Retrospective Review

Evaluation of the Use of CT Attenuation for the Prediction of Subsequent Vertebral Fracture in Patients with Osteoporosis

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Background: Subsequent vertebral fracture (SVF) is one of the most common complications of percutaneous vertebral augmentation (PVA), which leads to lower back pain in patients. Low bone mineral density (BMD) is an independent risk factor for SVF. BMD measured using computed tomography (CT) trabecular attenuation correlates closely with BMD.

Objectives: This study aims to analyze the risk factors of SVF after PVA and to estimate the predictive role of CT trabecular attenuation.

Study Design: A retrospective review.

Setting: Department of spinal surgery in an affiliated hospital of a medical university.

Methods: A total of 515 patients were retrospectively enrolled between January 2015 and December 2019 into a 5-year follow-up investigation. Trabecular attenuation (Hounsfield units [HU]) was retrospectively measured at L1 on preoperative lumbar or thoracic CT scans, and the receiver operating characteristic (ROC) curve was used to evaluate its value for the prediction of SVF. Kaplan–Meier analysis and Cox proportional hazards regression were performed to identify the risk factors for SVF.

Results: A total of 166 patients (32.2%) experienced SVF. ROC curve analysis demonstrated that an L1 trabecular attenuation of ≤ 95 HU has a sensitivity of 70.5% and a specificity of 79.9% for the prediction of SVF. Kaplan–Meier analysis showed that L1 trabecular attenuation ≤ 95 HU was significantly associated with lower SVF-free survival ($P = 0.001$; log-rank test). Multivariate analysis demonstrated that advanced age (hazard ratio [HR] = 1.03, $P = 0.022$), low body mass index (HR = 0.83, $P = 0.001$), diabetes status (HR = 1.50, $P = 0.024$), antiosteoporosis drugs use (HR = 0.65, $P = 0.031$), and decreased L1 trabecular attenuation (HR = 0.95, $P = 0.001$) were risk factors for SVF.

Limitations: A single-center retrospective study of a consecutive cohort of patients may include the inevitable bias. We periodically reviewed the full-length x-ray of the spine at every 3 months of follow-up visit, which we may miss some patients with SVF without low back pain.

Conclusions: SVF is highly prevalent in patients with osteoporotic vertebral fracture who undergo single-level PVA. Low L1 trabecular attenuation is associated with a significant reduction in SVF-free survival, and when their L1 trabecular attenuation is ≤95 HU, patients may be at higher risk of SVF.

Key words: Computed tomography, Hounsfield units, vertebral fracture, osteoporosis, percutaneous vertebral augmentation

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Osteoporosis is a common disease characterized by low bone mass and changes in the bone microstructure, and vertebral fractures are the most common type of osteoporotic fracture (1). Percutaneous vertebral augmentation (PVA) is a minimally invasive procedure that can achieve faster pain relief and mobility recovery, and it has become a common treatment for osteoporotic vertebral fracture (OVF) (2). However, vertebral fracture after PVA is related to increased risk for subsequent vertebral

fracture (SVF), as well as increased mortality (3,4). A number of studies have determined that low bone mineral density (BMD) is an independent risk factor for SVF (5,6). However, because of economic and practical factors, dual-energy x-ray absorptiometry (DXA) is not widely used. Only 1.5% of patients underwent a DXA scan before they experienced a vertebral fracture, and 0.6% only underwent a DXA scan 1 year after OVF (7). Therefore a simple and effective method to compensate for this deficiency needs to be explored.

As a complement to DXA, opportunistic BMD measurements of computed tomography (CT) attenuation (in Hounsfield units [HUs]) can be conveniently made prospectively or retrospectively using clinical CT, which can be used to detect the loss of bone mass and identify patients at increased fracture risk without increasing the cost of the procedure or exposing the patient to additional radiation (8,9). Studies have indicated that trabecular attenuation measured in the first lumbar vertebral body trabecular bone is an effective method for identifying patients at increased risk of fracture (10,11). With a decrease in L1 HU, 10-year fracture-free survival in patients with previous fractures was significantly lower than in patients without (6). However, it is currently not clear how well CT trabecular attenuation values correlate with the prevalence of SVF after PVA.

Therefore the purpose of the present study was to determine whether L1 trabecular attenuation is associated with SVF-free survival in a cohort of patients with PVA undergoing preoperative thoracolumbar CT, and to determine the prevalence of SVF during the 5 years following PVA.

Methods

Patients

The study was approved by the ethics committee of our hospital. We reviewed data obtained between January 1, 2015 and December 31, 2019, regarding 515 patients who had experienced OVF and underwent single-level percutaneous vertebroplasty or percutaneous kyphoplasty in the spinal surgery department of our hospital (Fig. 1).

