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A nomogram for postoperative pain relief in patients with osteoporotic vertebral compression fracture treated with polymethylmethacrylate bone cement

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Osteoporotic vertebral compression fractures (OVCFs) can be painful. Percutaneous kyphoplasty (PKP) aims at strengthening the vertebra and reducing pain, but efficacy can vary among patients. The purpose of this study was to establish a risk prediction model for pain relief following PKP in patients with OVCF. This retrospective study included 208 (training set) and 54 (validation set) OVCF patients who underwent bone cement treatment between January 2018 and October 2023. Based on postoperative VAS scores, patients were divided into two groups (0–2 and 3–6). Univariable and multivariable logistic regression identified significant factors affecting VAS scores, leading to the creation of a nomogram model. Internal validation was performed using the bootstrap method. The model's performance and clinical value were evaluated using the area under the receiver operating characteristic curve (AUC), decision curve analysis (DCA), and calibration curves. Four predictors were identified: number of segments, PMMA dose, comorbidities, and central nervous system (CNS) medications. The AUC, DCA, and calibration curves demonstrated good model discrimination and accuracy. The clinical impact plot highlighted the model's practical value. We developed and validated an intuitive nomogram model for predicting a postoperative VAS score ≤ 2, reflecting therapeutic efficacy in OVCF patients treated with PMMA. The model could be used for a more careful selection of patients suitable for PKP and who would benefit the most from PKP. The other patients should at least be advised of the risk of suboptimal pain control or directed toward other treatments.

Keywords Postoperative pain, Osteoporosis, Vertebral compression fractures, Nomogram, Percutaneous kyphoplasty, PMMA dose

As the global population ages, the prevalence of osteoporotic vertebral compression fracture (OVCF) is on the rise, affecting over 1.4 million people worldwide annually and becoming a non-negligible problem for older adults[1]. In addition, OVCF often leads to chronic back pain, limited mobility, impaired physical function, decreased quality of life, and increased mortality in older adult patients, seriously affecting the quality of life of older adult patients. The initial management of stable OVCF is typically conservative and may include medications for pain management, initial activity reduction, a back brace, and medications to help prevent additional fractures. Other conservative management options include a period of bed rest, fracture reduction with axial traction, and a body cast in hyperextension. Conservative treatment for OVCF has many drawbacks, including delayed pain relief, prolonged treatment duration, and long-term bed rest, which can easily cause complications like bedsores, respiratory and urinary tract infections, and constipation[2]. Recently, spinal surgeons, interventional radiologists, and others have developed an interest in vertebral augmentation techniques, such as percutaneous vertebroplasty (PVP) and percutaneous kyphoplasty (PKP)[3,4]. These technologies are known for low trauma, reliable pain relief, and vertebral stabilization, gaining wide acceptance[3].

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The most commonly used filler is polymethylmethacrylate (PMMA) bone cement. Recent studies indicate that PKP does not significantly affect the overall sagittal alignment of OVCF patients; however, patients undergoing PKP have shown significant improvements in pain scores at one or more levels[5]. PKP using bone cement of both high and low viscosity has been shown to alleviate patient pain and aid in rehabilitation. Accordingly, the visual analogue scale (VAS) score has been adopted by several studies as a metric to gauge the postoperative effectiveness of PKP[6,7]. Nevertheless, research dedicated to creating a VAS-based predictive model for postoperative outcomes in PKP remains limited.

A retrospective study evaluated five predictors for a high post-treatment VAS score (≥ 5) after conservative, sham, or PVP: female, a baseline VAS score > 8, long-term baseline pain, a mild/severe Genant score, and the development of new fractures during a 12-month follow-up[8]. In the field of orthopedic surgery, studies have used VAS indicators to construct models for predicting surgical efficacy[9,10]. One such study evaluated possible predictors for moderate to severe postoperative pain in ankle fracture surgeries in the post-anesthesia care unit. Using a VAS or verbal numeric rating scale for pain assessment, it was noted that females reported higher pain intensity scores than males[9].

A nomogram is a graphical representation of a regression equation to simplify the prediction of an outcome event. It works by assigning points to each predictor variable proportional to its regression coefficients, and the sum of these points yields a total score indicating the predicted probability of an event. Its user-friendly nature and straightforward interpretation have made the nomogram a popular choice in clinical practice for simultaneous diagnosis and prediction of multifactorial diseases[11,12]. Rather than simply identifying risk factors for an outcome or quantifying the risk based on single factors, a nomogram considers multiple factors that are already weighted to each other through multivariable analyses. It could provide a fast and visual means to evaluate the risk of suboptimal pain control after PKP. Some previous studies developed nomograms for postoperative pain or poor outcomes related to pain in ankle fractures[13], tibial fractures[14], and hip fractures[15,16], but the treatment methods are very different from PKP.

