

## Original Article

# LASSO Logistic Regression was Used to Analyze the Risk Factors for Cauda Equina Injury Secondary to Lumbar Spinal Stenosis and to Build a Risk Model

Kai Liu<sup>1</sup>, Yue Wu<sup>2</sup>, Pengfei Ma<sup>1</sup>, Can Zheng<sup>1</sup>, Xuefeng Ma<sup>1</sup>, Xinhua Hu<sup>1</sup>, Wenping Lin<sup>1</sup>, Xu He<sup>1</sup><sup>1</sup>Department of Spine, Shenzhen Pingle Orthopedic Hospital, Shenzhen, China;<sup>2</sup>Department of Nursing, Shenzhen Pingle Orthopedic Hospital, Shenzhen, China

## Abstract

**Objective:** To analyze the risk factors for secondary cauda equina injury in lumbar spinal stenosis using LASSO logistic regression and to construct a risk prediction model in the form of a nomogram. **Methods:** Patients with lumbar spinal stenosis were divided into a secondary injury group (90 cases) and a non-secondary injury group (110 cases). LASSO logistic regression was applied, and a risk nomogram was generated. The predictive efficacy of the model was evaluated using receiver operating characteristic (ROC) curves and calibration curves. **Results:** The ROC curve analysis showed that the area under the curve (AUC) of the risk nomogram model was 0.865 (95% CI: 0.755–0.948), with a sensitivity of 91.11% (82/90), specificity of 93.64% (103/110), and accuracy of 92.50% (185/200). The risk nomogram model demonstrated good fit ( $\chi^2 = 3.347$ ,  $df = 7$ ,  $P = 0.341$ ), and the C-index of Bootstrap internal validation was 0.823. **Conclusion:** Age > 60 years, disease duration > 1 year, multiple stenosis segments, small median sagittal diameter, small cross-sectional area of the spinal canal, and shorter segment length are risk factors for secondary cauda equina injury in patients with lumbar spinal stenosis. The risk prediction model based on this nomogram has good clinical application value.

**Keywords:** Cauda Equina Injury, LASSO Regression, Lumbar Spinal Stenosis, Risk Nomogram

## Introduction

Lumbar spinal stenosis is a common condition in orthopedics, characterized by bone hyperplasia or fibrous tissue hyperplasia and hypertrophy caused by various factors. This results in the narrowing of the spinal canal and compression of the dural sac, spinal cord, or nerve roots, leading to corresponding neurological dysfunction<sup>1,2</sup>. Lumbar spinal stenosis typically has a subtle onset and a slow disease progression, and is most common in middle-

aged and elderly individuals. Its main clinical manifestations include lumbosacral pain, leg pain, progressive weakness and numbness in the lower limbs, intermittent claudication, and difficulty walking. In severe cases, it can also lead to paraplegia and urinary and fecal incontinence<sup>3</sup>.

Cauda equina injury is a common nerve damage condition resulting from lumbar spine disease. When lumbar spinal stenosis occurs, the venous pressure in the spinal canal increases, leading to compression of the peripheral dural sac, inflammatory edema in the spinal canal, and compression of the cauda equina, resulting in ischemia and neuroinflammation, which causes secondary injury<sup>4,5</sup>. The main clinical manifestations of cauda equina injury include bladder motor nerve damage, leading to dysuria, saddle numbness, local tingling, and other muscle strength and sensory dysfunction<sup>6</sup>. Secondary cauda equina injury in patients with lumbar spinal stenosis indicates significant neurological damage, which has a considerable negative impact on their treatment and prognosis<sup>7</sup>. In recent years, potential risk factors for cauda equina injury, such as age, lumbar segment height, and the history of lumbar spinal

The authors have no conflict of interest.

Corresponding author: Kai Liu, Department of Spine, Shenzhen Pingle Orthopedic Hospital, No. 15 Lanjinsi Road, Pingshan District, Shenzhen, Guangdong Province, China  
E-mail: LKAb30@163.com

Edited by: G. Lyritis

Accepted 24 January 2025



stenosis, have gradually attracted clinical attention<sup>8</sup>.

Currently, there is no standardized clinical treatment process for cauda equina injury secondary to lumbar spinal stenosis. Therefore, it is essential to clarify the causes and risk factors of secondary cauda equina injury in lumbar spinal stenosis patients, which may provide theoretical support for diagnosing secondary cauda equina injury. This study collected data from patients with lumbar spinal stenosis, explored the risk factors for secondary cauda equina injury, and developed a risk prediction model that could assist in the clinical treatment and diagnosis of cauda equina injury.

