Retrospective Study

ANVCFV Score System: Assessment for Probability of New Vertebral Compression Fractures after Percutaneous Vertebroplasty in Patients with Vertebral Compression Fractures

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Background: Percutaneous vertebroplasty (PVP) is widely used for the treatment of painful vertebral compression fractures (VCFs). However, new VCFs occur frequently after PVP.

Objectives: We aim to establish an objective risk score system to assess the possibility of new vertebral fractures in patients with VCFs undergoing PVP.

Study Design: This study was a retrospective study, and it was approved by the Institutional Review Board of our 2 institutions.

Setting: This study consists of patients from 2 large academic centers.

Methods: Patients with VCFs who underwent their first PVP and met the inclusion criteria between January 2007 and December 2013 at Hospital A (training cohort) and Hospital B (validation cohort) were included. In the training cohort, the independent risk factors for new VCFs after PVP were identified by multivariate stepwise backward Cox regression analysis from the risk factors selected by univariate analysis and Harrell's C-statistics and used to develop the score system (assessment for new VCFs after PVP [ANVCFV]) to predict the probability of new VCFs.

Results: In total, 397 patients (training cohort: n = 241; validation cohort: n = 156) were included in this study. In the training cohort, the ANVCFV score was developed based on 5 independent risk factors for the new VCFs after PVP, including lower computed tomography (CT) values, pre-existing old VCFs, intradiscal cement leakage, more than one vertebra treated, and superior or inferior marginal cement distribution in the vertebra. The patients were divided into 2 groups by the ANVCFV score of -1.5 to 8.5 vs. > 8.5 points in the probability of new VCFs (median fracture-free time: 1846 vs. 732 days; $P < 0.001$) in the training cohort. The accuracy of this score system was 77.4% for the training cohort and 85.3% for the validation cohort.

Limitations: The main limitations of this study are that it is a retrospective study and that there is a significant difference of the treated vertebrae of PVP per session between the 2 cohorts.

Conclusion: Patients who underwent their first PVP with an ANVCFV score > 8.5 points may exhibit an increased chance of suffering from new VCFs.

Key words: Vertebral compression fracture, percutaneous vertebroplasty, newly developed, risk factors, risk score system, Cox regression model, accuracy, validation

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Vertebral compression fractures (VCFs) are common in the elderly population, and approximately 1.4 million new fractures occur annually worldwide (1). Percutaneous vertebroplasty (PVP) is widely used to treat painful VCFs despite controversy regarding the usefulness of this procedure reported by several multicentric randomized control trials (2-5). The subsequent development of vertebral fractures following PVP occurs at rates as high as 12 to 52% after the first PVP (6-8). The risk factors correlated with new VCFs after PVP are uncertain (6,9-13). The aim of this study was to identify the risk factors for new VCFs throughout the spine after the first PVP and to establish an objective risk scoring system (assessment for new VCFs after percutaneous vertebroplasty [ANVCFV] score) for predicting the risk of subsequent new VCFs after the first PVP.

Methods

Patient Criteria

The ethical review committee of our 2 institutions separately approved this retrospective study. Patients enrolled in this study met the following inclusion criteria: 1) fresh VCFs between T1 to L5 vertebra based on the results of computed tomography (CT) and magnetic resonance imaging (MRI), or CT and nuclear bone scan imaging; 2) age ≥ 55 years; 3) unrelieved serious fresh VCF-related focal spinal pain [defined as unrelieved by conservative therapy (analgesics, bed rest, and bracing) for at least 4 weeks]; 4) post-procedure CT scans within 3 days after the procedure; and 5) the ability to comply with the follow-up evaluations on the new fracture after the first PVP. The exclusion criteria were 1) incomplete imaging data; 2) concurrent vertebral metastases, hemangioma, symptomatic Schmorl's nodes, infection, or myeloma; 3) history of senile dementia, malignancy, stroke, or spinal surgical treatments (including prior and post PVP); and 4) vertebral burst fracture.

PVP Procedure

PVP was performed using a unilateral transpedicle approach with a Murphy set (Cook, Inc., Bloomington, Indiana) under fluoroscopic guidance with a C-arm angiographic unit (Innova3100, GE Healthcare System or FD 20, Philips Medical) by interventional radiologists (G.J.T. or S.C.H in the training cohort and C.G.W. in the validation cohort). All procedures were performed under local anesthesia using 2% lidocaine. The volume of the cement [a mixture containing of 70% polymethylmethacrylate (PMMA) (Corinplast TM3, Corin, Inc., Gloucestershire, United Kingdom) and 30% sterilized barium powder (Dongfeng Chemical, Inc., Qingdao, China)] varied by the location (3 – 5 mL per thoracic vertebrae and 4 – 6 mL per lumbar vertebrae). Multiple vertebral levels were treated during a single session as long as the patient could tolerate the operation. CT scanning was performed for all patients within 3 days after the operation to observe the distribution of PMMA.