This study aims to address the gap in predicting postoperative pain by developing a nomogram model for the early prediction of pain relief following PKP. Establishing a nomogram model benefiting clinical workers for early prediction of pain relief for OVCF patients. The model could be used for a more careful selection of patients suitable for PKP and who would benefit the most from PKP. The other patients should at least be advised of the risk of suboptimal pain control or directed toward other treatments.

Methods

Participants

This retrospective study was conducted at Harbin 242 Hospital between January 2018 and October 2023, and included 262 patients with OVCF. Of those, 208 patients who underwent treatment between January 2018 and December 2022 were included in the training set, while 54 patients treated between January 2023 and October 2023 were included in the validation set. Inclusion criteria: 1. Patients underwent PMMA bone cement treatment; 2. patient age range from 65 to 90 years; 3. Patients received PKP operation under local anesthesia performed by the same surgeon. Exclusion criteria: 1. Metastatic tumors of the thoracic and lumbar vertebrae; 2. Thoracic and lumbar vertebral burst fractures; 3. Thoracic and lumbar vertebral fractures accompanied by spinal cord and cauda equina nerve injury; 4. Lumbar spondylolisthesis; 5. Lumbar tuberculosis; 6. Infection of lumbar vertebrae or intervertebral discs; 7. Lumbar spinal stenosis (severe); 8. Lumbar brucellosis; 9. Lumbar disc herniation accompanied by radiculopathy, etc. For patients with severe lumbar spinal stenosis, residual compression of the lumbar nerve root may persist after PKP surgery for OVCF. This can result in back and leg pain, which can significantly influence the patient's treatment outcome.

This study adhered to the tenets of the Declaration of Helsinki, and ethical approval was approved by the Ethics Committee of Harbin 242 Hospital (K-2022003). All patients participated in the trial and signed informed consent voluntarily.

Information collection

Variables were obtained from medical records, including age, sex, admission date, discharge date, height, weight, fracture segment, PMMA dose, preoperative VAS score, expense, degree of preoperative compression, calcium tablet and Vitamin D consuming month, basic diseases, long time medication, and dietary habits.

After discharge, the postoperative VAS score was measured at different follow-up times. The postoperative follow-up protocol stipulates that if the modified VAS score for pain drops to 0–1 points between the 1st and 7th days post-surgery, additional follow-up is deemed unnecessary. Typically, at the three-month check-up post-surgery, most patients maintain a VAS score within the 0–1 range. If pain levels are reduced to 4–5 points during the first week, a follow-up at months is recommended to assess if there is a further decrease to 1–2 points. If the score is still 3–4 points three months after surgery, follow-up should continue at six, nine, and twelve months post-surgery. Follow-up is concluded if the patient dies within three months post-surgery due to underlying internal medicine diseases. Otherwise, all cases will have follow-up from one week to 3/6 months post-surgery. The degree of preoperative compression was evaluated as degree 1: mild compression fracture, compression of 20–25% at the height of the protovertebral body, degree 2: moderate compression fracture, 25–40% compression at the height of the protovertebral body, and degree 3: severe compression fracture, compression of > 40% at the height of the protovertebral body. Spine average BMD of 0.929–0.800 was considered as decreased bone mass, and < 0.8 was considered osteoporosis.

Based on the postoperative VAS score, patients were categorized into two groups: the 0–2 group and the 3–6 group. Within these classifications: A score of 0 indicated a cured condition; scores of 1–2 indicated a significant improvement; scores of 3–4 indicated pain reduction, suggesting the treatment was effective; scores

of 5–6 indicated relieved pain; scores of 7–8 indicated no significant improvement, suggesting the treatment was poor or ineffective.

Basic diseases included hypertension, diabetes, spinal diseases, heart diseases, and other diseases. Long-term medications include bone metabolism drugs, metabolic drugs, CNS drugs, cardiovascular system drugs, hormones, antineoplastic drugs, nonsteroidal anti-inflammatory drugs, respiratory system drugs, and adjuvants. For details on these medications, refer to Supplementary Table 1. Dietary Habits included mixed foods, vegetarian, low-salt/low-fat diets, and diabetic diets.

Statistical analysis

Hospitalization days were calculated by discharge date and Admission date. Lesions were defined as follows: involvement of successive vertebral segments was counted as a single lesion. If the two vertebral body segments were discontinuous, each segment was counted as a separate lesion.

