip strength analysis; NSA: femoral neck shaft angle; CSA: bone cross-sectional area; CSMI: cross-sectional moment of inertia; Z: section modulus (an index of bending resistance); W: femoral neck subperiosteal width; ESW: femoral neck endosteal width; aCT: averaged cortical thickness; BR: buckling ratio (an index of bone geometric instability); IA: infero-anterior; IP: infero-posterior; Est CTh: estimated cortical thickness; CvBMD: cortical volume BMD; TvBMD: trabecular volume BMD.
[a] Calculated using covariance analysis after adjustments according to age, height, and weight. Differences in cortical thickness of the supero-anterior (SA) and supero-posterior (SP) quadrant were tested using the Mann-Whitney U test.
* Statistically significant (i.e., $P < 0.05$).

4. Discussion

Previous studies have investigated density and structure in subjects with femoral neck and trochanteric fractures using DXA or QCT. However, the number of these studies with direct comparisons between types of fracture is limited. Furthermore, the number of studies with direct comparisons between fracture types stratified by sex is even smaller, complicating the comparison of our findings with those in the literature. To complicate the comparisons further, most studies have used different image analysis approaches. Nevertheless, we identified four DXA and seven QCT relevant studies investigating femoral neck and trochanteric fractures in Asian and Caucasian populations, and in general, our findings agree with those in the literature.

Because the sex differences in the distribution of bone in relation to hip fracture had been explored by Johannesdottir et al. [19] and Marques et al. [20], which is also confirmed by our study, we divide the following discussion as two main subsections with respect to sex.

Most relevant studies were focus on women to explore the results of DXA-HSA or QCT-HSA, QCT-cortical thickness, DXA-BMD or QCT-BMD.

In terms of DXA-HSA and QCT-HSA, results varied. Gnudi et al. [21] showed larger DXA-NSA for neck fractures than for trochanteric fractures (fractures vs. controls); However, Ito et al. [22] showed larger values of QCT-NSA for intertrochanteric fractures, and HAL and BR for neck fractures in Japanese (fractures vs. controls). After directly compared the two types of fracture, Szulc et al. [23] reported significant larger CSA and cortical thickness for neck fractures, significant larger BR for trochanteric fractures, by using DXA (data collected before fracture). In our results, nonsignificant differences between QCT-HSA parameters were detected between neck and trochanteric fractures (with similar mean values between fracture types). Therefore, the value of DXA-HSA or QCT-HSA parameters to discriminate different types of hip fractures remains questionable.

With regard to QCT-cortical thickness, femoral neck area division is

Table 3
Odds ratios for discrimination of hip fracture type per 1 SD of variables with $P < 0.01$ from Table 2, adjusted for height, weight and age.

Parameters	Unadjusted OR (95% CI)	Adjusted OR (95% CI)	Unadjusted *P* value	Adjusted *P* value
IT aBMD (g/cm^2)	1.8 (1.5–2.2)	1.6 (1.2–2.0)	< 0.001	< 0.001*
TR aBMD (g/cm^2)	2.8 (2.2–3.7)	2.6 (1.9–3.5)	< 0.001	< 0.001*
SA- Est CTh (mm) of FN	1.3 (1.0–1.5)	1.3 (1.1–1.7)	0.018	0.002*
IA- Est CTh (mm) of FN	1.6 (1.3–2.0)	1.5 (1.2–1.8)	< 0.001	0.001*
SP- Est CTh (mm) of FN	1.5 (1.2–1.8)	1.2 (0.9–1.5)	0.001	0.14
IP- TvBMD (mg/cm^3) of FN	1.7 (1.4–2.1)	1.4 (1.2–1.8)	< 0.001	0.002*

aBMD: area bone mineral density; AUC: area under receiver operating characteristic curve; CI: Confidence interval; Est CTh: estimated cortical thickness; FN: femoral neck area; IA: infero-anterior; IP: infero-posterior; IT: intertrochanter area; OR: odds ratio; SA: supero-anterior; SP: supero-posterior; TR: trochanter area; TvBMD: trabecular volume BMD.

