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Original Article

A Nomogram Model for Prediction of Tracheostomy in Patients With Traumatic Cervical Spinal Cord Injury

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Objective: To develop a nomogram for the prediction of tracheostomy in patients with traumatic cervical spinal cord injury (TCSCI).
Methods: A total of 689 TCSCI patients were included in our study. First, the variable selection was performed using between-group comparisons and LASSO regression analysis. Second, a multivariate logistic regression analysis (MLRA) with a step-by-step method was performed. A nomogram model was developed based on the MLRA. Finally, the model was validated on the training set and validation set.
Results: The nomogram prediction model incorporated 5 predictors, including smoking history, dislocation, thoracic injury, American Spinal Injury Association (ASIA) grade, and neurological level of injury (NLI). The area under curve in the training group and in the validation group were 0.883 and 0.909, respectively. The Hosmer-Lemeshow test result was $p = 0.153$. From the decision curve analysis curve, the model performed well and was feasible to make beneficial clinical decisions.
Conclusion: The nomogram combining dislocation, thoracic injury, ASIA grade A, NLI, and smoking history was validated as a reliable model for the prediction of tracheostomy.

Keywords: Nomogram, Risk forecasting model, Spinal cord injury, Tracheostomy

INTRODUCTION

Traumatic cervical spinal cord injury (TCSCI) is a devastating disease that leads to lifelong disability and long-term risk of medical complications.[1-3] TCSCI often results in acute respiratory failure.[4] Many researchers have demonstrated that early tracheostomy (≤7 days from intubation) can bring many benefits to patients with TCSCI.[4-7] For example, early tracheostomy may reduce mechanical ventilation (MV) time and allow for more comfortable and efficient breathing. To take advantage of these benefits and allocate resources accordingly, it is important for surgeons to have a tool to predict whether a patient might need a tracheostomy.

Although several factors for tracheostomy have been identified through multivariate logistic regression analysis (MLRA) and classification and regression tree (CART) model,[8-11] early prediction of tracheostomy in TCSCI patients is still difficult. The nomogram is an essential part of modern medicine and is considered a reliable and practical predictive tool.[12,13] The nomogram can visually display the results of MLRA, and can also predict the probability through a simple picture representation.[14-16] To the best of our knowledge, no nomogram prediction model of tracheostomy has been reported in TCSCI patients. The purpose of this study was to develop and validate a simple and convenient nomogram model for predicting tracheostomy after TCSCI.

MATERIALS AND METHODS

1. Study Design

This was a retrospective study. This study was based on data from a university hospital in Chongqing, China between January 2008 to December 2021. It was approved by the Ethics Committee of our hospital. TCSCI was diagnosed by taking into ac-

count a history of trauma, symptoms, consciousness, sensory and motor, complete neurological testing, and imaging findings such as computed tomography and/or magnetic resonance imaging.[17] The decision to perform a tracheostomy was made by the spine surgeon in conjunction with the intensive care unit physician and was made when prolongation of the MV was expected, considering the patient's neurologic function, respiratory function, age, concomitant injury, and other factors. Tracheostomy was performed if any of the following criteria were met: (1) the patient was retained in a transoral tracheal tube and failed to evacuate MV after several attempts; (2) the patient had a lot of sputum and poor coughing power, requiring retention of an artificial airway to drain sputum. All assessments were performed by experienced senior physicians on admission. The overall flow chart is shown in Fig. 1.

2. Study Participants

A total of 762 patients with TCSCI in the department of orthopedics were analyzed. The inclusion criteria were as follows: (1) clear history of trauma, (2) well-diagnosed cervical spinal cord injury, and (3) complete medical records. The exclusion criteria were as follows: (1) larynx injuries, (2) patients who underwent tracheostomy at other hospital, and (3) incomplete medical records. Finally, 689 patients were included in the study sample.