Statistical analysis was conducted using R (version 4.3.1). Univariable regression analysis was first performed on each independent variable to screen for potential predictors. An independent t-test or Mann–Whitney U test was used to compare continuous variables, while categorical variables were analyzed using the chi-square or Fisher's exact tests. Logistic regression analysis was conducted to explore the relationships between variables and outcomes. Logistic regression was selected because the outcome was binary. Variables exhibiting a p value < 0.05 in the univariable analysis were considered for entry into the multivariable logistic regression analysis. Subsequently, a nomogram was constructed based on the multivariable binary logistic regression model.

The internal validation of the nomogram model was performed using the bootstrap method, which involved 1000 bootstrap resamples. For each resample, 100 samples were drawn with replacements to form a validation dataset. The area under the receiver operating characteristic (ROC) curve (AUC), decision curve analysis (DCA), and calibration curve was used to evaluate the degree of differentiation and accuracy of the nomogram model, and clinical impact was used to investigate the potential clinical value of the nomogram model. The ROC, DCA, and calibration curve were also performed in the validation set.

Results

Patient characteristics

In this retrospective study, a total of 208 OVCF patients (148 males and 60 females) with an average age of 76.00 (66.75, 82.00) years were included in the training set; a total of 54 OVCF patients (46 males and 8 females) with an average age of 73.50 (68.00, 81.00) years were included in the validation set. There were differences in hospitalization length, BMI, expenses, spine BMD, sex, hypertension, other comorbidities, cardiovascular drugs, nonsteroidal anti-inflammatory drugs, adjuvants, and dietary habits between the two sets (Supplementary Table S2).

According to the postoperative VAS score, the patients in the training set were divided into two groups: 0–2 scores (142 patients) and 3–6 scores (66 patients) groups. The demographic characteristics, basic diseases, long-term medications, degree of preoperative compression, PMMA dose, and dietary habits of the two groups are detailed in Table 1. Among those who received ≥ 8 ml of cement, there were eight cases of anterior or lateral vertebral leakage but no intraspinal leakage or spinal cord or nerve injury. Supplementary Figure S1 presents a patient who received 8 ml of cement.

Characteristics selection

Potential predictors were selected by univariable regression analysis and included in multivariable logistic regression analysis. The odds ratio (OR), 95% confidence interval (CI), and p value of each variable were calculated. The number of segments, PMMA dose, comorbidities, and CNS drugs were statistically significant between groups (Table 2).

Development of the nomogram

The results of the stepwise regression were illustrated in a column chart (Fig. 1), including predictive factors such as the number of segments, PMMA dose, comorbidities, and CNS drugs. In the nomogram, each predictive factor is given a specific number of points proportional to its impact on the outcome. To use the nomogram, the user assigns points for each factor based on a patient's characteristics and then sums these points to get a total score. For each factor, a vertical line is drawn from the variable up to the "Points" axis. The total points are calculated by adding the points of the individual variables together. This total score corresponds to a predicted probability of the outcome. The total point is indicated on its axis, and a vertical line is drawn down to the "Probability" axis, which indicates the probability of scoring 0–2 on the VAS scale. For example, a patient has a fracture of 2 segments (17 points), PMMA dose was 6 (67 points), with comorbidities (9 points), and without CNS drugs (0 points). The total point score is 93, responding to the probability of postoperative VAS scores 0–2 was 0.86 (Supplementary Figure S2). The AUC value was 0.82 (95% CI 0.76–0.88) in the training set, 0.82 (95% CI 0.79–0.85 after 1000 bootstrap resamplings, and 0.70 (95% CI 0.54–0.86) in the validation set (Fig. 2 and Supplementary Figure S3), indicating that the model exhibited good discriminatory ability. The calibration curves of the training and validation sets closely approximated the ideal diagonal lines (Fig. 3). The DCA for the model revealed that when the threshold probability of an individual fell between 70 and 95%, using this model to predict the probability of adverse outcomes would provide a greater net benefit compared to the treat-all or treat-none strategies in the training and validation sets (Fig. 4).