The inclusion criteria in our study were (1) the patient met the diagnostic criteria for OVF in the clinical guidelines; (2) the patient had experienced a first fracture and had no history of prior spinal surgery; (3) the patient had experienced a single-level vertebral fracture and underwent PVA after the failure of conservative treatment; and (4) preoperative CT examination of the thoracolumbar spine had been completed.

The exclusion criteria in our study were (1) the presence of metabolic bone disease other than osteoporosis (including Cushing disease, hyperthyroidism, among others); (2) pathological fracture caused by bone tumor or bone tuberculosis; (3) the detection of inoperable vertebral wedge changes before the first PVA procedure; and (4) postoperative review of the PVA showed intervertebral disc leakage of bone cement.

The Criteria of PVA

The indication for performing PVA were as follows: (1) conservative treatment fails to treat painful OVF; (2) unstable fracture, such as vertebral compression, exceeds one-half of vertebral height, or with segmental kyphosis; (3) without neurologic damage; (4) fresh fracture of thoracolumbar vertebral body; and (5) elderly patients who are not bedridden for a long time.

Data Collection

The CT attenuation value, in HUs, of the first lumbar vertebral (L1) mid-body was measured on a single cross-section. Patient demographics, history, and treatment information were collected from their medical records and the structured comprehensive questionnaire. The age, gender, body mass index (BMI), smoking (≥ 3 cigarettes per day or ≥ 18 cigarettes per week for more than 1 year), drinking (> 3 drinks/day for men, > 2 drinks/day for women), hypertension, and diabetes status; bone turnover markers, including serum concentrations of 25(OH) D, β-type I collagen carboxyl terminal peptide (β-CTX), and the N-terminal fragment of osteocalcin (N-MID); and antiosteoporosis drug use was defined as a history of bisphosphonate or teriparatide use during the follow-up period of 5 years after PVA. All data were obtained from the questionnaire and medical records in the case system.

Evaluation of Bone Quality

As previous studies recommended (10), the L1 vertebral body was chosen as the site for HU measurements with the preoperative thoracolumbar CT images, which were obtained by the same CT scanner (Siemens, DEFINITION, tube voltage 120 KV, 1.5 mm slice thickness, Germany) using a picture archiving and communication system (PACS). We assessed vertebral BMD by placing a single oval click-and-drag region of interest (ROI) over an area of vertebral body trabecular bone and then measuring CT attenuation in HU, with lower HU representing low bone mass. The type of CT

window did not affect the CT attenuation value obtained (12). The principle of the ROI placement was to include as much trabecular bone as possible, and to avoid cortical bone, the posterior venous plexus, bone islands, compressed bone, and other heterogeneous areas. The largest ROI is drawn at L1 vertebral mid-body, and the PACS software automatically calculates the average CT HU value for the ROI (Fig. 2). We measured the HU value of L2 instead of L1 when patients had vertebral fractures of L1.

