

Establishment and Validation of a Risk Prediction Model for the Superior Cluneal Nerve Entrapment Neuropathy after Thoracic or Lumbar Fracture: A Case-Comparative Study

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Background: Superior cluneal nerve entrapment neuropathy (SCNEN) is a known complication following spinal fractures. There is a lack of comprehensive understanding of this condition, and clinical management strategies remain underdeveloped.

Methods: This study analysed the demographic and radiological data of 340 patients to develop a risk prediction model for SCNEN following surgery for thoracic or lumbar vertebral fractures. Patients were randomized into a derivation cohort (70%) and a validation cohort (30%). The least absolute shrinkage and selection operator (LASSO) regression was applied for variable selection, followed by tenfold cross-validation. Multivariate logistic regression was performed on the identified predictive variables. The model's accuracy and clinical utility were assessed through the receiver operating characteristic (ROC) curves, the calibration curves, and the decision curve analysis (DCA). A rationality analysis was also performed to evaluate the model's diagnostic performance.

Results: This study analysed 19 variables; following analysis using LASSO regression and multivariate logistic regression, it was found that the surgical segment (OR=4.993, 95% CI 2.053–14.200, P=0.001), surgical method (OR=0.549, 95% CI 0.322–0.936, P=0.027), the anteroposterior bone cement distribution ratio (OR=0.956, 95% CI 0.928–0.981, P=0.001), and Cobb angle restoration ratio (OR=0.973, 95% CI 0.952–0.993, P=0.011) were independent predictors of SCNEN (P < 0.05). We developed a nomogram. The AUC for the derivation cohort was 0.795, while the AUC for the validation cohort was 0.806. The Hosmer-Lemeshow test indicated good model calibration, with P-values of 0.9685 and 0.2422 for the two groups. The DCA demonstrated that the model provided greater net benefit. Further rationality analysis confirmed that combining multiple predictors resulted in better diagnostic performance than using a single predictor.

Conclusion: The nomogram identifies 4 independent risk factors for SCNEN: segment (lumbar vertebra), surgical method (pedicle screw internal fixation), the anteroposterior bone cement distribution ratio, and Cobb angle restoration ratio.

Keywords: SCNEN, fracture of thoracic or lumbar vertebrae, risk prediction model

Introduction

Thoracic or lumbar fractures are the most common type of spinal injury, accounting for approximately 90% of cases.¹ Surgical intervention often provides immediate relief from fracture-related low back pain by facilitating healing. However, some patients continue to experience persistent low back pain along with referred pain in one or both legs and feet following surgery.² Research indicates that this ongoing discomfort is linked to the development of superior cluneal nerve (SCN) entrapment neuropathy (SCNEN) postoperatively.^{3–5} Unfortunately, most clinicians currently do not know how to avoid the occurrence of SCNEN, and few reports have delved into its contributing factors.

The association between SCNEN and low back pain was first described by Strong and Davila in 1957.⁶ Subsequent anatomical studies revealed that the SCN originates from the dorsal branches of the T11-L5 spinal nerves.^{7,8} The SCN traverses the iliocostalis muscle and thoracolumbar fascia before traveling laterally between the thoracolumbar fascia and the iliac crest, where it innervates sensory regions of the lower lumbar and superior gluteal areas.⁹ Research indicates that as the SCN passes through the iliac crest, its medial branches are often compressed within a narrow fibro-osseous tunnel formed by the thoracolumbar fascia and the iliac crest. This entrapment can lead to a range of symptoms.¹⁰ Clinically, SCNEN often mimics radiculopathy caused by lumbar disc herniation or spinal stenosis, leading to its designation as “pseudosciatica”.^{11,12}

Currently, research on SCNEN remains limited. This condition is often caused by factors such as pulling, friction, and compression, which can lead to edema, inflammatory infiltration, and scarring of the SCN, ultimately impairing its ability to move freely within the narrow fibro-osseous tunnel.^{13–15} Vertebral fractures have been linked to an increased risk of SCNEN. While less-invasive microsurgical decompression of the SCN has shown promising results in treating postoperative SCNEN following vertebral fractures.^{4,14} However, clinicians have limited understanding of SCNEN. This study aims to address this gap by analyzing the incidence and risk factors of postoperative SCNEN after thoracic or lumbar fractures. Additionally, it seeks to develop and validate a risk prediction model to evaluate its clinical utility. By providing insights into these factors and offering practical strategies to mitigate risks, the study aims to guide both patients and clinicians in reducing the occurrence of SCNEN. Improved understanding and application of preventative techniques may help minimize patient suffering and enhance clinical outcomes.

Materials and Methods

Patients Selection and Recruitment

A total of 340 patients (66 men and 274 women) with an average age of 72.27 ± 9.91 years underwent surgery for thoracic or lumbar fractures at Wuxi Affiliated Hospital of Nanjing University of Chinese Medicine (Figure 1). Surgical approaches were selected based on each patient’s physical condition and the severity of their injury, with all procedures performed by two experienced spine surgeons. All patients were classified into two groups: the SCNEN group and the Non- SCNEN group, based on the diagnostic criteria for SCNEN. Patients were then randomly assigned to either the derivation cohort (70%, $n = 237$) or the validation cohort (30%, $n = 103$). The derivation cohort was used to develop the nomogram model, while the validation cohort was used to validate the model. Informed consent was waived for the present study considering that it was a retrospective study (Evidence grade: III b).¹⁶ This study was approved by the Ethics Committee of Wuxi Affiliated Hospital of Nanjing University of Chinese Medicine (YJS2023031316). All the procedures were followed by the Declaration of Helsinki. All procedures were implemented to ensure participant safety, maintain confidentiality of data, and comply with recognized international research standards. The study was registered with the International Platform of Research Registry (Registration number: researchregistry10906).

Inclusion and Exclusion Criteria

Inclusion criteria: (1) Patients with a confirmed acute vertebral fracture based on anterolateral spine radiography and spinal MRI. (2) Availability of demographic and complete clinical data necessary for the study. (3) Patients who underwent thoracic or lumbar fractures surgery, including pedicle screw internal fixation, percutaneous kyphoplasty (PKP), or percutaneous vertebroplasty (PVP). (4) No history of other spinal injuries during the six-month postoperative follow-up period. Exclusion criteria: (1) Patients with incomplete clinical data required for the study. (2) Patients who developed secondary spinal conditions due to other factors during the six-month postoperative follow-up period. (3) Patients diagnosed with fractures caused by spinal tuberculosis, tumors, infections, or other specific conditions prior to surgery.

