RESEARCH ARTICLE

Establishment and verification of a surgical prognostic model for cervical spinal cord injury without radiological abnormality

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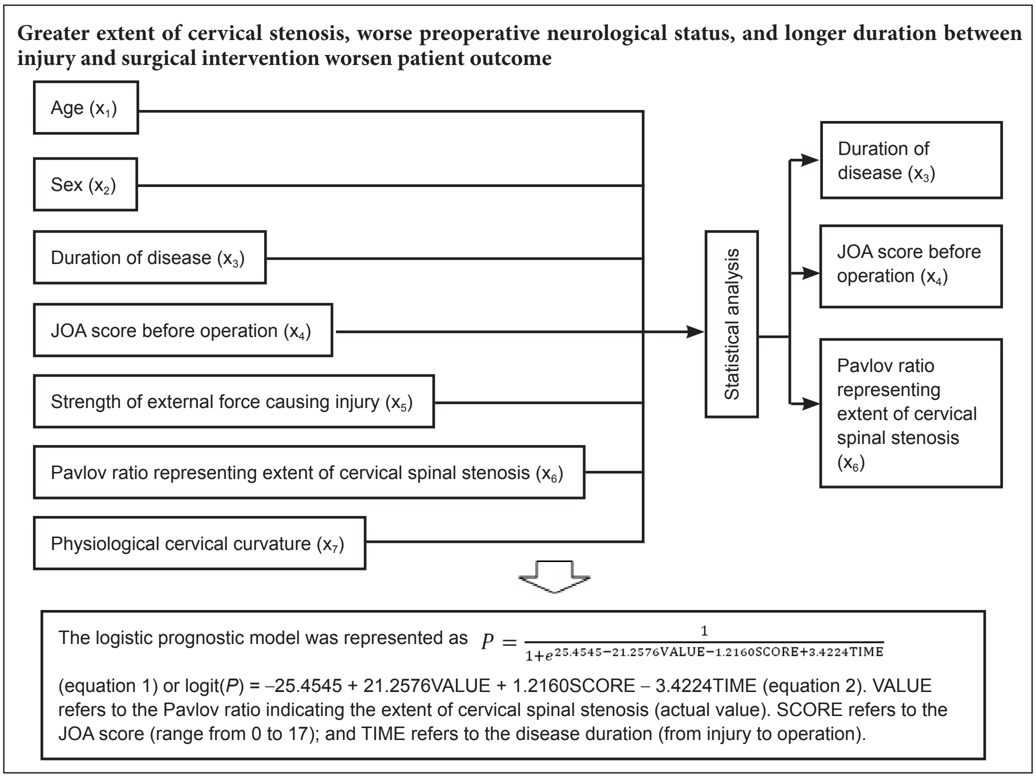
Graphical Abstract



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Abstract

Some studies have suggested that early surgical treatment can effectively improve the prognosis of cervical spinal cord injury without radiological abnormality, but no research has focused on the development of a prognostic model of cervical spinal cord injury without radiological abnormality. This retrospective analysis included 43 patients with cervical spinal cord injury without radiological abnormality. Seven potential factors were assessed: age, sex, external force strength causing damage, duration of disease, degree of cervical spinal stenosis, Japanese Orthopaedic Association score, and physiological cervical curvature. A model was established using multiple binary logistic regression analysis. The model was evaluated by concordant profiling and the area under the receiver operating characteristic curve. Bootstrapping was used for internal validation. The prognostic model was as follows: logit(P) = −25.4545 + 21.2576VALUE + 1.2160SCORE − 3.4224TIME, where VALUE refers to the Pavlov ratio indicating the extent of cervical spinal stenosis, SCORE refers to the Japanese Orthopaedic Association score (0–17) after the operation, and TIME refers to the disease duration (from injury to operation). The area under the receiver operating characteristic curve for all patients was 0.8941 (95% confidence interval, 0.7930–0.9952). Three factors assessed in the predictive model were associated with patient outcomes: a great extent of cervical stenosis, a poor preoperative neurological status, and a long disease duration. These three factors could worsen patient outcomes. Moreover, the disease prognosis was considered good when logit(P) ≥ −2.5105. Overall, the model displayed a certain clinical value. This study was approved by the Biomedical Ethics Committee of the Second Affiliated Hospital of Xi'an Jiaotong University, China (approval number: 2018063) on May 8, 2018.