Data Collection

In the training cohort, patient spinal imaging data, including the occurrence of new fractures, were retrospectively reviewed with a PACS system (NEUSOFTPACS/RIS, Shengyang Neusoft Co., Ltd., China) by 2 radiologists who each had more than 5 years of experience in diagnostic radiology (W.F., H.D.Z.). Disagreements between the 2 radiologists were solved by consensus. The data included the following: 1) demographics, such as age and gender, previous vertebral fracture throughout the spine, duration of follow-up, and the CT values with the units of Hounsfield Unit (HU) that were defined as the mean CT values of T11-L2 vertebrae (Fig. 1); 2) parameters related to the fractured vertebra, such as the number of VCFs, fracture types (wedge, biconcave, or crush), location (thoracolumbar junction, non-thoracolumbar junction), anterior/middle vertebral height loss, anterior–posterior ratio (A/P = AHV/PHV, where AHV = anterior height of the vertebra and PHV = the posterior height of the vertebra, A/P represents the degree of wedging in the fractured vertebra), and Kummell's sign; and 3) parameters related to the PVP procedure, such as cement leakage into the disc (defined as any cement extending beyond the superior or inferior endplates), anterior vertebral height restoration (percentage), middle vertebral height restoration (percentage), volume of injected cement per vertebra and per session, single or multiple approaches, the cemented vertebral body fraction (CVBF, CVBF = ICV/VBV, where ICV is the volume of cement infection of the fractured vertebra and VBV is the vertebral body volume), cement distribution (graded as full distribution versus superior or inferior distribution, full distribution versus anterior or posterior distribution, and full distribution versus unilateral distribution), and the number of treated fractured vertebrae. In this study, CT values were used to reflect the patient's degree of osteoporosis. All patients received follow-up CT and MRI examinations at one, 3, and 6 months and then every 6 months after the PVP proce-

