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ORIGINAL RESEARCH

Development and Validation of a Nomogram Predicting Postoperative Recurrent Lumbar Disc Herniation Based on Activity Factors

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Purpose: To develop an individualized predictive model for postoperative recurrent lumbar disc herniation (PRLDH) in patients undergoing percutaneous endoscopic transforaminal discectomy (PETD) by considering postoperative activity factors.

Patients and Methods: Retrospectively collected data from 612 LDH patients who underwent PETD in our institution from January 2017 to June 2023. They were divided into a training group (429 cases) and a validation group (183 cases). Lasso regression (Model 1) and random forest (Model 2) were applied for variable selection in the training group. The two models were compared in terms of discrimination (the area under curve, AUC), calibration (calibration curve), and clinical utility (decision curve analysis, DCA). Akaike information criterion (AIC) was used for model comparison, and internal validation employed 1000 times Bootstrap + 10-fold cross-validation. Finally, a Nomogram was constructed to display the results and uploaded to the web version.

Results: Among 612 treated LDH patients, 66 (10.78%) developed PRLDH. Model 1, superior in AUC, calibration, DCA, and AIC over Model 2, was chosen as the predictive model. Logistic regression in the training group identified BMI, smoking, activity level score, time to first ambulation, diabetes, Modic change, and Pfirrmann grade as independent predictors of PRLDH. Model 1 exhibited a training group AUC of 0.813 (95% CI 0.753–0.872) and a validation group AUC of 0.868 (95% CI 0.773–0.962). At a Youden index of 0.50, sensitivity was 0.73, specificity was 0.77. Internal validation (1000 times Bootstrap + 10-fold cross-validation) for the training group showed accuracy of 0.889, kappa consistency of 0.112, and AUC of 0.757. The Hosmer-Lemeshow goodness-of-fit tests indicated good discriminative ability for Model 1 in both the training (χ^2=2.895, P=0.941) and validation groups (χ^2=8.197, P=0.414). The DCA and Nomogram are accessible at https://sofarnomogram.shinyapps.io/PRLDHNom/.

Conclusion: The Nomogram predictive model, developed based on postoperative activity factors in this study, demonstrates excellent predictive capability, facilitating risk assessment for the occurrence of PRLDH after PETD.

Keywords: Lumbar disc herniation, percutaneous endoscopic transforaminal discectomy, postoperative recurrent lumbar disc herniation, predictive model

Introduction

Lumbar disc herniation (LDH) represents the most prevalent type of chronic lower back pain, accounting for 39% of patients with chronic lumbar back pain, significantly impacting their daily lives and work.[1] In the treatment of LDH, percutaneous endoscopic transforaminal discectomy (PETD) has gradually emerged as an effective alternative to traditional open surgery, owing to its advantages of minimal invasiveness and rapid recovery.[2] However, postoperative recurrent lumbar disc herniation (PRLDH) remains a challenge for patients undergoing PETD. Despite significant improvement in neurological symptoms following PETD, PRLDH manifests with a recurrence of pronounced neurological impairment six

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months later, confirmed by imaging studies to be a recurrence of disc herniation on the same side and segment.[3] Studies report PRLDH occurrence rates ranging from 5% to 15%, posing considerable challenges for both patients and healthcare providers.[4] Therefore, analyzing and exploring the risk factors for PRLDH post-PETD treatment is crucial in mitigating its risk. With the increasing popularity of daytime surgical procedures and the rapid recovery concept, scholars widely advocate early post-PETD ambulation to reduce associated complications.[5–8] From both patient and societal perspectives, the ability to promptly resume normal life and work post-PETD surgery is a crucial measure of surgery success. However, Kim et al[9] argue that early ambulation may increase the load on the injured intervertebral disc, potentially leading to PRLDH. They suggest considering delaying the first ambulation. Additionally, Wang et al's[10] study indicates that engaging in functional exercises one month postoperatively contributes to improving patient prognosis. Controversy persists regarding the relationship between postoperative activity level, time to first ambulation, and the occurrence of PRLDH. Moreover, the comprehensive assessment and effective application of risk factors in clinical practice face challenges due to the lack of reliable statistical methods. To the best of the authors' knowledge, existing Nomogram models on PRLDH occurrence have not explored the impact of postoperative activity factors.[11–13] So, there is a need to develop a relevant Nomogram model to investigate its influence on PRLDH occurrence.

This study aims to elucidate the role of postoperative activity factors in predicting PRLDH, providing a scientific basis for subsequent clinical treatments. By examining the relationship between postoperative activity factors and PRLDH, we seek to reveal their potential roles in its occurrence, offering novel insights and guidance for clinical practice. This study strictly adheres to the guidelines of the "Transparent Reporting of a Multivariable Prediction Model for Individual Prognosis or Diagnosis (TRIPOD)" with Table S1 providing detailed information.