SCNEN Diagnostic Criteria

The diagnostic criteria used in this study were based on an article published in the *Spine Journal* in 2017. Patients were considered to have SCNEN if they met the following conditions: (1) Persistent low back pain or leg symptoms were reported

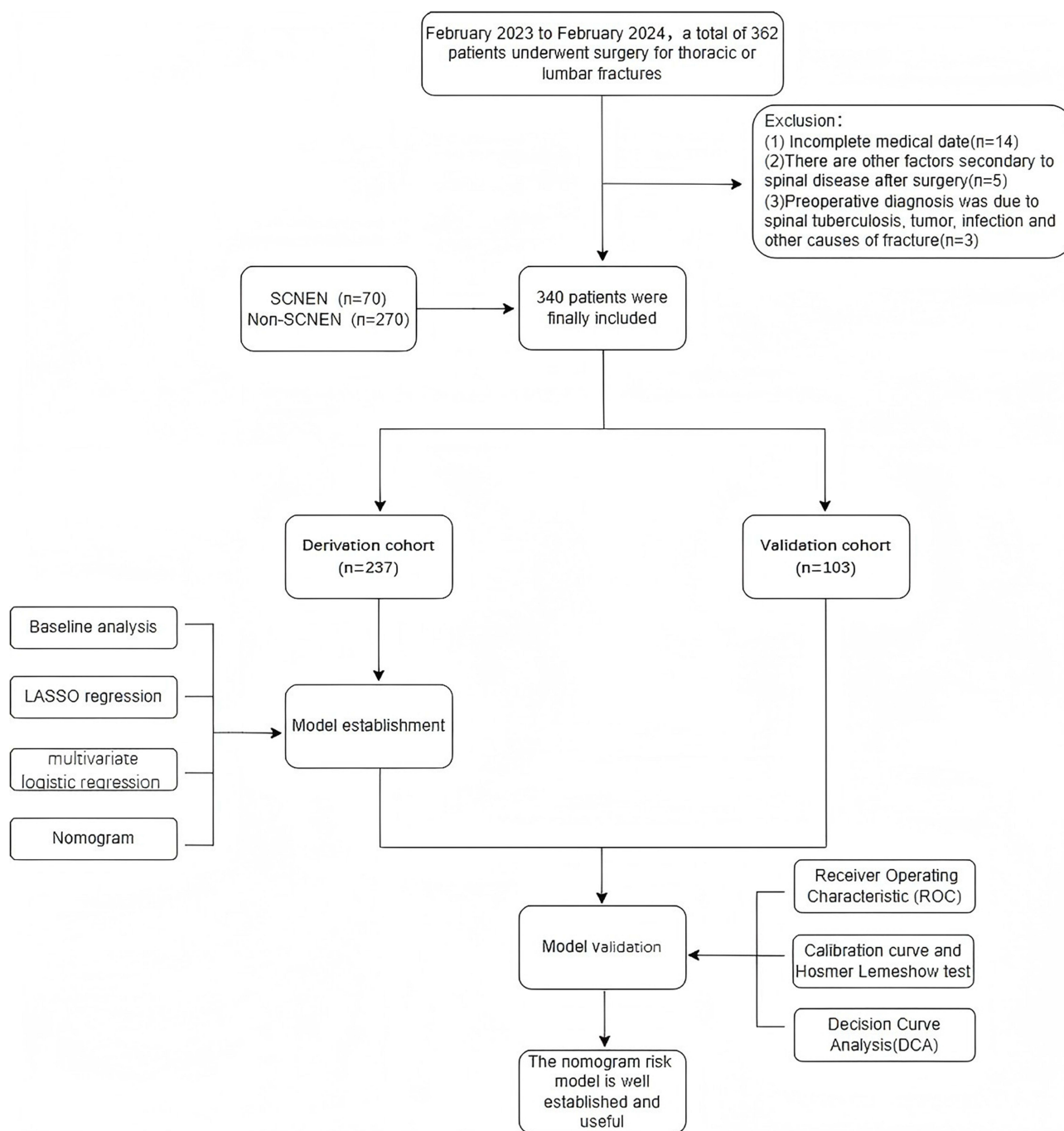


Figure 1 The flow chart describes the process of selection and statistical analysis of SCNEN patients in this study.

after undergoing thoracic or lumbar fracture surgery at our hospital, even after fulfilling the inclusion and exclusion criteria. (2) The most pronounced tender point associated with SCNEN was located 7 cm above the iliac crest along the midline. Pressing this point elicited lower back pain, hip pain, or referred pain in the lower limb, indicative of Tinel's sign. To confirm the diagnosis, a nerve block was administered at the tender point using 2 mL of 1% lidocaine. If symptoms were alleviated by more than 75% within two hours after the injection, the patient was diagnosed with SCNEN.¹⁷

Data Collection

Patient data included general demographics such as gender (male or female), age, BMI, fracture segment (thoracic or lumbar vertebra), fracture to surgery time, and history of thoracic or lumbar vertebral fractures. Surgical data: the type of surgical procedure performed—pedicle screw internal fixation, PKP, or PVP—was recorded. Imaging data: Preoperative MRI scans were reviewed to assess thoracolumbar fascial dropsy (Figure 2C–E). The radiographs were analyzed to measure preoperative vertebral height and preoperative Cobb angle. Postoperative radiographs were used to evaluate the anteroposterior bone cement distribution ratio, lateral bone cement distribution ratio, bone cement leakage, vertebral height, and Cobb angle. Measurement methods: (1) Bone Cement Distribution Ratio: Defined as the mean ratio of the bone cement area to the total vertebral area in both anteroposterior and lateral views on X-ray (Figure 2A and B).¹⁸ (2) Vertebral Height: the average height between the anterior and posterior edges of the vertebral body. (3) Vertebral body compression rate (VBCR): The ratio of the height of the fractured vertebra to the average height of the adjacent vertebrae. (4) Vertebral height restoration ratio: preoperative VBCR minus postoperative VBCR.¹⁹ (5) Cobb Angle: Measured as the angle formed between the upper and lower endplates of the fractured vertebra. (6) Reduction angle: Cobb angle before operation minus Cobb angle after operation (positive lordosis and negative kyphosis). Cobb angle restoration ratio: reduction angle ratio to the preoperative Cobb angle (Figure 2F–H). To ensure consistency, all imaging measurements were independently performed by two experienced spine surgeons. Ten patients were randomly selected for repeat measurements one week later by both spine surgeons and radiologists.²⁰