3. Data Collection

The relevant patient's data were recorded, including sex, age, smoking history, dislocation, diabetes mellitus, hypertension, preexisting lung disease, brain injury, American Spinal Injury Association (ASIA) impairment scale grade, neurological level of injury (NLI), and thoracic injury. ASIA impairment scale grade was assessed using the ASIA standards.[18] ASIA impairment scale grade was divided into grades A and B–D. NLI was divided into C1–4 and C5–8. The dislocation was defined as traumatic cervical facet dislocation confirmed by radiological examination. Preexisting lung diseases included chronic obstructive pulmonary disease, bronchial asthma, and restrictive lung disease. According to World Health Organization, smoking was defined as continuous or cumulative smoking for 6 months or more in a lifetime.[19]

4. Statistical Analysis

All patients were randomized into training and validation groups, in a 7:3 ratio for nomogram construction and validation. Pearson chi-square test and LASSO regression analysis were used to screen variables. The screened variables were brought into MLRA in a step-by-step method to determine the independent predictors. Based on the MLRA, a nomogram prediction model of tracheostomy was constructed. The area under curve (AUC) was calculated in training and validation groups

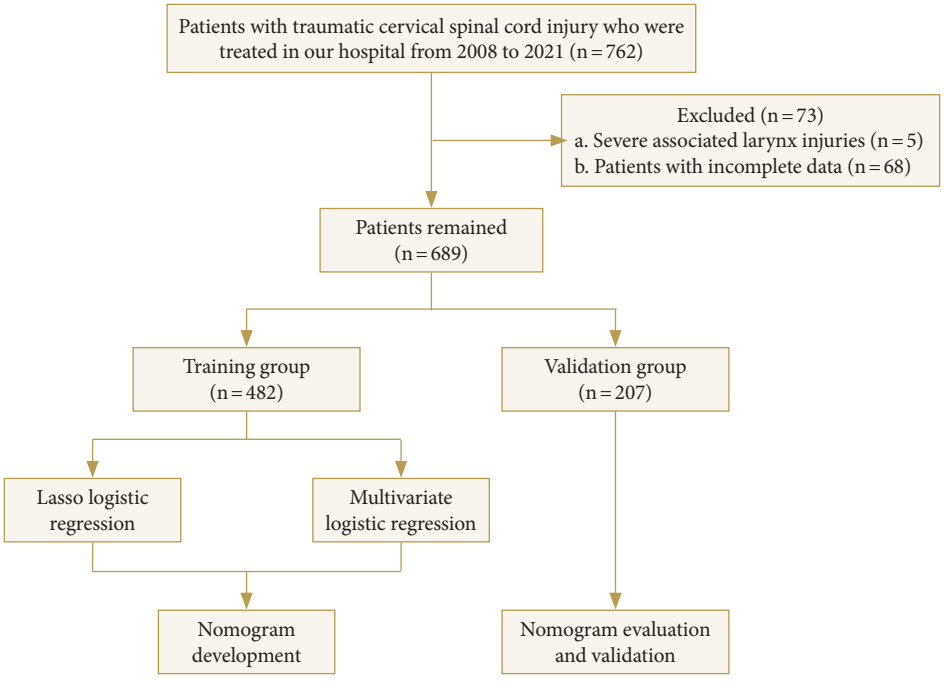

Fig. 1. Study flow diagram.

to measure the predictive accuracy of the nomogram model. The calibration curve and Hosmer-Lemeshow test were performed to assess the predictive ability of the nomogram. The decision curve analysis (DCA) was performed to evaluate the predictive model. All analyses and nomogram development were performed using R ver. 4.2.0 (R Foundation for Statistical

Table 1. Characteristics of patients with traumatic cervical spinal cord injury in the training and validation groups

Characteristic	Training group (n = 482)	Validation group (n = 207)
Sex		
Male	382 (79.3)	167 (80.7)
Female	100 (20.7)	40 (19.3)
Age (yr)		
≥ 60	145 (30.1)	54 (26.1)
< 60	337 (69.9)	153 (73.9)
Smoking history		
Yes	163 (33.8)	80 (38.6)
No	319 (66.2)	127 (61.4)
Dislocation		
Yes	195 (40.5)	86 (41.5)
No	287 (59.5)	121 (58.5)
Diabetes mellitus		
Yes	25 (5.2)	7 (3.4)
No	457 (94.8)	200 (96.6)
Hypertension		
Yes	36 (7.5)	21 (10.1)
No	446 (92.5)	186 (89.9)
ASIA impairment scale		
A	65 (13.5)	27 (13)
B–D	417 (86.5)	180 (87)
Neurological level of injury		
C1–4	148 (30.7)	77 (37.2)
C5–8	334 (69.3)	130 (62.8)
Preexisting lung disease		
Yes	40 (8.3)	19 (9.2)
No	442 (91.7)	188 (90.8)
Brain injury		
Yes	117 (24.3)	50 (24.2)
No	365 (75.7)	157 (75.8)
Thoracic injury		
Yes	81 (16.8)	32 (15.5)
No	401 (83.2)	175 (84.5)
Tracheostomy		
Yes	74 (15.4)	28 (13.5)
No	408 (84.6)	179 (86.5)

