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Original Article

Utility of Radiographic Parameter in Assessing Bone Density and Subsequent Fractures in Patients With Osteoporotic Vertebral Compression Fracture

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Objective: To investigate the ability of radiological parameter canal bone ratio (CBR) to assess bone mineral density and to differentiate between patients with primary and multiple osteoporotic vertebral compression fracture (OVCF).
Methods: A retrospective analysis was conducted on OVCF patients treated at our hospital. CBR was measured through full-spine x-rays. Patients were categorized into primary and multiple fracture groups. Receiver operating characteristic curve analysis and area under the curve (AUC) calculation were used to assess the ability of parameters to predict osteoporosis and multiple fractures. Predictors of T values were analyzed by multiple linear regression, and independent risk factors for multiple fractures were determined by multiple logistic regression analysis.
Results: CBR showed a moderate negative correlation with dual-energy x-ray absorptiometry T values ($r = -0.642$, $p < 0.01$). Higher CBR (odds ratio [OR], -6.483; 95% confidence interval [CI], -8.234 to -4.732; $p < 0.01$) and lower body mass index (OR, 0.054; 95% CI, 0.023–0.086; $p < 0.01$) were independent risk factors for osteoporosis. Patients with multiple fractures had lower T values (mean ± standard deviation [SD]: -3.76 ± 0.73 vs. -2.83 ± 0.75, $p < 0.01$) and higher CBR (mean ± SD: 0.54 ± 0.07 vs. 0.46 ± 0.06, $p < 0.01$). CBR had an AUC of 0.819 in predicting multiple fractures with a threshold of 0.53. T values prediction had an AUC of 0.816 with a threshold of -3.45. CBR > 0.53 was an independent risk factor for multiple fractures (OR, 14.66; 95% CI, 4.97–43.22; $p < 0.01$).
Conclusion: CBR is negatively correlated with bone mineral density (BMD) and can be a novel opportunistic BMD assessment method. It is a simple and effective measurement index for predicting multiple fractures, with predictive performance not inferior to T values.

Keywords: Bone density, Osteoporotic fractures, Osteoporosis, Radiographs, Dual-energy x-ray absorptiometry

INTRODUCTION

Osteoporotic vertebral compression fractures (OVCFs) not only reduce patients' quality of life but are also associated with increased mortality.[1] Vertebral fracture is the most common type of osteoporotic fracture, accounting for up to 27%.[2] In fact, this proportion may be greatly underestimated, as a study reviewing spinal imaging data of hip fracture patients found that

41% of patients had concomitant vertebral fractures, with nearly half of them not reported by radiologists. This highlights significant gaps in the understanding and treatment of osteoporotic fractures. A meta-analysis involving 40 randomized controlled trials showed that on average, among 100 patients who had experienced vertebral fractures, 16.6% and 35.1% of patients experienced at least one vertebral refracture within 2 and 4 years, respectively, of the index fracture. Furthermore, the incidence rate increases with the number of previous vertebral fracture occurrences.[3] Therefore, early identification and antiosteoporosis intervention are crucial for preventing subsequent fractures.[4] A survey involving 349 orthopedic or neurosurgeons showed that only 19.6% of respondents regularly assessed bone density for patients, and the use of dual-energy x-ray absorptiometry (DEXA) was also low.[5] Computed tomography (CT)-based Hounsfield units (HUs) are often used as a substitute for DEXA in assessing bone density. Previous studies have indicated that HUs < 50 is a risk factor for secondary vertebral compression fractures.[6] However, advanced imaging modalities such as CT scan or CT myelography have become the standard in high-income countries but are still not widely available in low-income countries. The benefits of stereoscopic radiography over CT or magnetic resonance imaging are evident for low-income and middle-income countries, even though whether it truly improves clinical outcomes is still under investigation.[7] However, there is a lack of methods to assess bone density and subsequent vertebral fractures in patients with OVCF by radiographic examination.