Statistical Analysis

Data analysis was conducted using SPSS (version 22.0) and R software (version 4.2.0). The “caret” package in R software was used to randomly divide participants into a derivation cohort for model development and a validation cohort for model validation, following a theoretical 7:3 ratio. Baseline characteristics were then compared between the two groups. Quantitative data were presented as mean \pm standard deviation (SD) or the median [interquartile range

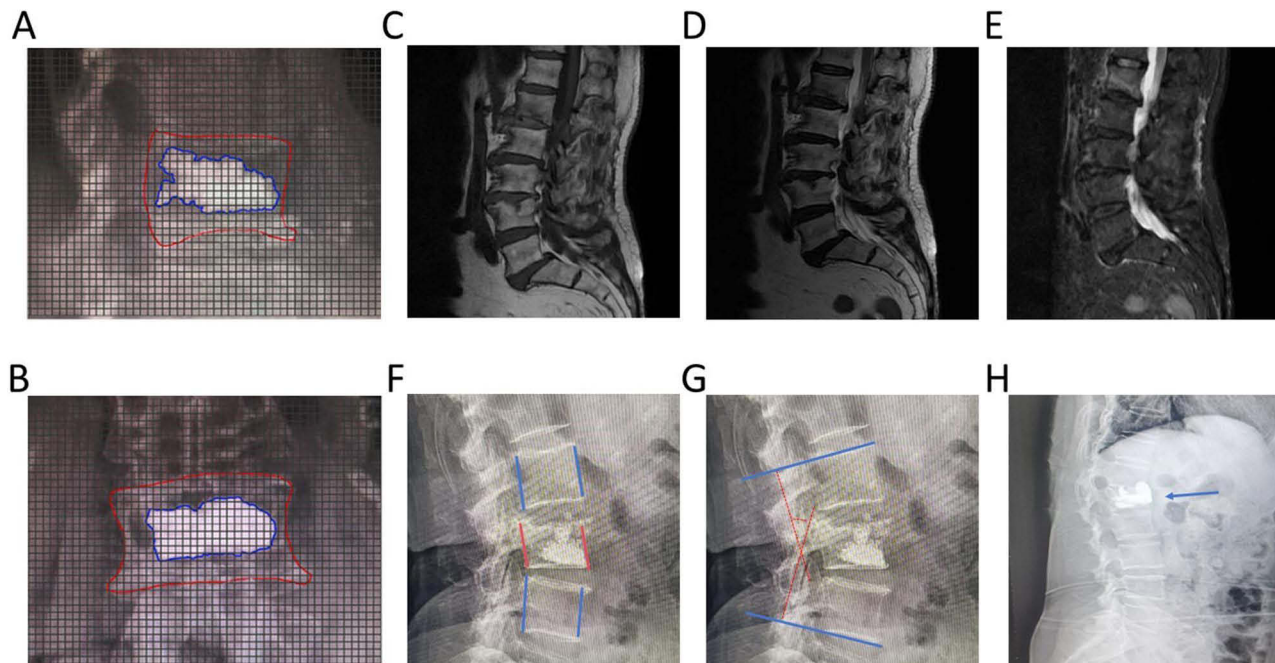


Figure 2 The definition of imaging-based variables. (A and B) The measurement of the anteroposterior bone cement distribution ratio and the lateral bone cement distribution ratio. The red border represents the vertebral border line; the blue border represents the cement border line. (C–E) MRI judge thoracolumbar fascial dropsy (MRI T1W; MRI T2W; MRI T2W FS). (F) The measurement of vertebral body compression rate and vertebral height restoration ratio (The blue lines above are labelled Hs1 and Hs2; the red lines in the middle are denoted by Hf1 and Hf2; the blue lines below are labelled Hi1 and Hi2. Postoperative vertebral height (Hf) = (Hf1 + Hf2) / 2; the average height of vertebral = (Hs1 + Hs2 + Hi1 + Hi2) / 4). (G) The measurement of reduction Cobb angle and Cobb angle restoration ratio. (H) Determine the bone cement leakage. The blue arrow represents the leaked bone cement.

(IQR)], depending on the distribution. Independent sample *t*-tests were applied for normally distributed data, and the Mann–Whitney *U*-test was used for nonparametric data. Categorical data were expressed as percentages and analyzed using Pearson’s Chi-square test or Fisher’s exact test. A *p*-value of less than 0.05 was considered statistically significant.

The least absolute shrinkage and selection operator (LASSO) regression was used for statistical analysis, employing the “glmnet” package in R software to identify potential risk factors. The lambda value was determined using 10-fold cross-validation, and the Rad-Scores for both the derivation and validation cohorts were calculated. Variables selected through LASSO regression were incorporated into a multivariate logistic regression analysis (using stepwise backward selection) to finalize predictive variables, with a significance threshold of $P < 0.05$. To visualize the weight of each predictive factor, the “rms” package in R software was used to construct the risk prediction model. Ultimately, a nomogram was developed to predict SCNEN after thoracic or lumbar surgery based on the finalized predictive model.

In this study, receiver operating characteristic (ROC) curves and the area under the curve (AUC) were used to assess the model’s accuracy and discriminative ability. A risk prediction model was considered to have good discrimination when $AUC > 0.7$, whereas an AUC close to 0.5 indicated low diagnostic value. Calibration curves and the Hosmer–Lemeshow test were used to evaluate the variance between predicted and actual values. The clinical applicability of the model was assessed using decision curve analysis (DCA). All analyses were conducted using the bootstrap method with 500 resampling iterations. Additionally, rationality analysis was performed to further evaluate the model’s superior diagnostic capability.