Values are presented as number (%).
ASIA, American Spinal Injury Association.

Table 2. Comparison of data between patients with and without tracheostomy in the training group

Variable	Tracheostomy (n = 74)	Without tracheostomy (n = 408)	p-value
Sex			0.048
Male	65 (87.8)	317 (77.7)	
Female	9 (12.2)	91 (22.3)	
Age (yr)			0.033
≥ 60	30 (40.5)	115 (28.2)	
< 60	44 (59.5)	293 (71.8)	
Smoking history			0.001
Yes	39 (52.7)	124 (30.4)	
No	35 (47.3)	284 (69.6)	
Dislocation			0.001
Yes	54 (73.0)	141 (34.6)	
No	20 (27.0)	267 (65.4)	
Diabetes mellitus			1.000
Yes	4 (5.4)	21 (5.1)	
No	70 (94.6)	387 (94.9)	
Hypertension			0.820
Yes	6 (8.1)	30 (7.4)	
No	68 (91.9)	378 (92.6)	
ASIA impairment scale			0.001
A	38 (51.4)	27 (6.6)	
B–D	36 (48.6)	381 (93.4)	
Neurological level of injury			0.001
C1–4	49 (66.2)	99 (24.3)	
C5–8	25 (33.8)	309 (75.7)	
Preexisting lung disease			0.190
Yes	9 (12.2)	31 (7.6)	
No	65 (87.8)	377 (92.4)	
Brain injury			0.138
Yes	23 (31.1)	94 (23.0)	
No	51 (68.9)	314 (77.0)	
Thoracic injury			0.001
Yes	27 (36.5)	54 (13.2)	
No	47 (63.5)	354 (86.8)	

Values are presented as number (%).
ASIA, American Spinal Injury Association.

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Computing, Vienna, Austria). A p-value of <0.05 was considered statistically significant.

RESULTS

1. Baseline Characteristics in Training Group

In the training group, 482 patients with TCSCI, and 74 patients (15.4%) underwent tracheostomy. The baseline characteristics of patients in the training group are shown in Table 1. A comparison of patients with and without tracheostomy is shown in Table 2. Compared with the nontracheostomy group, the tracheostomy group presents a significant difference in age ≥ 60 years, sex, smoking history, dislocation, ASIA impairment scale, NLI, and thoracic injury ($p<0.05$).

2. LASSO Regression and MLRA

The variables screened by LASSO regression analysis were: age, smoking history, dislocation, ASIA impairment scale grade,