Proximal femoral morphological parameters used in joint surgery, such as cortical bone ratio (CBR), have been shown to correlate with bone density measured by DEXA, effectively screening for osteoporotic candidates. Additionally, cortical bone parameters have been found to predict early periprosthetic femoral fractures after total hip arthroplasty.[8] Rapid cortical bone loss at the distal radius is associated with a higher fracture risk.[9]

Deformity and kyphosis caused by vertebral fractures are associated with deterioration in sagittal balance.[10] Full-spine x-rays are essential for identifying old fractures and observing sagittal balance.[11] The proximal end of the femur is usually visible on a full-spine x-ray. This study aims to (1) investigate the ability of CBR measured by full-spine x-rays to predict osteoporosis and multiple fractures, and (2) compare the predictive ability of x-ray-based and DEXA-based indices for predicting multiple fractures.

MATERIALS AND METHODS

1. Patient Cohort

A retrospective analysis was conducted on female patients with OVCF treated at the Third Hospital of Hebei Medical University from January 2018 to January 2022 after obtaining approval from the Institutional Review Board of the Third Hospital of Hebei Medical University (K2022-064-1). This study was retrospective, and written, signed informed consent was waived. Inclusion criteria: (1) age greater than 60 years; and (2) low-trauma osteoporotic fractures, such as falls or lifting heavy objects; and (3) available full-spine x-ray and DEXA. Exclusion criteria: (1) severe trauma, such as motor vehicle accidents or falls from height; (2) patients with conditions affecting bone metabolism, such as metastatic tumors; (3) patients with incomplete visualization of the proximal femur on full-spine x-rays. Since Mills et al.[4] found that vertebroplasty did not increase the incidence of subsequent vertebral fractures compared to conservative treatment, this study did not distinguish between patients with multiple fractures who had received vertebral augmentation or not. Patients were divided into primary and multiple fracture groups based on the number of fractures.

2. Radiographic and Bone Density Parameters

A reference line perpendicular to the longitudinal axis of the femoral shaft was drawn on the full-spine x-ray, passing through the lesser trochanter. The femoral shaft width and medullary canal width were measured 7 cm below this reference line. CBR was calculated as the ratio of medullary canal width to femoral shaft width (Fig. 1).

Before the start of the study, observers reviewed the original manuscripts to reference measurement methods.[12-14] Pilot measurements were conducted on 10 cases to standardize the measurement process. During pilot testing, the measurement process was inaccurate and straining on the eyes due to the smaller display of the medullary cavity and femoral shaft width (on-screen distance), as shown in the original x-ray images. Therefore, we initially used the “move, zoom” function in the PACS (picture archiving and communication systems) to enlarge the local area as much as possible. At this point, the medullary cavity and cortical bone boundaries became clearly visible, allowing for more accurate measurements.

CBR measurements were performed by a trained researcher (YW) who was blinded to T values. YW and MD repeated the measurements 2 weeks later in 20 randomly selected patients to assess intraobserver and interobserver reliability of measure-