Key Words: *nerve regeneration; surgical prognostic model; cervical spinal cord injury; retrospective study; multiple binary logistic regression analysis; bootstrapping; internal validation; multiple imputations; cervical spinal stenosis; duration of disease; Pavlov ratio; neural regeneration*

Chinese Library Classification No. *R441; R741*

Introduction

Cervical spinal cord injury without radiological abnormality is a special type of cervical spinal cord injury caused by an outside force without radiographic abnormalities (Pang and Wilberger, 1982; Hong et al., 2005). This injury has gradually come to our attention with the development of imaging technologies. Most affected patients had cervical vertebral joint degeneration and cervical spinal stenosis caused by ossification of the posterior longitudinal ligament before the development of this injury (Saruhashi et al., 1998; Gupta et al., 1999; Koyanagi et al., 2000). The presence of acute spinal cord injury caused by external forces without fracture or dislocation and a ratio of < 0.75 of the sagittal diameter of the spinal canal to the vertebral body on a lateral image of the cervical vertebra is highly suggestive of cervical spinal cord injury without radiological abnormality (Dang et al., 2003; Wenger et al., 2003; Tewari et al., 2005). Although many publications have focused on cervical spinal cord injury without radiological abnormality, only a few studies have addressed the prognostic evaluation of cervical spinal cord injury without radiological abnormality. Therefore, this study was performed to establish a prognostic model and evaluate the surgical prognosis of cervical spinal cord injury without radiological abnormality. A prognostic model for patients who have undergone operations for cervical spinal cord injury without radiological abnormality with a retrospective analysis was established to better understand and evaluate various factors involved in cervical spinal cord injury without radiological abnormality.

Subjects and Methods

Subjects

This was a retrospective study. According to the calculation method of sample correlation in multiple and binary logistic regression analysis (Knottnerus, 1992; Janssens et al., 2005), the required sample size was ≥ 40. Forty-three patients presented to the Orthopedics Department of the Second Affiliated Hospital of Xi'an Jiaotong University, China. The patients (24 males and 19 females aged 37–68 years) were recruited from April 2010 to November 2017. The average age was 52 years (25th percentile, 45 years; 75th percentile, 59 years). The disease duration ranged from 3 to 27 days; the mean disease duration was 14.1 ± 6.3 days. The patients were selected according to the following inclusion criteria: (1) a definite external cervical injury before hospitalization, (2) an age of ≥ 20 years, (3) an uneven distribution (intramedullary hyperintensity) of spinal cord signals and no significant signal changes in the vertebral body on T2-weighted magnetic resonance imaging (T2WI MRI) of the cervical vertebra (Diaz et al., 2005; Maeda et al., 2012), (4) MRI examinations of all patients performed on the same scanner (MAGNETOM ESSENZA 1.5T; Siemens, Munich, Germany), (5) posterior longitudinal ligament or yellow ligament thickening or ossification or a herniated disc on MRI, (6) follow-up of > 6 months, and (7) patient's desire for surgery. Patients were excluded based on the following criteria: presence of (1) structural cervical changes (cervical vertebral body fracture, cervical dislocation, vertebral arch fracture or dislocation, and lamina fracture) on radiographs and CT, (2) cervical spondylosis and severe spinal nerve trauma before external injury, (3) craniocerebral trauma, and (4) any disease that may affect the assessment of nerve function (especially in the nervous system). A study flow chart is shown in **Figure 1**. Under the approval of the Biomedical Ethics Committee of the Second Affiliated Hospital of Xi'an Jiaotong University, China (approval number: 2018063) on May 8, 2018, all patients in this retrospective analysis study had left the hospital. Moreover, their privacy was protected when their data were used as clinical materials with permission and supervision. All patients provided written informed consent. The writing and editing of the article were performed in accordance with the STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) statement (**Additional file 1**).