Results

Patient Characteristics

A total of 340 patients (66 males, 274 females) met the inclusion and exclusion criteria for this study, comprising 70 with SCNEN and 270 Non- SCNEN, with a mean age of 72.27 years (SD \pm 9.91). Patients were randomly assigned to the derivation cohort ($n = 237$) and the validation cohort ($n = 103$) in a 7:3 ratio. Baseline characteristics of the two cohorts are presented in Table 1. Apart from the fracture to surgery time, no significant differences were observed between the cohorts across other variables ($P > 0.05$). The incidence of SCNEN was 17.2% (41/237) in the derivation cohort and 18.4% (19/103) in the validation cohort (Table 1).

Table 1 Comparison of Patient Baseline Characteristics Between the Derivation and Validation Cohorts

Variables	Overall (n=340)	Derivation Cohort (n=237)	Validation Cohort (n=103)	P-value
Sex, n (%)				0.291
Male	66(19.41%)	50(21.10%)	16(15.53%)	
Female	274(80.59%)	187(78.90%)	87(84.47%)	
Age (years)	72.27(9.91)	72.09(9.90)	72.67(9.95)	0.623
BMI (kg/m ²)	22.90(3.00)	23.00(2.98)	22.68(3.04)	0.361
Segment, n (%)				0.322
Thoracic vertebra	114(34%)	75(32%)	39(38%)	
Lumbar vertebra	226(66%)	162(68%)	64(62%)	
Fracture to surgery time (days)	6.25(6.57)	6.81(7.22)	4.96(4.52)	0.005**
History of thoracic or lumbar vertebral fractures, n (%)				0.518
Yes	82(24%)	60(25%)	22(21%)	
No	258(76%)	177(75%)	81(79%)	
Thoracolumbar fascial dropsy, n (%)				0.821
Yes	40(12%)	29(12%)	11(11%)	
No	300(88%)	208(88%)	92(89%)	

(Continued)

Table 1 (Continued).

Variables	Overall (n=340)	Derivation Cohort (n=237)	Validation Cohort (n=103)	P-value
Surgical method, n (%)				0.955
Pedicle screw internal fixation	25(7%)	17(7%)	8(8%)	
PVP	52(15%)	37(16%)	15(15%)	
PKP	262(77%)	182(77%)	80(78%)	
Bone cement leakage, n (%)				0.807
Yes	30(9%)	22(9%)	8(8%)	
No	310(91%)	215(91%)	95(92%)	
The anteroposterior bone cement distribution ratio (%)	52.56(13.47)	51.79(13.37)	54.34(13.58)	0.112
The lateral bone cement distribution ratio (%)	52.64(13.53)	52.08(13.19)	53.93(14.26)	0.265
Preoperative vertebral height (mm)	16.56(4.55)	16.64(4.64)	16.4(4.34)	0.653
Postoperative vertebral height (mm)	20.25(3.83)	20.31(3.83)	20.13(3.86)	0.693
Vertebral body compression rate (%)	65.95(14.55)	66(14.68)	65.79(14.3)	0.905
Vertebral height restoration ratio (%)	15.37(13.38)	15.34(13.9)	15.42(12.16)	0.958
Preoperative Cobb angle (°)	10.32(5.58)	10.21(5.77)	10.57(5.13)	0.562
Postoperative Cobb angle (°)	5.77(3.85)	5.86(3.94)	5.56(3.66)	0.502
Reduction angle (°)	4.55(3.7)	4.35(3.63)	5.01(3.83)	0.137
Cobb angle restoration ratio (%)	44.74(24.32)	43.89(24.16)	46.7(24.68)	0.332

Note: **Statistical significance ($P < 0.01$).

LASSO Regression Analysis

This study analyzed 19 variable factors, and LASSO regression was employed for variable selection in the derivation cohort. Based on the cross-validation results, the optimal model was achieved at $\lambda_{1se} = 0.04413152$. 5 key variables were identified: segment, surgical method, the anteroposterior bone cement distribution ratio, postoperative Cobb angle, and Cobb angle restoration ratio. The shrinkage coefficient and cross-validation plots are illustrated in [Figure 3A](#) and [B](#). Subsequently, the Rad-Score for each sample was calculated. A comparison of the Rad-Score between the 237 patients in the derivation cohort and the 103 patients in the validation cohort revealed that SCNEN patients had significantly higher the rad-Score compared to Non-SCNEN patients, with notable differences ([Figure 3C](#) and [D](#)).

Multivariate Analysis

Based on the results of LASSO regression analysis, 5 feature variables—segment, surgical method, the anteroposterior bone cement distribution ratio, postoperative Cobb angle, and Cobb angle restoration ratio—were selected as independent variables, with SCNEN occurrence as the dependent variable. Multivariable logistic regression analysis, using a stepwise backward selection method, mention 4 factors (segment, surgical method, the anteroposterior bone cement distribution ratio, and Cobb angle restoration ratio) were found statistically significant ($P < 0.05$) ([Table 2](#)).

Construction and Validation of the Nomogram

Using the 4 factors identified by multivariable logistic regression analysis, we developed a nomogram to predict the incidence of SCNEN ([Figure 4](#)). The nomogram indicated that lumbar vertebral fractures, pedicle screw internal fixation, the anteroposterior bone cement distribution ratio, and the Cobb angle restoration ratio were independent risk factors for SCNEN. To evaluate the model's accuracy, a ROC curve was plotted. The area under the curve (AUC) was 0.795 (95% CI: 0.7279–0.8617) in the derivation cohort and 0.806 (95% CI: 0.7027–0.9101) in the validation cohort, demonstrating the model's strong predictive ability for SCNEN risk ([Figure 5A](#) and [D](#)). Calibration of the model was evaluated using the Bootstrap method (500 resamples). The Hosmer-Lemeshow test yielded $P = 0.9685$ (mean absolute error = 0.020) in the derivation cohort and $P = 0.2422$ (mean absolute error = 0.031) in the validation cohort, indicating excellent model calibration ([Figure 5B](#) and [E](#)). The DCA further confirmed the model's clinical utility, with a risk threshold probability