Materials and Methods

Patients and Risk Factors

This retrospective study selected 612 LDH patients admitted to our hospital between January 2017 and June 2023 as the research cohort. Inclusion criteria were as follows: (1) patients meeting the diagnostic criteria for LDH;[14] (2) a minimum duration of symptoms lasting at least three months with ineffective conservative treatment; (3) preoperative confirmation through imaging examination and treatment plan involving PETD as the initial surgical intervention. Exclusion criteria were as follows: (1) patients who had previously undergone laminotomy or endoscopic nucleotomy procedures; (2) no significant improvement in symptoms after surgery; (3) presence of concomitant spinal tumors, tuberculosis, or deformities; (4) incomplete clinical data; (5) presence of severe cardiovascular or cerebrovascular diseases or other congenital conditions. The surgeries for the ultimately included patients were uniformly performed by a team of highly skilled and experienced surgeons. This study adheres to the relevant requirements of the World Medical Association's Helsinki Declaration. Furthermore, prior to the commencement of the study, all research protocols received approval from our institutional ethics committee.

The risk factors considered in this study encompassed various variables, including age, gender, body mass index (BMI), diabetes, hypertension, smoking and drinking history, preoperative visual analog scale (VAS) score, activity level score, time to first ambulation, educational level, occupation, Pfirrmann grade, Modic change, herniation direction, herniation segments, total disease duration. We have provided a detailed description of the definition of PRLDH in the introduction. Follow-up procedures were primarily conducted through outpatient visits, electronic medical record tracking, and telephone follow-ups for a minimum duration of six months.

Postoperative Activity Factors

This study focuses on postoperative activity factors, specifically time to ambulation and activity level scores. Time to ambulation is defined as the days from surgery to the patient's first instance of getting out of bed. Activity level scores are based on the Chinese Classification of Physical Labor Intensity (GB 3869–1997) and WHO guidelines,[15] categorizing activities into low, medium, and high intensity. Low-intensity activities include seated tasks, slight hand or leg movements, and slow walking (<3.0 METs). Medium-intensity activities involve continuous hand and arm movements, transporting operations, weeding, hoeing, and moderately heavy lifting (>3.0–6.0 METs). High-intensity activities encompass heavy-duty work and fast running (>6.0 METs). Activity duration is categorized as ≤30 minutes/session, 30 minutes-1 hour/session, and >1 hour/session, while total weekly activity time is classified as 1–2 times/week, 3–4 times/week, 5–6 times/week, and above.

Patient postoperative activity levels were assessed through a questionnaire survey. Scores were assigned based on activity intensity and duration, with low, moderate, and high-intensity activities receiving 0, 1, and 2 points, respectively. Similarly, activity duration and weekly frequency were scored on a scale of 0 to 2. Summing these scores yielded a total activity score, representing the patient's overall activity level during the follow-up period. For instance, a patient primarily engaged in low-intensity activities, such as slow walking, for 2 hours each (>1 hour/session) during 6 sessions per week (5–6 times/week and above) would accumulate a weekly low-intensity activity score of 4 points according to the scoring criteria.

Statistical Analysis

All statistical analyses were conducted using R Studio software (v4.2.3, http://www.rproject.org/). Unlike randomized controlled trials, there is no specific standard for sample size calculation in prognostic modeling. Sample size calculations in this study were performed using the "pmsampsize" package. The sample size for the predictive study was computed from four perspectives, and the maximum calculated sample size was adopted as the final sample size. The normality of continuous data was assessed using the Shapiro–Wilk test. Normally distributed metric data were expressed as mean ± standard deviation (±*s*), and comparisons between groups were performed using independent samples *t*-test. Non-normally distributed metric data were represented as median (*P25, P75*), and group comparisons were made using the Mann–Whitney *U*–test. Categorical data were presented as frequencies (%), and group comparisons were conducted using the chi-square test or Fisher's exact probability test. Variable selection for PRLDH occurrence was conducted using random forest and LASSO regression. Logistic regression was then applied separately to the variables selected by both methods.

Two models constructed with different independent variables were compared. The "pROC" package was employed to plot the Area Under the Curve (AUC) of ROC curves for assessing the accuracy of the two models. The "rms" package was used to generate calibration curve and perform the Hosmer-Lemeshow goodness-of-fit test to assess the calibration of the two models. The "rmda" package was utilized for Decision Curve Analysis (DCA) to confirm the clinical utility of the two models. The Akaike Information Criterion (AIC) was computed to determine the optimal model between the two. Internal validation of the best model was performed using the "reportROC" package (Bootstrap + 10-fold cross-validation). Subsequently, results were presented using a Nomogram created with the "nomogramFormula" package, and the Nomogram was uploaded to a web interface via the "rsconnect" package. Statistical significance was defined as $P < 0.05$.

Results

Sample Size Calculation

Sample size calculation, employing the "pmsampsize" package, was performed in four steps, and the results are presented in Table 1. The final computed required sample size is 545.