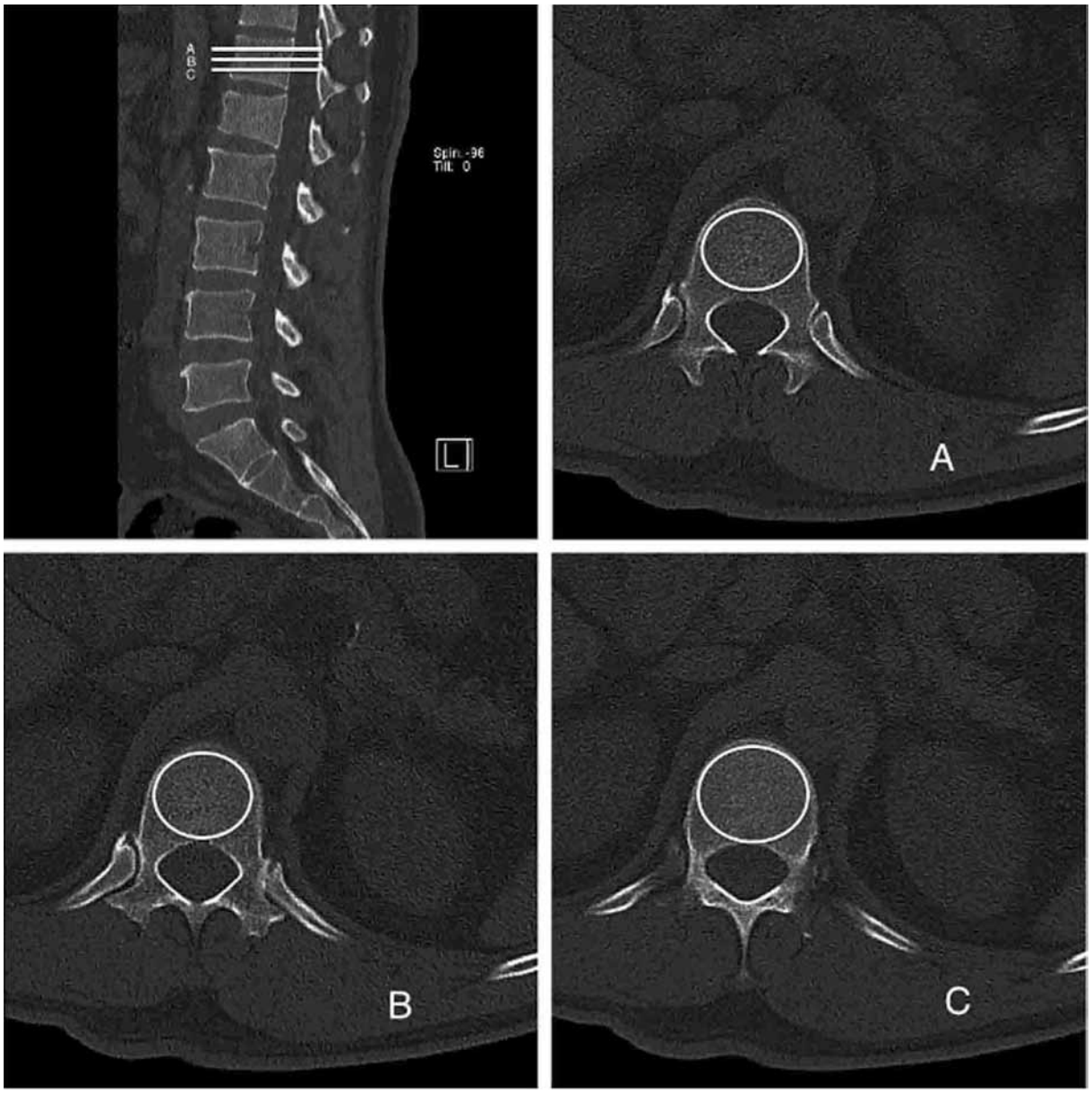

Fig. 1. *CT values around vertebrae T11-L2 were measured by using an image archiving and communication system (PACS). From a reconstructed sagittal image, we selected the following 3 axial planes: slice (A) was obtained just inferior to the superior endplate, slice (B) was obtained from the middle of the vertebral body, and slice (C) was obtained immediately superior to the inferior endplate. The PACS program calculated the mean CT values of the regions of interest, which were automatically marked with ellipses in the figure. The average of the CT values from 3 axial cuts was regarded as the values of such vertebra. Then, the average of the 4 vertebraes' CT values was considered to be the patient's CT values.*

dure. We strongly suggested that patients return to our departments for further examination when indicated (sudden new onset of back pain or persisting back pain). The criteria of a new fracture were based on CT and MRI examinations. MRI played a critical role in determining whether the fracture was fresh. The fracture-free time was defined as the period from the time of the first PVP to the time when the new fracture occurred or the

final follow-up. The final date of follow-up was January 18, 2014. The follow-up period was defined to be equal to the fracture-free time. The fracture-free probability was defined as the proportion of the number of the patients without new VCFs in the group.

Statistical Analysis

Fracture-free probability curves were calculated using the Kaplan-Meier method. The factors with *P*-value < 0.200 for the univariate analysis were adjusted for potential confounding factors by using Harrell's C-statistics. Then, the variables in the final model of Harrell's C-statistics were entered as candidate variables into a stepwise Cox regression model. To facilitate the use of point numbers to calculate the ANVCFV score, the regression coefficients of the Cox regression model were multiplied by 5 and rounded. A P-value < 0.05 was considered to indicate a statistically significant difference in the Cox regression model. Model discrimination was assessed using Harrell's C statistic. All statistical analyses were performed using the Stata 13.0 (Stata, College Station, Texas) and PASW Statistics software (Version 18.0, IBM Corporation, Somers, NY, USA).

Results

Patient Characteristics

From January 2007 to December 2013, 819 patients who underwent PVP at Hospital A (training cohort) were screened to establish an objective risk scoring system, and 661 patients who underwent PVP at Hospital B (validation cohort) in the same period were screened to assess this objective risk scoring system (Fig. 2). In the training cohort, 255 patients met the inclusion criteria. During a follow-up period of 924 (SD 654) days, 10 patients died (unrelated to the PVP treatment) and 4 patients were lost to follow-up; therefore, a total of 241 patients were analyzed. In the validation cohort, 165 patients met the inclusion criteria. During a follow-up period of 764 (SD 580) days, 4 patients died (unrelated to the PVP treatment) and 5 patients were lost to follow-up; as a result, a total of 156 patients were analyzed. The demographic characteristics of both co-

Table 1. *Patient characteristics*.