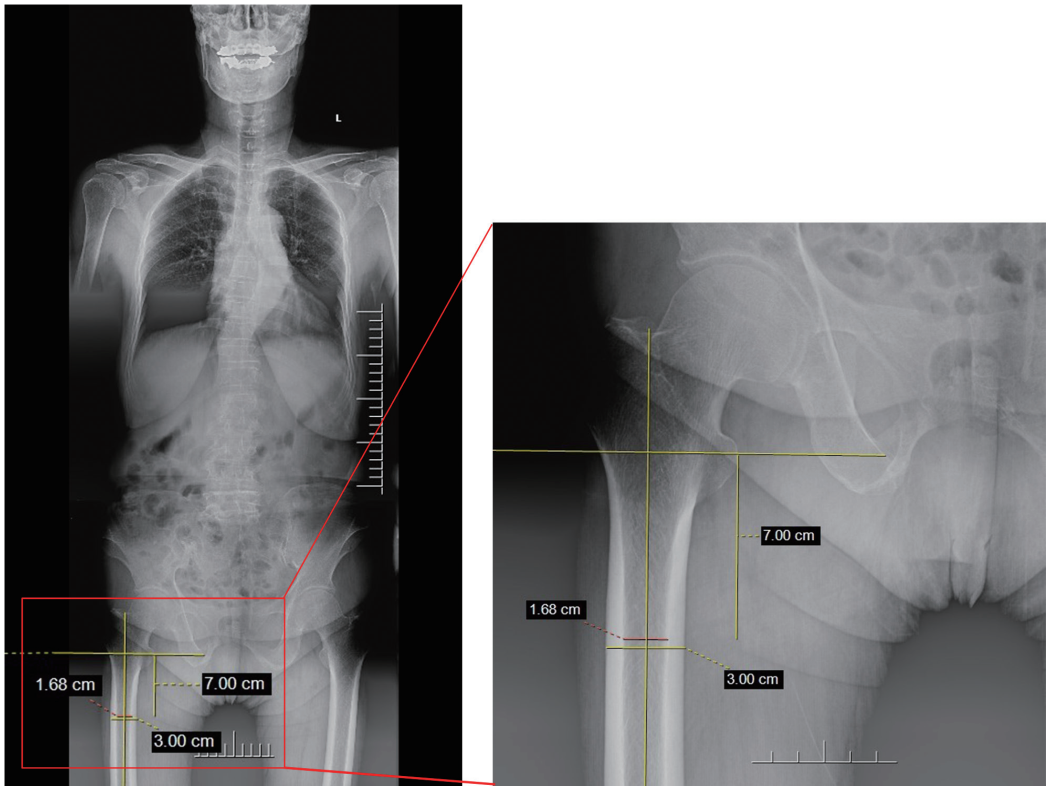

Fig. 1. Representative image measuring canal bone ratio (CBR) on full-spine x-ray: medulla width = 1.68 cm, bone width = 3 cm; CBR = 0.56 (1.68/3).

ments.

Following World Health Organization diagnostic criteria, bone density was categorized as normal (T ≥ -1.0), osteopenia (-1.0 > T > -2.5), and osteoporosis (T ≤ -2.5) based on the lowest T score among femoral neck, total hip, and lumbar spine.

3. Statistical Analysis

Statistical analysis and graphical representations were performed using IBM SPSS Statistics ver. 26.0 (IBM Co., Armonk, NY, USA) and GraphPad Prism 8 (GraphPad Software Inc., La Jolla, CA, USA). Continuous variables were presented as means (standard deviations [SD]). Student t-test was used to compare demographic information and radiographic parameters between groups. Intraclass correlation coefficients were used to assess intra- and interobserver reliability. Pearson correlation analysis and linear regression analysis were used to assess the correlation between CBR and T values. Multiple linear regression analysis was used to predict factors for DEXA T values. Receiver operating characteristic (ROC) analysis and the area under the curve (AUC) calculation were performed to evaluate diagnostic performance. The maximum Youden index was used to determine the optimal sensitivity and specificity threshold. Multiple logistic regression analysis was used to identify independent predictors of recurrent fractures.

RESULTS

1. Assessment of Bone Density Using CBR

A total of 121 Han Chinese female patients were finally confirmed, with a mean age of 69.67 ± 6.99 years. There were 98 individuals in the osteoporotic group, 23 individuals in the nonosteoporotic group. Intra- and interobserver reliability of CBR measures were excellent (≥ 0.8). Osteoporotic patients had higher CBR (mean ± SD: 0.509 ± 0.072 vs. 0.435 ± 0.052, $p < 0.01$). Correlation analysis and linear regression showed a moderate negative correlation between CBR and T values (r = -0.642, adjusted $R^2 = 0.407$, $p < 0.01$) (Fig. 2). Multiple linear regression analysis showed that higher CBR (OR, -6.483; 95% CI, -8.234 to -4.732, $p < 0.01$) and low body mass index (BMI) (OR, 0.054; 95% CI, 0.023 to 0.086, $p < 0.01$) were independent risk factors for osteoporosis (Table 1). ROC analysis showed that the AUC for CBR predicting osteoporosis was 0.80 ($p < 0.01$), with a threshold (sensitivity, specificity) of 0.464 (73.5%, 78.3%) (Fig. 3).