Clinical Data Comparison Between Two Patient Groups

The study enrolled 612 patients (383 males, 229 females) with an age range of 19–82 years and a mean age of 51.87 ±12.99 years. Follow-up duration averaged 7.99±1.29 months, during which 66 cases experienced recurrence, yielding

Table 1 Sample Size Calculation

	Samp_size	Shrinkage	Parameter	Rsq	Max Rsq	Nag Rsq	EPP
Criteria 1	441	0.900	17	0.288	0.52	0.554	3.11
Criteria 2	545	0.917	17	0.288	0.52	0.554	3.85
Criteria 3	163	0.917	17	0.288	0.52	0.554	1.15
Final	545	0.917	17	0.288	0.52	0.554	3.85

Abbreviations: Rsq, R-squared; Max Rsq, maximum R-squared; Nag Rsq, Nagelkerke R-squared; EPP, Events per Predictor Parameter.

a recurrence rate of 10.78%. Random sampling using the "createDataPartition" function from the "caret" package in R divided the collected cases into a training group (n=429) and a validation group (n=183) in a 7:3 ratio (Table 2).

Model Development

Lasso Regression for Variable Selection

Lasso regression was employed for variable selection in the training group, using PRLDH as the dependent variable (0 for absence, 1 for presence). Among 17 independent variables, the optimal lambda values were selected via 10-fold cross-validation, corresponding to minimum error (min) and one standard deviation error (1se). This study chose

Table 2 Comparison of Characteristics Between the Training and Validation Sets

Characteristics	**Training set (n=429)**	**Validation set (n=183)**	**$t/z/\chi^2$**	***P***
Age	51.83±13.20	51.98±12.52	0.133	0.894
Gender (Male)	266(62.00%)	117(63.93%)	0.129	0.719
BMI(kg/m²)	24.57±2.94	24.64±3.17	0.272	0.785
Diabetes	46(10.72%)	16(8.74%)	0.356	0.551
Hypertension	116(27.04%)	56(30.60%)	0.639	0.424
Smoking	142(33.10%)	65(35.52%)	0.236	0.627
Drinking	88(20.51%)	29(15.85%)	1.517	0.218
Preoperative VAS score*	5(5, 6)	5(5, 6)	12.800	0.418
Time to first ambulation (days)	5(4, 6)	5(4, 6)	12.392	0.873
Activity level score*	4(3, 5)	4(3, 5)	12.684	0.620
Course of disease (months)	7(6, 8)	8(6, 9)	13.619	**0.011**
Educational level			0.578	0.749
Primary school≤	142(33.10%)	59(32.24%)		
Secondary and High school	198(46.15%)	90(49.18%)		
≥College	89(20.75%)	34(18.58%)		
Occupation			3.655	0.455
Unemployed	101(23.54%)	41(22.40%)		
Laborer	49(11.42%)	29(15.85%)		
Farmer	119(27.74%)	48(26.23%)		
office worker	82(19.11%)	39(21.31%)		
Self-employed households	78(18.18%)	26(14.21%)		
Modic change			4.840	0.184
Normal	196(45.68%)	79(43.17%)		
Type I	35(8.16%)	22(12.02%)		
Type II	173(40.33%)	77(42.08%)		
Type III	25(5.83%)	5(2.73%)		
Pfirrmann grade			4.133	0.248
Grade II	57(13.29%)	31(16.94%)		
Grade III	222(51.75%)	100(54.64%)		
Grade IV	130(30.30%)	48(26.23%)		
Grade V	20(4.66%)	4(2.19%)		
Herniation Segments			1.440	0.487
L4/5	229(53.38%)	88(48.09%)		
L5/S1	175(40.79%)	83(45.36%)		
Others	25(5.83%)	12(6.56%)		
Herniation Direction			11.489	**0.003**
Left	202(47.09%)	66(36.07%)		
Right	155(36.13%)	93(50.82%)		
Bilateral	72(16.78%)	24(13.11%)		

Notes: Characteristics marked in bold font indicate significance at $P<0.05$ *Median (*P25, P75*).
Abbreviations: BMI, Body mass index; VAS, Visual analog scale.

lambda=0.027 at 1se, achieving the best performance with 7 variables (Figure 1): smoking, diabetes, BMI, postoperative activity level score, postoperative time to ambulation, Modic changes, and Pfirrmann grade. The multifactorial logistic regression model derived is denoted as Model 1.

Random Forest for Variable Selection

The training group underwent variable selection using the random forest method in machine learning, assessing 17 variables. Variable importance was ranked (Figure 2), and eight variables with importance >4 were identified based on the Gini coefficient. The final selected variables—BMI, postoperative activity level score, postoperative time to ambulation, and Modic changes (*P*<0.05)—were incorporated into the multifactorial logistic regression model denoted as Model 2.

