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Research article

A nomogram for predicting the necessity of tracheostomy after severe acute brain injury in patients within the neurosurgery intensive care unit: A retrospective cohort study

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A R T I C L E I N F O

Keywords:
Severe acute brain injury
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Prediction
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A B S T R A C T

Objective: This retrospective study was aimed to develop a predictive model for assessing the necessity of tracheostomy (TT) in patients admitted to the neurosurgery intensive care unit (NSICU).

Method: We analyzed data from 1626 NSICU patients with severe acute brain injury (SABI) who were admitted to the Department of NSICU at the Affiliated People's Hospital of Jiangsu University between January 2021 and December 2022. Data of the patients were retrospectively obtained from the clinical research data platform. The patients were randomly divided into training (70%) and testing (30%) cohorts. The least absolute shrinkage and selection operator (LASSO) regression identified the optimal predictive features. A multivariate logistic regression model was then constructed and represented by a nomogram. The efficacy of the model was evaluated based on discrimination, calibration, and clinical utility.

Results: The model highlighted six predictive variables, including the duration of NSICU stay, neurosurgery, orotracheal intubation time, Glasgow Coma Scale (GCS) score, systolic pressure, and respiration rate. Receiver operating characteristic (ROC) analysis of the nomogram yielded area under the curve (AUC) values of 0.854 (95% confidence interval [CI]: 0.822–0.886) for the training cohort and 0.865 (95% CI: 0.817–0.913) for the testing cohort, suggesting commendable differential performance. The predictions closely aligned with actual observations in both cohorts. Decision curve analysis demonstrated that the numerical model offered a favorable net clinical benefit.

Conclusion: We developed a novel predictive model to identify risk factors for TT in SABI patients within the NSICU. This model holds the potential to assist clinicians in making timely surgical decisions concerning TT.

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1. Introduction

Severe acute brain injury (SABI) include a distinct array of neurological conditions that lead to acute neurological impairment. These conditions consist of ischemic or hemorrhagic stroke, aneurysm subarachnoid hemorrhage, and traumatic brain injury (TBI) [1]. SABI is responsible for approximately 12 million fatalities annually. Due to the profound nature of the initial brain injury and compromised airway protective reflexes, individuals diagnosed with SABI often require intubation and mechanical ventilation during the early critical care phase. A subset of these patients may experience prolonged neurological deficits, subsequently necessitating long-term airway support through a tracheostomy (TT). Notably, TT stands as one of the most common surgical procedures performed for SABI patients who requir mechanical ventilation [2].

A TT involves the surgically incision of the anterior wall of the trachea and the subsequent securing to the neck's skin [3]. This procedure can be conducted either in an operating room or at the bedside, typically within a neurosurgery intensive care unit (NSICU). The comprehensive the Extubation strategies in Neuro-Intensive care unit (ICU) patients and associations with Outcomes (ENIO) study evaluated extubation outcomes in acute brain injury and found that 19.4% of patients required reintubation within 5 days of attempting extubation, while 21.1% underwent a direct TT [4]. Among institutions participating in the CENTER-TBI study, the TT rate reached up to 31 % [5]. The frequent use of TT in SABI cases can be attributed to its manifold benefits, such as the decreased injury to the oropharyngeal and laryngeal mucosa, reduced risk of sinusitis, improved oropharyngeal hygiene, facilitated tracheal suctioning, enhanced patient comfort, and a more secure airway during increased mobilization [6]. In addition, tracheostomies minimize the need for sedation, streamline patient care, maintain glottal closure during swallowing, facilitate potential reintubation, and allow smoother weaning from mechanical ventilation [7]. While tracheostomies are generally considered safe, it is important to acknowledge that complications can arise. Early complications include bleeding and cannula dislodgment, whereas late-stage complications encompass fistula formation, cannula occlusion, and tracheal stenosis [8]. Hence, not all SABI patients are suitable candidates for a TT.

However, limited guidelines are available concerning the indications or optimal timing for a TT subsequent to SABI [3,4]. The decision to perform a TT following SABI is often made amid substantial prognostic uncertainties, especially in the initial stages of SABI. As a result, significant variability exists in the actual surgical procedures due to individual considerations. Some researchers reported that with each additional day before undergoing the TT, there is a noticeable 4% increase in the risk of an unfavorable outcome and a 6% heightened mortality hazard [9]. Early TT has been associated with improved neurological outcomes [10]. Therefore, during the initial phases of SABI, it is imperative to rigorously evaluate the indications for TT. Prompt identification of patients in need of a TT is crucial. However, determining this need at an early stage remains a predominant challenge in clinical practice.

Our current study aims to develop a nomogram based on clinical characteristic features to predict the necessity of TT in SABI patients. This tool would assist clinicians in making timely surgical decisions pertaining to TT.