## Materials and Methods

### Participants

200 patients with lumbar spinal stenosis admitted to our unit were selected and divided into two groups: a secondary injury group (90 cases) and a non-secondary injury group (110 cases), based on whether they had secondary cauda equina injury.

### Inclusion Criteria:

- patients who met the diagnostic criteria for lumbar spinal stenosis<sup>9</sup>.
- patients who exhibited intermittent claudication symptoms, with a walking distance of  $\leq 1000$  m.
- patients who were diagnosed with lumbar spinal stenosis based on lumbar MRI examination.
- patients who had complete imaging data available.

### Exclusion Criteria:

- Patients with dysfunction of important organs, such as the heart, liver, or kidneys.
- Patients with a history of lumbar spine surgery.
- Patients with severe acute or chronic infections.
- Patients with congenital spinal developmental malformations.
- Patients who had previously undergone invasive lumbar spine examinations.
- Patients with secondary lumbar spinal stenosis.
- Patients with severe scoliosis or trauma.
- Patients with malignant tumors.
- Patients with severe mental illness.

### Methodology

#### Data collection

The following data were recorded: patients' age, sex, BMI, disease course, most stenotic location, lumbar lordosis angle, type of stenosis, obvious lateral recess stenosis, number of stenosis segments, obvious stenosis of intervertebral foramen, effective sagittal diameter, median sagittal diameter, spinal canal cross-sectional area, segment length, segment height, cross-sectional area of the most stenosis segment, hypoproteinemia, diabetes mellitus, hypertension, chronic obstructive pulmonary disease (COPD), smoking and alcohol consumption.

### Measurement Method of Imaging Indexes

#### Lumbar Lordosis Angle:

In the sagittal position, a line connecting the anterior inferior angle and the anterior superior angle of the L5 and S1 vertebral bodies was drawn. The midpoint of this line was taken, and a perpendicular line was drawn to the midpoint of the line connecting the posterior inferior angle and posterior superior angle of the L5 and S1 vertebral bodies. Similarly, a perpendicular line was drawn between the T12 and L1 vertebral bodies. The angle between the two perpendicular lines was measured as the lumbar lordosis.

#### Obvious Stenosis of Lateral Recess:

Stenosis of the lateral recess was considered when the width at the narrowest point of the lateral recess in the L3-L5 segment was less than 2mm.

#### Obvious Stenosis of Intervertebral Foramen:

Obvious stenosis of the intervertebral foramen was identified by vertical and transverse perineural fat occlusion, nerve collapse, or morphological changes of the nerve roots.

#### Effective Sagittal Diameter:

This is measured as the median sagittal diameter.

#### Spinal canal cross-sectional area:

This is the area enclosed by the posterior longitudinal ligament of the segment and the medial edges of the bilateral pedicles, specifically the ligamentum flavum.

#### Segment Length:

A straight line was drawn from the posterior upper angle of the sagittal L1 vertebral body to the posterior upper angle of the L2 vertebral body. This process was repeated until reaching the posterior upper angle of the S1 vertebral body. The length was then measured.

#### Segmental Height:

This is the distance from the posterior superior angle of the L1 vertebral body to the posterior superior angle of the S1 vertebral body in the sagittal position.

## Statistical analysis

SPSS 25.0 was used to analyze the data. Data with a normal distribution were described as  $\bar{x} \pm s$  for measurement data. Repeated measurement data between multiple groups were analyzed using analysis of variance (ANOVA). The data between two groups were compared using the t-test, and counting data were presented as n (%). The Chi-square ( $\chi^2$ ) test was used to evaluate statistical significance, with  $P < 0.05$  considered significant. Logistic regression analysis was performed to identify the influencing factors of secondary cauda equina injury in patients with lumbar spinal stenosis. A risk nomogram model was constructed, and the predictive performance of the model was evaluated using a receiver operating characteristic (ROC) curve and a calibration curve. The assessment value of injury was classified as