Discussion

In OVCF patients treated with PKP, postoperative VAS scores are crucial for assessing postoperative efficacy. To the best of our knowledge, this study is the first to identify risk factors for achieving low postoperative

Variables	Total (n = 208)	0–2 (n = 142)	3–6 (n = 66)	*P*
Age, M (Q_1, Q_3)	76.00 (66.75, 82.00)	75.00 (65.00, 82.00)	78.00 (72.00, 81.75)	0.151
BMI (kg/m^2), Mean ± SD	24.26 ± 2.21	24.26 ± 2.06	24.27 ± 2.53	0.969
Hospital time (days), M (Q_1, Q_3)	3.00 (2.00, 7.00)	3.00 (2.00, 7.00)	4.00 (3.00, 7.00)	0.111
PMMA dose, M (Q_1, Q_3)	8.00 (6.00, 9.00)	8.00 (6.00, 9.00)	6.00 (5.00, 8.00)	< .001
Postoperative VAS score, M (Q_1, Q_3)	2.00 (1.00, 3.00)	1.00 (1.00, 2.00)	3.50 (3.00, 4.00)	< .001
Follow-up (months), M (Q_1, Q_3)	3.00 (3.00, 6.00)	3.00 (3.00, 6.00)	3.00 (3.00, 5.00)	0.024
Expense (CNY), M (Q_1, Q_3)	32,270.25 (30,292.48, 36,115.05)	32,297.62 (30,295.44, 35,438.65)	32,149.69 (30,301.52, 37,624.76)	0.835
Calcium tablet VD, M (Q_1, Q_3)	12.00 (3.00, 12.00)	12.00 (6.00, 12.00)	6.00 (1.25, 12.00)	0.030
Spine average BMD, M (Q_1, Q_3)	0.79 (0.75, 0.89)	0.81 (0.75, 0.90)	0.78 (0.74, 0.84)	0.062
Number of lesions, M (Q_1, Q_3)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	0.096
Number of segments, M (Q_1, Q_3)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 2.00)	0.036
Degree or preoperative compression, n (%)				0.168
1	72 (34.62)	52 (36.62)	20 (30.30)	
2	101 (48.56)	70 (49.30)	31 (46.97)	
3	35 (16.83)	20 (14.08)	15 (22.73)	
Sex, n (%)				0.318
Female	148 (71.15)	98 (69.01)	50 (75.76)	
Male	60 (28.85)	44 (30.99)	16 (24.24)	
Basic diseases, n (%)				0.002
No	42 (20.19)	37 (26.06)	5 (7.58)	
Yes	166 (79.81)	105 (73.94)	61 (92.42)	
Hypertension, n (%)				0.684
No	125 (60.10)	84 (59.15)	41 (62.12)	
Yes	83 (39.90)	58 (40.85)	25 (37.88)	
Diabetes, n (%)				0.932
No	174 (83.65)	119 (83.80)	55 (83.33)	
Yes	34 (16.35)	23 (16.20)	11 (16.67)	
Spinal diseases, n (%)				0.773
No	171 (82.21)	116 (81.69)	55 (83.33)	
Yes	37 (17.79)	26 (18.31)	11 (16.67)	
Heart disease, n (%)				0.932
No	174 (83.65)	119 (83.80)	55 (83.33)	
Yes	34 (16.35)	23 (16.20)	11 (16.67)	
Other basic diseases, n (%)				0.014
No	155 (74.52)	113 (79.58)	42 (63.64)	
Yes	53 (25.48)	29 (20.42)	24 (36.36)	
Bone metabolism drugs, n (%)				0.029
No	55 (26.44)	44 (30.99)	11 (16.67)	
Yes	153 (73.56)	98 (69.01)	55 (83.33)	
Metabolic drugs, n (%)				0.726
No	177 (85.10)	120 (84.51)	57 (86.36)	
Yes	31 (14.90)	22 (15.49)	9 (13.64)	
Nervous system drugs, n (%)				0.007
No	201 (96.63)	141 (99.30)	60 (90.91)	
Yes	7 (3.37)	1 (0.70)	6 (9.09)	
Cardiovascular system drugs, n (%)				0.511
No	116 (55.77)	77 (54.23)	39 (59.09)	
Yes	92 (44.23)	65 (45.77)	27 (40.91)	
Hormones, n (%)				1.000
No	203 (97.60)	139 (97.89)	64 (96.97)	
Yes	5 (2.40)	3 (2.11)	2 (3.03)	
Antineoplastic drugs, n (%)				0.237
No	205 (98.56)	141 (99.30)	64 (96.97)	
Yes	3 (1.44)	1 (0.70)	2 (3.03)	
Nonsteroidal anti-inflammatory drug, n (%)				0.388
No	150 (72.12)	105 (73.94)	45 (68.18)	
Continued				