Evaluation of the Predictive Model

Model 1 exhibited an AUC of 0.813 (95% CI 0.753–0.872) in the training group and 0.868 (95% CI 0.773–0.962) in the validation group. Model 2 demonstrated an AUC of 0.756 (95% CI 0.686–0.826) in the training group and 0.790 (95% CI 0.663–0.916) in the validation group. Both Model 1 and Model 2 demonstrated discernment capability for the presence or absence of PRLDH (Figure 3).

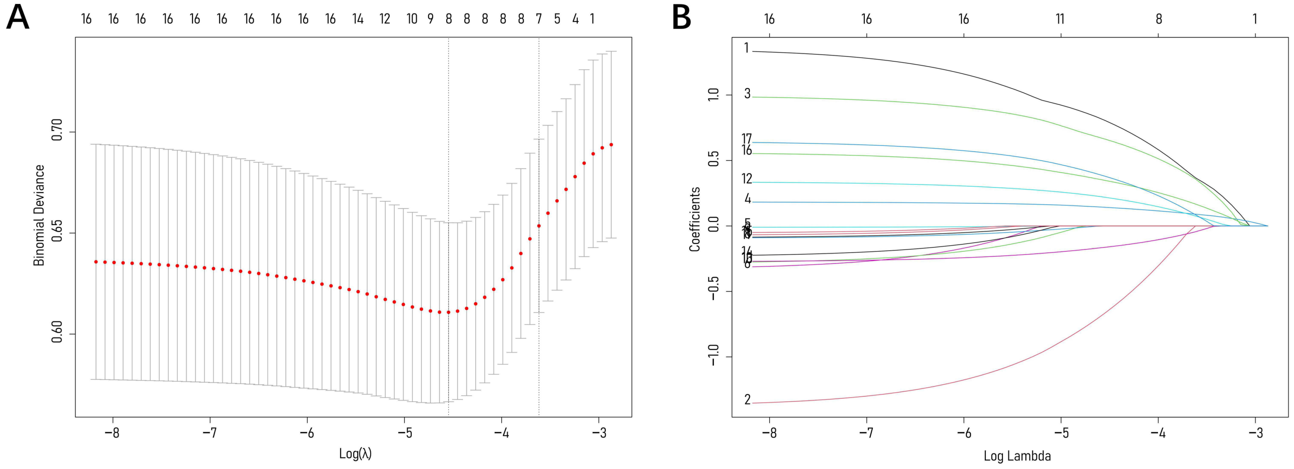

Figure 1 Visualization of LASSO regression analysis results. (**A**) Changes in LASSO regression coefficients. (**B**) Cross-validation identifies the optimal lambda value; the left dashed line corresponds to the lambda that yields the minimum mean, indicating optimal model performance.

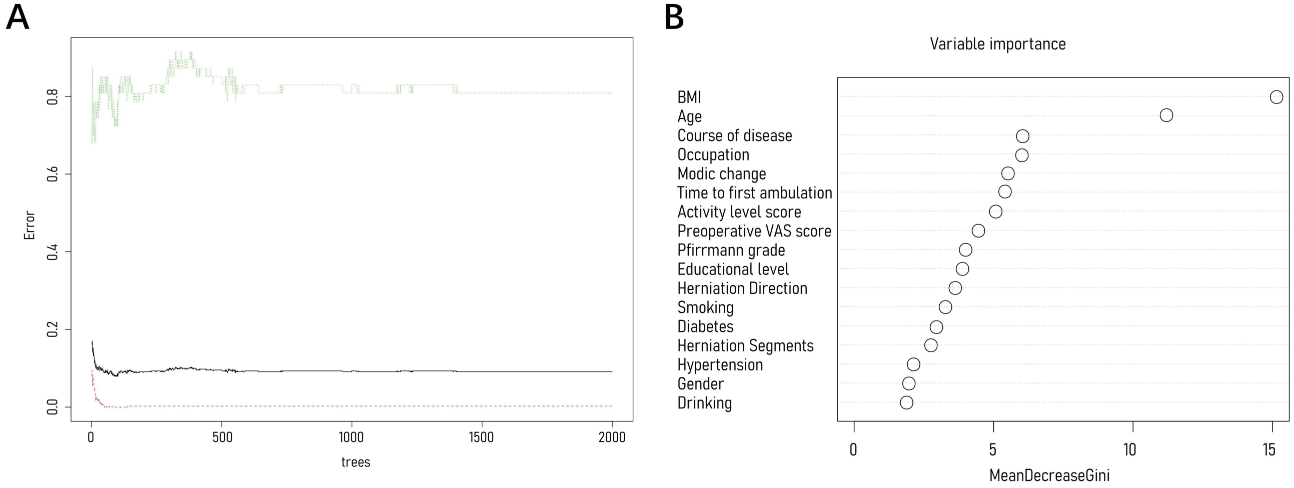

Figure 2 Clinical feature selection using a random forest. (**A**) Relationship between trees and errors in a random forest. (**B**) Variable importance ranking in a random forest.