2. Method

2.1. Study design and patients

A total of 1626 patients with SABI who were admitted to the NSICU Department at the Affiliated People's Hospital of Jiangsu University from January 2021 to December 2022 were considered for enrollment in our study. The subjects' data were retrospectively collected from our clinical research data platform. In our department, we employed Seldinger's technique as a guide: percutaneous TT involves the insertion of a tracheal cannula by means of blunt dissection of the pretracheal tissues [3].

The medical reasons for TT placement in our cohort include: (1) Facilitating weaning from mechanical ventilation; (2) Facilitating earlier discharge from intensive care, particularly with early TT; (3) Improving patient safety during transport and nursing care; (4) Providing prolonged life-sustaining treatment, potentially through a time-limited trial; (5) Administering more comfortable mechanical ventilation; and (6) Accelerating discharge from the acute care hospital [1].

Patients were excluded based on the following criteria: (1) Patients with an NSICU stay for fewer than 3 days, including individuals undergoing rtPA treatment for a transient ischemic attack. Subarachnoid hemorrhage patients were diagnosed as not having aneurysms through digital subtraction angiography, and individuals who declined treatment despite their critical condition. (2) Patients with a history of TT, admitted to the hospital with a pre-existing tracheal cannula in their neck. (3) Patients under 18 years of age or those with contraindications for percutaneous tracheotomy, including cervical instability, anterior neck infections, prior neck treatments (surgical or radiotherapy), anatomical localization challenges (obesity, short neck, thyroid gland hypertrophy), and cervical rigidity. (4) Patients with missing significant laboratory indicators, specifically those lacking more than 20% of their records. (5) Patients admitted to the NSICU for reasons other than SABI, such as brain tumor surgery.

After refining and extracting the baseline data, a total of 793 subjects' medical records were included in the statistical analysis. These subjects were then randomly divided into training and testing groups at a ratio of 7:3. This retrospective study received ethical approval from the Medical Ethics Committee of the Affiliated People's Hospital of Jiangsu University (Approval No.: K-20230129-W). As all patient data underwent anonymization and de-identification prior to analysis, informed consent was not required, ensuring compliance with the Declaration of Helsinki.

2.2. Data collection of patients

Patient demographics and clinical data, including age, gender, orotracheal intubation [11], diagnosis, NSICU stay, gastrostomy tube (G-tube) or jejunostomy tube (J-tube) intubation [12] and surgical history were extracted from the medical record system. Each piece of data underwent rigorous validation by experts to ensure precision and consistency. Serological tests were conducted within the first week, with reference ranges as follows: white blood cell count: 3.5–9.5 × $10^{\hat{}9}$/L; neutrophil percentage: 0.40–0.75; C-reactive protein (CRP): 0–5 mg/L; urea nitrogen: 2.1–7.5 mmol/L; creatinine: 35–135 μmol/L; and body mass index (BMI): considered overweight if > 28 kg/$m^{\hat{}2}$.

Detailed past medical histories, complications, unique clinical attributes, and academic and clinical biomarkers were compiled. Selected indicators, such as breathing variability [13], systolic and diastolic blood pressures, were meticulously determined from the point of NSICU admission, prioritizing the peak value. Concurrently, the Glasgow Coma Scale (GCS) score was employed to assess patient consciousness. Patients were categorized into three levels as per guidelines [10], selecting the minimal score for categorization. Our research methodology is depicted in Fig. 1.

2.3. *Risk factor selection and nomogram construction*

Both univariate and multivariate logistic regression techniques were employed to scrutinize clinical parameters. All attributes were incorporated into the least absolute shrinkage and selection operator (LASSO) regression analysis, with penalty parameter adjustments undertaken via tenfold cross-validation. This approach identified significant risk factors for tracheotomy as previously described [14]. These factors were amalgamated using multivariate logistic regression in the primary cohort, resulting in a user-friendly nomogram for medical practitioners.

2.4. *Statistical analysis*

Statistical analyses were conducted utilizing SPSS 22.0 and R software (4.1 version) [14]. Continuous variables were reported as either median (interquartile range) or mean ± standard deviation (SD), based on the results of the Shapiro–Wilk test. Categorical data, however, were expressed as proportions. Differences across cohorts were assessed using Chi-squared test, Fisher's exact test, and the Mann–Whitney *U* test. The performance of the developed models was evaluated through receiver operating characteristic (ROC) curve analysis, with the area under the curve (AUC) serving as the primary evaluation metric. Calibration curves were employed to evaluate the accuracy of the nomogram, followed by a goodness-of-fit assessment. The clinical utility of the refined models was further evaluated using decision curve analysis (DCA), which assessed net benefits at various probability thresholds for both cohorts. A p-value below 0.05 was considered statistically significant in this study.

