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Original Article

Bone Mineral Density and Clinical Outcome after Ankle Fracture

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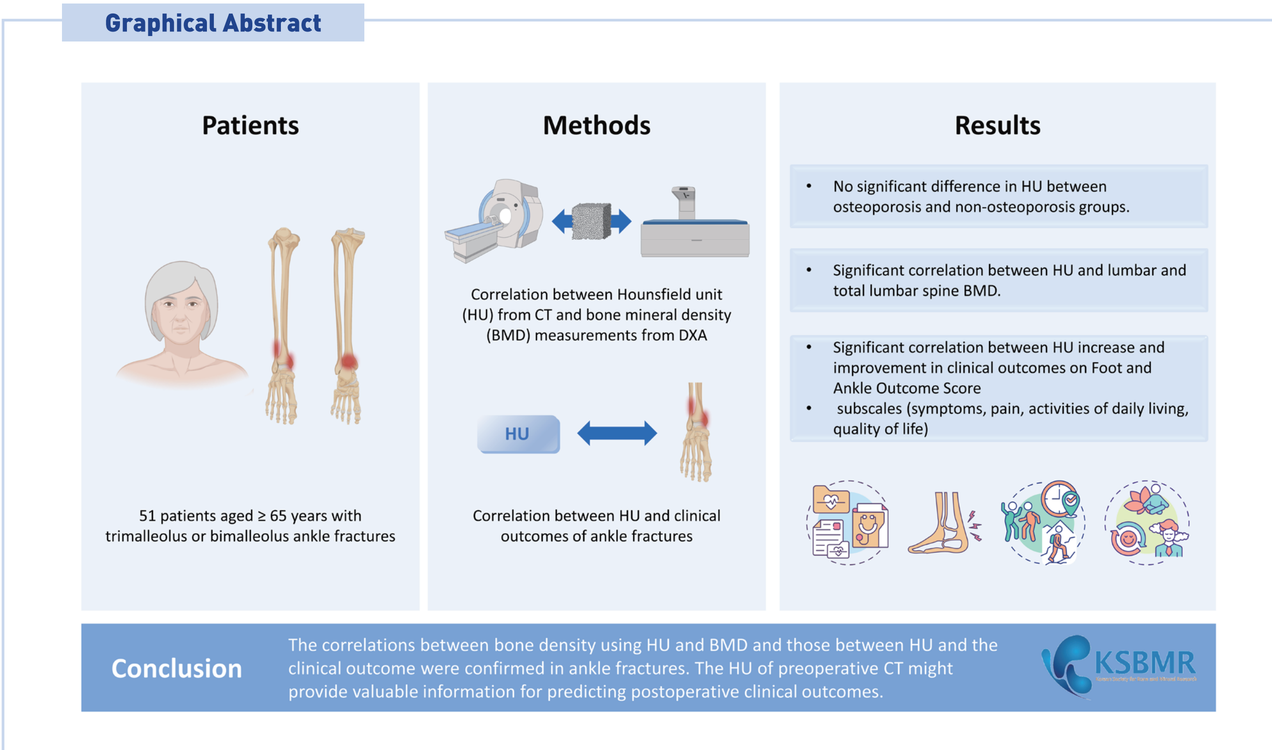
Background: No gold standard exists for bone mineral density (BMD) measurement of the ankle. This study aimed to determine the correlation between bone density using Hounsfield units (HU) based on computed tomography (CT) and BMD using dual energy X-ray absorptiometry (DXA) as well as to evaluate the correlation between HU and clinical outcome of ankle fracture. **Methods:** Fifty-one patients aged ≥65 years who underwent surgical treatment for trimalleolus or bimalleolus ankle fractures were included. The HU were measured at the distal tibia metaphyseal region approximately 1 cm proximal to the plafond on the axial images of preoperative CT. BMD was measured using DXA within one year before the injury. The clinical outcome was evaluated according to the Foot and Ankle Outcome Score (FAOS). **Results:** Although the HU of an osteoporosis group was lower than that of a non-osteoporosis group, we observed no significant difference between the two groups. The mean HU significantly correlated with the lumbar and total lumbar spine BMD using DXA. Increased HU significantly correlated with improved clinical outcomes in three of five FAOS subscales: symptoms, pain, activity of daily living (ADL), and quality of life (QOL). In a linear regression analysis adjusted for age and body mass index, increased HU significantly correlated with improved clinical outcomes in three of five FAOS subscales: symptoms, pain, ADL, and QOL. **Conclusions:** The correlations between bone density using HU and BMD and those between HU and the clinical outcome were confirmed in ankle fractures. The HU of preoperative CT might provide valuable information for predicting postoperative clinical outcomes.