**Table 1.** Univariate Analysis of Secondary Cauda Equina Injury in Patients with Lumbar Spinal Stenosis [n (%)].

| Factor   | Secondary injury group (n=90) | Non-secondary injury group (n=110) | $\chi^2/t$ |        |
|--|-------------------------------|------------------------------------|------------|--------|
| Sex  |                               |                                    |            |        |
| Male   | 34 (37.78)                    | 60 (54.55)                         | 5.587      | 0.018  |
| Female   | 56 (62.22)                    | 50 (45.45)                         |            |        |
| Age  |                               |                                    |            |        |
| < 50 years old   | 23 (25.56)                    | 49 (44.55)                         | 16.118     | <0.001 |
| 50-60 years old  | 28 (31.11)                    | 41 (37.27)                         |            |        |
| > 60 years old   | 39 (43.33)                    | 20 (18.18)                         |            |        |
| BMI  |                               |                                    |            |        |
| <18.50kg/m <sup>2</sup>  | 35 (38.89)                    | 38 (34.55)                         | 0.797      | 0.671  |
| 18.50-23.90kg/m <sup>2</sup>   | 29 (32.22)                    | 42 (38.18)                         |            |        |
| >23.90kg/m <sup>2</sup>  | 26 (28.89)                    | 30 (27.27)                         |            |        |
| Disease course   |                               |                                    |            |        |
| > 1 year   | 48 (53.33)                    | 33 (30.00)                         | 11.184     | 0.001  |
| ≤ 1 year   | 42 (46.67)                    | 77 (70.00)                         |            |        |
| Effective sagittal diameter (mm)                                     | 8.32±1.16                     | 9.75±1.44                          | 7.613      | <0.001 |
| Median sagittal diameter (mm)  | 14.35±1.45                    | 19.23±1.88                         | 20.194     | <0.001 |
| Spinal canal cross-sectional area (mm <sup>2</sup> )                 | 63.85±18.23                   | 91.85±17.35                        | 11.098     | <0.001 |
| Segment length (cm)  | 15.15±1.08                    | 16.74±1.13                         | 10.098     | <0.001 |
| Segment height (cm)  | 14.95±1.38                    | 16.39±1.20                         | 7.890      | <0.001 |
| Number of stenosis segments  |                               |                                    |            |        |
| Single   | 40 (44.44)                    | 66 (60.00)                         | 4.808      | 0.028  |
| Multiple   | 50 (55.56)                    | 44 (40.00)                         |            |        |
| Most stenotic location   |                               |                                    |            |        |
| L <sub>1-2</sub>   | 2 (2.22)                      | 3 (2.73)                           | 2.325      | 0.676  |
| L <sub>2-3</sub>   | 8 (8.89)                      | 5 (4.55)                           |            |        |
| L <sub>3-4</sub>   | 10 (11.11)                    | 15 (13.64)                         |            |        |
| L <sub>4-5</sub>   | 61 (67.78)                    | 72 (65.45)                         |            |        |
| L <sub>5</sub> -S <sub>1</sub>                                       | 9 (10.00)                     | 15 (13.64)                         |            |        |
| Cross-sectional area of the most stenotic segment (cm <sup>2</sup> ) | 0.35±0.13                     | 0.46±0.15                          | 5.475      | <0.001 |
| Lumbar lordosis angle (°)  | 31.20±5.45                    | 32.45±5.56                         | 1.596      | 0.112  |
| Type of stenosis   |                               |                                    |            |        |
| Lumbar disc herniation   | 66 (73.33)                    | 72 (65.45)                         |            |        |
| Vertebral spondylolisthesis  | 3 (3.33)                      | 10 (9.09)                          |            |        |
| Both   | 21 (23.33)                    | 28 (25.45)                         |            |        |
| Obvious stenosis of intervertebral foramen                           |                               |                                    |            |        |
| Yes  | 29 (32.22)                    | 20 (18.18)                         | 5.275      | 0.022  |
| No   | 61 (67.78)                    | 90 (81.82)                         |            |        |
| Obvious lateral recess stenosis                                      |                               |                                    |            |        |
| Yes  | 37 (41.11)                    | 31 (28.18)                         | 3.687      | 0.055  |
| No   | 53 (58.89)                    | 79 (71.82)                         |            |        |
| Hypoproteinemia  |                               |                                    |            |        |
| Yes  | 15 (16.67)                    | 13 (11.82)                         | 0.966      | 0.326  |
| No   | 75 (83.33)                    | 97 (88.18)                         |            |        |
| Diabetes mellitus  |                               |                                    |            |        |
| Yes  | 20 (22.22)                    | 22 (20.00)                         | 0.147      | 0.701  |
| No   | 70 (77.78)                    | 88 (80.00)                         |            |        |
| Hypertension   |                               |                                    |            |        |
| Yes  | 15 (16.67)                    | 23 (20.91)                         | 0.579      | 0.447  |
| No   | 75 (83.33)                    | 87 (79.09)                         |            |        |

Table 1. (Cont. from previous page).

| Factor              | Secondary injury group (n=90) | Non-secondary injury group (n=110) | $\chi^2/t$ |       |
|---------------------|-------------------------------|------------------------------------|------------|-------|
| COPD                |                               |                                    |            |       |
| Yes                 | 12 (13.33)                    | 10 (9.09)                          | 0.910      | 0.340 |
| No                  | 78 (86.67)                    | 100 (90.91)                        |            |       |
| Smoking             |                               |                                    |            |       |
| Yes                 | 38 (42.22)                    | 44 (40.00)                         | 0.101      | 0.751 |
| No                  | 52 (57.78)                    | 66 (60.00)                         |            |       |
| Alcohol consumption |                               |                                    |            |       |
| Yes                 | 41 (45.56)                    | 42 (38.18)                         | 1.109      | 0.292 |
| No                  | 49 (54.44)                    | 68 (61.82)                         |            |       |