3. Results

3.1. *Patient characteristics*

We retrospectively analyzed data from 1626 patients at our institution, of whom 793 were included in this study. Among them, 263 underwent TT, while 530 did not. The cohort was randomly divided into training and testing groups at a ratio of 7:3 (Fig. 1). Except for CRP, no significant discrepancies were observed across all variables between the training and testing groups (Table 1, $p > 0.05$). The overall TT rate was 33.2% (263/793), with 33.0% (184/555) in the training group and 33.3% (79/238) in the testing group. The mean duration to TT was 4.89 days.

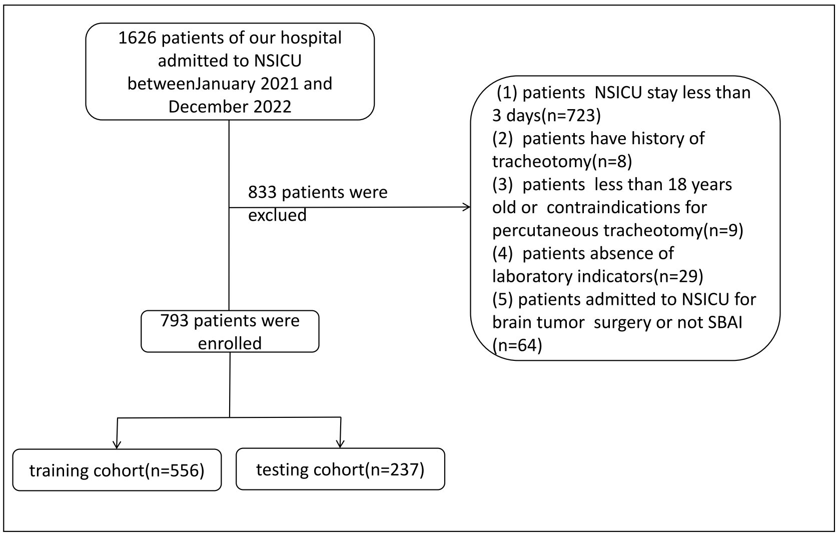

Fig. 1. Recruitment pathway for eligible patients in this study.

Table 1
Baseline characteristics of the enrolled patients in the training and validation cohorts.