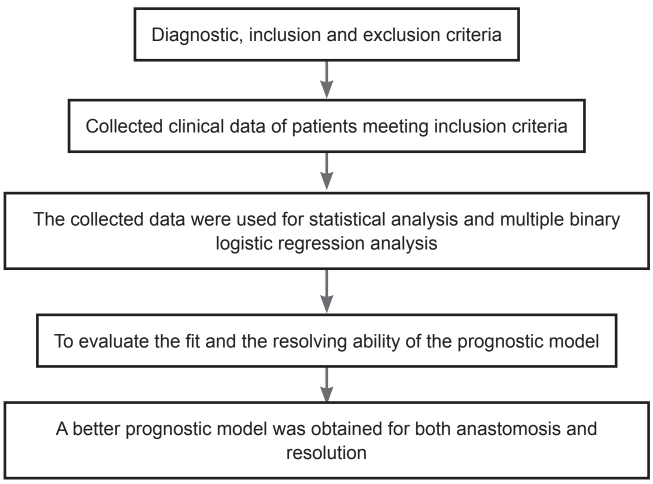

Figure 1 Flow chart of the present study.

Clinical features and diagnoses

All patients had varying degrees of cervical spinal cord injury (Aarabi et al., 2013), including 40 patients with cervical pain, 28 with limited neck movement, 41 with somatosensory disorders, 39 with dyskinesia, 39 with positive pathological reflex, 32 with an inability to move after injury, and 6 with defecation dysfunction. According to the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI-2013) (Franz et al., 2016; Schuld et al., 2016; Alexander et al., 2017; Armstrong et al., 2017), 24 patients presented with level C injury and 19 with level D (**Table 1**).

The patients were diagnosed mainly based on imaging results and clinical symptoms; some symptoms after injury did not appear as cervical fracture but as obvious cervical spinal stenosis on the anterior and lateral images of the cervical spine. However, obvious changes were present in the cervical spinal signal on T2WI MRI (**Figure 2**).

Table 1 Patients' clinical characteristics

Item	Data
Age (years)[a]	52.0±9.5 (37–68)
Sex (male/female, *n*)	24/19
Duration more than 2 weeks (*n*)	21
JOA score before operation[a]	9.3±1.6 (0–17)
JOA score 2 weeks after operation[a]	12.1±1.4 (0–17)
JOA score 6 months after operation[a]	13.1±1.8 (0–17)
Improvement rate of ≥ 60% in JOA score after operation (*n*)	14
Cervical spinal stenosis (*n*)	43
Wounding external forces (weak/strong) (*n*)	28/15
Changes in physiological curvature of the cervical spine (*n*)	7
Cervical pain (*n*)	40
Limited neck movement (*n*)	28
Somatosensory disorder (*n*)	41
Dyskinesia (*n*)	39
Pathologic positivity (*n*)	39
Inability to move after injury (*n*)	32
Defecation dysfunction (*n*)	6
ISNCSCI score	
The level of C (*n*)	24
The level of D (*n*)	19

[a]Values are presented as the mean ± standard deviation (range). JOA: Japanese Orthopaedic Association; ISNCSCI: International Standards for Neurological Classification of Spinal Cord Injury.