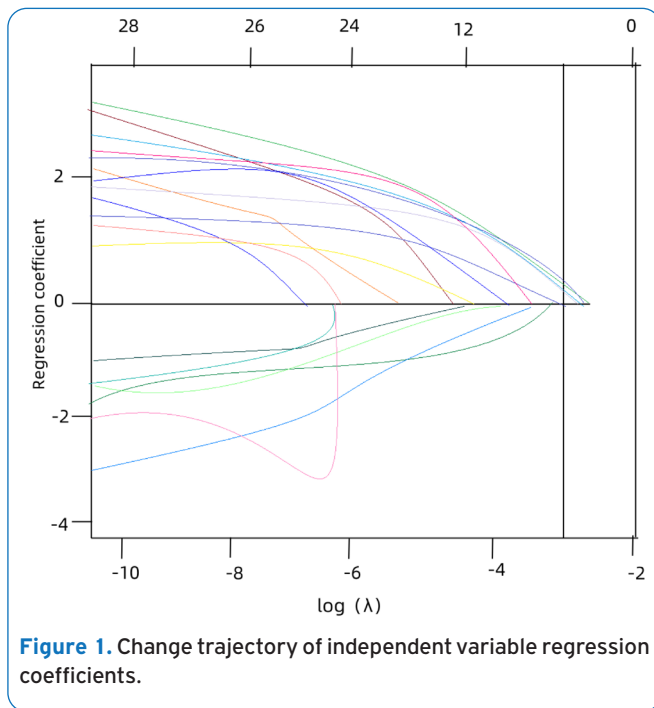


Figure 1. Change trajectory of independent variable regression coefficients.

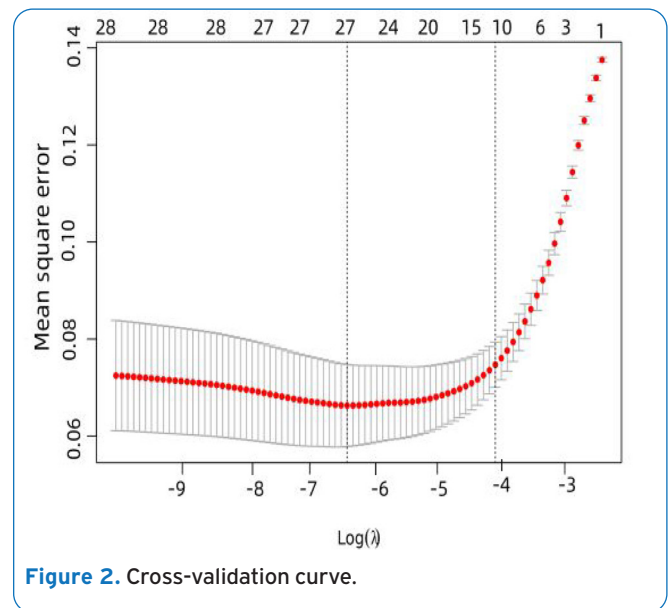


Figure 2. Cross-validation curve.

follows:  $0.50 < AUC \leq 0.70$  indicates low predictive ability;  $0.70 < AUC \leq 0.90$  indicates good predictive ability; and  $AUC > 0.90$  indicates very high predictive ability, with  $P < 0.05$  considered statistically significant.

## Results

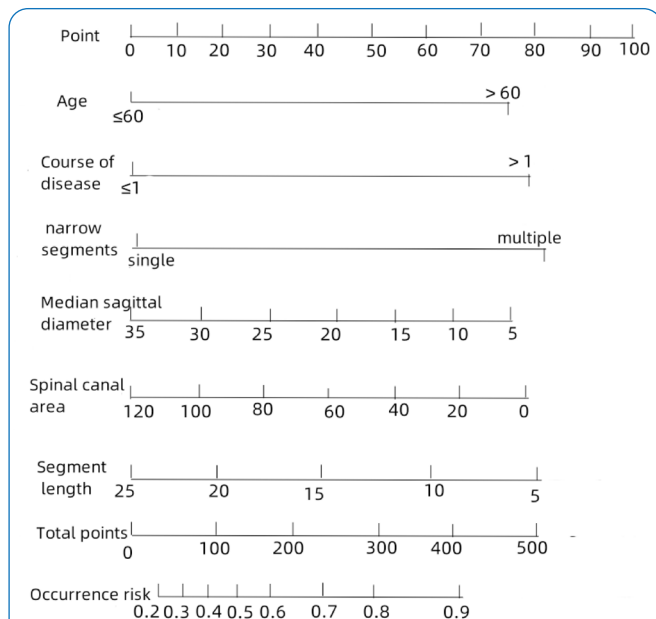
### Univariate Analysis of Influencing Factors for Secondary Cauda Equina Injury in Patients with Lumbar Spinal Stenosis