Model Accuracy

In the training group, Model 1's Hosmer-Lemeshow goodness-of-fit test yielded χ^2=2.895, *P*=0.941, and in the validation group, χ^2=8.197, *P*=0.414. For Model 2, the Hosmer-Lemeshow goodness-of-fit test in the training group resulted in χ^2=7.038, *P*=0.533, and in the validation group, χ^2=6.591, *P*=0.581. The Hosmer-Lemeshow test indicates good consistency between the predicted and actual risk in Model 1 for the training group (Figure 3).

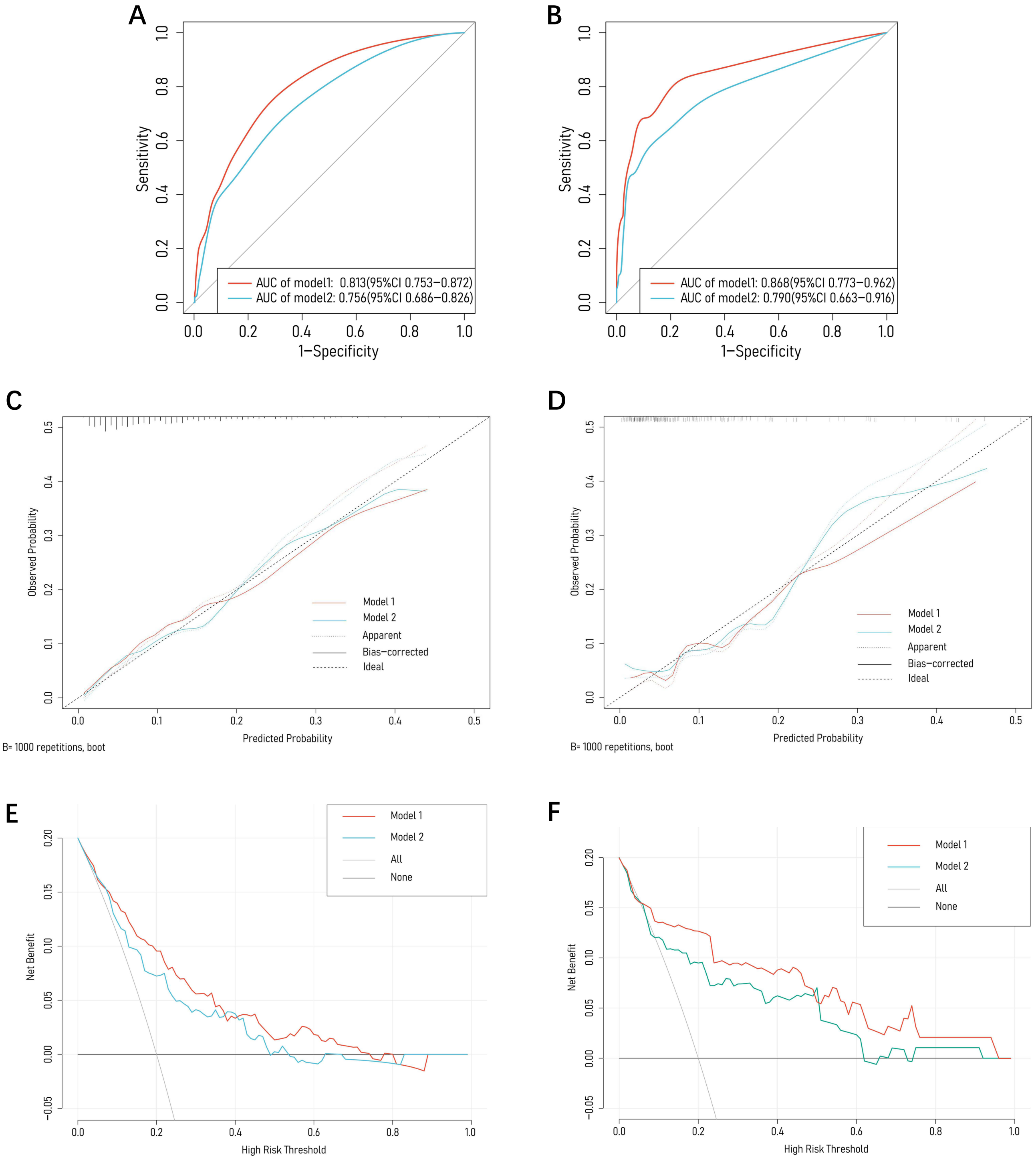

Figure 3 The ROC curve of the predictive model for forecasting PRLDH occurrence. (**A**) Training group. (**B**) Validation group; Calibration curve of the predictive model for forecasting PRLDH occurrence. (**C**) Training group. (**D**) Validation group. Decision curve analysis and Nomogram of the model for forecasting PRLDH occurrence. (**E**) Training group. (**F**) Validation group.

Clinical Utility of the Model

Clinical utility of predictive models, Model 1 and Model 2, was assessed through DCA in the training and validation groups. In the training group, when the threshold probability ranged from 0.02–0.74, Model 1 exhibited higher net benefit than Model 2, with both showing clinical benefit. In the validation group, when the threshold probability ranged from 0.05–0.96, Model 1 demonstrated greater net benefit than Model 2, indicating superior clinical utility within a specified range (Figure 3).