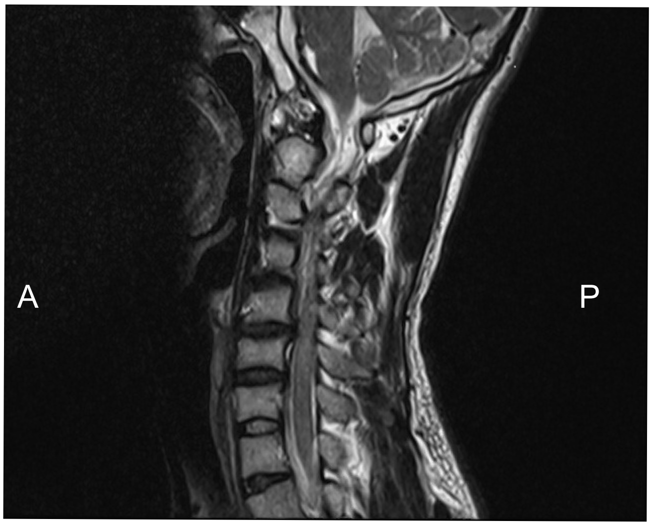

Figure 2 T2-weighted magnetic resonance imaging (T2WI MRI) of cervical spinal cord injury without radiological abnormality.
The physiological curvature of the cervical spine appeared straight on T2WI MRI before the operation, and the intervertebral disc signal appeared weakened. The C3/4, C4/5, and C5/6 discs bulged outward, and the anterior division of the spinal cord became narrow. The intraspinal signal on C4–6 was unevenly distributed, indicating that the T1 and T2 signals were slightly stronger than the other signals. A: Anterior; P: posterior.

Clinical treatment

All operations were performed by the head of our department, who is also the corresponding author. Based on the patients' symptoms and imaging characteristics, all surgeries were posterior cervical expansive open-door laminoplasty. Before treatment, the patients underwent X-ray imaging of the frontal and lateral cervical spine or CT scanning and MRI. Imaging was performed to comprehensively understand the situation of the vertebra, cervical spine, and soft tissue, and no obvious vertebral fracture or dislocation was observed. After the operation, the patients were subjected to external head and neck stabilization and rehabilitation training and were encouraged to exercise as soon as possible. The frontal and lateral cervical spine was assessed by MRI after 1 week to observe the degree of expansive laminoplasty and internal fixation. The external head and neck stabilization was continued for 3 months, and the patients were rechecked and subjected to Japanese Orthopaedic Association scoring at 6 months (Fukui et al., 2007; Tanaka et al., 2014; Furlan and Catharine Craven, 2016; Zheng et al., 2016; Tanaka, 2018).

Observed indicators

The Pavlov ratio was used to measure and evaluate the extent of cervical stenosis. The Pavlov ratio of the lateral cervical spine was calculated as follows: sagittal diameter of cervical spinal canal "b" (mm) / sagittal diameter of cervical vertebral body "a" (mm) (Yue et al., 2001; Song et al., 2009). Independent measurements were obtained by three researchers, and the three values were analyzed for variance; no significant differences were found ($P > 0.05$). These mean values were then taken for analysis; otherwise, they were remeasured. A Pavlov ratio of ≤ 0.75 indicates the presence of cervical spinal stenosis (Chen et al., 1994; Wang et al., 2015). This examination was performed before surgery.

The Japanese Orthopaedic Association score was obtained during treatment and the improvement rates, especially at 6 months postoperatively, were calculated. The Japanese Orthopaedic Association score was determined as follows: (postoperative score – preoperative score)/(17 – preoperative score) × 100%.

The physiological curvature of the cervical spine was measured using the Borden method as follows: Line A was drawn from the posterior upper margin of the axis odontoid process to the posterior margin of the vertebral body; line B was drawn along the posterior border of the body of the cervical vertebra; and line C represented the widest part of the vertical intersection between lines A and B and indicated the depth of the physiological curvature of the cervical vertebra. The measurement was performed before surgery. The measured values are expressed in absolute numbers. The external injury force was classified as weak or strong (Kawano et al., 2014).