There were no statistically significant differences in BMI, most stenotic location, lumbar lordosis angle, type

of stenosis, presence of obvious lateral recess stenosis, hypoproteinemia, diabetes mellitus, hypertension, chronic obstructive pulmonary disease (COPD), smoking, and alcohol consumption between the two groups ( $P > 0.05$ ). The proportion of women, patients aged over 60 years, those with a disease duration greater than 1 year, a higher number of stenosis segments, and those with obvious stenosis of the intervertebral foramen were higher in the secondary injury group compared to the non-secondary injury group ( $P < 0.05$ ). Additionally, the effective sagittal diameter, median sagittal diameter, cross-sectional area of the spinal canal, segment length, segment height, and cross-sectional area of the narrowest segment in the secondary injury group were significantly lower than those in the non-secondary injury group ( $P < 0.05$ ) (Table 1).

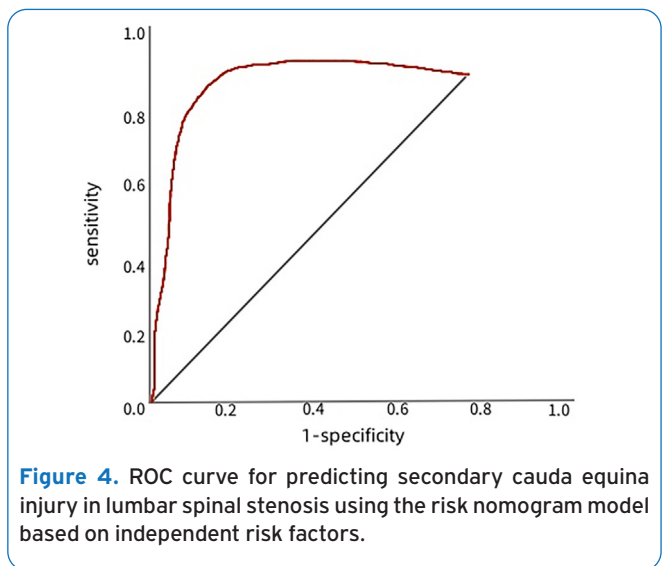
**Table 2.** Logistic Regression Analysis of Factors Associated with Secondary Cauda Equina Injury in Patients with Lumbar Spinal Stenosis.

| Factor                            | $\beta$ | S.E.  | Wald $\chi^2$ | P value | OR value | 95%CI       |
|-----------------------------------|---------|-------|---------------|---------|----------|-------------|
| Age                               | 0.692   | 0.298 | 5.392         | <0.001  | 1.998    | 1.185-3.607 |
| Disease course                    | 0.671   | 0.310 | 4.685         | <0.001  | 1.956    | 1.116-3.587 |
| Number of stenosis segments       | 0.71    | 0.342 | 4.310         | <0.001  | 2.034    | 1.177-4.285 |
| Median sagittal diameter          | 0.708   | 0.305 | 5.388         | <0.001  | 2.030    | 1.168-4.550 |
| Spinal canal cross-sectional area | 0.667   | 0.299 | 4.976         | <0.001  | 1.948    | 1.104-3.897 |
| Segment length                    | 0.706   | 0.325 | 4.719         | <0.001  | 2.026    | 1.156-3.987 |

**Figure 3.** Risk nomogram model constructed using independent risk factors for secondary cauda equina injury in lumbar spinal stenosis.

#### LASSO-Logistic Regression Analysis of Influencing Factors for Secondary Cauda Equina Injury in Patients with Lumbar Spinal Stenosis