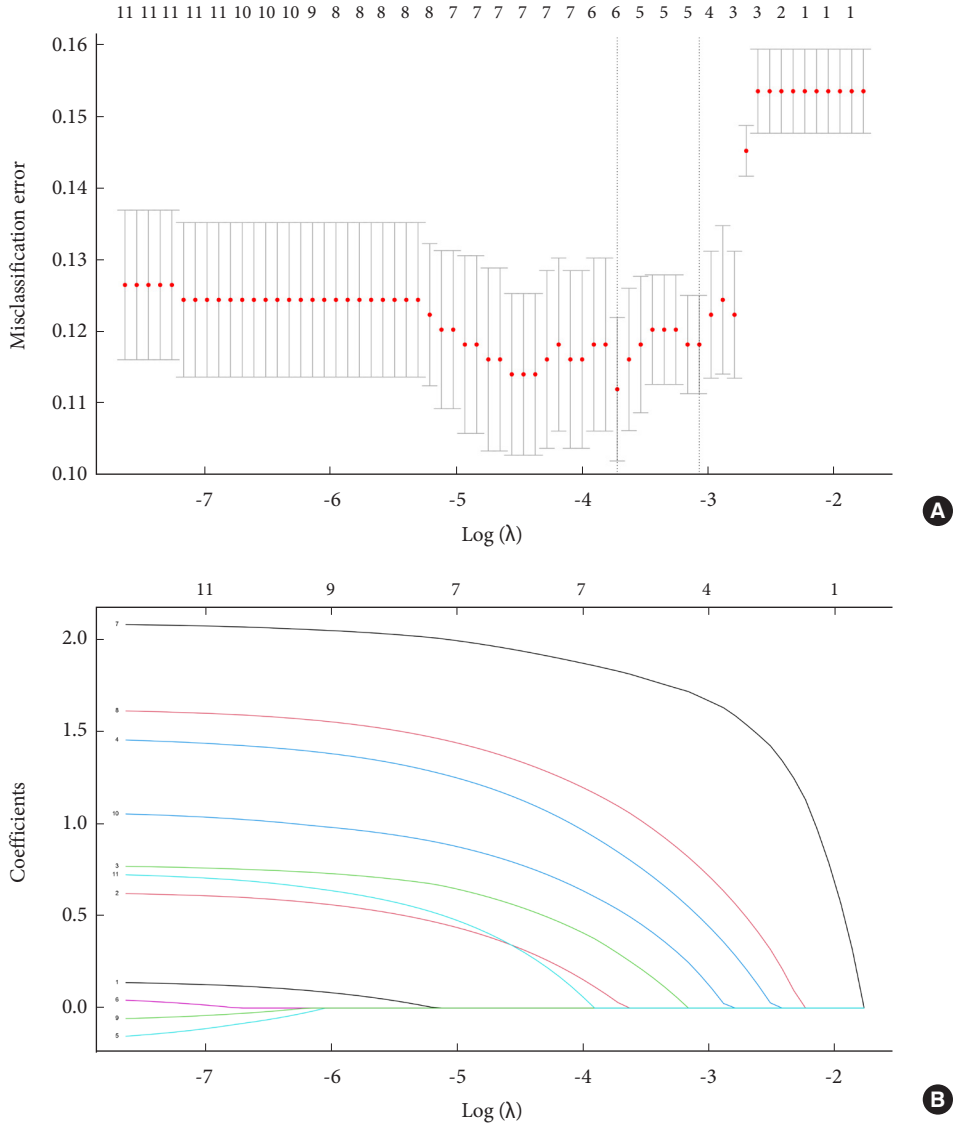

Fig. 2. (A) LASSO regression model screening predictors. By verifying the optimal parameter (lambda) in the LASSO model, the partial likelihood deviance (binomial deviance) curve was plotted versus log (lambda), while dotted vertical lines were drawn based on 1 standard error criteria. (B) A coefficient profile plot was produced against the log (lambda) sequence. 1: sex, 2: age, 3: smoking history, 4: dislocation, 5: diabetes mellitus, 6: hypertension, 7: American Spinal Injury Association grade, 8: neurological level of injury, 9: brain injury, 10: thoracic injury, 11: preexisting lung disease. Six variables with nonzero coefficients were selected by optimal lambda.

NLI, and thoracic injury (Fig. 2A, B). Their optimal coefficients were 0.029, 0.297, 0.847, 1.830, 1.097, and 0.535, respectively. These 6 variables selected by the LASSO regression with nonzero coefficients were included in the MLRA analysis. The results of the MLRA are given in Table 3. Five variables, including smoking history, dislocation, thoracic injury, ASIA impairment scale grade, and NLI, showed significant statistical differences.

3. Nomogram Model Development

Using these 5 variables, a nomogram model for predicting tracheostomy was developed (Fig. 3). Each factor corresponded to a score at the top of the nomogram, and the total score was calculated and compared to the bottom of the nomogram to predict tracheostomy risk. The AUC in the training group was 0.883. The best cutoff point was 0.124 (sensitivity, 0.838; specificity, 0.770) (Fig. 4A), which indicated that the discrimination of the nomogram model was good. The calibration curve of the nomogram model revealed satisfactory consistency (Fig. 5A).