Statistical methods

Modeling

Binary logistic regression analysis was adopted for statistical modeling (Royston et al., 2009). Seven potential factors were recorded: age, sex, strength of external force causing injury, duration of disease, extent of cervical spinal stenosis, Japanese Orthopaedic Association score, and physiological cervical curvature. The duration of disease was stratified as < 2 or > 2 weeks (Chen et al., 2014). The external wounding forces were stratified as weak or strong. Cervical spinal stenosis was evaluated using the Pavlov ratio. Some scholars have used the Japanese Orthopaedic Association improvement rate to evaluate the prognosis of spinal cord injury as follows: ≥ 75% is excellent, 50% to 74% is good, 25% to 49% is effective, and < 25% is poor or invalid (Grosso et al., 2013). The treatment results were evaluated based on the improvement rates, especially at 6 months postoperatively, with a threshold value of 60%; if the improvement rate was ≥ 60%, the disease was considered almost cured, while an improvement rate of < 60% indicated the lack of curative effect. We regarded the rate of improvement in the Japanese Orthopaedic Association score after the operation as a dichotomous dependent variable and the seven potential factors as independent variables. Stepwise selection of variables was used to obtain a regression model. All accessors of the factors are listed in **Table 2**. Because of the different measurement units of the partial regression coefficients in the multiple regression equations, the coefficients could not be compared. Therefore, we eliminated the influence of metrology with standardized partial regression coefficients and compared the relative contribution size of each independent variable through odds ratios (*OR*s).

Table 2 All accessors of the factors in the surgical prognostic model for cervical spinal cord injury without radiological abnormality

Variable	Value
Improvement rates of the JOA score at 6 months after operation (y)	"≥ 60%" = 1, "< 60%" = 0
Age (x_1)	Actual value (rounding)
Sex (x_2)	Female = 0, male = 1
Duration of disease (x_3)	"< two weeks" = 0, "≥ two weeks" = 1
JOA score before operation (x_4)	Actual value
Strength of external force causing injury (x_5)	Weak force = 0, strong force = 1
Pavlov ratio representing extent of cervical spinal stenosis (x_6)	Actual value
Physiological cervical curvature (x_7)	Actual value

JOA: Japanese Orthopaedic Association.

Missing values

The missing values were considered completely random when they were few in number. Thus, we performed multiple imputations (Tetreault et al., 2015); otherwise, we revised our plan.

Evaluation

To evaluate the clinical prognostic model, we determined whether the model was consistent with and specific to the disease. The fit of the model was determined by the degree of overlap between the positive value between the clinical outcomes and the estimation by the prognostic model, and the fitness line guided the development and evaluation of the clinical prognostic model. The resolution was determined by the ability of the model to distinguish the result as positive or negative, and we used the area under the receiver operating characteristics curve to evaluate the effectiveness of resolution using the clinical prognostic model. Additionally, we used the nonparametric conditional bootstrap method run 1000 times in the limited cases, analyzing and dividing the cases into 10 groups in rank order. A fitness line was drawn with prediction probability as the x-coordinate and observation proportion as the y-coordinate. The sampled data were also used to draw receiver operating characteristic curves and determine the area under the receiver operating characteristic curve for the patients. If the area under the receiver operating characteristic curve showed a normal distribution, the approximate normal distribution method was used to calculate 95% confidence intervals (*CI*s), whereas the percentile method was deemed more suitable for a skewed distribution (Gu et al., 2008; Altman et al., 2009). A receiver operating characteristic curve was drawn with (1 − specificity) as the x-coordinate and sensitivity as the y-coordinate. The area under the receiver operating characteristic curve was used to comprehensively evaluate the accuracy of diagnosis with a range of 0 ≤ area under the receiver operating characteristic curve ≤ 1. An area under the receiver operating characteristic curve of 0.5 indicated that the model was unable to predict the results. In contrast, for area under the receiver operating characteristic curves of > 0.5, the resolving ability tended to improve as the area under the receiver operating characteristic curve approached 1, and the model was satisfactory when the area under the receiver operating characteristic curve was ≥ 0.8.

The above-described procedure was completed using an in-house program with IBM SPSS Statistics Version 20 (IBM Corp., Armonk, NY, USA). The additional analyses were executed using an in-house program in SAS 9.3 (SAS Institute Inc., Cary, NC, USA).