Characteristic	Training Cohort (n = 241)	Validation Cohort (n = 156)	*P*-value*
Gender			0.411
Male	54 (22.4%)	28 (17.9%)	
Female	187 (77.6%)	128 (82.1%)	
Age (year)	73.5 (7.9)	71.1 (8.2)	0.332
CT Values (HU)	66.1 (34.7)	69.5 (35.6)	0.473
Follow-up period (day)	924 (654)	764 (580)	0.081
Fracture type			0.308
Wedge	178 (53.9%)	183 (51.7%)	
Biconcave	116 (35.2%)	134 (37.8%)	
Crush	36 (10.9%)	37 (10.5%)	
No. patients with old VCFs	139 (57.7%)	100 (64.1%)	0.096
Vertebral level			0.270
T1 – T10	48 (14.5%)	58 (16.4%)	
T11 – L1	163 (49.4%)	182 (51.4%)	
L2 – L5	119 (36.1%)	114 (32.2%)	
Treatment			
Treatment sessions	241	156	
Treatment VCFs	330	354	
No. patients with multiple VCFs	70 (29.0%)	93 (59.6%)	< 0.001
Mean VCFs treated per patient	1.4	2.3	< 0.001

Chi-square test or one-way ANOVA was used. Data are mean (SD) or number (%). CT = computed tomography. HU = Hounsfield unit. VCFs = vertebral compression fractures.

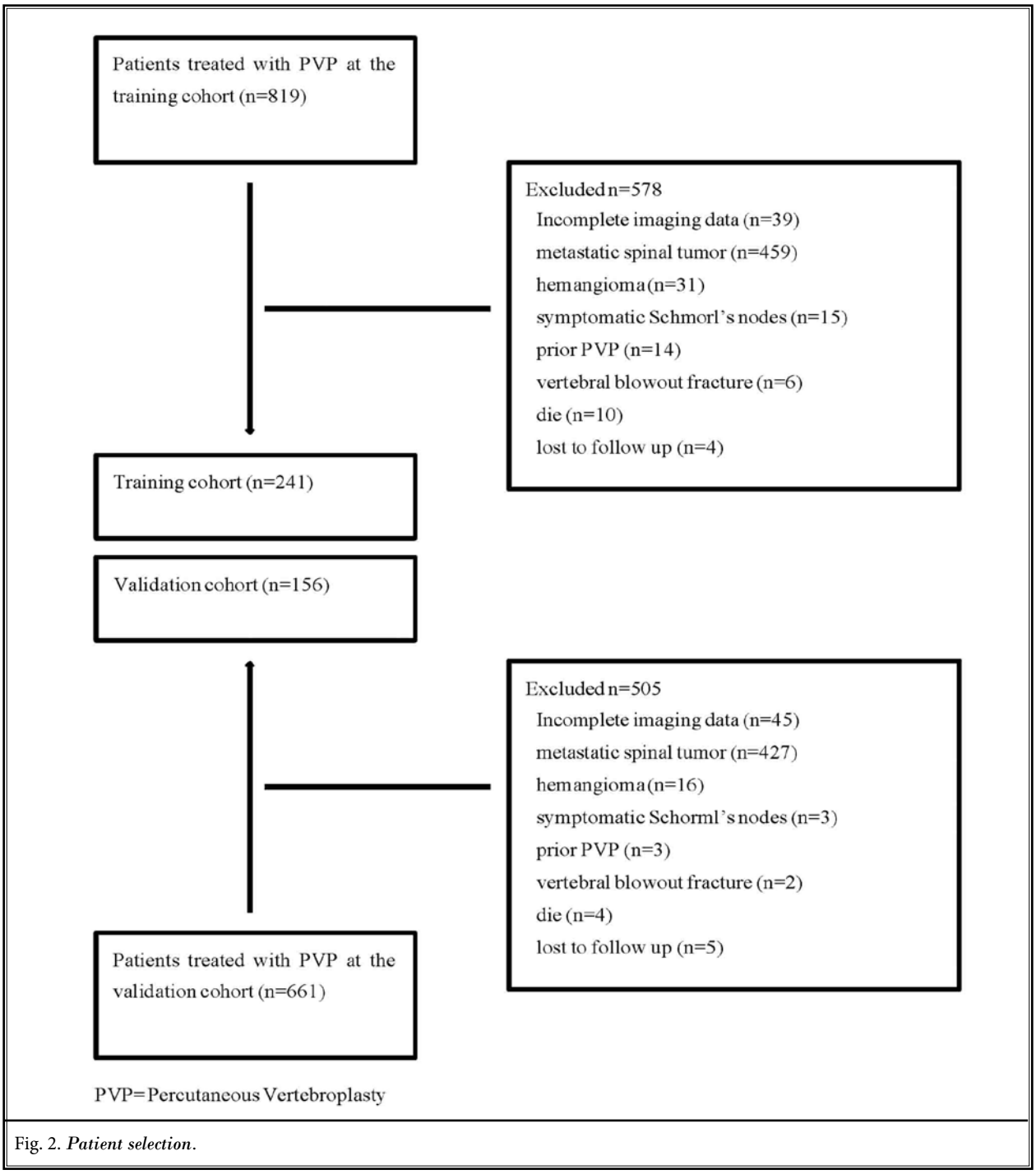

Fig. 2. *Patient selection*.

horts are presented in Table 1. Statistically significant differences were noted between the 2 groups for "Mean VCFs treated per patient" ($P < 0.001$) and "No. Patients with multiple VCFs" ($P < 0.001$).