4. Validation With Validation Set

Twenty-eight patients (13.5%) in the validation group underwent tracheostomy. The result of the Hosmer-Lemeshow test was p = 0.153. The AUC in the validation group was 0.909. The best cutoff point was 0.136 (sensitivity, 0.893; specificity, 0.777) (Fig. 4B), which indicated that the discrimination of the nomogram model was good. The calibration curve of the nomogram model revealed satisfactory consistency in the validation group (Fig. 5B).

Table 3. Multivariate logistic regression analysis performed in a step-by-step method for the tracheostomy in patients with traumatic cervical spinal cord injury in training group

Intercept and variable	β	Wald	p-value	OR	95% CI
Intercept	-4.282	116.149	0.001	0.014	
Dislocation	1.408	17.899	0.001	4.089	2.130–7.862
ASIA A	2.139	37.412	0.001	8.490	4.278–16.849
NLI C1–4	1.630	25.690	0.001	5.104	2.717–9.586
Smoking history	0.806	6.288	0.012	2.238	1.192–4.201
Thoracic injury	1.028	8.248	0.004	2.796	1.386–5.639

OR, odds ratio; CI, confidence interval; ASIA, American Spinal Injury Association; NLI, neurological level of injury.

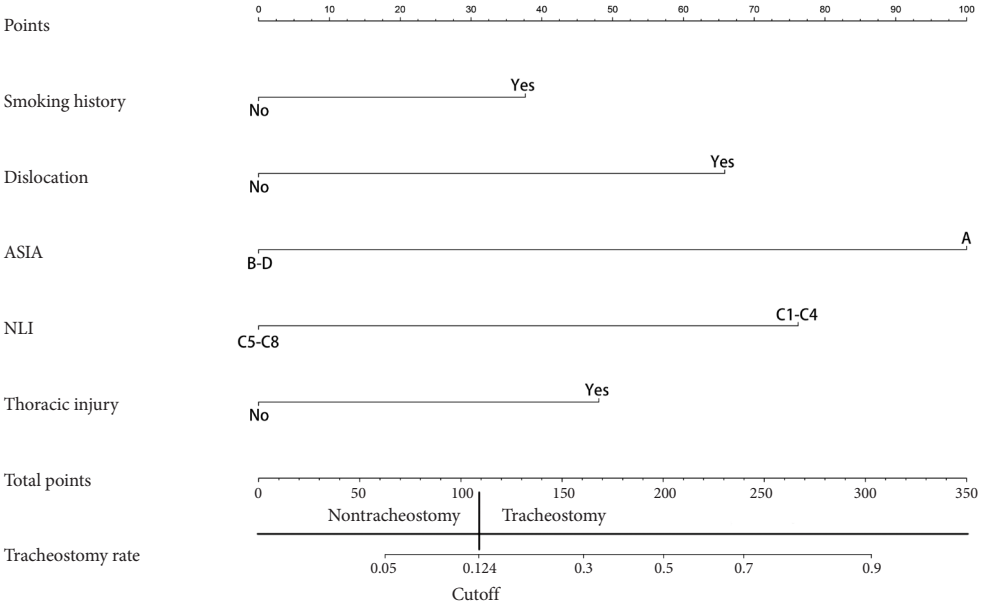

Fig. 3. The nomogram model for prediction of tracheostomy. ASIA, American Spinal Injury Association; NLI, neurological level of injury.

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5. DCA of the Nomogram Model

The clinical validity of the nomogram model was assessed using DCA (Fig. 6A, B). From the DCA, the nomogram performed well, and was feasible to make beneficial clinical decisions.