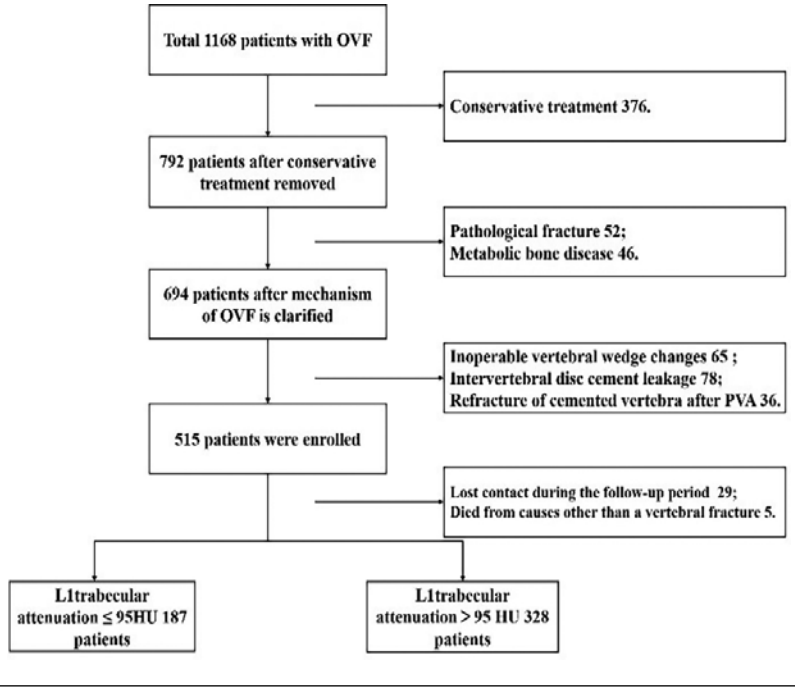

Fig. 1. *Flow diagram for screening patients.*

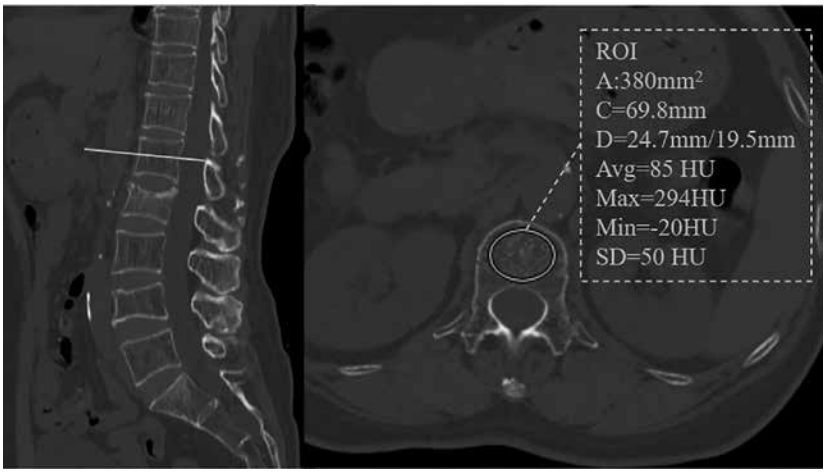

Fig. 2. *An example of CT HU values measured over an axial image of L1 vertebral body. The single oval click-and-drag ROI was placed on the axial image in the L1 vertebral mid-body. After the maximum ROI is plotted, the PACS software automatically calculates the average CT HU for the ROI. After the maximum ROI is plotted, the PACS software automatically calculates the average CT HU for the ROI.*

Definition of SVF

In the first 3 months after PVA surgery, patients were followed up monthly at the outpatient department, and subsequently at 3-month intervals. Magnetic resonance imaging (MRI) examination was performed in patients with recurrent low back pain and suspected new vertebral fracture occurred. A diagnosis of SVF was made when the imaging outcome met one of the following criteria: x-ray or CT indicated a moderate to severe vertebral fracture according to the Genant semiquantitative scale (13), or T1-weighted MRI showed low attenuation and T2-weighted MRI showed high attenuation. We defined SVF to include remote and adjacent vertebral fractures. All the SVFs recorded for the study patients occurred during the 5-year follow-up period.

Statistical Analysis

The data were analyzed using R software version 3.1.0 (R Foundation, Vienna, Austria) and MedCalc software version 11.2 (MedCalc Software Ltd, Belgium). Continuous variables were assessed using independent samples Student t-tests and categorical data were assessed using χ^2 tests. The receiver operating characteristic (ROC) curve was used to evaluate the sensitivity and specificity of L1 trabecular attenuation for the evaluation of the risk of SVF after PVA, and to determine the most appropriate cutoff value to predict this outcome.

Patients were grouped according to their L1 trabecular attenuation for univariate survival analysis, and the threshold was determined using the ROC outcome for SVF. Kaplan–Meier curves were used to compare differences in SVF-free survival, and log-rank tests were used for the statistical evaluation of this outcome. The potential risk factors for SVF were assessed using both univariate survival analysis ($\alpha \leq 0.10$) and Cox time-to-event regression.

Results

At the end of the study, data from a total of 515 patients had been collected, and their characteristics are shown in Table 1. Patients who experienced SVF during follow-up were significantly older than those who did not (71.2 ± 6.0 vs. 69.4 ± 6.5 years; $P = 0.003$). Some 166 patients (32.2%) experienced SVF in the 5 years follow-up time. Twenty-nine patients lost contact during the follow-up period, and 5 patients died from causes other than a vertebral fracture. There were no significant differences in the baseline data between the patients who were lost to follow-up and those who remained ($P > 0.05$). The mean duration of follow-up was 19.0 ± 15.3 months for the SVF group, and the survival rates for those who experienced SVF after 12, 24, 36, 48, and 60 months were 84.3%, 75.3%, 68.0%, 62.4%, and 57.2%, respectively. Women accounted for a larger proportion of both the SVF and non-SVF groups. The BMI of the non-SVF group was higher than that of the SVF group ($P = 0.001$); the serum 25(OH)D of the SVF group was lower than that of the non-SVF group ($P < 0.05$); the mean L1 attenuation was significantly lower among patients with an SVF compared with those without an SVF ($P = 0.001$) (Fig. 3). The prevalence of diabetes in patients with SVF was higher than that of the non-SVF group ($P = 0.007$), and the proportion of patients using an antiosteoporosis drug in the SVF group was significantly lower than that in the non-SVF group.