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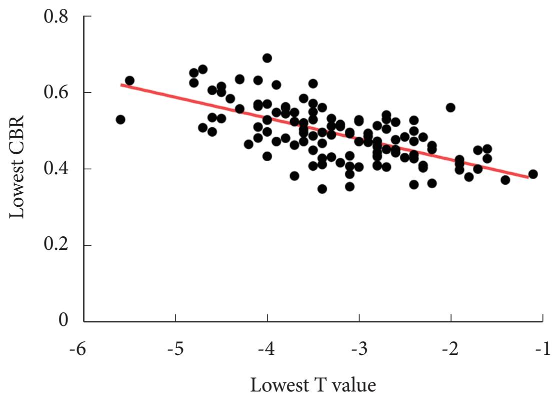

Fig. 2. The correlation between canal bone ratio (CBR) and dual-energy x-ray absorptiometry T values.

Table 1. Multiple linear regression analysis of predictors for bone density T values

Variable	β	95% CI	p-value
Age	-0.003	-0.021 to 0.015	0.73
Body mass index	0.054	0.023–0.086	< 0.01
Lower CBR	-6.483	-8.234 to -4.732	< 0.01

CI, confidence interval; CBR, canal bone ratio.

2. Assessment of Recurrent Fractures Using CBR

Among the identified patients, there are 66 with primary fractures and 55 with multiple fractures. Compared to patients with primary fractures, those with multiple fractures were older, had lower BMI, lower T values, and the lowest T values at various sites (mean ± SD: -3.76 ± 0.73 vs. -2.83 ± 0.75, $p < 0.01$). Bilateral and lower CBR were higher (mean ± SD: 0.54 ± 0.07 vs. 0.46 ± 0.06, $p < 0.01$) in multiple fracture patients (Table 2). ROC analysis showed that the ability of CBR to predict recurrent fractures was AUC = 0.819 ($p < 0.01$), with a threshold (sensitivity, specificity) of 0.53 (60.0%, 92.4%). The predictive ability of DEXA was AUC = 0.816 ($p < 0.01$), with a threshold (sensitivity, specificity) of -3.45 (74.5%, 84.8%) (Table 3, Fig. 4). Multiple logistic regression analysis showed that CBR > 0.53 was an independent risk factor for multiple fractures (OR, 14.66; 95% CI, 4.97–43.22; $p < 0.01$) adjusting for age and BMI (Table 4).

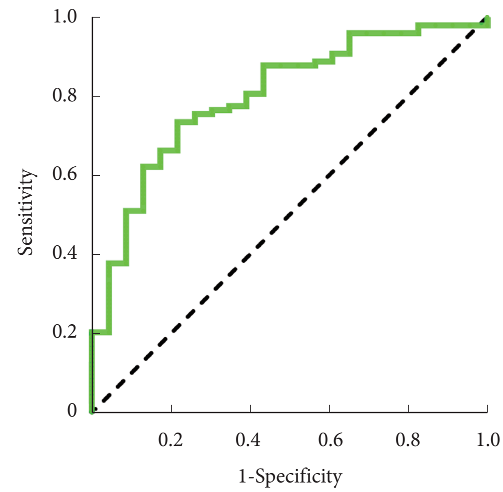

Fig. 3. Receiver operating characteristic curve for canal bone ratio predicting osteoporosis.