Optimal Model and Visualization

Statistical significance was observed in the comparison between Model 1 and Model 2 (χ^2=21.236, P<0.001). Model 1, with an AIC of 263.569, outperformed Model 2 (AIC=274.805), leading to the selection of Model 1 as the predictive model. The final logistic regression results (Table 3) are expressed as P=1/(1+e^-y), where Y=−9.276–0.202×BMI +0.918×diabetes+0.946×smoking+0.328×activity level score-0.322×time to first ambulation+0.750×Modic changes (I) +0.992×Modic changes (II)+1.616×Modic changes (III)+0.731×Pfirrmann grade (III)+1.783×Pfirrmann grade (IV) +0.568×Pfirrmann grade (V). At the maximum Youden's index of 0.50, sensitivity is 0.73, and specificity is 0.77. Internal validation of Model 1 in the training group, using 1000 Bootstrap iterations and 10-fold cross-validation, yielded accuracy of 0.889, Kappa consistency of 0.112, and AUC of 0.757. The final model was presented as a Nomogram (Figure 4) and uploaded to *https://sofarnomogram.shinyapps.io/PRLDHNom/*.

Discussion

PETD, involving surgical removal of protruding intervertebral disc tissue, effectively decompresses nerve roots and serves as a therapeutic option for managing low back and leg pain caused by LDH, especially when conservative treatments are ineffective. However, the pathogenesis of LDH is multifaceted, involving factors such as degenerative changes in the nucleus pulposus due to disc injury, alterations in collagen fiber alterations from inflammatory cell infiltration, resulting in structural instability, tissue damage, and progressive degenerative changes leading to LDH.[16,17] Consequently, exclusive disc tissue removal during PETD may not adequately address these underlying factors, increasing the risk of postoperative recurrence. Furthermore, routine activities exert their influence upon the aforementioned pathological factors.[18] In the present investigation, we innovatively developed a Nomogram model based on postoperative activity factors to predict the risk of PRLDH occurrence. We observed associations between BMI, smoking, postoperative activity level score, time to first ambulation, diabetes, Modic changes, Pfirrmann grade, and the occurrence of PRLDH. The Nomogram model, based on postoperative activity factors, offers a novel perspective for

Table 3 Logistic Regression Analysis of Risk Factors for PRLDH Occurrence in the Trainset Patients

Variable	***B***	***S.E***	***P***	***OR***	**OR 95% CI**	
					Lower	**Upper**
BMI	0.202	0.062	0.001	1.224	1.087	1.386
Diabetes	0.918	0.461	0.046	2.503	0.987	6.087
Smoking	0.946	0.354	0.007	2.576	1.290	5.198
Activity level score	0.328	0.142	0.021	1.388	1.056	1.845
Time to first ambulation	−0.322	0.148	0.029	0.724	0.540	0.965
Modic change						
I	0.750	0.633	0.236	2.117	0.575	7.080
II	0.992	0.405	0.014	2.696	1.246	6.187
III	1.616	0.664	0.015	5.031	1.294	18.185
Pfirrmann grade						
III	0.731	0.699	0.296	2.076	0.596	9.991
IV	1.784	0.704	0.011	5.948	1.707	29.056
V	0.568	1.030	0.581	1.765	0.196	13.407