Key Words: Ankle fractures · Bone density · Osteoporosis

INTRODUCTION

The frequency of osteoporotic fractures increases as a population ages. As a result, the socioeconomic cost of preventing and treating osteoporotic fractures are continuously increasing.[1,2] Proximal femur, vertebral body compression, and distal radius fractures are the most representative osteoporotic fractures, and the correlation between these fractures and bone mineral density (BMD) is well-known in many studies.[2-4] In contrast, although ankle fracture is common in patients aged >50 years, there is relatively little evidence on whether ankle fracture can be considered an osteoporotic fracture.[5,6] Ankle fractures are more closely related to trauma and body mass index (BMI) rather than BMD.[5]

However, the frequency of ankle fractures caused by low energy injury is increasing in postmenopausal women diagnosed with osteoporosis.[7,8] Among



older patients with ankle fractures, only 58% reported satisfactory results from surgery.[9] Moreover, there is high possibility of poor clinical outcome, such as nonunion, malunion, infection, and wound problem.[9,10] Decreased BMD and bone quality change were reported in older patients with ankle fractures.[11,12] Accurate analysis of bone density and appropriate treatment may be necessary in older patients with ankle fractures.

Currently, dual energy X-ray absorptiometry (DXA) is considered a gold standard for BMD measurement.[13] However, DXA mainly measures central BMD in the proximal femur and lumbar spine, not in distal regions, such as the foot and ankle.[14] Several studies have not found an association between ankle fractures and central BMD measurement using DXA in the proximal femur and lumbar spine.[15] However, other studies reported decreased BMD and change in bone quality in elderly patients with ankle fractures.[11] In a recent meta-analysis, the BMD of older patients with ankle fractures was related to low BMD at the proximal femur, and this association appeared to be weaker than that for osteoporosis-related fractures, such as the hip, spine, and distal radius.[16] Currently, there is no gold standard for measuring ankle BMD.

Computed tomography (CT) is frequently used to evaluate fractures, and to establish the treatment plan before operation in ankle fracture. Patterson et al. [17] reported that there was a significant association between the cortical thickness measured using CT and BMD measured using DXA. Schreiber et al. [18] used the Hounsfield units (HU; a standard linear attenuation coefficient of a tissue) to evaluate bone density as a surrogate maker for BMD. Additionally, several studies reported that HU measurement using CT was correlated with BMD measurement using DXA in several anatomical regions.[19,20]

This study aimed to determine the correlation between bone density measurement using HU based on preoperative CT images and BMD measurement using DXA and to evaluate the correlation between HU and clinical outcomes in ankle fracture.

METHODS

This study was approved by the appropriate Institutional Review Board (Ethics Committee). All methods were performed in accordance with the relevant guidelines and regulations (Declaration of Helsinki). The requirement for informed consent was waived by the Institutional Review Board because of the retrospective nature of the study.

1. Patients

We retrospectively reviewed patients who underwent surgical treatment for bimalleolus or trimalleolus ankle fractures between January 2016 and December 2021. Inclusion criteria were as follows: (1) age ≥65 years old; (2) low energy trauma; (3) preoperative CT image; and (4) BMD measurement using DXA within one year before injury. Patients who had high energy trauma, polytrauma, or open fracture (N=3), neurologic impairment (N=1), or follow-up periods of <1 year (N=5) were excluded. Finally, 51 patients were enrolled in the study (Fig. 1). Demographic characteristics, such as, age at operation, sex, BMI, smoking, diabetes, mechanism of injury, and follow-up periods were evaluated. The bimalleolus or trimalleolus ankle fractures were classified according to the Lauge-Hansen classification or Denis-Weber classification.