* $P < 0.01$.

important. Poole et al. [24] reported that in Caucasian women, both fracture types showed cortical bone defect in the superior neck, but the differences was greater for femoral neck fracture cases (n = 86) than tranchanteric fracture cases (n = 52) compared with controls. Yu et al. [25] reported that in Chinese women, neck fracture cases (n = 72) had thinner cortical bone in the superior anterior aspect of the femoral neck compared to trochanteric cases (n = 21) by using surface-based statistical parametric mapping. With this study of the more samples (femoral neck fractures: 293 cases; trochanter fractures: 175 cases), our quadrant analyses strengthened those results that femoral neck cases had a significantly lower cortical thickness of SA quadrant of femoral neck. However, the results were different in other femoral neck areas. Johannesdottir et al. [19] reported that trochanteric cases (n = 41) had lower cortical thickness of IA quadrant (data collected before fracture). Our quadrant analyses found trochanteric cases had significant thinner cortical thickness not only in IA quadrant, but also in IP and SP quadrants. These findings of other quadrants (not SA) of femoral neck are consistent with the following discussion that the trochanteric cases had severer osteoporosis.

With respect to DXA-BMD and QCT-BMD, direct comparisons between neck and trochanteric fractures were done in few articles. Szulc et al. [23] reported that trochanteric ones (n = 23) had lower femoral neck aBMD (DXA) in French women of the EPIDOS study. Johannesdottir et al. [19] used the same image analysis software as our study. In their prospective fracture study, authors reported no significant BMD differences between neck and trochanteric fractures (47 neck, 41 trochanteric), although lower femoral neck BMD and integral mid-femoral neck vBMD were observed in the trochanteric group. Li et al. [26] reported nonsignificant differences in femoral neck or trochanteric vBMD between the two types of fracture (29 neck and 8 trochanteric) in Chinese (lower mean values in the trochanteric group). With using voxel-based morphometry (VBM), Yu et al. [25] reported that in Chinese women that significant deficits in trabecular vBMD were observed in the greater trochanter in the trochanteric cases. In addition, trochanteric cases had lower cortical vBMD in the posterior and lateral aspects of the greater trochanter, and lower endosteal vBMD laterally in the greater trochanter and sparsely in posterior regions of the femur, by using surface-based statistical parametric mapping (SPM). In our study, in the trochanteric cases of Chinese women, significant lower aBMD values (total hip, femoral neck, intertrochanter and trochanter) were observed by using CTXA, and significant lower trabecular vBMD values were also observed in IA, IP and SP quadrant of femoral neck with using QCT quadrant analysis. These findings strengthened the above results that trochanteric cases were with more pronounced bone loss.

However, in the SA quadrant, we found that femoral neck fracture cases were with significantly lower cortical vBMD and not statistically higher trabecular vBMD. Combined with the thinner cortex of this quadrant, we may identify the SA quadrant as a fragile area to the pathogenesis of femoral neck fractures in Chinese women, which needs to be more explored in the future.

In addition, our study suggested that the differences between the two groups were mainly due to two parameters: the estimated cortical thickness of the SA quadrant of femoral neck and the aBMD of the trochanter area, among these parameters from QCT.

In contrast to female, the numbers of studies about male hip fractures are rather small. We only identified three studies, none of which was about Chinese men or Asian men. Tuck et al. [27] reported that in UK men, there were no significant differences in DXA-NSA between femoral neck (n = 31) and trochanteric (n = 16) fractures. In the study of Treece et al. [28], authors reported that both cortical mass surface density and endosteal trabecular BMD were significantly different between fractures and controls in regions appropriate to fracture type (55 neck, 44 trochanteric) in Caucasian men. However, they did not directly compare the fracture groups. In the prospective study of Johannesdottir et al. [19], significantly lower cortical thickness for the trochanteric cases in the IP quadrant was reported, but not for the other parameters including HAL, femoral neck aBMD, and cortical thickness of the other three quadrants et al. In our study, Chinese male trochanteric fractures were only with lower aBMD of tranchanter and cortical vBMD of SP quadrant. All of these indicate that the trachanteric fractures of men are with a little severer osteoporosis. Different from the findings of female patients, in men, the evidence of cortical fragility of SA quadrant of femoral neck wasn't found in femoral neck fracture cases. These results suggest that the pathogenesis of hip fractures may be sex different.