Variables	Total (n = 208)	0–2 (n = 142)	3–6 (n = 66)	*P*
Yes	58 (27.88)	37 (26.06)	21 (31.82)	
Respiratory system drugs, n (%)				1.000
No	200 (96.15)	137 (96.48)	63 (95.45)	
Yes	8 (3.85)	5 (3.52)	3 (4.55)	
Adjuvants, n (%)				0.966
No	192 (92.31)	131 (92.25)	61 (92.42)	
Yes	16 (7.69)	11 (7.75)	5 (7.58)	
Dietary habit, n (%)				0.240
Mixed food	126 (60.58)	89 (62.68)	37 (56.06)	
Vegetarian diet	18 (8.65)	11 (7.75)	7 (10.61)	
Low salt and fat diet	49 (23.56)	35 (24.65)	14 (21.21)	
Diabetic diet	15 (7.21)	7 (4.93)	8 (12.12)	
Spine average BMD degree, n (%)				0.026
Decreased bone mass	96 (46.15)	73 (51.41)	23 (34.85)	
Osteoporosis	112 (53.85)	69 (48.59)	43 (65.15)	

Table 1. Demographics and clinical characteristics of 208 patients in the training set.

VAS scores (≤2). Independent predictors included the number of segments, PMMA dose, comorbidities, and CNS medications. A well-calibrated nomogram was established, offering clinicians a visual tool to predict the likelihood of successful pain relief post-PKP.

OVCF is common in older adults due to bone fragility. A study aimed to delineate the differences in radiographic and bone fragility features between single and multiple vertebral fractures. They found that 20% of acute OVCF cases involve multiple vertebrae. Moreover, multiple OVCF tend to occur in adjacent vertebrae and are associated with a longer duration of back pain before hospital admission compared to single OVCF cases[17]. Our study also found that OVCF patients with fewer fractured vertebrae who undergo PKP surgery are more likely to achieve lower postoperative VAS scores.

In PKP treatment for OVCF, appropriate adjustment of the PMMA injection volume is essential. Studies have shown that bone cement augmentation enhances screw extraction resistance and lowers the risk of postoperative complications such as screw loosening and vertebral height loss[18,19]. Post-surgical biomechanical stress changes can affect recurrent fracture risk in OVCF patients. PMMA usage during surgery notably affects load transfer and intervertebral disc mechanics[20]. The present study also found an obvious correlation between increasing PMMA volumes and better postoperative VAS scores, indicating that for this type of procedure, choosing the appropriate amount of bone cement is clinically beneficial. The amount of cement to be used depends upon the lesion but also on the surgeon's experience.

The global incidence of comorbidities is increasing with an aging population. Several comorbidities are age-related, and the prevalence of comorbidities increases with age[21,22]. Comorbidities are associated with postoperative complications in older adults, including pain[23–25].

The global incidence of mental and neurological disorders is increasing with age. CNS medications have been reported to heighten fracture risk[26]. Bone injuries can activate sensory nerve fibers' mechanotransducers and lead to the upregulation of pain-promoting neurotransmitters, receptors, and ion channels. This may result in central sensitization in the brain, intensifying pain perception[27]. Patients undergoing surgical treatment for fractures who have neurological damage and are on neurological medications may experience heightened pain sensitivity. A multicenter study found that the patients with acute stroke in the fluoxetine group had a higher fracture rate compared to those in the placebo group, suggesting a potential link between CNS medications and increased fracture risk[28]. The present study also found that neurological drug use is associated with higher VAS scores following PKP. However, clinical studies exploring the relationship between prior neurological drug use and postoperative VAS scores in OCVF patients are limited, indicating a need for further investigation. Nevertheless, considering the high risk of pain in patients taking CNS medication, physicians should evaluate whether the patients really need such medication and whether the patient needs it. Furthermore, the present study could not determine causality. Therefore, it was not possible to determine whether CNS drugs were related to lower pain or whether they were markers of another underlying process influencing pain. It will have to be examined in future studies. PMMA dose and CNS medication are modifiable risk factors since they can be changed. Nevertheless, the model could be used for a more careful selection of patients suitable for PKP and who would benefit the most from PKP. The other patients should at least be advised of the risk of suboptimal pain control or directed toward other treatments.