Table 2 shows the variables that were used in the Cox model for univariate analysis. Age, BMI, diabetes status, low serum 25(OH)D concentration, antiosteoporosis drugs use, and L1 trabecular attenuation were in line with the statistical significance of this study ($P < 0.10$ was used as the rejection criterion). Factors that were significantly different between the groups in the univariate analysis were regarded as potential confounding factors and were included in a Cox proportional hazards model for multivariate analysis. The results of this model, after adjustment for all these potentially confounding variables, are shown in Table 2. The totally likelihood ratio test for the model was highly significant ($P < 0.001$), indicating that at least one of the variables involved was significantly related

Table 1. *Baseline characteristics of the patients.*

	Non-SVF (n = 349)	SVF (n = 166)	*P*
Age, years	69.4 ± 6.5	71.2 ± 6.0	0.003
Male/female	120/229	65/101	0.169
Height, cm	163.8 ± 7.3	162.5 ± 7.2	0.066
Weight, kg	60.0 ± 7.1	57.1 ± 7.1	0.001
BMI, kg/m2	22.4 ± 1.6	21.4 ± 1.8	0.001
25(OH)D, ng/mL	19.9 ± 7.6	18.3 ± 8.1	0.031
β-CTX, ng/mL	0.542 ± 0.253	0.551 ± 0.271	0.712
N-MID, ng/mL	17.3 ± 7.4	16.6 ± 7.6	0.333
Hypertension, yes	80/349 (22.9%)	43/166 (25.9%)	0.507
Diabetes, yes	53/349 (15.2%)	41/166 (24.7%)	0.007
Drinking, yes	28/349 (8.0%)	16/166 (9.6%)	0.613
Smoking, yes	36/349 (10.3%)	23/166 (13.8%)	0.240
Antiosteoporosis drugs use, yes	160/349 (45.8%)	34/166 (20.5%)	0.001
L1 trabecular attenuation (HU)	105.7 ± 15.4	89.2 ± 20.7	0.001
Follow-up time, months	37.0 ± 17.9	19.0 ± 15.3	0.001

Mean ± standard deviation or (reported/available).

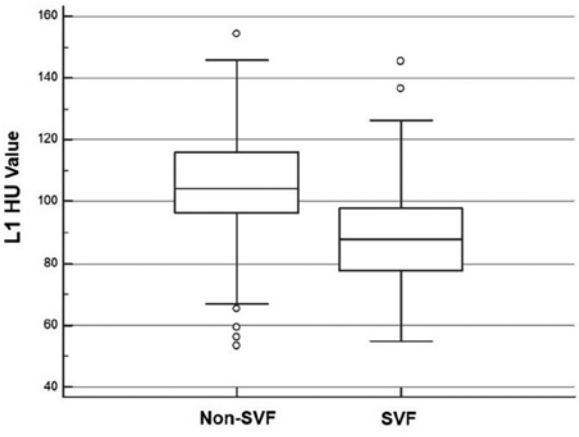

Fig. 3. *L1 trabecular attenuation values in patients with and without prevalent SVF. Box-and-whisker plot shows distribution of L1 trabecular attenuation values in patients with and without prevalent SVF. Middle lines in boxes show median HU, upper lines of boxes show third quartile limit, lower lines of boxes show first quartile limit, whiskers show range (excluding outliers). ○ = outliers.*

Table 2. *Significant predictors of SVF at 5-year follow-up in univariable and multivariable Cox regression analyses.*

Variables	Univariate	*P*	Multivariate	*P*
	HR (95% CI)			
Age, years	1.04 (1.02–1.07)	0.001	1.03 (1.01–1.05)	0.022
Gender, female	1.31 (0.71–2.42)	0.390	–	
BMI, kg/m^2	0.79 (0.73–0.85)	0.001	0.83 (0.76–0.91)	0.001
25(OH)D, ng/mL	0.98 (0.96–1.00)	0.048	0.98 (0.97–1.00)	0.088
β-CTX, ng/mL	0.99 (0.56–1.78)	0.979	–	–
N-MID, ng/mL	0.99 (0.97–1.00)	0.283	–	–
Hypertension, yes	1.06 (0.75–1.45)	0.753	–	–
Diabetes, yes	3.34 (2.22–5.03)	0.001	1.50 (1.06–2.14)	0.024
Drinking, yes	1.25 (0.74–2.01)	0.403	–	–
Smoking, yes	1.42 (0.91–2.21)	0.124	–	–
Antiosteoporosis drugs use, yes	0.51 (0.29–0.91)	0.023	0.65 (0.44–0.96)	0.031
L1 trabecular attenuation (HU)	0.94 (0.93–0.95)	0.001	0.95 (0.94–0.96)	0.001

CI, confidence interval.

to SVF-free survival. Specifically, lower L1 trabecular attenuation was significantly associated with a higher risk of SVF (hazard ratio [HR] = 0.95, $P = 0.001$).