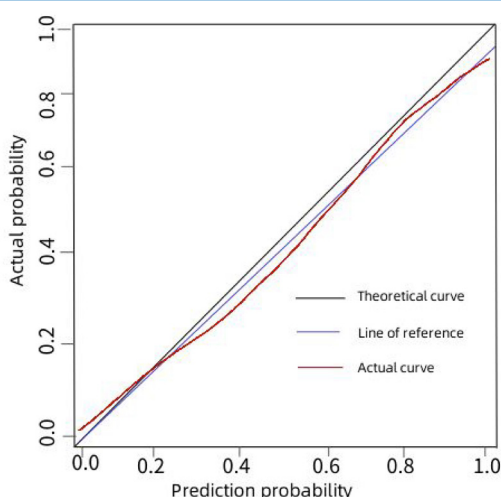
LASSO-logistic regression was used to identify the influencing factors of secondary cauda equina injury in patients with lumbar spinal stenosis, and the optimal  $\lambda$  value was determined through cross-validation. With 10-fold cross-validation, the optimal  $\lambda$  value was found to be 0.021 ( $\log(\lambda) = -2.385$ ). The selected factors included age, disease duration, number of stenosis segments, median sagittal diameter, spinal canal cross-sectional area, and segment length, as shown in Figures 1 and 2. Logistic regression analysis, using secondary cauda equina injury as the dependent variable and the six factors identified

**Figure 4.** ROC curve for predicting secondary cauda equina injury in lumbar spinal stenosis using the risk nomogram model based on independent risk factors.

by LASSO as independent variables, revealed that age > 60 years, disease duration > 1 year, multiple stenosis segments, small median sagittal diameter, small spinal canal cross-sectional area, and small segment length were significant influencing factors for secondary cauda equina injury in patients with lumbar spinal stenosis ( $P < 0.05$ ) (Table 2).

#### Establishment of a Risk Nomogram Model for Secondary Cauda Equina Injury in Patients with Lumbar Spinal Stenosis

Using age, disease duration, number of stenotic segments, median sagittal diameter, cross-sectional area of the spinal canal, and segment length as predictors, a risk nomogram model for secondary cauda equina injury in patients with lumbar spinal stenosis was constructed. Based on the scores assigned to each variable, the total score was used to predict the probability of secondary cauda equina injury in these patients. The model indicated that for patients aged over 60 years, with a disease duration greater than 1 year, multiple stenotic segments, smaller median sagittal



**Figure 5.** Calibration curve of the risk nomogram model based on independent risk factors for secondary cauda equina injury in lumbar spinal stenosis.

diameter, smaller cross-sectional area of the spinal canal, and smaller segment length, the risk of secondary cauda equina injury was higher in patients with lumbar spinal stenosis, as shown in Figure 3.

#### *Predictive Value of the ROC Curve Analysis of the Risk Nomogram Model for Secondary Cauda Equina Injury in Lumbar Spinal Stenosis*

The predictive accuracy of the risk nomogram model was evaluated using the area under the receiver operating characteristic (AUC-ROC) curve. The ROC analysis showed that the AUC of the risk nomogram model was 0.865 (95% CI: 0.755–0.948), with a sensitivity of 91.11% (82/90), specificity of 93.64% (103/110), and accuracy of 92.50% (185/200), as shown in Figure 4.

#### *Calibration Curve Validation of the Risk Nomogram Model*

The calibration curve was constructed to validate the risk nomogram model. The results indicated a high degree of fit ( $\chi^2 = 3.347$ ,  $df = 7$ ,  $P = 0.341$ ). Internal validation using Bootstrap showed a concordance index (C-index) of 0.823, suggesting that the model has good predictive accuracy, as shown in Figure 5.

## Discussion

Cauda equina injury is often associated with lumbar degeneration and is one of the complications of lumbar spinal stenosis<sup>10</sup>. This injury can lead to morphological changes in the cauda equina nerves, which may result in serious conditions such as intraspinal tumors. These

complications can significantly affect patients' daily lives and prognosis, as well as increase the financial burden on families. Therefore, diagnosing cauda equina injury is of paramount importance<sup>11,12</sup>. Analyzing clinical data from patients with lumbar spinal stenosis, this study found that the incidence of secondary cauda equina injury was 45.00%, which is consistent with findings from Nikjou DA et al.<sup>13</sup>, indicating a high incidence of cauda equina injury in patients with lumbar spinal stenosis.

In this study, LASSO-Logistic regression was employed to analyze the risk factors for secondary cauda equina injury in patients with lumbar spinal stenosis. Based on these factors, a line-like diagram prediction model was constructed. The model revealed that for patients aged over 60 years, with a disease course longer than 1 year, multiple stenotic segments, smaller median sagittal diameter, smaller cross-sectional area of the spinal canal, and shorter segment length, there was an increased risk of secondary cauda equina injury in lumbar spinal stenosis patients. Previous studies have shown that the incidence of cauda equina injury in patients with multi-segment lumbar spinal stenosis is significantly higher than in those with single-segment stenosis<sup>14</sup>. The greater the number of stenotic segments, the higher the compression on the cauda equina nerve. The activity of the cauda equina nerve in patients with multi-segmental spinal stenosis is greatly restricted, affecting nerve root function. During spinal movement, the cauda equina nerve is subjected to more stress, which leads to nerve damage. Additionally, lumbar spinal stenosis can impair blood circulation, resulting in ischemic damage to the cauda equina<sup>15,16</sup>.