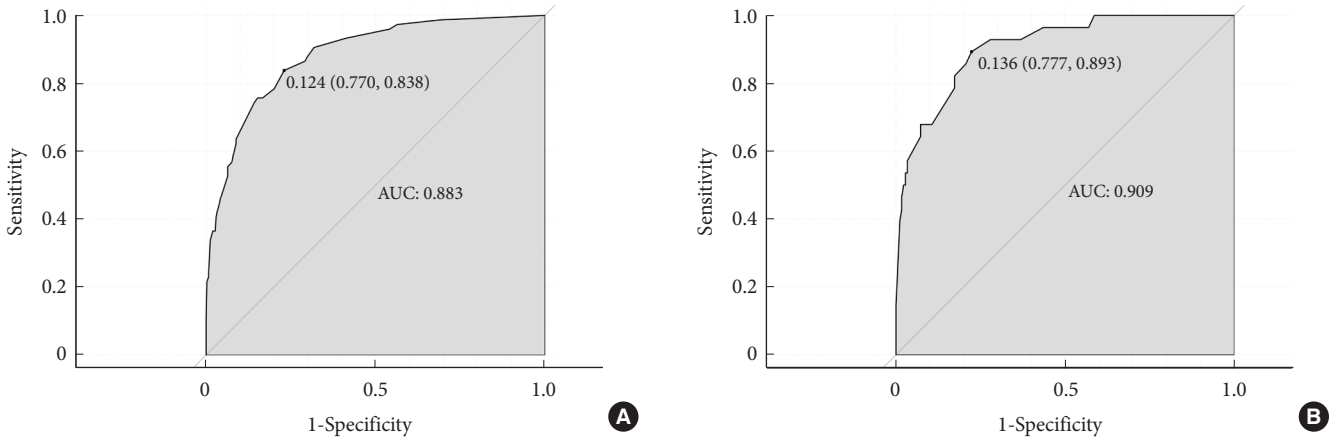

Fig. 4. Receiver operating characteristic (ROC) curve of the nomogram model. The training group (A) and the validation group (B). AUC, area under the curve.