Table 3 shows the SVF prevalence progressively increased as the L1 trabecular attenuation was lowered. SVFs were present in 18.4% of patients with an L1 trabecular attenuation value ≤ 90 HU. This prevalence increased to 27.5% in patients with an L1 trabecular attenuation ≤ 85 HU. The positive predictive value of a fracture at the 85-HU threshold was 80.7%. The negative predictive value of a threshold of 110 HU was 88.6%. ROC analysis indicated that a L1 trabecular attenuation of 95 HU had a sensitivity of 70.5% and a specificity of 79.9% for the prediction of SVF and yielded an area under the curve of 0.802 (95% confidence interval, 0.77–0.84) (Fig. 4).

The Kaplan–Meier curve in Fig. 5 shows that when using an L1 trabecular attenuation threshold of 95 HU, there was a significant difference in SVF-free survival. When patients with an L1 attenuation value above and those with a value below 95 HU were compared, the SVF-free survival was significantly different ($P = 0.001$, according to the log-rank test). Antiosteoporosis drug use was significantly associated with a reduced risk of SVF (HR = 0.65, $P = 0.031$). HR of SVF on the basis of L1 trabecular attenuation both with and without antiosteoporosis drug use is presented in Fig. 6.

Table 3. *Characteristics of different attenuation thresholds for predicting SVF.*

L1 HU	Sensitivity (%)	Specificity (%)	Prevalence (%)	PPV (%)	NPV (%)
≤85	42.8	95.1	27.5%	80.7	77.8
≤90	63.3	85.4	21.2%	66.9	83.0
≤95	70.5	79.9	18.4%	62.6	85.1
≤100	81.9	56.2	8.7%	47.1	86.7
≤105	84.9	48.7	6.8%	44.1	87.2
≤110	90.4	35.5	3.9%	40.0	88.6

NPV, negative predictive value; PPV, positive predictive value.

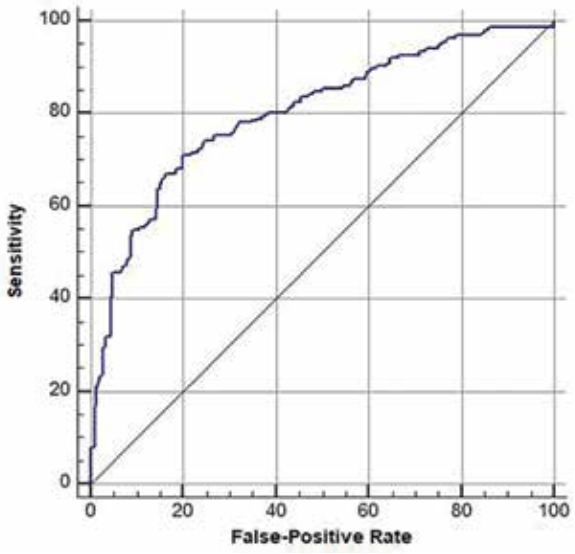

Fig. 4. *ROC curve analysis of various attenuation thresholds for capturing prevalent SVF. Diagonal line is line of no discrimination, which references proximity to random association. The area under the ROC curve of the L1 trabecular attenuation value was 0.802, the cutoff value was 95 HU, the sensitivity was 70.5%, and the specificity was 79.9%.*

Discussion

PVA is an efficient, minimally invasive, and relatively safe procedure that is used for the treatment of symptomatic OVF, or at least for initial pain control (14). SVF is one of the major complications that occurs in patients with OVF who underwent PVA (15), and the incidence of SVF in the present study was 32.2%. We found that in a cohort of patients with OVF, those who underwent single-

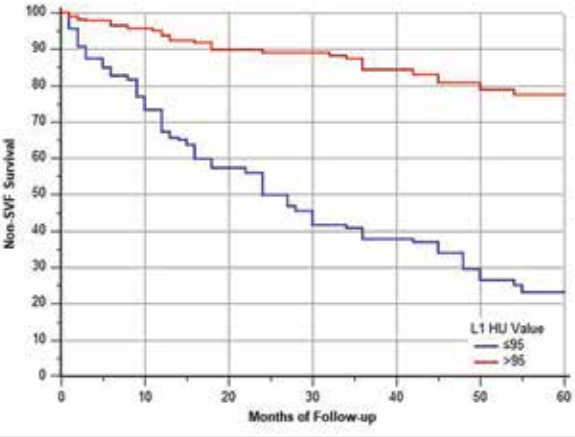

Fig. 5. *Kaplan–Meier curves for patients divided into L1 trabecular attenuation categories using a 95 HU threshold.*