New Vertebral Fractures

In the training cohort, 330 VCFs (T4-L5) were present in 241 patients before PVP, and 85 new vertebral fractures were noted in 66 patients (27.4%) during a

follow-up of 924 (SD 654) days after the first PVP. In the validation cohort, 354 VCFs (T5-L5) were present in 156 patients before PVP, and 52 new vertebral fractures were noted in 38 patients (24.4%) during a follow-up of 764 (SD 580) days after the first PVP.

Univariate Analysis of Risk Factors in the Training Cohort

The median fracture-free time in the training cohort was 924 (SD 654) days. The factors with *P* < 0.200 in the univariate analysis were lower CT values, the presence of previous VCFs, intradiscal cement leakage, treatment of more than one vertebra, a high A/P ratio, Kummell's sign, fracture type, and superior or inferior marginal distribution of the cement in the injected vertebra (90% or more of the cement was distributed in the superior or inferior marginal of the injected vertebra because there was less than 10% cement in the other half of the vertebra) (Table 2).

Table 2. *Univariate analysis of risk factors for the newly developed VCFs.*

Characteristic	HR	95% CI	*P*-value*
Gender (male, female)	0.848	0.525 – 1.370	0.501
Age (year), (55 – 74, ≥ 75)	1.219	0.827– 1.797	0.317
Fracture type			
1 = wedge	1		
2 = biconcave	1.760	0.984 – 3.147	0.057
3 = crush	0.829	0.459 – 1.494	0.532
Kummell's sign (without, with)	0.692	0.432 – 1.108	0.126
Location (non-TL junction, TL junction)	1.041	0.701– 1.547	0.840
CT values			
1st Quartile (< 40 HU)	1		
2nd Quartile (40 – 63 HU)	1.383	0.867 – 2.206	0.174
3rd Quartile (63 – 83 HU)	0.598	0.341 – 1.049	0.073
4th Quartile (≥ 83 HU)	0.343	0.176 – 0.668	0.002
Number of treated vertebra(e)			
1	1		
2	2.415	1.559 – 3.740	< 0.001
≥ 3	2.374	1.409 – 3.998	0.001
Cement leakage (no, yes)	1.739	1.169 – 2.587	0.006
Pre-existing old fracture (no, yes)	3.419	2.273 – 5.142	< 0.001
Distribution of the bone cement			
Full, Superior/inferior	1.890	1.264 – 2.824	0.002
Full, Unilateral	1.046	0.605 – 1.807	0.873
Full, Anterior/posterior	1.192	0.602 – 2.361	0.615
Multi puncture (no, yes)	1.245	0.789 – 1.966	0.346
Cement volume (< 5 mL, ≥ 5 mL)	1.089	0.740 – 1.603	0.664
CVBF (<3 7%, ≥ 37%)	0.988	0.689 – 1.487	0.950
A/P ratio (< 85%, ≥ 85%)	1.673	1.132 – 2.473	0.010
Loss of the anterior height in the fractured vertebra (< 19%, ≥ 19%)	0.810	0.550 – 1.191	0.284
Restoration of the anterior height in the fractured vertebra (< 7%, ≥ 7%)	1.139	0.775 – 1.674	0.509
Restoration of the middle height in the fractured vertebra (< 7%, ≥ 7%)	1.034	0.703 – 1.520	0.865

* Log Rank test was used. The grouping of each parameter was based on the statistical meaning. VCFs = vertebral compression fractures. HR = hazard ratio. TL = thoracolumbar. CT = computed tomography. HU = Hounsfield unit. CVBF = cemented vertebral body fraction. A/P ratio = anterior height of the vertebra/posterior height of the vertebra.

Verification of the Independent Risk Factors Predicting New VCFs in the Training Cohort and Establishment of the ANVCFV Scoring System

To eliminate potential confounding factors, 8 factors with $P < 0.200$ were analyzed by using Harrell's C-statistics. Five risk factors, including lower CT values, the presence of previous VCFs, intradiscal cement leakage, treatment of more than one vertebra, and superior or inferior marginal distribution of the cement in the injected vertebra, were chosen as candidate predictors due to the significant decrease in Harrell's C when removing any of these 5 variables. Finally, these 5 variables were verified as independent factors for predicting new VCFs following the first PVP by the Cox regression analysis (Table 3). To facilitate the use of point numbers for calculating the ANVCFV score, the regression coefficients (B-values) of the Cox regression model were multiplied by 5 and rounded (Table 3).