2. Hounsfield units (HU)

The patients were placed in the supine position with fully extended knee joints and neutrally positioned ankle joints for preoperative CT using a 64-layer CT scanner (Siemens, Erlangen, Germany). Scanning parameters were 1.0 mm layer thickness and 0.6 mm reconstruction interval. Image files were obtained using the INFINIT program (INFINITT, Seoul, Korea) from a high-resolution medial picture archiving communication system (PACS; IMPAX; Agfa Healthcare, Mortsel, Belgium). The HU was measured at the distal tibia metaphyseal region approximately 1 cm proximal to the plafond on axial images. If the epiphyseal plate was located at the level of 1 cm above the plafond or the fracture fragment was so large that it was impossible to measure the HU at the level of 1 cm above the plafond, the HU was measured above the level of 1 cm above the plafond. By raising one or two cut on the CT axial image, the measurement of HU was possible without the influence of the fracture fragment and epiphyseal plate. The largest possible elliptical region of the distal tibia metaphysis was drawn on the PACS system, except the fracture area and cortical margin to prevent volume averaging (Fig. 2). Three axial images were obtained from the lowest CT axial image without the influence of the fracture fragment and epiphyseal plate by raising one or two cut on the CT axial image. The HU from three axial images were averaged to generate a mean HU value. Inter- and intra-observer reliabilities were assessed using the intraclass correlation coefficient (ICC) of the radiographic measurements, and an agreement of 0.75 was considered excellent.[21]

3. DXA

DXA scans were conducted at the proximal femur and lumbar spine using the Horizon-W DXA scanner (Hologic Inc., Bedford, MA, USA). Bone mass density (g/cm^2), T score, and Z score were obtained using DXA in all the patients. To evaluate the correlations between DXA and HU, the patients were required to have a complete DXA scan within one year before ankle CT. According to the T score, patients

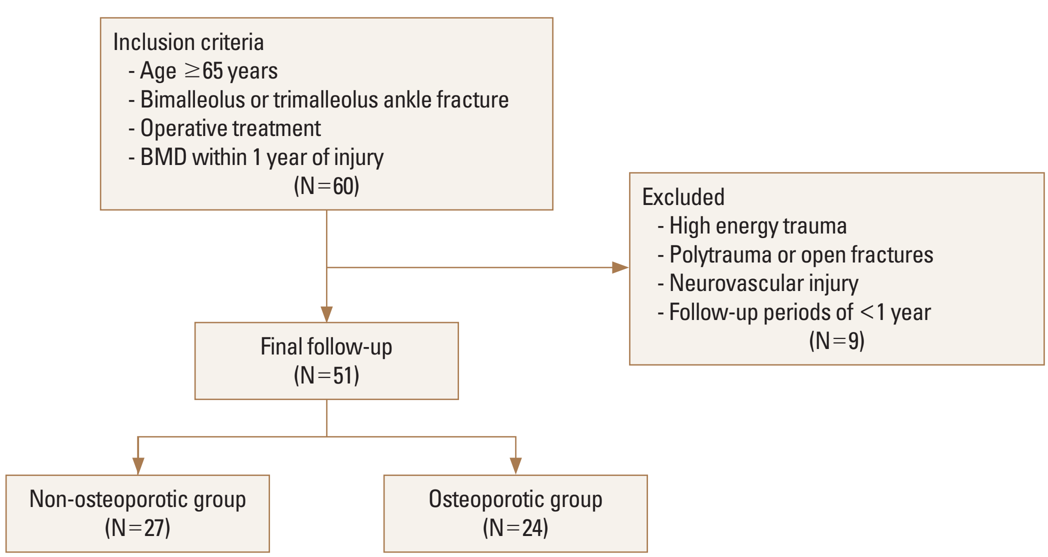


Fig. 1. Flowchart of patient inclusion. BMD, bone mineral density.