Table 2. Comparison of data between patients with primary and multiple fractures

Variable	Primary fracture (n = 66)	Multiple fractures (n = 55)	p-value
Age (yr)	67.92 ± 5.53	71.76 ± 7.96	< 0.01*
BMI (kg/m^2)	26.12 ± 3.84	24.47 ± 3.98	0.022*
L femoral neck	-2.37 ± 0.77	-3.32 ± 0.71	< 0.01*
R femoral neck	-2.42 ± 0.81	-3.16 ± 0.84	< 0.01*
L total hip	-1.71 ± 0.75	-2.82 ± 0.86	< 0.01*
R total hip	-1.72 ± 0.80	-2.74 ± 0.82	< 0.01*
Lumbar	-2.23 ± 1.09	-3.06 ± 1.24	< 0.01*
Lowest T value	-2.83 ± 0.75	-3.76 ± 0.73	< 0.01*
L CBR	0.47 ± 0.06	0.54 ± 0.07	< 0.01*
R CBR	0.47 ± 0.06	0.55 ± 0.08	< 0.01*
Lower CBR	0.46 ± 0.06	0.54 ± 0.07	< 0.01*

Values are presented as mean ± standard deviation.
BMI, body mass index; L, left; R, right; CBR, canal bone ratio.
*$p < 0.05$, statistically significant differences.

DISCUSSION

Barnett and Nordin[15] initially utilized the cortical bone thickness defined as the difference between the width of the femoral shaft and the medullary cavity width measured on proximal femur x-rays to assess bone density. Subsequently, the correlation between cortical bone thickness at multiple anatomical sites and bone density measured by DEXA was verified. The derived CBR is defined as the ratio of the medullary cavity width to the width of the femoral shaft. The ratio somewhat eliminates differences due to individual body size compared to the difference. A higher ratio indicates thinner cortical bone and lower bone density,[13] consistently with our findings in OVCF patients, osteoporotic patients had higher CBR. Correlation and linear regression showed a moderate negative correlation between CBR and the lowest T values. The International Society for Clinical Densitometry recommends that patients planning to undergo total hip arthroplasty should undergo further bone density evaluation if cortical

Table 3. Performance of CBR and DEXA T values in predicting recurrent fractures

Variable	AUC	95% CI	Threshold	Sensitivity	Specificity	p-value
CBR	0.819	0.744–0.895	0.53	60.0	92.4	< 0.01*
DEXA	0.816	0.739–0.893	-3.45	74.5	84.8	< 0.01*

CBR, canal bone ratio; DEXA, dual-energy x-ray absorptiometry; AUC, area under the curve; CI, confidence interval.
*p < 0.05, statistically significant differences.

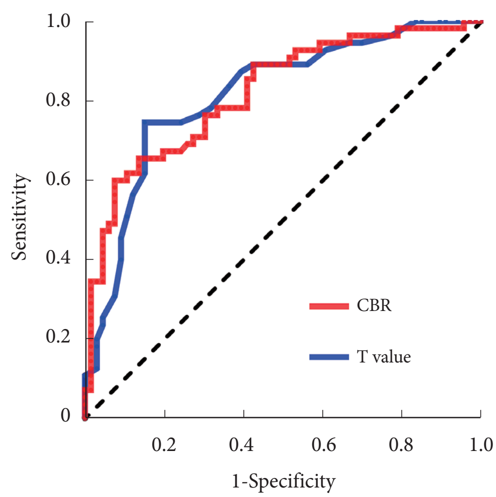

Fig. 4. Receiver operating characteristic curves for distinguishing between primary and recurrent fractures using canal bone ratio (CBR) and dual-energy x-ray absorptiometry T values.