Results

Establishment of prognostic model

We performed multiple imputations to determine the integrity of the analysis. According to the statistical results in **Table 3**, the *P* value of these three factors was < 0.05. The prognosis could be attributed to these three factors because they were statistically significant. Three factors were finally selected: disease duration, preoperative Japanese Orthopaedic Association score, and extent of cervical spinal stenosis. The logistic prognostic model was represented as P=1/(1+e^(25.4545-21.2576VALUE-1.2160SCORE+3.4224TIME)) (Equation 1) or logit(P) = −25.4545 + 21.2576VALUE + 1.2160SCORE − 3.4224TIME (Equation 2), and the standardized partial regression coefficients were b_{VALUE}' = 80.6613, b_{SCORE}' = 0.2295, and b_{TIME}' = 2.1089. VAL-

Table 3 Independent variables in the surgical prognostic model for cervical spinal cord injury without radiological abnormality

Variable	Variance	Estimated value	Standard error	Wald value	*P* value
Duration of disease	1	–3.4224	1.5353	4.9694	0.0258*
JOA score before operation	1	1.2160	0.4703	6.6868	0.0097*
Pavlov ratio at the cervical spinal canal	1	21.2576	9.4543	5.0555	< 0.0001*

*$P \le 0.05$. JOA: Japanese Orthopaedic Association.

UE refers to the Pavlov ratio indicating the extent of cervical spinal stenosis (actual value), SCORE refers to the Japanese Orthopaedic Association score (range of 0–17), and TIME refers to the disease duration (from injury to operation).

Verification of prognostic models

The fitness line and receiver operating characteristic curve of the prognostic model are shown in **Figures 3** and **4**. Because the area under the receiver operating characteristic curve followed a normal distribution, it was determined to be 0.8941 (95% *CI*, 0.7930–0.9952).

We drew the fitness line on the prognostic model with predicted probability as the x-coordinate and observed proportion as the y-coordinate. The figure shows scatter plots along the diagonal, indicating satisfactory prediction ability of the model. The scatter diagram represents the accuracy, and the results showed good fit of the model.

An area under the receiver operating characteristic curve of ≥ 0.8 was obtained; thus, the resolving ability of the prognostic model was sound, and the upper left value (the 18th point in ascending order) was adopted as the best threshold value.

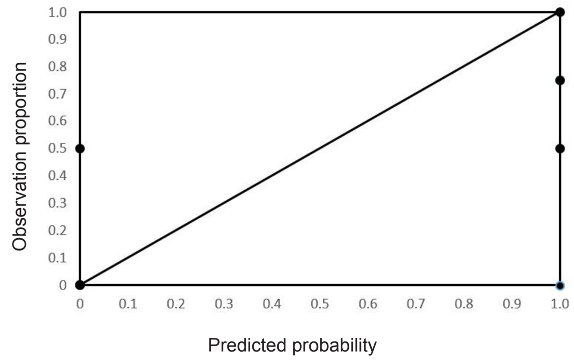

Figure 3 Fitness line of the surgical prognostic model for cervical spinal cord injury without radiological abnormality.
The figure shows scatter plots along the diagonal, indicating satisfactory prediction ability of the model.

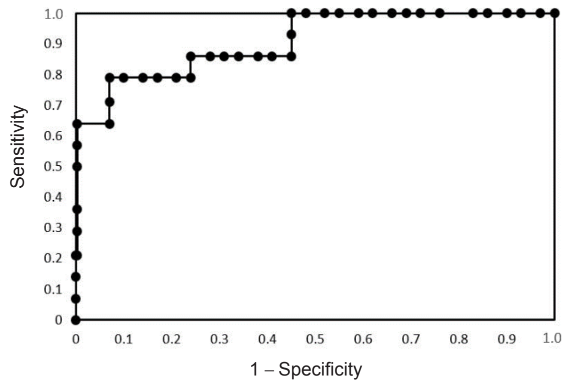

Figure 4 Receiver operating characteristic curve of the surgical prognostic model for cervical spinal cord injury without radiological abnormality.
We obtained an area under the curve of ≥ 0.8; thus, the resolving ability of the prognostic model was sound, and we adopted the upper left value (the 18th point in ascending order) as the best threshold value.