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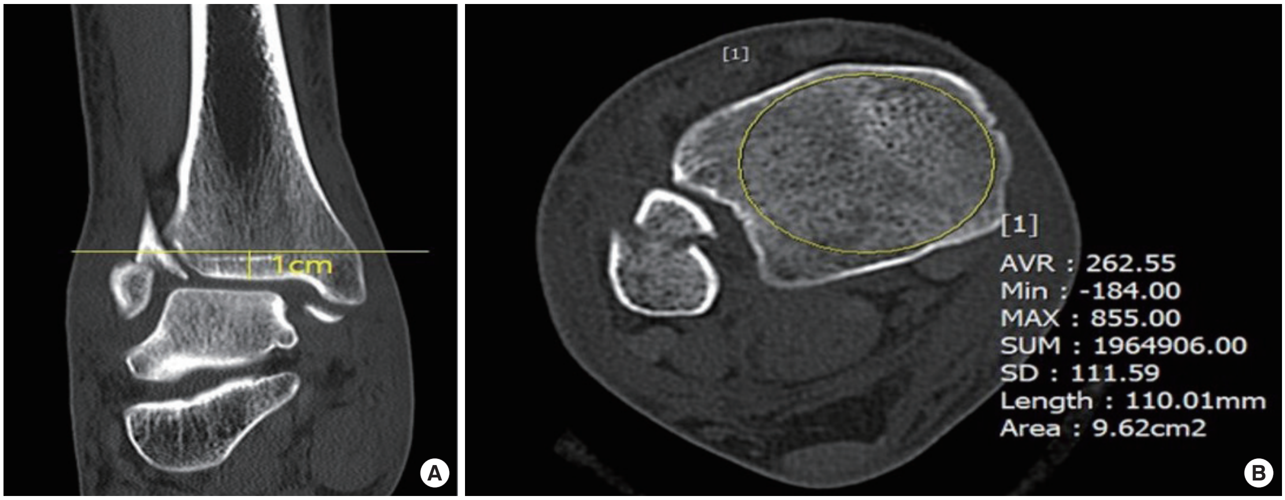

Fig. 2. (A) Method for determining the Hounsfield units at the distal tibia metaphyseal region approximately 1 cm proximal to the plafond on computed tomography axial images. (B) The Hounsfield unit was calculated elliptical region of the distal tibia. AVR, average; Min, minimum; MAX, maximum; SUM, summation; SD, standard deviation.

with T score -2.5 or less were classified into an osteoporosis group, and other patients were classified into a non-osteoporosis group.

4. Surgical technique

All of the surgeries were performed under spinal anesthesia. All the fractures were treated using an injury-specific method according to the injury pattern. Associated lateral, medial, and/or posterior malleolus was treated with open reduction and internal fixation, according to standard principles, which included internal fixation of the fibular and posterior malleolus fractures using the posterolateral approach and a separate medial approach for the medial malleolus fracture. Postoperatively, posterior short-leg splints were applied for the first two weeks. Thereafter, the splint was removed, and controlled ankle motion boots were applied to encourage an early range of motion for four more weeks. Weight-bearing was not allowed during this period. At six weeks, when the fracture appeared stable and any associated fractures were healed, the boots were removed and progressive rehabilitation (progressive weight bearing and ankle range of motion exercise) was allowed. The patients had outpatient visits for the first two weeks, four weeks, three months, six months, and then every six months postoperatively.

5. Clinical outcome

The clinical outcome was evaluated based on the Foot and Ankle Outcome Score (FAOS). The FAOS is a subjective foot and ankle clinical outcome score for patient-relevant outcomes after a foot and ankle injury.[22] The FAOS consists of 42 items grouped into five subscales: pain (9 items), other symptoms (7 items), activities of daily living (ADL; 17 items), sport and recreational function (sport/recreation, 5 items), and foot and ankle related quality of life (QOL; 4 items). Each question of the item was scored on a five-point Likert scale between 0–4 (non, mild, moderate, severe, and extreme problems). Scores were calculated by summing the total items score of the sub-scale and dividing it by the maximum subscale score. The final score was transformed into a scale of 0–100 (0=extreme problem, 100=no problem). The FAOS was evaluated at one year postoperatively.

6. Statistics

Inter- and intra-observer reliabilities of HU measurements were assessed using ICC of the radiographic measurements, and an agreement of 0.75 was considered excellent.[21] Values are presented as mean and standard deviation for continuous data and number or percentage for categorical data. The relationship between HU and BMD measurement using DXA were evaluated using the Pearson's correlation coefficient. Correlations between HU and the FAOS were determined using the Pearson's correlation coefficient, followed by a linear regression model, which was adjusted for age and BMI, as both are potential

Table 1. Demographic characteristics

Variables	Total patients	Non-osteoporotic group	Osteoporotic group	*P*-value
No. of patients	51	27	24	
Age (yr)	70.2±7.4	68.8±6.2	71.8±8.6	0.061
Gender				
Female	51 (100.0)	27 (100.0)	24 (100.0)	
BMI (kg/m^2)	25.5±4.3	25.9±4.2	24.3±5.0	0.139
Smoke	3 (5.8)	2 (7.4)	1 (4.2)	0.485
Pattern of fracture				0.145
Bimalleolus	27 (52.9)	14 (51.9)	13 (54.2)	
Trimalleolus	24 (47.1)	13 (48.1)	11 (45.8)	
Denis-Weber				0.733
A type	13 (25.5)	7 (25.9)	6 (25.0)	
B type	34 (66.7)	18 (66.7)	16 (66.7)	
C type	4 (7.8)	2 (7.4)	2 (8.3)	
Lauge-Hansen				0.563
SER	29 (56.9)	15 (55.6)	14 (58.3)	
PER	19 (37.3)	10 (37.0)	9 (37.5)	
SA	3 (5.9)	2 (7.4)	1 (4.2)	