Table 4. Logistic regression analysis of predictors for recurrent fractures

Variable	OR	95% CI	p-value
Age	1.05	0.98–1.13	0.14
Body mass index	0.95	0.85–1.07	0.38
CBR > 0.53	14.66	4.97–43.22	< 0.01*

OR, odds ratio; CI, confidence interval; CBR, canal bone ratio.
*p < 0.05, statistically significant differences.

thickness index (cortical bone thickness/femoral shaft width) < 0.4.[16] Cortical bone parameters have also been used to predict fragility hip fractures and periprosthetic fractures after total hip arthroplasty.[17,18]

Plais et al.,[10] based on follow-up imaging data of thoracolumbar disease patients, found that new fractures led to an approximately 2.78-cm deterioration in sagittal vertical axis (SVA). And a history of previous fractures was a risk factor for recurrent fractures. Full-spine x-rays are necessary for screening old fractures and observing sagittal balance. We conducted this study with the question of whether CBR measured by full-spine x-rays can replace DEXA as an opportunistic scanning method to predict osteoporosis and recurrent fractures in OVCF patients without additional radiation and costs.

Our results indicated that CBR can effectively distinguish osteoporotic patients, with higher CBR and lower BMI being predictive factors for osteoporosis. Patients with multiple fractures were older and had lower BMI. Park et al.[19] confirmed that low body weight is a risk factor for fractures. Additionally, patients with multiple fractures had lower DEXA T values at various anatomical sites, higher CBR and relatively thinner cortical bones. Low bone density remains a major factor for recurrent fractures, and timely antiosteoporosis treatment, especially drug injections, is still an effective measure to avoid recurrent fractures.[4,20] ROC analysis showed that the predictive performance of CBR was not inferior to T values. As confirmed by D'Amore et al.[21] that a cortical thickness index ≤ 0.50 is a reliable independent predictor for the risk of fragility fractures in Gaucher disease patients, with predictive performance superior to lumbar spine, femoral neck, and forearm T scores.

For patients with osteoporosis, C7–S1 SVA greater than 3.81 cm is significantly associated with the risk of future vertebral compression fractures,[22] and future research hopes to combine CBR with sagittal parameters and demographic information to develop precise models for predicting recurrent fractures. With the advancement of artificial intelligence technology, this method is promising. We believe that CBR can serve as a novel opportunistic method for assessing bone density. In situations where DEXA results are unavailable, radiographic parameters such as CBR can replace DEXA to predict recurrent fractures, and when DEXA is available, CBR can be used as a supplement to predict the risk of recurrent fractures more comprehensively in patients.

As an exploratory study, this study is observational with a relatively small sample size, and our conclusions need to be validated by large-scale longitudinal studies. Previous research in joint surgery has shown sex differences in the accuracy of CBR predictions for bone density, with better performance in females than males. Because osteoporosis and compression fractures have a higher prevalence in females, this study only included female patients. Not all full-spine x-rays show the proximal femur, which may partially limit the application of this indicator,

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but with the application of EOS full-body imaging,[23] this issue can be resolved. CBR measurements may be influenced by x-ray projection conditions such as projection distance, angle, and patient positioning. Cases of unclear recognition of the inner cortical boundary may occur due to overlap, rotation, etc. This study did not differentiate between x-ray imaging devices. CBR serves as a morphological indicator of the femur, and its ability to reflect local bone density at the hip joint appears to be superior to that of the lumbar spine.

CONCLUSION

CBR is a novel opportunistic assessment method for bone density in patients with OVCF. CBR can distinguish between primary and multiple fractures as effectively as DEXA. CBR > 0.53 can independently predict recurrent fractures.

NOTES

Conflict of Interest: The authors have nothing to disclose.