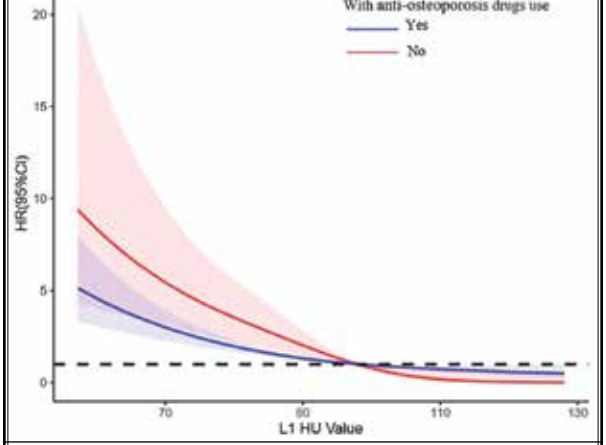

Fig. 6. *HR of SVF on the basis of L1 trabecular attenuation both with and without antiosteoporosis drugs use.* {*AU: Please cite Figure 6 in the text*}

level PVA and had lower L1 trabecular attenuation were more likely to experience SVF, and there were significant differences in SVF-free survival between patients with an L1 trabecular attenuation of ≤ 95 or > 95 HU. Multivariate Cox proportional hazard analysis indicated that advanced age, low BMI, low serum 25(OH)D concentration, diabetes, lack of antiosteoporosis drug use, and low CT attenuation were risk factors for SVF. Furthermore, multivariate survival analysis showed that the effect of L1 trabecular attenuation remained significant after adjustment for potential confounding factors.

In numerous previous studies, various factors have been identified that influence the incidence of SVF. It is generally believed that advancing age correlates negatively with BMD (16). Indeed, aging has been consistently identified as a major risk factor for SVF. Diabetes is also thought to be a risk factor for SVF because of the defects in bone metabolism that develop in the presence of hyperglycemia, inadequate insulin secretion, and diabetic complications (17). Previous studies have shown that the prevalence of SVF in patients with osteoporosis with chronic diabetes is much higher than in nondiabetic patients (18). Obesity could be related to increased BMD, reflecting the enhanced bone mass stimulated by larger skeletal loading. A study of 1,099 older adults demonstrated that patients with high BMI were at a lower risk of major osteoporotic fractures (19). Hypovitaminosis D is also thought to be an important risk factor for osteoporotic fracture and malunion. Maier et al (20) reported a prevalence of vitamin D insufficiency of 89% in 246 patients with OVF, and the present results indicate that the 25(OH)D status in patients who experience SVF is significantly lower than in those who do not. Furthermore, chronic vitamin D deficiency can lead to secondary hyperparathyroidism and progressive bone loss, which increase the risk of osteoporotic fracture (21).

The use of antiosteoporosis drugs as an active intervention method for osteoporosis has shown efficacies by increasing BMD and decreasing the risk of vertebral fractures and SVF (22,23). Indeed, the present results suggest that treatment with antiosteoporosis drugs reduces the risk of SVF by 35% (P = 0.001), and HR of SVF on the basis of L1 trabecular attenuation in patients with antiosteoporosis drug use is significantly higher than in patients without (P = 0.032). However, the rate of antiosteoporosis drug use after PVA was lower in both the SVF group and the non-SVF group. Malik et al (24) reported that less than one-third of patients experiencing a sentinel OVF receive antiosteoporotic medication within the year following the fracture, which increases the rate of vertebral refracture. Therefore we should consider using antiosteoporosis therapy positively in patients with the first occurrence of OVF, especially those with L1 trabecular attenuation ≤ 95 HU.

However, the most important risk factor for SVF is poor bone quality. Schreiber et al (8) demonstrated that BMD, measured using clinical CT scan data, represents an alternative method of assessing local bone quality. BMD measured using CT correlates closely with vertebral compression data and DXA scan results. Similar studies have shown that CT attenuation is closely related to BMD T-score and that local BMD, assessed on CT scans,

is useful for fracture risk evaluation, the diagnosis and management of osteoporosis, and the identification of candidates for early therapeutic intervention (25-27). Graffy et al (11) reported that patients with moderate or severe vertebral fracture have significantly lower L1 CT attenuation than those without, and that when the L1 attenuation is < 90 HU, the patient may be at greater risk of vertebral fracture. The present findings also show that the CT attenuation of patients who experience an SVF is significantly lower than that of those who do not ($P = 0.001$), and the SVF-free survival differed significantly from the patients with an L1 trabecular attenuation of ≤ 95 HU. To date, research on CT attenuation has mainly focused on the measurement of BMD and its use to predict vertebral fracture risk. To our knowledge, this is the first long-term follow-up cohort study of the relationship between the L1 trabecular attenuation and SVF. The aim of the study was to evaluate a simple tool that could be used in daily clinical practice and as a predictor of SVF.