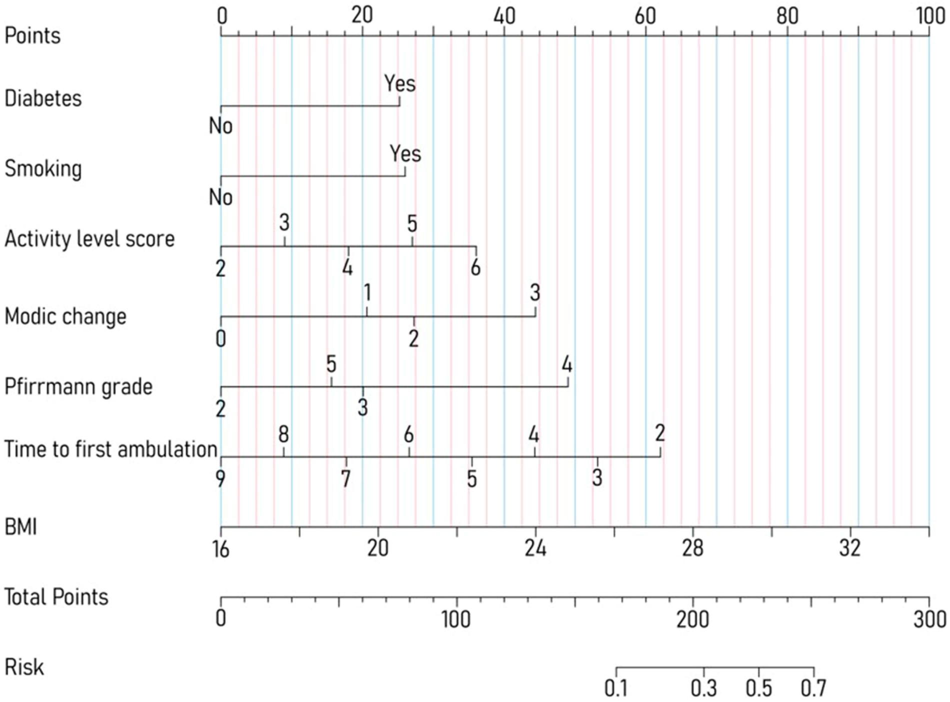

Figure 4 Nomogram for predicting PRLDH.

prognostic assessment in PETD, providing a comprehensive understanding of patient risks and facilitating tailored interventions to reduce the risk of PRLDH occurrence.

BMI, derived from height and weight calculations, has gained wide acceptance as a means to evaluate an individual's body health status. Normally, the intervertebral disc maintains a state of uniform fluid hydrostatic pressure. However, pathological changes disrupt this equilibrium, resulting in an uneven pressure distribution within the disc. Increased BMI exacerbates this situation, thereby elevating the risk of PRLDH. Consequently, weight control and maintaining a normal BMI are advantageous in preventing and mitigating the likelihood of PRLDH occurrence. A substantial body of previous research has consistently substantiated a strong correlation between BMI and LDH, as well as the identification of overweight and obesity as risk factors for PRLDH.[19,20] Moreover, Siccoli et al's[20] prospective study identified the highest incidence of PRLDH among overweight smokers. Smoking's impact on PRLDH occurrence may involve: 1) misalignment and damage to the annulus fibrosus,[21] 2) nicotine-induced vasoconstriction inhibiting proteoglycan synthesis, rendering the intervertebral disc more vulnerable,[22] 3) chronic cough increasing intradiscal pressure,[23] and 4) influencing wound healing.[24] Hence, risk prevention and reduction of PRLDH can be achieved by controlling weight and smoking cessation.

Previous research consistently suggested that postoperative activity factors play a crucial role in the occurrence of PRLDH recurrence. These factors primarily include time to first ambulation postoperatively and the level of post-operative activity. The research regarding the time to first ambulation is outlined as follows. According to the study conducted by Qin et al[6] a 3-month follow-up of 90 patients who underwent percutaneous endoscopic lumbar discectomy (PELD) was performed to investigate the impact of early mobilization (within 3–24 hours, 24–72 hours, and 3–7 days postoperatively) on recurrence. The results showed a recurrence rate of 12.5% in patients who engaged in early mobilization within 3–24 hours, while the other two groups had no recurrence. The researchers suggested that compared to the supine position, standing posture increases intradiscal pressure (IDP), which may be further exacerbated during daily activities. Factors such as annular fiber ring tear and insufficient healing of the annulus fibrosus after PELD contribute to poor recovery, thereby increasing the risk of recurrence. In another study by Kim et al[9] a prospective investigation was conducted involving 300 patients with LDH who underwent PELD. The patients were followed up to assess recurrence rates. Early mobilization was categorized into two groups: early mobilization within 2 days and bed rest for more than 3 days. The overall recurrence rate was 9.33%, with a significantly higher recurrence rate observed in the early mobilization group within 2 days compared to those with bed rest for more than 3 days (16.42% vs 3.13%, *P*=0.001). The researchers attributed the increased risk of recurrence to the elevation of IDP caused by early mobilization. Furthermore, Liang et al[25] conducted a 12-month follow-up study on 213 patients who underwent PELD to observe the recurrence rates between the restricted and unrestricted mobilization groups. Restricted mobilization was defined as less than 1 hour of daily mobilization within 2 weeks postoperatively, with each session lasting less than 30 minutes. Non-restricted mobilization referred to patients engaging in daily activities on the second day after surgery. The results showed a significant difference in recurrence rates between the restricted and non-restricted mobilization groups (4.63% vs 12.38%, *P*=0.042). The researchers also emphasized that the transition from the supine position to upright or flexed positions gradually increases IDP, eventually leading to the re-entry of nucleus pulposus tissue into the spinal canal through the incompletely repaired annular fissures. In clinical practice, the majority of physicians advocate rapid recovery and recommend patients to first ambulation on the day after surgery. However, some physicians suggest that patients should remain bedridden for 3 or 7 days postoperatively, or even longer. Certain researchers propose that, considering the characteristics of fibrous soft tissue scarring and wound healing, patients should be confined to bed for at least 3 weeks.[26] Nevertheless, adhering to such requirements proves challenging for many patients. Our study found that the average time to ambulation was 4.59±1.05 days in the recurrence group and 5.25±1.18 days in the non-recurrence group, with a statistically significant difference.