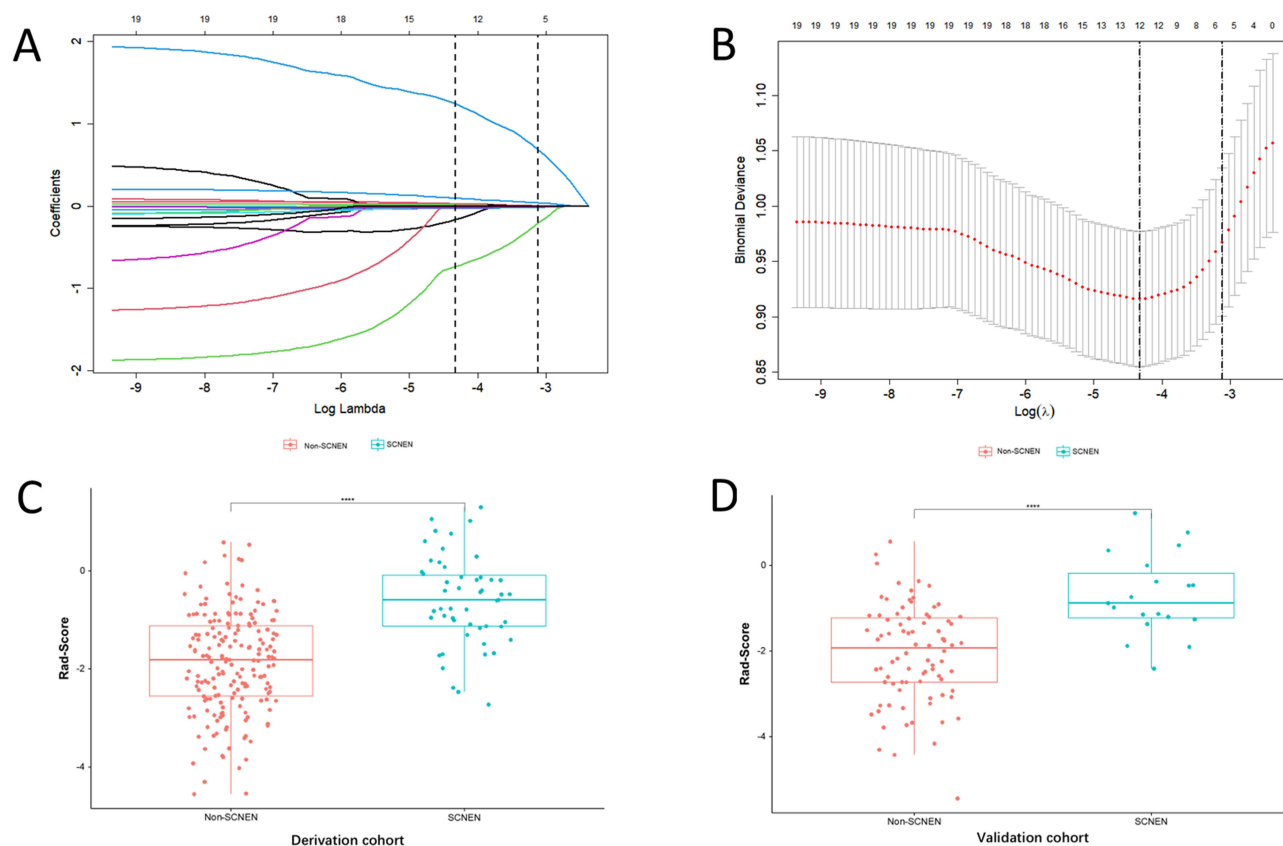


Figure 3 This is Lasso regression. **(A)** Variables were screened and a coefficient profile plot was generated to show the log (lambda) sequence. **(B)** The optimal value of lambda was determined using 10-fold cross-validation. **(C and D)** The derivation cohort and the validation cohort of Rad-Score. The red dots represent the Rad-Score for each non-SCNEN patient, whilst the blue dots represent the Rad-Score for each SCNEN patient. Non-SCNEN vs SCNEN, **** $P < 0.001$.

range of 2.5–80% for the derivation cohort and 7–50% for the validation cohort (Figure 5C and F). Overall, the model showed strong performance in distinguishing the risk of SCNEN.

Rationality Analysis

To evaluate the plausibility and performance of the model, we compared the AUC of the prediction model to the AUCs of its individual predictors (segment, surgical method, the anteroposterior bone cement distribution ratio, and Cobb angle restoration ratio). The results indicated that the AUC of the nomogram model was significantly larger than those of the individual predictors, highlighting the superior diagnostic capability of the combined model (Figure 6A and B).

Table 2 Results of Multivariate Logistic Regression Analyses

Characteristics	Multivariate Analysis			
	β	OR	95% CI	P-value
Segment, n (%)	1.608	4.993	2.053–14.200	0.001***
Surgical method, n (%)	-0.599	0.549	0.322–0.936	0.027*
The anteroposterior bone cement distribution ratio (%)	-0.045	0.956	0.928–0.981	0.001***
Postoperative Cobb angle (°)	0.091	1.095	0.989–1.214	0.079
Cobb angle restoration ratio (%)	-0.027	0.973	0.952–0.993	0.011*

Notes: The values shown in bold black type in this table represent the β , OR, 95% CI and P-value for the 4 statistically significant risk factors. *Statistical significance ($P < 0.05$). ***Statistical significance ($P < 0.001$).

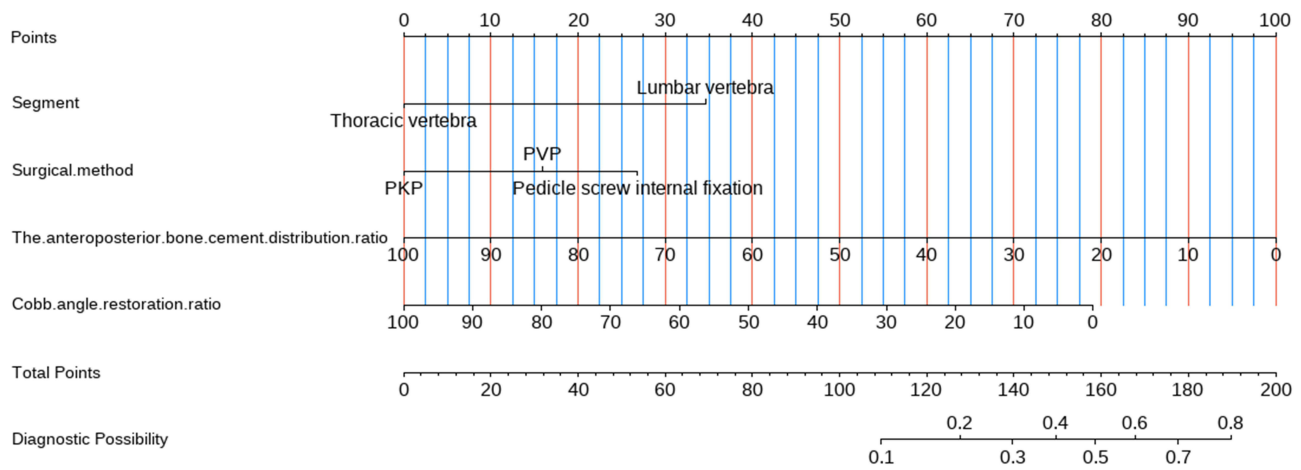


Figure 4 The constructed nomogram for predicting SCNEN.