One clear advantage of CT over DXA for BMD measurement is that CT attenuation can be assessed using a standard preoperative thoracolumbar CT scan of the patient; therefore additional exposure to radiation can be avoided. Moreover, patients with fractures often have lower back pain, and the use of the method described can also reduce the number of examinations and shorten the examination time for the patient, which should reduce the pain induced by the required changes in posture.

When DXA is used to measure BMD, spinal degenerative diseases, which involve osteophyte formation, abdominal aortic calcification, and adult spinal deformities, can affect the accuracy of the measurement. Therefore another advantage of the use of CT to assess bone trabecular quality is that such measurements are less influenced by these factors (28). We have emphasized the use of L1 vertebral measurements in the present study for several reasons. First, when the results of multilevel assessments were compared, the accuracy at L1 was higher than that at other levels (11). Second, the L1 level is easily identifiable, which improves the efficiency and reproducibility of the assessment. Finally, this level is included on all standard chest and abdominal CT scans, which substantially increases the potential of the approach for widespread screening.

Although the use of L1 trabecular attenuation to assess bone quality has more advantages than traditional DXA, it also has limitations. First, the manual manipulation required for the measurement of L1 attenuation presents a potentially significant problem in the diagnosis of osteoporosis and osteopenia. Recently, a machine-learning model has been used for opportunistic CT screening for osteoporosis, and it is also possible to implement spinal segmentation algorithms in an automated fashion. The implementation of an automated CT attenuation measurement method may be associated with greater reproducibility, occupy less time in either a research or clinical context, and be applicable for the screening of large populations (29). Furthermore, the International Society for Clinical Densitometry recently published an opinion that when opportunistic CT screening for osteoporosis is conducted, the CT attenuation is influenced by the specific scanner manufacturer and model, and the attenuation were significantly different when results generated using scanners from different manufacturers are compared (30). Owing to differences in parameters of clinical CT scans, HU in vertebral body of the same patient may have different results based on image measured by different clinical CT scans. Therefore future studies need to quantify different clinical CT scan parameters for the measurement of HU value of vertebral trabecular bone, which may be valuable to guide the future work of SVF risk assessment.

The present study had some limitations. First, it was a single-center retrospective study of a consecutive cohort of patients, which implies the existence of heterogeneity, and the low sensitivity and specificity of the determined diagnostic threshold may be related to this. Second, we periodically reviewed the full-length x-ray of the spine at every 3-month follow-up, in which we may have missed some patients with SVF without low back pain. This may have artificially lowered the number of prevalent SVF. Therefore long-term follow-up studies with large multicenter samples are needed to verify our results in the future.

Conclusions

We have shown that SVF is highly prevalent in patients with OVF who undergo single-level PVA. Lower L1 trabecular attenuation is associated with significantly lower SVF-free survival, and when the L1 attenuation is < 95 HU, a patient may be at higher risk of SVF. Thus the measurement of CT attenuation at L1 represents a simple tool that could be used in daily clinical practice to evaluate bone mass and as a predictor of SVF following PVA.