The data is presented as mean±standard deviation or N (%).
BMI, body mass index; SER, supination external rotation; PER, pronation external rotation; SA, supination abduction.

confounder. To compare the osteoporosis and non-osteoporosis groups, a nonparametric Mann–Whitney test and Fisher's exact test were used for continuous and categorical data, respectively. All analyses were performed using SPSS version 24.0 (IBM Corp., Armonk, NY, USA), and *P* value of less than 0.05 was considered significant.

RESULTS

Among the 51 patients that met the inclusion criteria, 27 and 24 were included in the non-osteoporosis and osteoporosis groups, respectively, according to the T score. There was no significant difference in baseline characteristics, such as age at operation, BMI, smoking, pattern of fracture, and fracture classifications in both groups (Table 1).

Mean HU value of all the patients was 155.6±41.0. Inter-observer reliability was excellent with a value of 0.856, and the intra-observer reliability was also excellent with a value of 0.879. Although the HU value of the osteoporosis group was lower than that of the non-osteoporosis group, there was no significant difference (Table 2). The mean HU values were significantly correlated with lumbar and total lumbar spine BMD measurement using DXA (Table 3).

Clinical outcome evaluated based on the FAOS was not significantly different between both groups (Table 4). Increased HU was significantly correlated with improved clinical outcome in three of five FAOS subscales: symptoms (Pearson r=0.576, *P*=0.003), pain (Pearson r=0.733, *P*<0.001), ADL (Pearson r=0.608, *P*=0.002), and QOL (Pearson r=0.692, *P*<0.001) (Table 5). In a linear regression analysis adjusted

Table 2. Hounsfield unit value and bone mineral density measured with dual energy X-ray absorptiometry

Variables	Total patients	Non-osteoporotic group	Osteoporotic group	*P*-value
HU	155.6±41.0	164.8±41.1	144.5±39.4	0.200
BMD (g/cm^2)				
Lumbar	-2.2±0.7	-1.7±0.6	-2.7±0.5	0.001
Femur	-1.9±0.9	-1.4±0.7	-2.4±0.9	0.002
Total	-1.4±0.9	-1.0±0.9	-1.9±0.8	0.003

The data is presented as mean±standard deviation.
HU, Hounsfield unit; BMD, bone mineral density.

Table 3. Correlation between Hounsfield unit value and bone mineral density measured with dual energy X-ray absorptiometry

	Lumbar BMD		Femur BMD		Total BMD	
	Pearson r	*P*-value	Pearson r	*P*-value	Pearson r	*P*-value
HU	0.419	0.041	0.393	0.057	0.593	0.002

HU, Hounsfield unit; BMD, bone mineral density.

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Table 4. Clinical outcome

FAOS	Non-osteoporotic group	Osteoporotic group	*P*-value
Symptom	89.7±10.7	84.7±12.5	0.230
Pain	89.3±10.2	86.7±9.7	0.597
ADL	90.1±7.1	82.1±22.7	0.186
Sports	76.2±14.4	73.2±11.2	0.493
QOL	87.4±17.0	83.1±21.5	0.953

The data is presented as mean±standard deviation.
FAOS, Foot and Ankle Outcome Score; ADL, activity of daily living; QOL, quality of life.

Table 5. Correlation between Hounsfield unit and clinical outcome

FAOS	Correlation analysis		Linear regression	
	Pearson r	*P*-value	Beta	*P*-value
Symptoms	0.576	0.003	0.602	0.008
Pain	0.733	<0.001	0.777	<0.001
ADL	0.608	0.002	0.629	0.007
Sports	0.328	0.118	0.322	0.301
QOL	0.692	<0.001	0.704	0.001

FAOS, Foot and Ankle Outcome Score; ADL, activity of daily living; QOL, quality of life.

for age and BMI, increased HU was significantly correlated with improved clinical out-comes in three of five of the FAOS subscales: symptoms (Pearson r=0.602, P=0.008), pain (Pearson r=0.777, P<0.001), ADL (Pearson r=0.629, P=0.007), and QOL (Pearson r=0.704, P=0.001) (Table 5).