ANVCFV scores of the patients with those 5 independent predictors in the training cohort (n = 241) were calculated. The largest significant difference in the median fracture-free time was observed between the patients with an ANVCFV score of -1.5 to 8.5 points (258 vertebrae) and the patients with an ANVCFV score > 8.5 points (72 vertebrae) [1846 (95% confidence interval [CI], 1742 to 1950 days) vs. 732 (95% CI, 506 to 957) days; $P < 0.001$] (Fig. 3A). Patients with an ANVCFV score of -1.5 to 8.5 points exhibited an increased one-year fracture-free probability compared with patients with an ANVCFV score > 8.5 points (86.1% vs. 42.4%, $P < 0.001$). Furthermore, the 2-year fracture-free probabilities were 81.7% and 30.4% ($P < 0.001$) for the 2 respective groups. The 3-year fracture-free probabilities were 79.0% and 26.4% ($P < 0.001$) for the 2 respective groups. The final fracture-free probabilities were 77.4% and 26.4% ($P < 0.001$) for the 2 respective groups. Of the patients with an ANVCFV score of -1.5 to 8.5 points, 90.7% did not have new VCFs after PVP during the follow-up period, whereas 49.0% of patients with an ANVCFV score > 8.5 points had new VCFs after PVP dur-

Table 3. *Multivariate stepwise backward Cox regression analysis of risk factors of the newly developed VCFs in patients in the training cohort.*

Variable	HR	95% CI	B	ANVCFV scores	*P*-value*
CT values (HU)					0.044
< 40	1		0	0	
40 – 63	1.6	1.0 – 2.7	0.496	2.5	0.044
63 – 83	0.9	0.5 – 1.6	-0.143	-0.5	0.631
≥ 83	0.7	0.4 – 1.5	-0.296	-1.5	0.411
Cement leakage					0.012
Without	1		0	0	
With	1.7	1.1 – 2.5	0.523	2.5	
Marginal cement distribution					0.002
Absent	1		0	0	
Present	1.9	1.3 – 2.9	0.650	3	
Treated vertebra(s) per session					0.004
1	1		0	0	
2	2.1	1.3 – 3.3	0.739	3.5	0.001
≥ 3	1.9	1.1 – 3.2	0.616	3	0.028
Pre-existing old fracture(s)					0.030
Without	1		0	0	
With	2.9	1.9 – 4.4	1.054	5	

*Cox Regression analysis was used. VCFs = vertebral compression fractures. HR = hazard ratio. ANVCFV = Assessment for New VCFs after Percutaneous Vertebroplasty. CT = computed tomography. HU = Hounsfield unit. Marginal cement distribution meant superior or inferior marginal cement distribution. B-values were regression coefficients.

ing the follow-up period. As stated above, we divided the patients into 2 groups: one group with an ANVCFV score < 8.5 points and the other group with a score of > 8.5 points. The right decision was made for patients without new vertebral fracture(s) in the lower-score group (< 8.5 points) and with new vertebral fracture(s) in another group (8.5 points). We calculated the "model accuracy" to assess the exactitude of the ANVCFV score system. The definition of "model accuracy" is the percentage of patients with the right decision being made as accounted for in the total. As a result, the general accuracy in the training cohort was 77.4%. The overall discrimination of the final model is 0.757 (95% CI, 0.713 to 0.800).

Then, we calculated the ANVCFV scores of the patients in the validation cohort. The median fracture-free times were 1,761 days (95% CI, 1,681 to 1,840 days) in patients with an ANVCFV score of -1.5 to 8.5 points (261vertebrae) and 513 days (95% CI, 375 to 652 days) in patients with an ANVCFV score > 8.5 points (93 vertebrae) ($P < 0.001$) (Fig. 3B). The one-year fracture-free probabilities were 93.1% in patients with an ANVCFV score of -1.5 to 8.5 points and 46.3% in patients with an ANVCFV score > 8.5 points ($P < 0.001$). Furthermore, the 2-year fracture-free probabilities were 89.7% and 33.0% ($P < 0.001$) in the 2 respective groups. The 3-year fracture-free probabilities were 86.3% and 27.8% ($P < 0.001$) in the 2 respective groups. The final fracture-free probabilities were 77% and 7% ($P < 0.001$) in the 2 respective groups. Of the patients with an ANVCFV score of -1.5 to 8.5 points, 87.4% did not have new VCFs after PVP during the follow-up period, whereas 79.6% of patients with an ANVCFV score > 8.5 points had new VCFs after PVP during the follow-up period. Additionally, the general accuracy in the validation cohort was 85.3%.