The present study had the following strengths. First, it included 625 low-energy hip fractures, which maybe the largest sample of any previous QCT or DXA hip fracture study. Second, limited the CT acquired within 48 h after injury to minimize the influence on BMD from the immobilization.

Our study also had several limitations, the first of which was that the spatial resolution of a clinical CT scanner is not optimized for thin cortical thickness assessment [29]. However, when measuring, we should define the cortex because our goal is to develop a technique that can be used in the clinical setting. Second, due to the limitations of these technologies, we have not measured the intertrochanter area using sub-region analysis with QCT. Third, our results maybe confine to Chinese or Asian people, though our results are consistent with a few Caucasian studies.

In conclusion, our findings emphasize that it is necessary to divide the femoral neck into quadrants for analysis. In women, it is suggested that the two types of hip fracture are due to different pathogenesis:

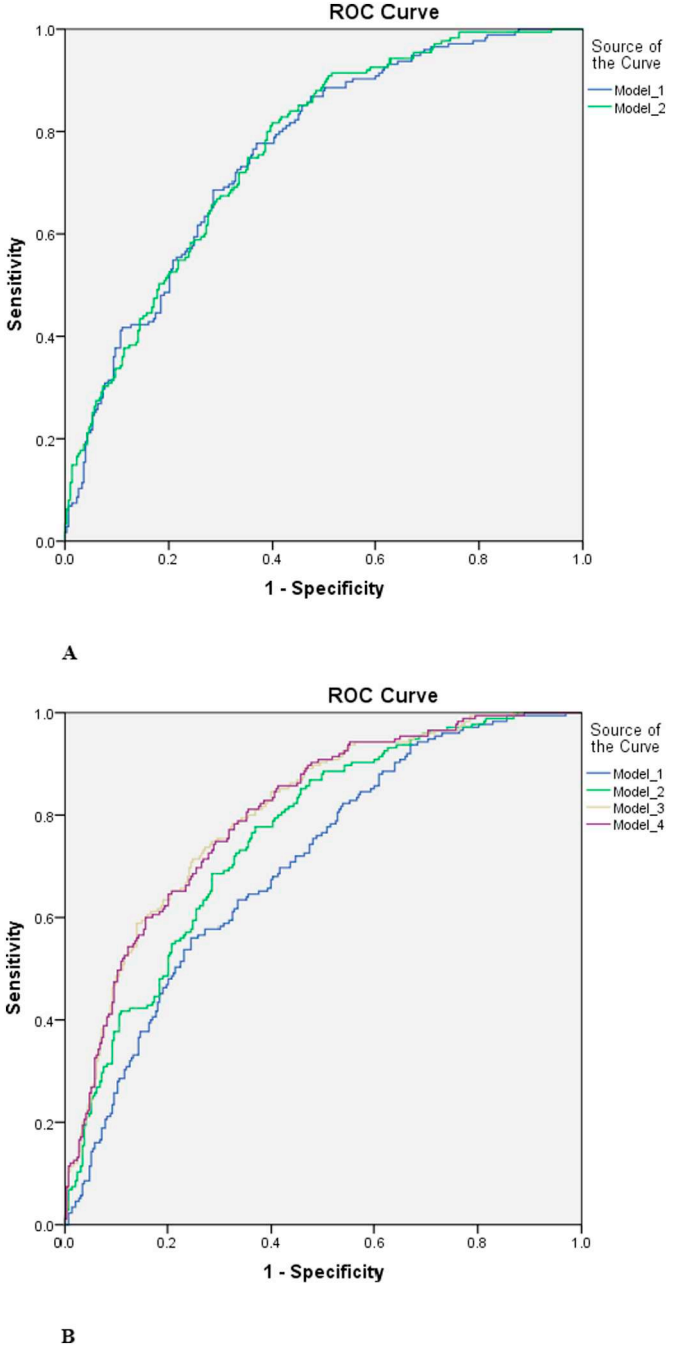

Fig. 3. Receiver operating characteristic curves of different models for discrimination of proximal femur fracture types. All of the models were adjusted for age, height and weight.
aBMD: area bone mineral density; AUC: area under receiver operating characteristic curve; Est CTh: estimated cortical thickness; FN: femoral neck area; IA: infero-anterior; IP: infero-posterior; IT: intertrochanter area; SA: supero-anterior; TR: trochanter area; TvBMD: trabecular volume BMD

trochanteric fractures are related to severer osteoporosis, whereas cortical fragility in the SA region of the femoral neck predominates in cases of femoral neck fractures. In men, trochanteric fractures are related to a little severer bone loss of trochanter area.