Discussion

Cervical spinal cord injury without radiological abnormality is a common condition in patients who have no nervous system symptoms after injury involving a weak external force, and this is consistent with our study findings. Patients with cervical spinal cord injury without radiological abnormality may develop a variety of symptoms, such as changes in sensory and motor functions and incomplete spinal cord injury. Although cervical spinal cord injury without radiological abnormality is characterized by the absence of vertebral fracture or displacement on X-ray and CT, MRI shows a positive result, and T2WI usually indicates an uneven appearance of the intraspinal signal, indicative of spinal cord injury. However, one simple factor cannot be used to evaluate the prognosis; instead, multiple factors are needed to enhance the credibility of the prognosis. Thus, the use of a prognostic model that can define the affecting factor among multiple options is encouraged. Moreover, a prognostic model can generally predict the prognostic value of most diseases by different combinations of factors that can be easily acquired in the clinical setting. By analyzing these factors, we can determine a relatively accurate prognosis. However, not all factors demonstrate a cause-and-effect relationship with the disease under study, nor do they display the same relationship with the etiology. The prognostic model mainly helps to predict the clinical prognosis and identify protective or risk factors from the disease under study; prognostic models can also guide research on the clinical prognosis.

The prognostic model in the present study indicated that three factors, namely the extent of cervical spinal stenosis, duration of disease, and preoperative Japanese Orthopaedic Association score, were the main factors affecting the prognosis. The preoperative Japanese Orthopaedic Association score was a protective factor, and as it increased by each unit, the logit(P) increased to 0.2295 and the standardized OR approached $e^{0.2295}$. The extent of cervical spinal stenosis was also a risk factor. The larger the Pavlov ratio, the lower the extent of cervical spinal stenosis; as the ratio increased by each unit, the logit(P) increased to 80.6613 and the standardized OR approached $e^{80.6613}$. Similarly, the disease duration was a risk factor, and as it increased, the logit(*P*) decreased to 3.4224 and the standardized OR approached $e^{-3.4224}$.

With respect to fit, the prognostic model showed a satisfactory result on the fitness line (**Figure 3**). Two points fell on the diagonal line, and most others fell on the bottom right of the diagonal. This indicated that the predictive ability was higher than the actual situation, and the prediction remained sound. A receiver operating characteristic curve of the resolving ability is exhibited in **Figure 4**. An area under the receiver operating characteristic curve of ≥ 0.8 was obtained; thus, the resolving ability of the prognostic model was sound, and the upper left value (the 18^{th} point in ascending order) was adopted as the best threshold value. The logit(*P*) at this point equaled −2.5105. When logit(*P*) ≥ −2.5105, the postoperative prognosis is satisfactory and the treatment is effective.

With respect to the disease duration, some authors have recommend surgery for patients with pre-existing canal stenosis because persistent cord compression might hinder neurological improvement (Chen et al., 1998; Yamazaki et al., 2005). La Rosa et al. (2004) demonstrated that spinal canal decompression performed within 24 hours after injury may have a relatively favorable effect compared with treatment performed a long time after injury. However, Kawano et al. (2010) reported a lack of obvious difference between operations performed during and after the acute stage. Academics hold many different opinions on the prognosis of cervical spinal cord injury without radiological abnormality. During the establishment and analysis of the prognostic model in the current study, the disease duration was considered a risk factor, consistent with the viewpoint expressed by La Rosa et al. (2004). This may be because cervical cord injury mainly involves direct pressure on the cervical cord and subsequent edema and bleeding, and spinal canal decompression in the early stage may be beneficial not only for releasing the pressure but also alleviating edema, bleeding, and other injuries. Therefore, spinal canal decompression as soon as possible may be favorable for recovery.