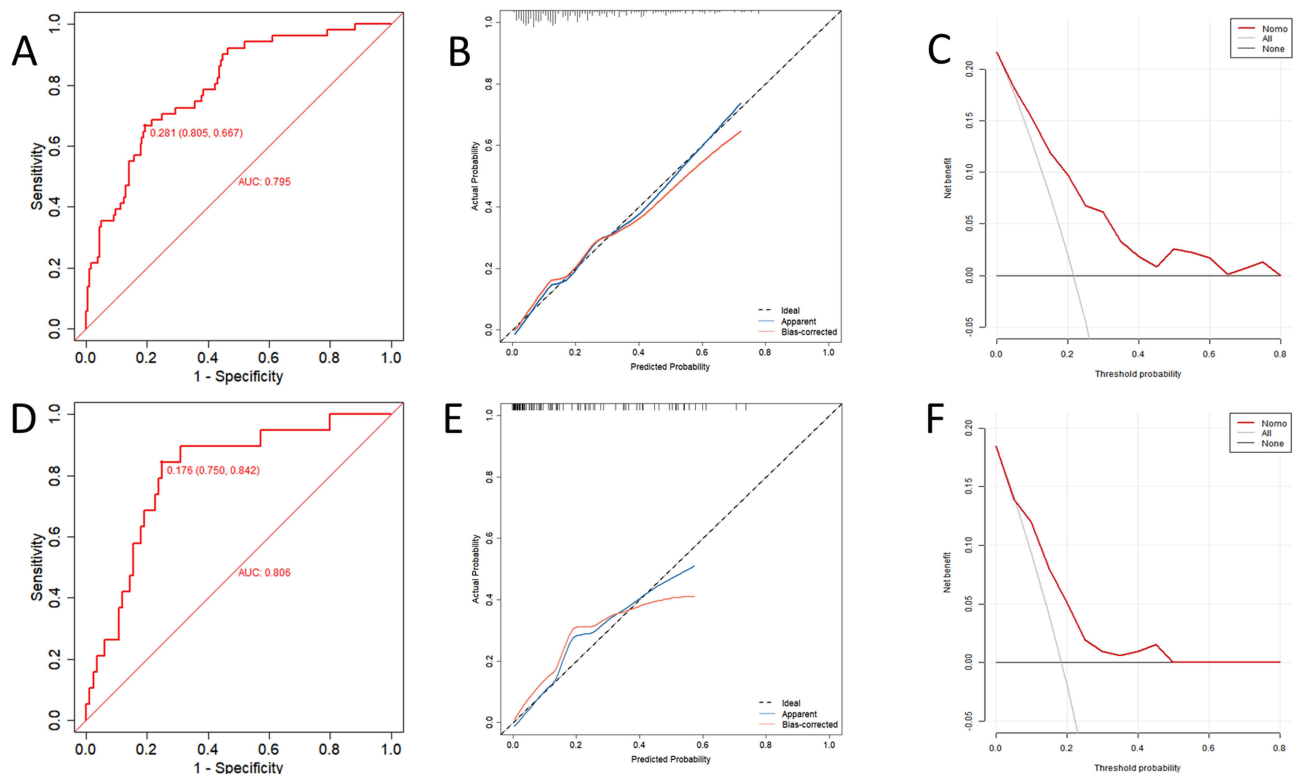


Figure 5 Assessment of the prediction model. (A–C) The ROC, the calibration curves and DCA in the derivation cohort. (D–F) The ROC, the calibration curves and DCA in the validation cohort. The y-axis shows the net benefit: x-axis shows the threshold probability. The red line represents the net benefit of our nomogram. The oblique gray line indicates the hypothesis that all patients had SCNEN. The black horizontal line represents the hypothesis that no patients had SCNEN.

Additionally, we calculated the Nomo-score for each sample based on the nomogram algorithm and created box plots to assess risk stratification. In both the derivation and validation cohorts, the Nomo-scores of the SCNEN group were significantly higher than those of the Non-SCNEN group, showing clear differentiation between the two groups (Figure 6C and D). These findings demonstrate that the prediction model offers better diagnostic performance and risk stratification compared to any single predictor.