Machine learning approaches are indeed promising for risk prediction. Nomograms and machine learning are both used to predict outcomes in clinical settings, but they have different strengths and weaknesses[29–31]. Nomograms use clinical and biological variables to estimate patient outcomes. Nomograms are transparent and can help with shared decision-making between patients and clinicians. However, nomograms are based on linear assumptions that cannot handle non-linear relationships[29,31]. On the other hand, machine learning uses computational algorithms to extract features without explicit pre-instructions. Machine learning models can handle non-linear relationships and are more accurate than linear regression models. However, ML models

	Univariable		Multivariable	
Variables	**OR (95%CI)**	***P***	**OR (95%CI)**	***P***
Age				
BMI	1.00 (0.88–1.14)	0.967		
Hospital time	1.02 (0.98–1.07)	0.294		
PMMA dose	0.85 (0.75–0.95)	0.005	0.62 (0.52–0.75)	< 0.001
Expense	1.00 (1.00–1.00)	0.859		
Calcium tablet VD	0.98 (0.95–1.01)	0.230		
Preoperative VAS score	0.81 (0.49–1.33)	0.409		
Number of lesions	1.88 (0.96–3.66)	0.064		
Number of Segment	1.68 (1.08–2.60)	0.020	10.35 (3.90–27.48)	< 0.001
Fracture Degree				
1	1.00 (Reference)			
2	1.15 (0.59 ~ 2.24)	0.679		
3	1.95 (0.84 ~ 4.54)	0.121		
Sex				
Female	1.00 (Reference)			
Male	0.71 (0.37–1.39)	0.319		
Basic diseases				
No	1.00 (Reference)		1.00 (Reference)	
Yes	4.30 (1.60–11.52)	0.004	3.26 (1.16–9.13)	0.025
Hypertension				
No	1.00 (Reference)			
Yes	0.88 (0.48–1.61)	0.684		
Diabetes				
No	1.00 (Reference)			
Yes	1.03 (0.47–2.27)	0.932		
Spinal diseases				
No	1.00 (Reference)			
Yes	0.89 (0.41–1.94)	0.773		
Heart disease				
No	1.00 (Reference)			
Yes	1.03 (0.47–2.27)	0.932		
Bone metabolism drugs				
No	1.00 (Reference)		1.00 (Reference)	
Yes	2.24 (1.07–4.70)	0.032	0.46 (0.13–1.64)	0.233
Metabolic drugs				
No	1.00 (Reference)			
Yes	0.86 (0.37–1.99)	0.727		
Nervous system drugs				
No	1.00 (Reference)		1.00 (Reference)	
Yes	14.10 (1.66–119.66)	0.015	10.76 (1.16–99.62)	0.036
Cardiovascular system drugs				
No	1.00 (Reference)			
Yes	0.82 (0.45–1.48)	0.511		
Hormones				
No	1.00 (Reference)			
Yes	1.45 (0.24–8.88)	0.689		
Antineoplastic drugs				
No	1.00 (Reference)			
Yes	4.41 (0.39–49.48)	0.229		
Nonsteroidal anti-inflammatory drug				
No	1.00 (Reference)			
Yes	1.32 (0.70–2.51)	0.389		
Respiratory system drugs				
No	1.00 (Reference)			
Continued				

Variables	Univariable		Multivariable	
	OR (95%CI)	*P*	OR (95%CI)	*P*
Yes	1.30 (0.30–5.63)	0.721		
Adjuvants				
No	1.00 (Reference)			
Yes	0.98 (0.32–2.93)	0.966		
Dietary habit				
Mixed food	1.00 (Reference)			
Vegetarian diet	1.53 (0.55–4.25)	0.414		
Low salt and fat diet	0.96 (0.46–1.99)	0.917		
Diabetic diet	2.75 (0.93–8.13)	0.068		
Spine average BMD degree, n (%)				
Decreased bone mass			1.00 (Reference)	
Osteoporosis	0.68	0.027	1.36 (0.62–2.96)	0.439

Table 2. Univariable and Multivariable Logistic Regression in the training set.

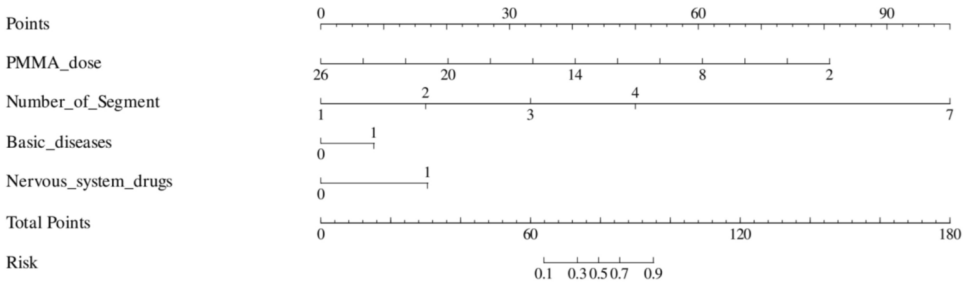

Fig. 1. Nomogram of the prediction model.