Discussion

Although new VCFs following PVP may be associated with the PVP procedure itself, the exact risk factors for such new VCFs are uncertain (6,9-13). Among the potential risk factors reported in the literature, increasing low bone mass (represented in our study by lower vertebral CT values) was one of the most important independent risk factors (9,12), whereas other risk factors, such as cement leakage and cement distribution in the injected vertebra, are under debate (10,13). In our study, lower CT values, pre-existing old VCFs, more than one vertebra treated per session, cement leakage to the disc, and superior and inferior marginal distribution of the cement in the injected vertebra were the independent risk factors for new VCFs after the first PVP.

In this study, lower CT values are independent risk

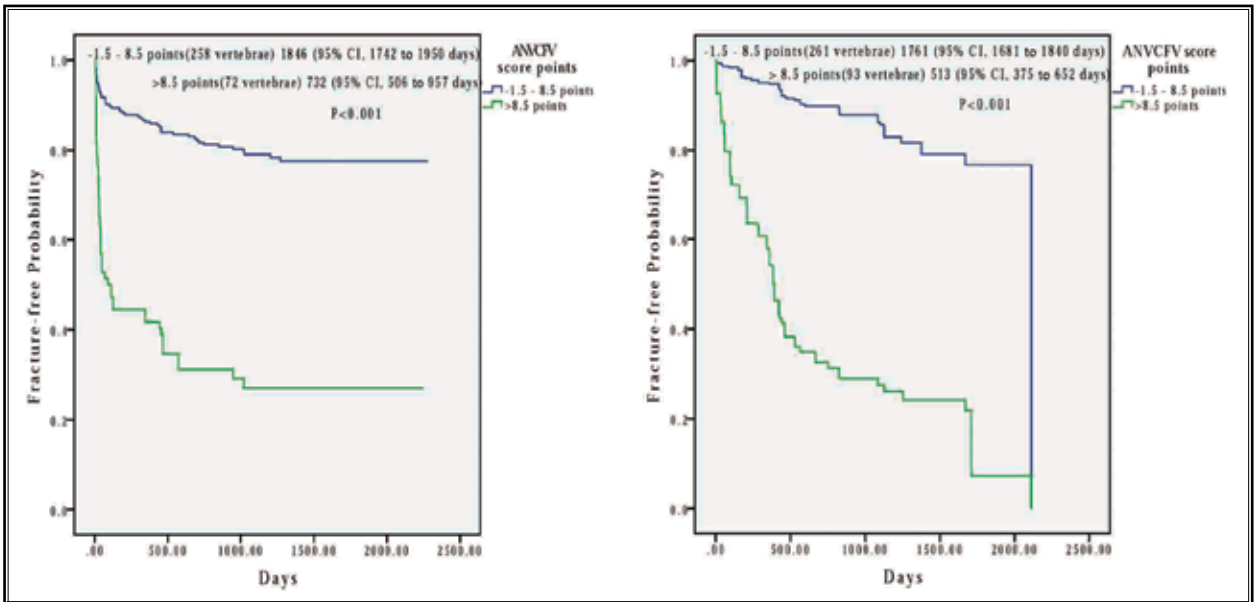

Fig. 3. *(A-B) (A) Fracture-free significance of the two ANVCFV score groups (-1.5 to 8.5 points, > 8.5 points) in the training cohort. (B) Fracture-free significance of the 2 ANVCFV score groups (-1.5 to 8.5 points, > 8.5 points) in the validation cohort. All analyses were performed with the Kaplan-Meier method and Log-rank test.*

factors for new VCFs after the first PVP (P = 0.044). The degree of osteoporosis is an important risk factor for new VCFs after PVP (10,12,14). Although bone mineral density (BMD) measured by dual energy x-ray absorptiometry is a standard measurement for osteoporosis (15), the accuracy of BMD may be affected by several factors, such as spine degeneration, diffuse idiopathic skeletal hyperostosis, and extra costs (16,17). Several studies showed that the CT values of the vertebrae correlate with BMD in osteoporotic patients (16,18). As an alternative method, CT values (Hounsfield units) may provide a method for determining the regional bone mineral density, even though the CT value of the vertebrae may be affected by the content of fatty marrow or red marrow (16,18,19). The thoracolumbar region is the optimal location for measuring the CT value to reflect the BMD (16,18,19). Our previous study also demonstrated that CT values are a suitable predictive risk factor for new VCFs following the PVP procedure (9).