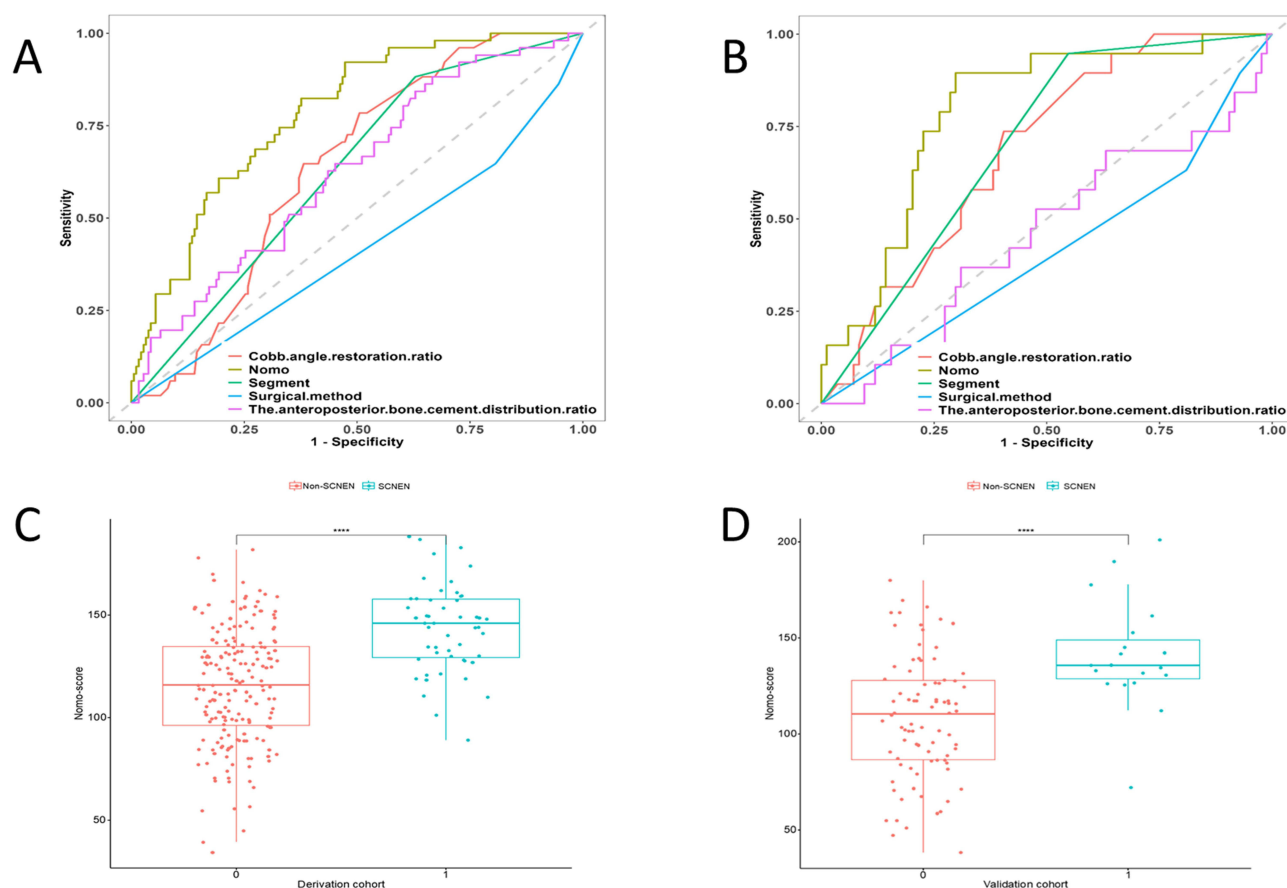


Figure 6 Reasonability analysis of the prediction model by ROC. **(A and B)** Comparison of ROC for the Nomogram model with other clinical indicators in the derivation cohort and the validation cohort. The area beneath each line represents the AUC value for each predictor. **(C and D)** A boxplot of Nomo-score between the derivation cohort and the validation cohort. The red dots represent the Nomo-score for each non-SCNEN patient, whilst the blue dots represent the Nomo-score for each SCNEN patient. Non-SCNEN vs SCNEN, **** $p < 0.001$.

Discussion

As the global population ages, the number of patients with thoracic or lumbar fractures is steadily increasing.²¹ A significant portion of these patients require surgical intervention to restore vertebral height and maintain spinal biomechanical balance. Long-term clinical studies have revealed that some of these patients experience persistent symptoms after surgery, including back pain, unilateral or bilateral radiating leg pain, and intermittent claudication.^{12,22} Extensive anatomical studies have shown that these symptoms are often caused by varying degrees of damage to the SCN following thoracic or lumbar vertebral fractures. This condition is known as SCNEN.²¹ In clinical practice, when SCNEN is suspected, the presence of Tinel's sign at the thoracolumbar fascia penetration point, as well as pain relief following nerve block (at a location 7 cm above the iliac crest from the midline), play a crucial role in the diagnosis. For patients already diagnosed with SCNEN, nerve block anesthesia and surgical decompression are the primary strategies for relief or treatment. However, both approaches have limitations, including the risk of recurrence and the need for repeat surgery.^{23–25} In this context, identifying the risk factors for SCNEN in patients after thoracic or lumbar fractures is crucial. However, to our knowledge, there is a lack of such studies. Therefore, this research aims to analyze data and demonstrate that factors such as fracture segment, surgical method, anteroposterior bone cement distribution ratio, and Cobb angle restoration ratio are associated with the occurrence of SCNEN. The goal is to guide clinicians in minimizing the risk of SCNEN development.

The SCN primarily originates from the dorsal branches of the T11-L5 spinal nerves. An initial study indicated that the main source of the SCN is the dorsal branches of the L1-L3 spinal nerves, with the L1 dorsal root contributing 60%, L2 contributing 27%, and L3 contributing 13%.²⁶ Subsequent research efforts in this field have further confirmed that the

SCN primarily originates from the dorsal branches of the T11-L5 spinal nerves.⁷ It is evident from the above research that, compared to the thoracic spine, the lumbar spinal nerves are the primary origin of the SCN. This results in a significantly higher probability of SCNEN development in patients with lumbar spine fractures than in those with thoracic fractures. Although research in this area is currently limited, our study supports this conclusion. We categorized the fracture segments into two types: thoracic vertebra and lumbar vertebra. The results showed that 10.00% (n=7) of SCNEN cases were caused by thoracic fractures, while 90.00% (n=63) were due to lumbar fractures. Multivariate logistic regression analysis revealed a significant statistical difference (OR=4.993, P=0.001), with lumbar vertebra fractures identified as a risk factor for SCNEN. Therefore, SCNEN should be given greater attention when lumbar vertebral fractures occur.