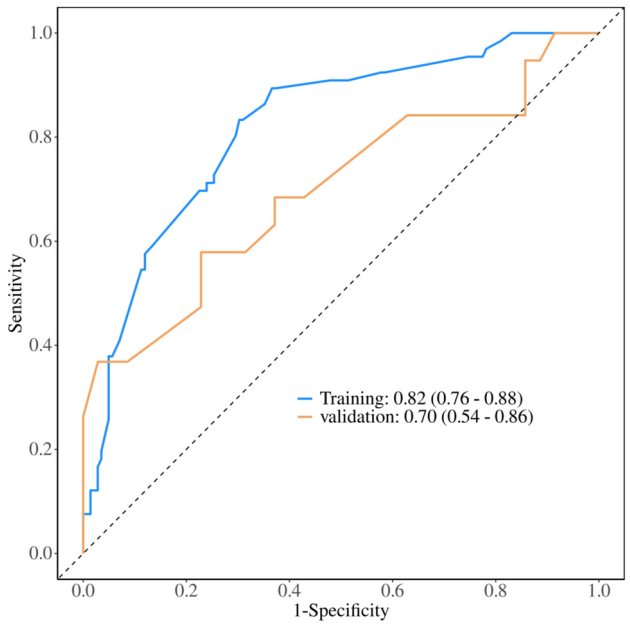

Fig. 2. The ROC curves of the nomogram for VAS. *Notes*: ROC, receiver operating characteristics curve, AUC, area under the curve.

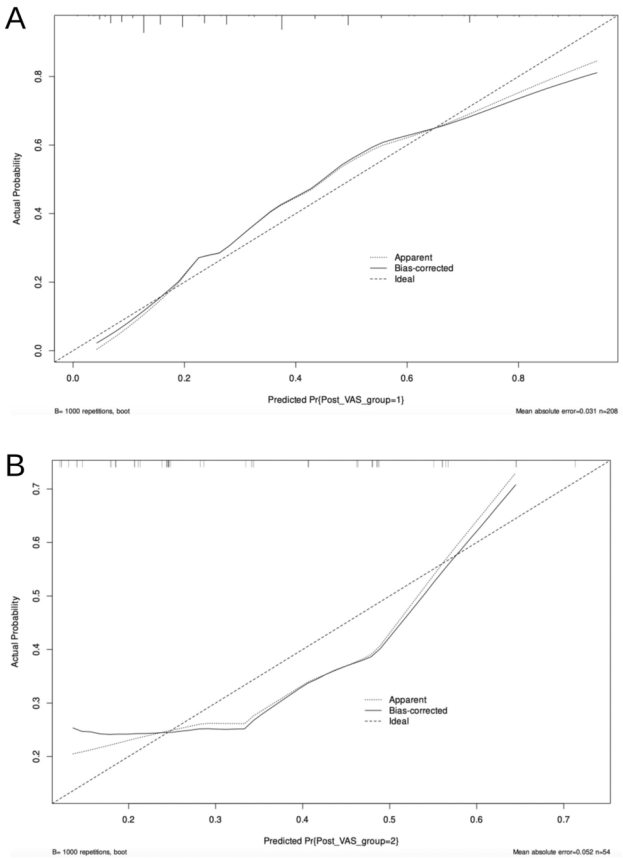

Fig. 3. Validation of NVCF nomogram: calibration curves. (**A**) Training set; (**B**) validation set. *Notes*: For internal calibration, we resampled the data set with replacement 1000 times (bootstrapping) and ran model fitting on all those data sets. When the solid line (predicted model) was closer to the dotted line (observed model), the calibration of the model was better. Smoothed curves between predicted and actual probability are generated using the original data set (apparent) and all resampled data sets (bias-corrected). Abbreviation: NVCF, new vertebral compression fractures

are considered "black-box" models, which can limit their clinical applicability[31,32]. Therefore, for clinical convenience, a nomogram was selected. The model could be used for a more careful selection of patients suitable for PKP and who would benefit the most from PKP. The other patients should at least be advised of the risk of suboptimal pain control or directed toward other treatments.