Herzog et al. (1991) believed that sagittal diameter measurement on a narrow section of the lateral cervical spine was the most accurate method for evaluation of the degree of expansive laminoplasty. However, Suk et al. (2009) suggested that magnification on X-ray imaging was not necessary but that the Pavlov ratio could eliminate some confounding factors associated with magnification and may be the best method with which to evaluate the extent of cervical spinal stenosis. Takao et al. (2013) reported that cervical spinal stenosis is an important risk factor for cervical spinal cord injury without radiological abnormality caused by traumatic cervical spinal stenosis. Aebli et al. (2013) suggested that a Pavlov ratio of 0.7 may indicate a risk of acute cervical spinal cord injury after external wounding. In our study of the prognostic model, we also found that cervical spinal stenosis was a risk factor affecting prognosis. Based on the clinical findings, spinal canal stenosis resulted in a relative decrease in the reserve volume of the spinal canal, and the external force could worsen the situation despite the lack of fracture and dislocation of the cervical vertebra. Our results are in accordance with the literature. Consequently, the patients exhibited obvious clinical symptoms of fracture and dislocation of the cervical vertebra in contrast to the imaging findings.

The preoperative Japanese Orthopaedic Association score represents the status of the cervical spinal cord to some extent. In the present study, the preoperative Japanese Orthopaedic Association score was a protective factor for the prognosis. A higher preoperative Japanese Orthopaedic Association score was associated with a more favorable prognosis of the cervical spinal cord, with milder mechanical compression and less severe subsequent edema and bleeding.

Notably, one patient in our study had a Japanese Orthopaedic Association score of 9, disease duration of 18 days, and Pavlov ratio of 0.73. Before treatment, we assumed that the curative effect would be unsatisfactory, but we predicted logit(*P*) = −2.4149 > −2.5105 using the model. Indeed, the treatment was successful. The improvement in the Japanese Orthopaedic Association score after the operation was 0.625, which was close to the predicted value of the model. These data emphasize the remarkable differences between clinical visual evaluations and the prediction of the model as well as the importance of using a clinical prognostic model. Unfortunately, another patient had an unfavorable outcome; he had a preoperative Japanese Orthopaedic Association score of 11, disease duration of 15 days, and Pavlov ratio of 0.64. Using the model, we predicted logit(*P*) = −1.8960 > −2.5105.

In addition, although the data showed a good prognostic value, the actual situation was the opposite. The improvement in the postoperative Japanese Orthopaedic Association score was 0.5, indicating that the model still has some limitations and must be improved by more comprehensive testing and evaluation using a larger number of cases. Because of the small sample size of the study and the limitations of the research conditions, bootstrapping was used for the data analysis; this solved the problem of the small sample size, but there were still some deficiencies. In future studies, we will use serial control and multicenter control to improve the validity of the surgical prognostic model. The model did not include some underlying health problems. Three patients recovered slowly from their injury because they had diabetes mellitus and long-term malnutrition, which affected their prognoses. These factors were not included in our model, and we need to consider such underlying health problems in future studies. This will allow us to obtain a more comprehensive and precise model to evaluate the patients' prognoses.

No other models that evaluate the surgical prognosis of cervical spinal cord injury without radiological abnormality are available in the clinical setting. However, our study has several limitations. (1) Our retrospective study had insufficient samples, and factors were incomplete. (2) Adoption of the Japanese Orthopaedic Association score as an evaluation standard is controversial and lacks consensus. (3) Underlying health problems were not taken into consideration.

In conclusion, the prognostic model was as follows: logit(P) = −25.4545 + 21.2576VALUE + 1.2160SCORE − 3.4224TIME, where VALUE refers to the Pavlov ratio (actual value), indicating the extent of cervical spinal stenosis; SCORE refers to the postoperative Japanese Orthopaedic Association score (0–17); and TIME refers to the disease duration (from injury to operation). The prognostic model was consistent with the disease and easy to distinguish. Three factors assessed in the predictive model were associated with worse patient outcomes: a greater extent of cervical stenosis, a worse preoperative neurological status, and a longer duration between injury and surgical intervention. Moreover, the disease prognosis was considered good when logit(P) ≥ −2.5105. Overall, the model displayed a certain clinical value, although it needs to be further improved.

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Biostatistics statement: *The statistical methods of this study were reviewed by the biostatistician of The Second Affiliated Hospital of Xi'an Jiaotong University.*
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Additional files:
Additional file 1: *STROBE checklist.*
Additional file 2: *Open peer review reports 1–3.*

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