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REFERENCES

1. Choi HG, Lee JK, Sim S, et al. Mortality and cause of death in patients with vertebral fractures: a longitudinal follow-up study using a national sample cohort. Spine (Phila Pa 1976) 2020;45:E280-7.
2. Burge R, Dawson-Hughes B, Solomon DH, et al. Incidence and economic burden of osteoporosis-related fractures in the United States, 2005-2025. J Bone Miner Res 2007;22:465-75.
3. Porcu G, Biffi A, Ronco R, et al. Refracture following vertebral fragility fracture when bone fragility is not recognized: summarizing findings from comparator arms of randomized clinical trials. J Endocrinol Invest 2024;47:795-818.
4. Mills ES, Hah RJ, Fresquez Z, et al. Secondary fracture rate after vertebral osteoporotic compression fracture is decreased by anti-osteoporotic medication but not increased by cement augmentation. J Bone Joint Surg Am 2022;104:2178-85.
5. Pantoja S, Molina M. Surgeon management of osteoporosis in instrumented spine surgery: AOSpine Latin America Survey. Global Spine J 2019;9:169-72.
6. Ji C, Rong Y, Wang J, et al. Risk factors for refracture following primary osteoporotic vertebral compression fractures. Pain Physician 2021;24:E335-40.
7. Diebo BG, Shah NV, Boachie-Adjei O, et al. Adult spinal deformity. Lancet 2019;394:160-72.
8. Jang SJ, Alpaugh K, Kunze KN, et al. Deep-learning automation of preoperative radiographic parameters associated with early periprosthetic femur fracture after total hip arthroplasty. J Arthroplasty 2024;39:1191-8.e2.
9. Gunsing E, Wagner PP, Whittier DE, et al. Rapid cortical bone loss at the distal radius is associated with higher risk of fracture in older men - the STRAMBO study. J Bone Miner Res 2023;38:841-50.
10. Plais N, Bustos JG, Mahillo-Fernandez I, et al. Osteoporotic vertebral fractures localized in the lumbar area significantly impact sagittal alignment. Osteoporos Int 2024;35:277-84.
11. Kato S, Demura S, Shinmura K, et al. Associations between abdominal trunk muscle weakness and future osteoporotic vertebral fracture in middle-aged and older adult women: a three-year prospective longitudinal cohort study. J Clin Med 2022;11:4868.
12. Yeung Y, Chiu KY, Yau WP, et al. Assessment of the proximal femoral morphology using plain radiograph-can it predict the bone quality? J Arthroplasty 2006;21:508-13.
13. Liu Y, Ma WJ, Huang K, et al. Radiographic indexes in AP

hip radiographs prior to total hip arthroplasty reveal candidates with low BMD. Osteoporos Int 2022;33:871-9.
14. Rohe S, Bohle S, Matziolis G, et al. Plain radiographic indices are reliable indicators for quantitative bone mineral density in male and female patients before total hip arthroplasty. Sci Rep 2023;13:19886.
15. Barnett E, Nordin BE. The radiological diagnosis of osteoporosis: a new approach. Clin Radiol 1960;11:166-74.
16. Anderson PA, Morgan SL, Krueger D, et al. Use of bone health evaluation in orthopedic surgery: 2019 ISCD Official Position. J Clin Densitom 2019;22:517-43.
17. Pothong W, Adulkasem N. Comparative evaluation of radiographic morphologic parameters for predicting subsequent contralateral fragility hip fracture. Int Orthop 2023;47:1837-43.
18. Alpaugh K, Chiu YF, Zlotnicki JP, et al. Femoral component undersizing and alignment are risk factors for early periprosthetic femur fracture. J Arthroplasty 2022;37(7S):S604-10.
19. Park J, Han S, Jang HD, et al. Underweight as a risk factor for vertebral fractures in the South Korean population. Spine J 2023;23:877-84.
20. Hwang SH, Cho PG, Kim KT, et al. What are the risk factors for a second osteoporotic vertebral compression fracture? Spine J 2023;23:1586-92.
21. D'Amore S, Sano H, Chappell DDG, et al. Radiographic cortical thickness index predicts fragility fracture in Gaucher disease. Radiology 2023;307:e212779.
22. Lin T, Lu J, Zhang Y, et al. Does spinal sagittal imbalance lead to future vertebral compression fractures in osteoporosis patients? Spine J 2021;21:1362-75.
23. Hey HWD, Chan CX, Wong YM, et al. The effectiveness of full-body eos compared with conventional chest x-ray in preoperative evaluation of the chest for patients undergoing spine operations: a preliminary study. Spine (Phila Pa 1976) 2018;43:1502-11.

 https://doi.org/10.14245/ns.2448310.155