Table 4
Measurements of CTXA, HSA, and femoral neck quadrant analysis using QCT of male patients (157 cases).

Parameter	Fracture group		P^a
	Femoral neck (82 cases)	Trochanter (75 cases)	
CTXA			
TH aBMD (g/cm^2)	0.67 (0.01)	0.63 (0.01)	0.02*
FN aBMD (g/cm^2)	0.54 (0.01)	0.54 (0.01)	0.76
IT aBMD (g/cm^2)	0.81 (0.02)	0.78 (0.02)	0.09
TR aBMD (g/cm^2)	0.47 (0.01)	0.42 (0.01)	< 0.01*
HSA			
NSA (°)	131.6 (0.6)	130.1 (0.7)	0.11
CSA (cm^2)	1.88 (0.04)	1.86 (0.04)	0.78
CSMI (cm^4)	2.09 (0.07)	2.02 (0.06)	0.42
Z (cm^3)	1.09 (0.03)	1.05 (0.03)	0.37
W (cm)	2.99 (0.03)	3.03 (0.04)	0.37
ESW (cm)	2.73 (0.04)	2.78 (0.04)	0.35
aCt (cm)	0.13 (0.00)	0.12 (0.00)	0.48
BR	15.83 (0.45)	16.44 (0.47)	0.35
Femoral neck quadrant analysis			
Quadrant SA			
Est CTh (mm)	0.37 (0.61)	0.23 (0.60)	0.21
CvBMD (mg/cm^3)	522 (6)	520 (6)	0.75
TvBMD (mg/cm^3)	70.3 (2.8)	63.8 (2.9)	0.11
Quadrant IA			
Est CTh (mm)	1.46 (0.06)	1.50 (0.06)	0.72
CvBMD (mg/cm^3)	666 (5.7)	672 (5.9)	0.46
TvBMD (mg/cm^3)	88.6 (3.3)	83.5 (3.4)	0.28
Quadrant IP			
Est CTh (mm)	2.81 (0.07)	2.86 (0.08)	0.62
CvBMD (mg/cm^3)	768 (6)	772 (7)	0.70
TvBMD (mg/cm^3)	94.0(3.4)	87.0 (3.5)	0.16
Quadrant SP			
Est CTh (mm)	0.50 (0.68)	0.32 (0.44)	0.64
CvBMD (mg/cm^3)	527 (6)	507 (6)	0.02*
TvBMD (mg/cm^3)	76.1 (2.6)	68.6 (2.8)	0.05

Data are presented as mean with standard error of the mean values in parentheses unless otherwise indicated.
CTXA: computed tomography X-ray absorptiometry; TH: total hip; FN: femoral neck area; IT: intertrochanter area; TR: trochanter area; aBMD: areal bone mineral density; HSA: hip strength analysis; NSA: femoral neck shaft angle; CSA: bone cross-sectional area; CSMI: cross-sectional moment of inertia; Z: section modulus (an index of bending resistance); W: femoral neck subperiosteal width; ESW: femoral neck endosteal width; aCT: averaged cortical thickness; BR: buckling ratio (an index of bone geometric instability); IA: infero-anterior; IP: infero-posterior; Est CTh: estimated cortical thickness; CvBMD: cortical volume BMD; TvBMD: trabecular volume BMD.
[a] Calculated using covariance analysis after adjustments according to age, height, and weight. Differences in cortical thickness of the supero-anterior (SA) and supero-posterior (SP) quadrant were tested using the Mann-Whitney *U* test.
* Statistically significant (i.e., $P < 0.05$).

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