In the present study, the model was based on the number of affected segments, PMMA dose, comorbidities, and CNS medication achieved an AUC of 0.70–0.82. A previous nomogram based on the presence of an intravertebral vacuum cleft, posterior fascia edema, severe paraspinal muscle degeneration, and blocky cement distribution showed an AUC of 0.780[33]. Another nomogram was based on the number of surgical vertebrae, preoperative BMD, smoking history, thoracolumbar fascia injury, intraoperative facet joint injury, and postoperative incomplete cementing of the fracture line, achieving an AUC of 0.86[34]. A nomogram that included depression, intravertebral vacuum cleft, no anti-osteoporosis treatment, cement volume < 3 ml, and cement distribution had an AUC of 0.83[35]. Of course, differences in the included variables will influence the performance of the nomogram. The variables themselves should also be considered. Compared with other nomograms, the one in the present study appears to include variables that are readily available from the charts without the need for image analysis or specific testing.

This study has several limitations. Firstly, the relatively small sample size constrains the generalizability of the findings, underscoring the need for external validation in larger populations. Although the predictive model was tested on a validation set, both the training and validation data were derived from the same center, which may introduce bias. Additionally, differences in patient characteristics between the two sets, potentially attributable to temporal variations, were observed. Furthermore, the applicability of the nomogram to other populations or settings, including those in different countries, remains uncertain and warrants further investigation through future studies incorporating external validation datasets. Secondly, variations in the timing of VAS score assessments may introduce inconsistencies, posing a limitation. Finally, the retrospective design may have introduced bias, and the analysis of potential risk factors did not account for all variables potentially influencing the postoperative efficacy of PKP.

In conclusion, this study presents a nomogram designed to predict post-PKP pain relief in OVCF patients. This tool aids clinicians in the early detection of patients likely to experience significant postoperative pain,

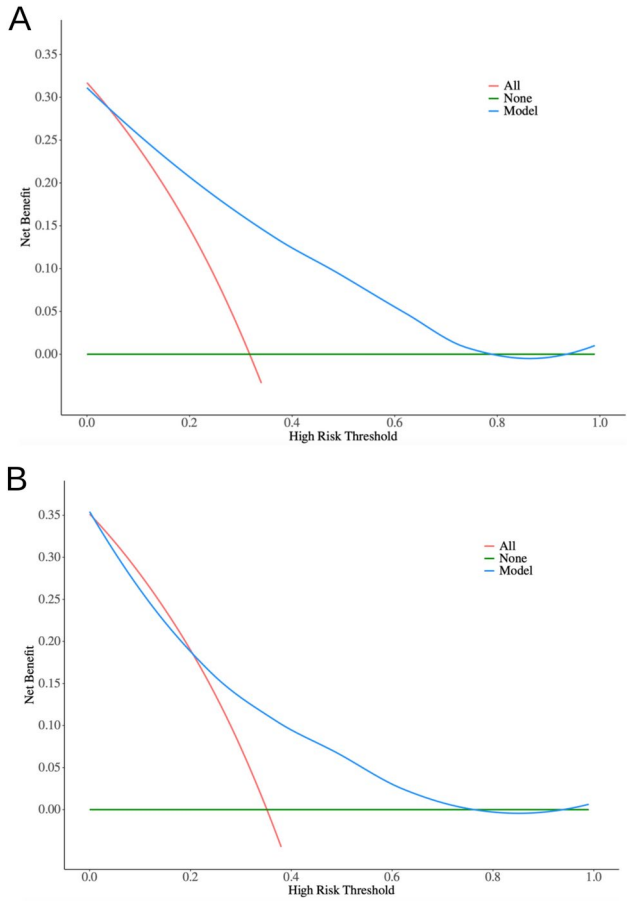

Fig. 4. Decision curve analysis (DCA) for the prediction model. (**A**) training set; (**B**) validation set. *Note*. The graph depicts the expected net benefit per patient relative to the model prediction. The net benefit increases as the model curve is extended.

allowing for personalized risk evaluation and intervention planning. However, the nomogram requires further external validation to determine the individual predictive capability and postoperative efficacy. Particularly, the nomogram needs validation in larger, more diverse populations and comparison with other pain relief prediction models within the same study populations.

Data availability

All data generated or analysed during this study are included in this article and its supplementary information file.

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Author contributions

S.L. and X.X. carried out the studies, participated in collecting data, and drafted the manuscript. S.L., X.S., and C.W. performed the statistical analysis and participated in its design. S.L., X.Q., and W.W. participated in the acquisition, analysis, or interpretation of data and drafted the manuscript. All authors read and approved the final manuscript.

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Declarations

Competing interests

The authors declare no competing interests.

Ethical approval
This study adhered to the tenets of the Declaration of Helsinki, and ethical approval was obtained from/ and is approved by the Ethics Committee of Harbin 242 Hospital (K-2022003).

Consent to participate
All patients participated in the trial and signed informed consent voluntarily.

Additional information
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