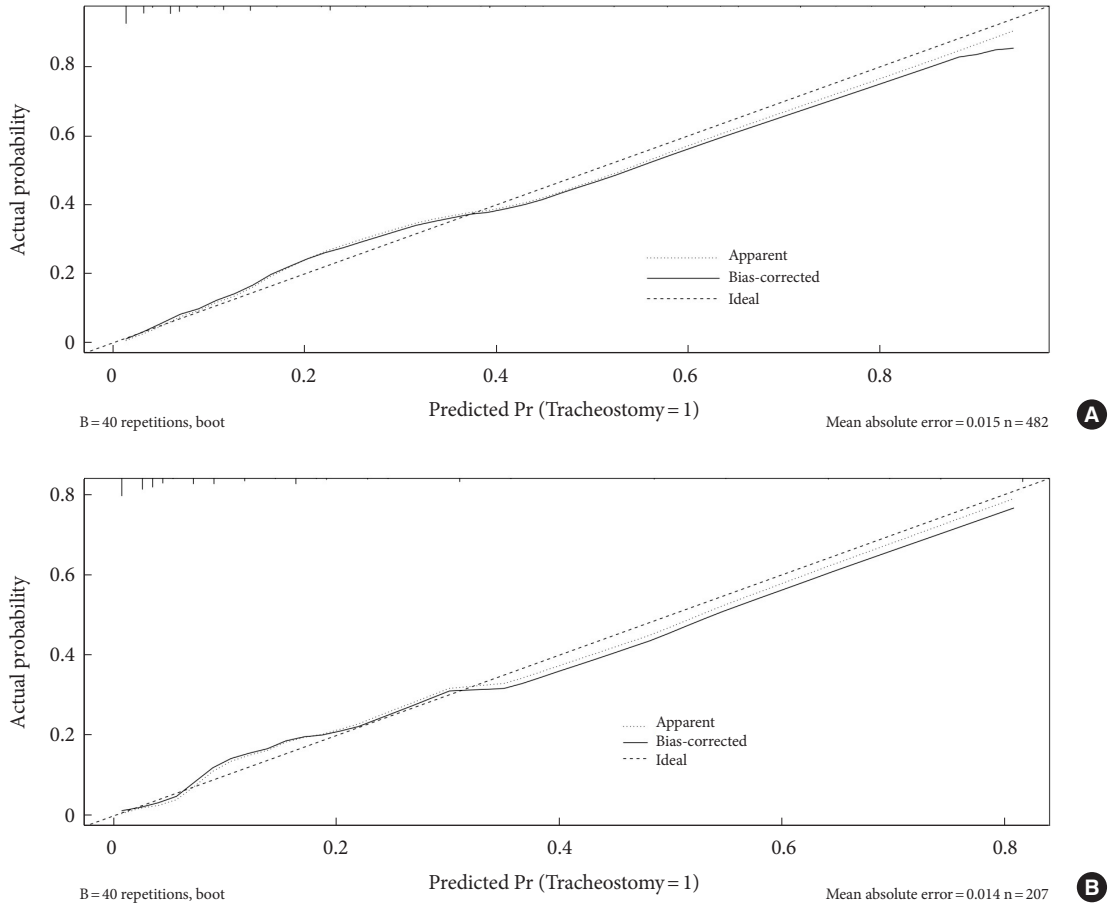

Fig. 5. Calibration curve to confirm the prediction performance stability of the nomogram. The training group (A) and the validation group (B).

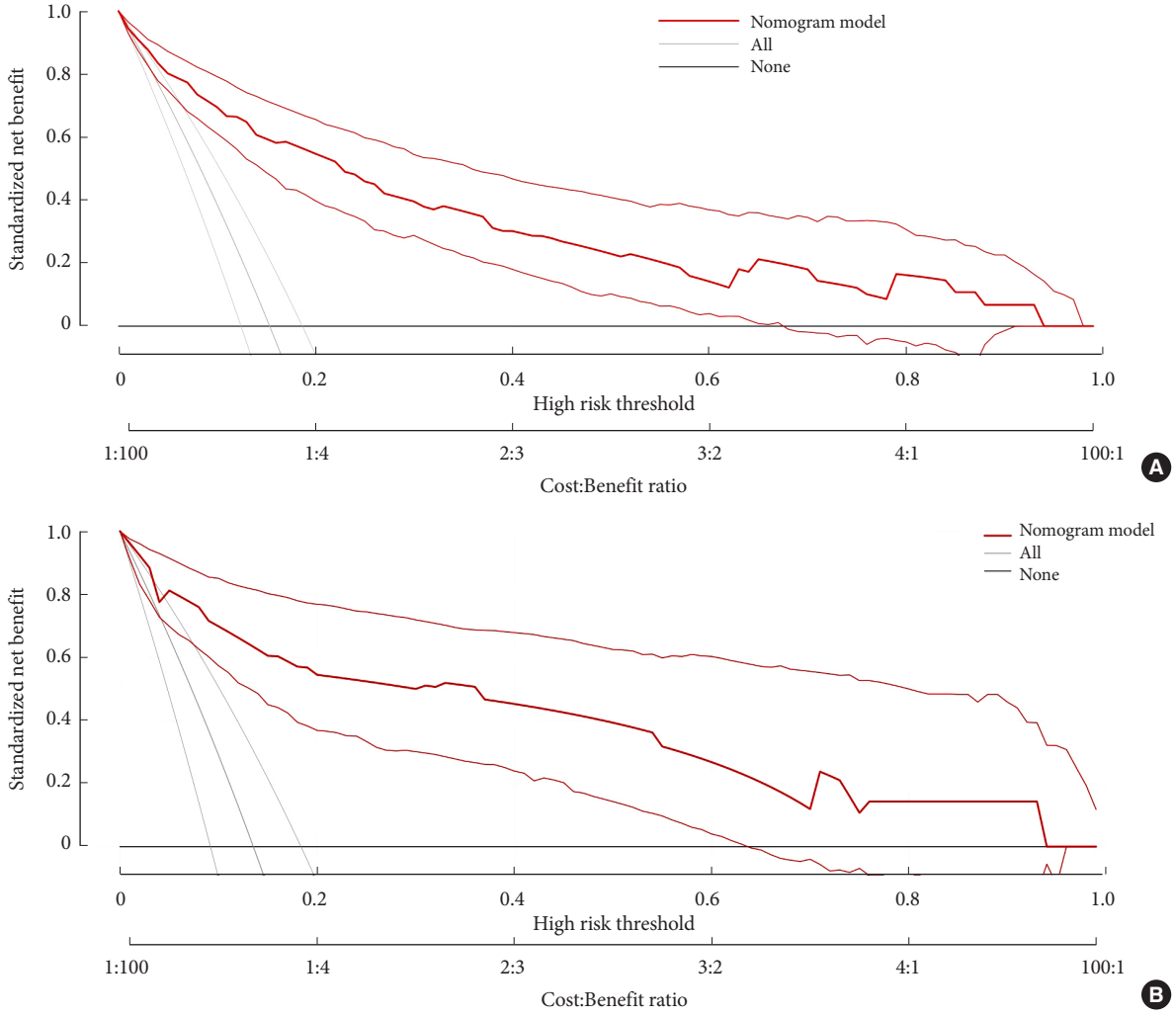

Fig. 6. Decision curve analysis for the training group (A) and the validation group (B).