The median sagittal diameter is a key indicator of stenosis in the central region of the spinal canal, while the cross-sectional area of the spinal canal is a direct indicator of the degree of lumbar spinal stenosis. A smaller median sagittal diameter reflects a narrower central spinal canal, and a smaller cross-sectional area of the spinal canal correlates with more severe stenosis<sup>17</sup>. The lumbar spinal canal contains densely packed nerve roots, and proper microcirculation is crucial for maintaining pressure balance and metabolism in the cauda equina nerve. A smaller cross-sectional area can lead to arteriole hyperperfusion, insufficient blood supply, and poor venous return, damaging the ultrastructure of the cauda equina nerve. Furthermore, a narrower spinal canal increases the compression and friction on the nerve roots, leading to mechanical traction on the cauda equina nerve, reducing its blood supply, and causing nerve damage<sup>18,19</sup>.

Segment length is also an important indicator of lumbar spinal stenosis severity. A shorter segment length causes a mismatch between the cauda equina nerve and the spinal canal, leading to excessive length of the cauda equina. This results in nerve root compression by the spinal canal, which inhibits proper blood supply to the cauda equina nerve and ultimately causes nerve damage<sup>20</sup>. As patients age and the duration of their disease increases, physical function declines. Spinal stenosis caused by osteophytes,

ligament hypertrophy, and calcification within the spinal canal worsens with age. Therefore, the longer the disease duration, the more severe the stenosis, the stronger the compression on the cauda equina nerve, and the greater the risk of cauda equina injury<sup>21</sup>.

In this study, a nomogram risk prediction model for secondary cauda equina injury in patients with lumbar spinal stenosis was constructed based on identified risk factors. ROC evaluation revealed that the model had an AUC of 0.865, falling within the range of 0.7 to 0.9, with sensitivity and specificity values of 91.11% and 93.64%, respectively. These results suggest that the model has high predictive accuracy and sensitivity. Internal validation through the calibration curve showed good alignment with the ideal curve, and the model's C-index was 0.823, indicating strong accuracy. This demonstrates that the model exhibits high consistency in predicting secondary cauda equina injury in patients with lumbar spinal stenosis. Therefore, this model can be used in clinical practice to accurately assess the risk of secondary cauda equina injury in these patients.

In conclusion, the risk nomogram model based on the risk factors for secondary cauda equina injury in patients with lumbar spinal stenosis demonstrates high predictive value, accuracy, and specificity in identifying the occurrence of secondary cauda equina injury. This model allows for the clinical evaluation of the risk of secondary cauda equina injury by assessing relevant risk factors in patients with lumbar spinal stenosis. It is valuable for early prevention and treatment, which can significantly improve the prognosis and survival rate of patients with lumbar spinal stenosis.

#### Ethics approval

The study was approved by the Ethics Committee of Shenzhen Pingle Orthopedic Hospital (approval number: KY-2025-074).

#### Consent to participate

Written informed consent was obtained from all participants. The study was performed in accordance with the principles outlined in the Helsinki Declaration.

#### Authors' contributions

KL and YW conceived and designed the study, and drafted the manuscript. YW, PM, CZ, XM, XHU, WL and XHE collected, analyzed and interpreted the experimental data. KL and PM revised the manuscript for important intellectual content. All authors read and approved the final manuscript.