The studies regarding postoperative activity level are as follows. In a study conducted by Kong et al[27] a six-month follow-up was conducted on 654 patients who underwent PETD to observe the occurrence of PRLDH. The results indicated that high physical load intensity was a risk factor for PRLDH. Unlike the impact of standing position (axial compression) and lying position (no axial compression) on the intervertebral discs, the influence of daily and occupational activities on the discs is diverse and can manifest as flexion, lateral bending, axial rotation, and axial compression. In accordance with Amin et al's[28] study, 30 human cadaveric lumbar discs were subjected to 20,000 cycles of flexion (13–15° and 13°), right axial rotation (2°), and axial compression (1.0 MPa and 1.7 MPa) to simulate the process of lifting heavy objects. The final results revealed that higher axial compression force and greater flexion angle were more likely to cause endplate damage and LDH occurrence. Furthermore, based on a meta-analysis by Belavy et al[29] examining the impact of different exercises on the intervertebral discs, it was found that compared to running, basketball, and other sports, swimming and baseball had a higher rate of intervertebral disc degeneration. This phenomenon could be attributed to the greater amount of repetitive twisting movements involved in the latter two sports. Analysis also demonstrated that an appropriate pattern of exercise-rest-exercise can lead to cyclic compression and rebound of the intervertebral discs, reflecting the movement of fluids within the discs and aiding in the acquisition of necessary nutrients.[30] Based on the aforementioned research findings, shorter postoperative bed rest durations and higher postoperative activity levels imply that the affected intervertebral discs have experienced greater and prolonged mechanical stress, thereby increasing the risk of PRLDH occurrence. To more accurately assess the risk of PRLDH in patients, it is necessary to comprehensively analyze various independent risk factors.

Diabetes also serves as a risk factor in our study. As an endocrine disorder, its influence on connective tissues, including bone and cartilage, is multifaceted. Previous research has demonstrated that diabetic patients with LDH have a higher probability of postoperative recurrence following lumbar disc excision compared to non-diabetic patients (28% vs 3.5%).[31] To elucidate this phenomenon, Robinson et al[32] conducted a mechanistic investigation, comparing intervertebral disc characteristics between diabetic and non-diabetic patients. They observed that diabetic patients exhibited a reduced glycosylation rate of proteoglycans and a decreased quantity of keratan sulfate within the intervertebral discs. Therefore, they hypothesized that these alterations might increase susceptibility to intervertebral disc protrusion. Additionally, diabetes is a major cause of atherosclerosis. Given the avascular nature of the adult intervertebral disc, which exclusively relies on nutritional supply originating from vessels within the annulus fibrosis and endplate, the onset of atherosclerosis in the abdominal aorta can severely constrict the nutritional provisions for the intervertebral disc.[33,34] This provides a theoretical foundation for the occurrence of postoperative recurrent lumbar disc herniation resulting from degenerative changes in the lumbar intervertebral disc. The present study found that Modic changes constitute a significant risk factor for PRLDH occurrence. Previous research has indicated that Modic Type I changes represent biomechanically unstable yet reversible inflammatory lesions, whereas Type II changes denote more stable and less reversible pathological state.[35] Additionally, during the surgical procedure, damage to the endplates of intervertebral discs is prone to occur, exacerbating the deterioration of the microecological environment and further intensifying the pathological changes, consequently elevating the risk of PRLDH occurrence. Pfirrmann grading stands as the preferred classification for IVDD. In this study, the risk of PRLDH occurrence was found to be higher in Pfirrmann grades III and IV compared to grade V. The likely mechanism involves reduced intervertebral mobility due to severe disc degeneration, resulting in localized stability of the intervertebral space.[36] Hasekawa et al[37] in comparing biomechanical parameters between normal and degenerated segments, observed that segments with preserved disc height in degenerated discs might be less stable than segments with collapsed discs. Thus, significant disc degeneration reduces segmental motion, enhancing biomechanical stability and reducing the incidence of PRLDH.

Several limitations exist in this study. Firstly, the study was a single-center retrospective study, and although internal validation using the enhanced Bootstrap method effectively assessed the performance of the model, additional large-scale clinical cohorts are needed for external validation. Secondly, we included only 17 predictive variables, while many other factors such as facet joint conditions and paravertebral muscle status were not incorporated. Therefore, future research should address these limitations and further explore the impact of additional relevant factors.

Conclusion

The Nomogram predictive model, developed based on postoperative activity factors in this study, demonstrates excellent predictive capability, facilitating risk assessment for the occurrence of PRLDH after PETD.

Ethics Approval and Consent to Participate

This study adhered to the Declaration of Helsinki. Ethical approval (2023-keyan-62) was obtained from the Medical Ethics Committee of Hefei Hospital Affiliated to Anhui Medical University, with a waiver for written informed consent. Each patient signed an informed consent at the initiation of diagnosis, allowing for further clinical researcher using the clinical records. For further clarification, please refer to the statement on informed consent waiver.

Disclosure

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