DISCUSSION

The study presented 102 of 689 TCSCI patients who underwent tracheostomy to comprehensively screen the independent risk factors. In the MLRA analysis, dislocation, thoracic injury, ASIA grade A, NLI, and smoking history were associated with tracheostomy in TCSCI patients. Based on these results, a nomogram model was developed. Then, the model was validated on the training set and validation set. This nomogram model showed that dislocation, thoracic injury, ASIA grade A, NLI at C1–4, and smoking history were key predictors. This study provided a relatively reliable nomogram model. It exhibited relatively good discrimination and calibration capabilities.

The ASIA grade A has been regarded as an essential predictor for tracheostomy in TCSCI patients.[10,20-26] It was also an important predictor in the CART model for predicting tracheostomy.[8] In the results of Childs et al.,[27] they even suggested early tracheostomy in all patients with ASIA A. Consistent with previous research, the present MLRA results revealed that the ASIA grade A was a significant predictor of tracheostomy. In this nomogram prediction model, the score corresponding to ASIA grade A was the highest.

Due to diaphragm and/or intercostal muscle dysfunction, NLI was considered to be another important predictor for tracheostomy in TCSCI patients.[25,28-31] Tanaka et al.[32] suggested that tracheostomy may be required in patients with NLI C4 or above. The present study also classified NLI into C1–4 and C5–8. Consistent with previous studies, the score corresponding to NLI at C1–4 were also high in our nomogram prediction model.

This predictive model also included dislocation, smoking history, and thoracic injury. Cervical dislocations mostly cause spinal cord compression and dramatic neurological deficits. Mu

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et al.[26] also found that facet dislocation was a significant risk factor for tracheostomy in patients with TCSCI. Smoking increases susceptibility to pulmonary infection and the development of cigarette smoke-induced lung diseases.[33] Similarly, Nakashima et al.[11] found that one of the risk factors for tracheostomy was smoking history. One intriguing finding of the study was that thoracic injury was a predictor of tracheostomy. In the nomogram prediction model, thoracic injury corresponds to a score roughly around 50, between smoking history and dislocation.

Several risk variables associated with tracheostomy were presented in other studies, but not included in the present study. Some authors found that age was a statistically significant risk factor and that older age groups were more likely to undergo tracheostomy.[10,21,26,34,35] Controversially, other authors argued that age is not a risk factor.[8,11,20,22,24,25,32] Some scholars have introduced the forced vital capacity (FVC) variable in their prediction models.[9,10] However, using FVC for the predicted predictions has some shortcomings. For example, those who suffer great injury had to receive a tracheostomy may not have acceptable and reproducible pulmonary function test results.[8,36]

There are 3 limitations to this study. First, this study was based on retrospective data from a single-specialty spine injury center, so the level of evidence is limited. Second, indications for tracheostomy in patients with TCSCI varied between institutions. Third, although the population was relatively large, the patients were from a single hospital. So, representation needs to be further improved.

CONCLUSION

The present study developed and validated a nomogram model that can predict tracheostomy in TCSCI patients. The nomogram combining dislocation, thoracic injury, ASIA grade A, NLI, and smoking history was validated as a reliable model for tracheostomy prediction. The present nomogram prediction model can help clinicians take timely and more targeted medical interventions.

NOTES

Conflict of Interest: The authors have nothing to disclose.

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Author Contribution: Conceptualization: YJ, ZZ; Data curation: YJ; Formal analysis: YJ; Methodology: YJ; Project administration: ZZ; Visualization: YJ; Writing - original draft: YJ; Writing - review & editing: DS, ZZ.

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