References

1. 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; 22:465-475.
2. Matsumoto T, Hoshino M, Tsujio T, et al. Prognostic factors for reduction of activities of daily living following osteoporotic vertebral fractures. *Spine (Phila Pa 1976)* 2012; 37:1115-1121.
3. Che H, Breuil V, Cortet B, et al. Vertebral fractures cascade: Potential causes and risk factors. *Osteoporos Int* 2019; 30:555-563.
4. Park SM, Ahn SH, Kim HY, et al. Incidence and mortality of subsequent vertebral fractures: Analysis of claims data of the Korea National Health Insurance Service from 2007 to 2016. *Spine J* 2020; 20:225-233.
5. Baroud G, Nemes J, Ferguson SJ, et al. Material changes in osteoporotic human cancellous bone following infiltration with acrylic bone cement for a vertebral cement augmentation. *Comput Methods Biomech Biomed Engin* 2003; 6:133-139.
6. Lee SJ, Graffy PM, Zea RD, et al. Future osteoporotic fracture risk related to lumbar vertebral trabecular attenuation measured at routine body CT. *J Bone Miner Res* 2018; 33:860-867.
7. Barton DW, Behrend CJ, Carmouche JJ. Rates of osteoporosis screening and treatment following vertebral fracture. *Spine J* 2019; 19:411-417.
8. Schreiber JJ, Anderson PA, Rosas HG, et al. Hounsfield units for assessing bone mineral density and strength: A tool for osteoporosis management. *J Bone Joint Surg Am.* 2011; 93:1057-1063.
9. Zou D, Li W, Deng C, et al. The use of CT Hounsfield unit values to identify the undiagnosed spinal osteoporosis in patients with lumbar degenerative diseases. *Eur Spine J* 2019; 28:1758-1766.
10. Pickhardt PJ, Pooler BD, Lauder T, et al. Opportunistic screening for osteoporosis using abdominal computed tomography scans obtained for other indications. *Ann Intern Med* 2013; 158:588-595.
11. Graffy PM, Lee SJ, Ziemlewicz TJ, et al. Prevalence of vertebral compression fractures on routine CT scans according to L1 trabecular attenuation: Determining relevant thresholds for opportunistic osteoporosis screening. *AJR Am J Roentgenol* 2017; 209:491-496.
12. Pickhardt PJ, Lee LJ, del Rio AM, et al. Simultaneous screening for osteoporosis at CT colonography: Bone mineral density assessment using MDCT attenuation techniques compared with the DXA reference standard. *J Bone Miner Res* 2011; 26:2194-2203.
13. Genant HK, Wu CY, van Kuijk C, et al. Vertebral fracture assessment using a semiquantitative technique. *J Bone Miner Res* 1993; 8:1137-1148.
14. Bae JS, Park JH, Kim KJ, et al. Analysis of risk factors for secondary new vertebral compression fracture following percutaneous vertebroplasty in patients with osteoporosis. *World Neurosurg* 2017; 99:387-394.
15. Buchbinder R, Johnston RV, Rischin KJ, et al. Percutaneous vertebroplasty for osteoporotic vertebral compression fracture. *Cochrane Database Syst Rev* 2018; 4:CD006349.
16. Chen Z, Chen Z, Wu Y, et al. Risk factors of secondary vertebral compression fracture after percutaneous vertebroplasty or kyphoplasty: A retrospective study of 650 patients. *Med Sci Monit* 2019; 25:9255-9261.
17. Adami S. Bone health in diabetes: Considerations for clinical management. *Curr Med Res Opin* 2009; 25:1057-1072.
18. Chen FP, Kuo SF, Lin YC, et al. Status of bone strength and factors associated with vertebral fracture in postmenopausal women with type 2 diabetes. *Menopause* 2019; 26:182-188.
19. Gandham A, Zengin A, Bonham MP, et al. Incidence and predictors of fractures in older adults with and without obesity defined by body mass index versus body fat percentage. *Bone* 2020; 140:115546.
20. Maier GS, Seeger JB, Horas K, et al. The prevalence of vitamin D deficiency in patients with vertebral fragility fractures. *Bone Joint J* 2015; 97-b:89-93.
21. Paranhos-Neto FP, Vieira Neto L, Madeira M, et al. Vitamin D deficiency is associated with cortical bone loss and fractures in the elderly. *Eur J Endocrinol* 2019; 181:509-517.
22. Kong M, Zhou C, Zhu K, et al. 12-Month teriparatide treatment reduces new vertebral compression fractures incidence and back pain and improves quality of life after percutaneous kyphoplasty in osteoporotic women. *Clin Interv Aging* 2019; 14:1693-1703.
23. Camacho PM, Petak SM, Binkley N, et al. American Association of Clinical Endocrinologists/American College of Endocrinology clinical practice guidelines for the diagnosis and treatment of postmenopausal osteoporosis-2020 update. Endocr Pract 2020; 26(Suppl 1):1-46.
24. Malik AT, Retchin S, Phillips FM, et al. Declining trend in osteoporosis management and screening following vertebral compression fractures--A national analysis of commercial insurance and Medicare advantage beneficiaries. *Spine J* 2020; 20:538-546.
25. Salzmann SN, Shirahata T, Yang J, et al. Regional bone mineral density differences measured by quantitative computed tomography: Does the standard clinically used L1-L2 average correlate with the entire lumbosacral spine? *Spine J* 2019; 19:695-702.
26. Meredith DS, Schreiber JJ, Taher F, et al. Lower preoperative Hounsfield unit measurements are associated with adjacent segment fracture after spinal fusion. *Spine (Phila Pa 1976)* 2013; 38:415-418.
27. Lee BG, Choi JH, Kim DY, et al. Risk factors for newly developed osteoporotic vertebral compression fractures following treatment for osteoporotic vertebral compression fractures. *Spine J* 2019; 19:301-305.
28. Link TM, Lang TF. Axial QCT: Clinical applications and new developments. *J Clin Densitom* 2014; 17:438-448.
29. Nam KH, Seo I, Kim DH, et al. Machine learning model to predict osteoporotic spine with Hounsfield units on lumbar computed tomography. *J Korean Neurosurg Soc* 2019; 62:442-449.
30. Engelke K, Lang T, Khosla S, et al. Clinical use of quantitative computed tomography-based advanced techniques in the management of osteoporosis in adults: The 2015 ISCD Official Positions-Part III. *J Clin Densitom* 2015; 18:393-407.