DISCUSSION

The bone density and quality may influence the treatment and clinical outcome after hip, spine, or distal radius fracture. However, there are few studies on the effect of bone density after ankle fracture. Therefore, this study is meaningful in that it is the study to confirm the correlation of HU values of preoperative CT and BMD measurement using DXA in ankle fractures. The validation of HU values of preoperative CT was confirmed with the high inter- and intra-observer reliabilities. Moreover, the correlation of HU values and clinical outcome may have significant implications in the treatment of ankle fractures.

As the incidence of osteoporosis increases in elderly patients, the effect of bone quality on incidence and prevention of fracture becomes more important.[23,24] Moreover, the influence of bone quality on treatment and results is increasingly important.[2] DXA is the gold standard for BMD in the proximal femur and lumbar spine, not in distal regions, such as the foot and ankle.[14] Recently, decreased BMD and bone quality change were reported in elderly patients with ankle fractures.[11,12] However, there is no gold standard for the measurement of ankle BMD. Quantitative CT (QCT) can be used as an alternative method to measure the BMD of specific regions.[25] However, there are limitation to clinical use because QCT requires specific software, calibrating phantoms, and personnel training.[18] Accurate analysis of bone density and appropriate treatment may be necessary in ankle fractures.

Several studies have reported a strong positive correlation between HU and BMD measurement with DXA, as well as good to excellent reliability.[18,26-28] Schreiber et al. [18] reported significant correlation between HU and T-score in the lumbar spine and suggested that HU could be an alternative method for determining regional bone density. Pompe et al. [26] showed good to excellent inter- and intra-observer reliabilities on vertebral HU on CT. Moreover, the HU values in areas where DXA cannot be applied, such as the foot and ankle, significantly correlated with central BMD measurement using DXA.[27,28] Warner et al. [28] reported that the HU measured from 1 cm above the plafond were significantly correlated with central BMD measurement using DXA. In this study, the correlation of HU values for preoperative CT and BMD measurement using DXA was confirmed in ankle fractures. Moreover, the validation of HU values for preoperative CT was confirmed with the high inter- and intra-observer reliabilities. We compared the HU value between osteoporosis and non-osteoporosis patients. Although the HU value for osteoporosis patients was lower than that of non-osteoporosis patients, there was no significant difference. Therefore, a large sample size study should be performed to establish the diagnostic criteria for osteoporosis using HU base on preoperative CT image.

It is well known that BMD measurement using DXA is associated with implant fixation strength and surgical outcome. Recently, several studies reported that HU values based on CT may influence the clinical and radiologic outcome in orthopedic surgery. Meredith et al. [29] demonstrated that decreased HU value was associated with increased risk for adjacent segmental fractures during spinal fusion. Schreiber et al. [30] reported the correlation between increased HU value and successful spinal fusion. Moreover, decreased preoperative HU value correlated with inferior clinical outcomes in tibial plateau and ankle fractures.[28,31] Lee et al. [27] confirmed that the decreased preoperative HU values were associated with inferior clinical and radiologic outcomes in calcaneal fracture. In this study, the correlation between HU values of preoperative CT and clinical outcome was confirmed in ankle fractures. The HU values of preoperative CT may provide valuable information for predicting postoperative clinical outcomes.

This study has several inherent limitations. First, because this study was a retrospective study, we included consecutive patients treated by a single senior surgeon with the same surgical and rehabilitation methods. Second, the relatively small sample size limited the study's validity for clinical practice. Third, all of the patients were female. Thus, further multicenter prospective studies may be required. Moreover, the clinical outcomes were evaluated in the short-term follow-up periods. To validate the association between clinical outcome and HU value, long term follow-up periods may be necessary. Finally, confounding variables, such as age and BMI, were controlled using a linear regression analysis. Unaccounted confounding variables may remain.

DECLARATIONS

Funding

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Ethics approval and consent to participate

This retrospective study was approved by the institutional review board of our hospital (IRB). All methods were performed in accordance with the relevant guidelines and regulations (Declaration of Helsinki).

Conflict of interest

No potential conflict of interest relevant to this article was reported.

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