We demonstrated that the presence of pre-existing old VCF(s) anywhere in the spine is an independent risk factor for a new VCF after the first PVP (P = 0.030). Pre-existing old VCFs may indicate the severity of osteoporosis (20,21), and patients with more severe osteoporosis have repeated VCFs. Prior VCFs may indicate defects in the bone microarchitecture, a skeletal factor that may increase new fracture risk independent of osteoporosis (22). Additionally, alterations in the load distribution onto other vertebrae and impaired bone quality may also lead to new VCFs (23).

This study revealed that cement leakage into the disc (P = 0.002) and superior or inferior distribution in the vertebra (P = 0.002) are independent risk factors for new VCFs in other vertebra(e) after the first PVP. Cement leakage into the disc can produce a direct-pillar effect (due to the difference in strength caused by cement augmentation) to an adjacent-level fracture (24). Additionally, cement leakage, a type of asymmetrical distribution of the bone cement, alters the biomechanics of the spine (8). The augmented vertebra can be 36 times harder than normal spinal cancellous bone (25), whereas the normal disc space and part of the trabecular of the treated vertebral body present as buffer tissues (26). However, the tissue cushion becomes weakened or lost when the cement leaks to the disc level (26). Thus, cement leakage into the disc increases the risk of the new VCFs, especially the risk of an adjacent vertebral fracture. In our training cohort, 48 vertebrae (56.5%) developed into new VCFs adjacent to the treated vertebra, more than half of which (26 vertebrae) exhibited cement leakage around the cemented vertebra. Partial filling and endplate filling of the cement in the vertebra produce apparent stiffness in the vertebral body sections (27). The superior or inferior distribution of the cement in the injected vertebra can also increase the focal vertebral stiffness and change the weight-bearing effect (9). Moreover, the compliance of the side without distribution becomes evident because this side is preferentially deformed, leading to single-sided load transfer (28).

Our study demonstrated that the treatment of more than one vertebra per session is an independent risk factor for new VCFs after the first PVP (P = 0.004). The injected cement can induce a greater modification to the biomechanics of the spine when more than one vertebra is treated with PVP (8). The compressive force on the spine acts along the long axis of the spine (29). This force is much greater when more than one vertebra is injected with cement. Thus, the load transfer that results from the alteration of the biomechanics may increase the burden not only on the adjacent vertebrae but also on the nonadjacent vertebrae (11). Given that the alteration of the biomechanics is due to the cement injection, the volume of injected cement has been suggested as a strong risk factor (30,31). To observe the alteration of the vertebral strength and density when various volumes are injected, we used the cemented vertebral body fraction (CVBF) parameter. In our study, no difference was observed with varying CVBFs in patients with or without a new VCF after the first PVP.

To our knowledge, this study is the first attempt to predict the probability of new VCFs after the first PVP by establishing a scoring system based on the regression coefficients of the significant variables of a Cox regression model. This method of creating a scoring system has been demonstrated as a reasonable, feasible approach in several disease models (32-35). The ANVCFV score identified 2 significantly different groups with respect to fracture-free time, and this score was a significant predictor of whether the patient had a high probability of having a new VCF after the first PVP. Crucially, this scoring system, which is based on the characteristics of the patients in the training cohort, could be applicable in an independent, external validation cohort. The 5 independent risk factors identified are easily measured in daily practice.

There are 2 main limitations of this study. First, this is a retrospective study, and a prospective cohort is warranted for validating the accuracy of this scoring system. Second, a significant difference was noted in the treated vertebrae of PVP per session between the

2 cohorts. This difference may contribute to more fresh fractures occurring in the validation cohort and a more aggressive attitude of the physicians who performed PVP in the validation cohort compared with the training cohort. Moreover, the scoring system might have a broader application if the accuracy in the validation cohort was statistically significantly higher than that in the training cohort (85.3% vs. 77.4%, $P < 0.001$).

Conclusion

In summary, our study verified the independent risk factors for new VCFs after the first PVP, including lower CT value, presence of previous VCFs, intradiscal cement leakage, more than one vertebra treated, and superior or inferior marginal distribution of the cement in the injected vertebra. The ANVCFV score system was developed and demonstrates that patients with an ANVCFV score > 8.5 points might exhibit an increased probability of new VCFs. The general accuracy of prediction for new patients with VCFs after the first PVP within this scoring system was 77.4% in the training cohort and 85.3% in the validation cohort.

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