## References

1. Lu Z, Ding A, Yu Q, Wang H, Ma L. Effect of the preoperative assessment of the anteroposterior diameters of the spinal canal and dural area on the efficacy of oblique lumbar interbody fusion in patients with lumbar spinal stenosis. *J Orthop Surg Res* 2023; 18(1): 440.
2. Aaen J, Banitalebi H, Austevoll IM, Hellum C, Storheim K, Myklebust TÅ, Anvar M, Weber C, Solberg T, Grundnes O, Brisby H, Indrekvam K, Hermansen E. Is the presence of foraminal stenosis associated with outcome in lumbar spinal stenosis patients treated with posterior microsurgical decompression. *Acta Neurochir (Wien)* 2023; 165(8): 2121-2129.
3. Gadjradj PS, Basilious M, Goldberg JL, Sommer F, Navarro-Ramirez R, Mykolajchuk C, Ng AZ, Medary B, Hussain I, Härtl R. Decompression alone versus decompression with fusion in patients with lumbar spinal stenosis with degenerative spondylolisthesis: a systematic review and meta-analysis. *Eur Spine J* 2023; 32(3): 1054-1067.
4. Kaye AD, Edinoff AN, Temple SN, Kaye AJ, Chami AA, Shah RJ, Dixon BM, Alvarado MA, Cornett EM, Viswanath O, Urits I, Calodney AK. A Comprehensive Review of Novel Interventional Techniques for Chronic Pain: Spinal Stenosis and Degenerative Disc Disease-MILD Percutaneous Image Guided Lumbar Decompression, Vertiflex Interspinous Spacer, MinuteMan G3 Interspinous-Interlaminar Fusion. *Adv Ther* 2021; 38(9): 4628-4645.
5. Wibowo HA, Rhatomy S. Cauda equina syndrome after caudal epidural sacral injection in severe lumbar spinal stenosis: Case report. *Int J Surg Case Rep* 2020; 77: 12-14.
6. Lee J, Choi H, Park C, Jeon S, Yune T. Jmjd3 Mediates Neuropathic Pain by Inducing Macrophage Infiltration and Activation in Lumbar Spinal Stenosis Animal Model. *Int J Mol Sci* 2021; 22(24): 13426.
7. Kim M, Kim H. Cauda equina syndrome by extrusion of lumbar disc after lumbar sympathetic neurolysis. *Neurosciences (Riyadh)*. 2023; 28(1): 53-56.
8. Kong Q, Li F, Sun K, Sun X, Ma J. Valproic acid ameliorates cauda equina injury by suppressing HDAC2-mediated ferroptosis. *CNS Neurosci Ther* 2024; 30(4): e14524.
9. Arabmotlagh M, Sellei RM, Vinas-Rios JM, Rauschmann M. Klassifikation und Diagnostik der lumbalen Spinalkanalstenose Classification and diagnosis of lumbar spinal stenosis. *Orthopade* 2019;48(10):816-823.
10. Loya VK, Krishna Narayan TV, Singh Dhillon C, Shashikant Pophale C. Intradural lumbar disc herniation with cauda equina syndrome: Case report and recent advances. *Brain Spine* 2023;4:102724.
11. Ko JH, Chong SW, Nguyen VL, Ham DH. Anterior approach for a stab wound with penetrating rebar injury causing incomplete cauda equina syndrome in lumbosacral spine lesion: a case report and literature review. *Eur Spine J* 2024;33(7):2870-2877.
12. Sath S. Does surgical decompression alleviate neglected cauda equina syndromes attributed to lumbar disc herniation and/or degenerative canal stenosis? *Surg Neurol Int* 2020;11:278.
13. Nikjou DA, Taggart CM, Lettieri SC, et al. Laminectomy for acute transverse sacral fractures with compression of the cauda equina: A neurosurgical perspective. *World Neurosurg* X 2024;23:100374.
14. Yu M, Zu PZ, Guo LY, et al. The beneficial effects of the

- herbal medicine Di-Huang-Yin-Zi in patients with spinal cord injury. A randomized, double-blind, placebo-controlled study. *Explore (NY)* 2025;21(2):103134.
15. Kanematsu R, Hanakita J, Takahashi T, Minami M, Inoue T, Miyasaka K, Shimauchi-Ohtaki H, Ueno M, Honda F. Improvement in Neurogenic Bowel and Bladder Dysfunction Following Posterior Decompression Surgery for Cauda Equina Syndrome: A Prospective Cohort Study. *Neurospine* 2021;18(4):847-853.
  16. Moussa MK, Alkefrawi P, Elkhalil JK. Large central disc herniation causing cauda equina syndrome in an adolescent. A case report. *Int J Surg Case Rep* 2021; 79:119-122.
  17. Jang SW, Lee DG. Can the severity of central lumbar stenosis affect the results of nerve conduction study? *Medicine (Baltimore)* 2020;99(30):e21466.
  18. Nikjou DA, Taggart CM, Lettieri SC, Collins MR, McCabe OT, Rousseau LA, Feiz-Erfan I. Laminectomy for acute transverse sacral fractures with compression of the cauda equina: A neurosurgical perspective. *World Neurosurg* 2024;23:100374
  19. Wibowo HA, Rhatomy S. Cauda equina syndrome after caudal epidural sacral injection in severe lumbar spinal stenosis: Case report. *Int J Surg Case Rep* 2020;77:12-14.
  20. Attabib N, Kurban D, Cheng CL, Rivers CS, Bailey CS, Christie S, Ethans K, Flett H, Furlan JC, Tsai EC, O'Connell C. Factors Associated with Recovery in Motor Strength, Walking Ability, and Bowel and Bladder Function after Traumatic Cauda Equina Injury. *J Neurotrauma* 2021; 38(3):322-329.
  21. Kim M, Kim H. Cauda equina syndrome by extrusion of lumbar disc after lumbar sympathetic neurolysis. *Neurosciences (Riyadh)* 2023;28(1):53-56.