Currently, three main surgical methods are used to treat patients with thoracic or lumbar fractures: pedicle screw internal fixation, PVP, and PKP. Our research indicates that pedicle screw internal fixation is a risk factor for SCNEN, while PKP serves as a protective factor against the condition. Although pedicle screw internal fixation provides a more stable biomechanical structure, its major drawbacks include significant surgical trauma, long operation time, substantial intraoperative blood loss, and a higher risk of complications. These factors can lead to prolonged traction, ischemia, and edema of the SCN during the procedure, thereby increasing the likelihood of SCNEN development post-surgery. In contrast, PVP and PKP are minimally invasive procedures that offer benefits such as smaller incisions, shorter operation times, less intraoperative blood loss, and faster postoperative recovery. Consequently, the risk of SCN injury is lower with PVP and PKP during the surgical process.²⁷ This is consistent with our research findings. Additionally, studies have shown that the flowability of bone cement and the high-pressure injection during surgery can lead to cement leakage. Furthermore, the heat released during the solidification of the bone cement may cause damage to the spinal nerves.²⁸ PKP is an advanced technique developed from PVP. It involves the use of a balloon to fully expand and create a sealed cavity within the vertebral body, followed by the injection of bone cement into the balloon. This method significantly reduces the risk of bone cement leakage and minimizes the thermal damage to spinal nerves during the cement hardening process.²⁹ Our research also indicates that, compared to PVP, PKP serves as a protective factor against SCNEN.

In this study, we also found a significant correlation between the anteroposterior bone cement distribution ratio in the fractured vertebra and the occurrence of SCNEN. Previous research has shown that the distribution of bone cement within the vertebral body can impact vertebral height and the Cobb angle. The ideal scenario is for the bone cement to be symmetrically distributed within the injured vertebra, but achieving this during surgery is challenging for several reasons. First, during the procedure, the puncture point is often located on one side of the vertebra.³⁰ Second, as the time since injury increases, the fractured vertebra is filled with hematomas, including tissue and fibrous scar tissue, which occupy space and hinder the spread of the bone cement. Research has shown that bone bleeding aspiration prior to the injection of bone cement can significantly enhance the cement's diffusion within the vertebra.^{31,32} Third, bone cement with certain flowability and viscosity can form solid clumps after it hardens within the vertebral body. When the bone cement consists of one or two solid clumps, it becomes difficult to fully fill the injured vertebra. This results in uneven distribution of the spinal stress load across the vertebra, increasing the risk of slight vertebral collapse postoperatively.³³ This can affect vertebral height restoration, Cobb angle reduction, and the subsequent release of SCN compression, traction, and dropsy, which are key factors contributing to SCNEN. Interestingly, our study indicates that the Cobb angle restoration ratio is a risk factor for SCNEN, while the vertebral height restoration ratio has no significant association with SCNEN. The results may be influenced by factors such as the relatively small sample size and the short observation period in the study.

Additionally, our study found that female patients make up the majority of SCNEN cases (Male = 15.71%, n=11), which is consistent with previous research. This may be attributed to factors such as bone mass, body composition, skeletal structure, and childbirth in women. However, there is currently a lack of relevant research reports on this topic.²⁵ Furthermore, in our study, approximately 25% (n=18) of SCNEN patients had a history of thoracic or lumbar fractures, which aligns with a previous statistic showing a 23% (n=26) incidence of such a history.¹¹ This may be due to the fact that previous fractures, although causing minor damage to the SCN, did not result in noticeable clinical symptoms. A fresh vertebral fracture could then trigger asymptomatic or subclinical SCNEN. The findings from earlier studies provide a solid foundation for our current research and have sparked significant interest, serving as motivation for us to conduct further studies in this area.

In our study, we identified, for the first time, the risk factors for SCNEN development following thoracic or lumbar surgery. Given the complexity of the multivariate logistic regression formula, we visualized our results using a nomogram to aid clinical application. The nomogram includes several risk factors (such as fracture segment, surgical method, anteroposterior bone cement distribution ratio, and Cobb angle restoration), with each factor assigned a score. The total score corresponds to the probability of SCNEN occurrence. To validate the accuracy and clinical applicability of the model, we conducted ROC curves, calibration curves, and DCA. The results demonstrated that the predictive model developed in this study has strong clinical performance. Finally, we conducted a rationality analysis, and all the findings indicate that the nomogram we constructed can serve as an effective clinical prediction tool for SCNEN.

However, in clinical practice, SCNEN must be differentiated from various conditions that cause low back pain and sciatica, including lumbar disc herniation, spinal stenosis, sacroiliac joint disorders, lumbosacral syndrome, piriformis syndrome, and paraspinal myofascial inflammation.³⁴ Among these, lumbar disc herniation and spinal stenosis warrant particular attention, with the key points being: physical examination findings and MRI results consistent with the diagnosis; and segmental sensory, motor, or reflex changes. For sacroiliac joint disorders, special attention should be paid to axial low back pain, accompanied by definitive physical examination findings such as the FABER sign, Gaenslen's sign, pelvic compression, and traction tests, with symptom relief following diagnostic testing.^{35,36} Iliopsoas syndrome can be confirmed by injecting a local anesthetic into the iliopsoas ligament; hip flexion may provoke unilateral low back pain.³⁷ Piriformis syndrome: Palpation of the piriformis muscle causes localized pain, and intramuscular injection provides significant pain relief.³⁸ Paraspinal myofascial pain syndrome: Pain is localized to areas of muscle spasm or trigger points, and trigger point injections provide pain relief.

This study also has limitations. The sample size is relatively small, and it is a single-center, short-term retrospective study. Although we made efforts to minimize confounding factors (such as having two experienced surgeons perform the surgeries and ensuring strict measurements of all data), the possibility of confounding factors cannot be entirely ruled out. Additionally, due to technical limitations, the variables included in this study were limited and will need further refinement (eg, bone cement injection volume, surgical duration, number of fractures, and patient bone density values). Therefore, although this model demonstrates high discriminatory power and good fit, it remains necessary to validate it in future external, multicenter cohort studies with larger sample sizes and longer follow-up periods across different geographic regions and populations of diverse racial and ethnic backgrounds.

Conclusion

In conclusion, this study is the first to develop a risk prediction model for SCNEN after thoracic or lumbar spine surgery, offering a faster and more accurate way to predict the incidence of SCNEN. The nomogram identifies four independent risk factors for SCNEN: segment (lumbar vertebra), surgical method (pedicle screw internal fixation), the anteroposterior bone cement distribution ratio, and Cobb angle restoration ratio. Furthermore, we validated the nomogram, and the results demonstrated its high accuracy and clinical applicability. This model provides valuable guidance for clinicians in assessing the risk of SCNEN in patients following thoracic or lumbar fracture surgery, facilitating early intervention. Additionally, it serves as a useful reference for creating personalized diagnostic and treatment plans for patients with SCNEN.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Disclosure

The authors have no conflicts of interest relevant to this article.

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