	[ALL] N = 793	Test N = 238	Train N = 555	p.overall
Group	0.33 (0.47)	0.30 (0.46)	0.34 (0.48)	0.249
Gender, n (%)				1.000
woman	303 (38.2%)	91 (38.2%)	212 (38.2%)	
man	490 (61.8%)	147 (61.8%)	343 (61.8%)	
Age (years), media [Q1; Q3]	62.0 [52.0; 70.0]	61.0 [52.0; 71.0]	62.0 [52.0; 70.0]	0.840
Academic, n (%)				0.564
No education	57 (7.20%)	19 (7.98%)	38 (6.86%)	
Primary education	617 (77.9%)	188 (79.0%)	429 (77.4%)	
Advanced education	118 (14.9%)	31 (13.0%)	87 (15.7%)	
BMI, n (%)				0.430
< 28 kg/m2	754 (95.1%)	229 (96.2%)	525 (94.6%)	
≥28 kg/m2	39 (4.92%)	9 (3.78%)	30 (5.41%)	
Respiratory rate (event/min), media [Q1; Q3]	24.0 [23.0; 26.0]	24.0 [23.0; 25.8]	24.0 [23.0; 26.0]	0.167
Systolic pressure (mmHg), media [Q1; Q3]	161 [149; 180]	160 [150; 178]	162 [149; 180]	0.901
Diastolic pressure (mmHg), media [Q1; Q3]	90.0 [81.0; 101]	91.0 [83.0; 101]	89.0 [80.0; 102]	0.265
GCS, n (%)				0.098
Mild disturbance of consciousness	199 (25.1%)	51 (21.4%)	148 (26.7%)	
Moderate disturbance of consciousness	64 (8.07%)	15 (6.30%)	49 (8.83%)	
Severe disturbance of consciousness	530 (66.8%)	172 (72.3%)	358 (64.5%)	
NSICU stay (days), media [Q1; Q3]	8.00 [5.00; 13.0]	8.00 [5.00; 13.8]	8.00 [5.00; 13.0]	0.455
Orotracheal Intubation, n (%)				0.310
Negtive	410 (51.7%)	116 (48.7%)	294 (53.0%)	
Positive	383 (48.3%)	122 (51.3%)	261 (47.0%)	
Orotracheal Intubation Time (days), media [Q1; Q3]	0.00 [0.00; 2.00]	1.00 [0.00; 3.00]	0.00 [0.00; 2.00]	0.163
Neurosurgery, n (%)				0.186
Negtive	210 (26.5%)	55 (23.1%)	155 (27.9%)	
Positive	583 (73.5%)	183 (76.9%)	400 (72.1%)	
Craniotomy, n (%)				0.398
Negtive	316 (39.8%)	89 (37.4%)	227 (40.9%)	
Positive	477 (60.2%)	149 (62.6%)	328 (59.1%)	
Basic Medical History, n (%)				0.624
No underlying diseases	334 (42.1%)	105 (44.1%)	229 (41.3%)	
1-2 underlying diseases	420 (53.0%)	120 (50.4%)	300 (54.1%)	
more than 2 underlying diseases or important organ lesions	39 (4.92%)	13 (5.46%)	26 (4.68%)	
Pneumothorax or haemothorax, n (%)				0.297
Negtive	783 (98.7%)	237 (99.6%)	546 (98.4%)	
Positive	10 (1.26%)	1 (0.42%)	9 (1.62%)	
Smoke, n (%)				0.625
Negtive	682 (86.0%)	202 (84.9%)	480 (86.5%)	
Positive	111 (14.0%)	36 (15.1%)	75 (13.5%)	
Drink, n (%)				0.643
Negtive	714 (90.0%)	212 (89.1%)	502 (90.5%)	
Positive	79 (9.96%)	26 (10.9%)	53 (9.55%)	
Sedation, n (%)				0.539
Negtive	520 (65.7%)	152 (63.9%)	368 (66.4%)	
Positive	272 (34.3%)	86 (36.1%)	186 (33.6%)	
Diagnosis, n (%)				0.137
Intracerebral hemorrhage	289 (36.4%)	77 (32.4%)	212 (38.2%)	
Ischemic stroke	504 (63.6%)	161 (67.6%)	343 (61.8%)	
Intracerebral aneurysm				0.858
Brain trauma	250 (31.5%)	72 (30.3%)	178 (32.1%)	
Mechanical ventilation, n (%)	67 (8.45%)	19 (7.98%)	48 (8.65%)	
Negtive	161 (20.3%)	47 (19.7%)	114 (20.5%)	
Positive	315 (39.7%)	100 (42.0%)	215 (38.7%)	
Aspiration pneumonia, n (%)				0.714
Negtive	436 (55.0%)	128 (53.8%)	308 (55.5%)	
Positive	357 (45.0%)	110 (46.2%)	247 (44.5%)	
WBC count (109/L), media [Q1; Q3]	13.2 [10.3; 16.7]	12.9 [9.60; 16.6]	13.4 [10.6; 16.8]	0.302
Neutrophil percent, media [Q1; Q3]	0.88 [0.84; 0.90]	0.88 [0.84; 0.91]	0.87 [0.83; 0.90]	0.783
CRP (mg/L), media [Q1; Q3]	66.0 [27.3; 134]	68.2 [27.6; 132]	64.6 [27.1; 134]	0.905
Ureanitrogen (mmol/L), media [Q1; Q3]	6.10 [4.60; 8.00]	6.20 [4.60; 8.28]	6.00 [4.60; 7.95]	0.799
Creatinine (umol/L), media [Q1; Q3]	68.0 [53.0; 93.0]	70.0 [54.0; 96.0]	67.0 [52.0; 90.0]	0.342
G-tube, n (%)				0.809
Negtive	453 (57.1%)	138 (58.0%)	315 (56.8%)	
Positive	340 (42.9%)	100 (42.0%)	240 (43.2%)	
J-tube, n (%)				0.759
Negtive	781 (98.5%)	234 (98.3%)	547 (98.6%)	
Positive	12 (1.51%)	4 (1.68%)	8 (1.44%)	

3.2. Selection of risk factors and construction of the nomogram

A forest plot illustrating all of the univariate logistic regression analyses was constructed (Fig. 2). LASSO regression identified four prominent risk factors associated with TT (Fig. 3 A - C): J-tube intubation, neurosurgery, duration of NSICU stay, and G-tube intubation. All of the aforementioned factors were then included in multivariate logistic regression analyses, resulting in the identification of six determinants for TT: respiratory rate, systolic pressure, GCS scores denoting moderate to severe disturbances in consciousness, duration of NSICU stay, orotracheal intubation, and neurosurgery. A forest plot illustrating these associations was constructed (Fig. 4). Univariate and multivariate logistic regression analyses are also provided in Table 2. As shown in Fig. 5, a clinical nomogram was developed to predict the probability of TT by considering all six identified factors. Each factor was assigned a proportional score ranging from 0 to 100 in the nomogram, reflecting its respective regression coefficient relative to the necessity of TT. To estimate an individual's likelihood of TT, the cumulative score was calculated by summing up the scores associated with each factor. This calculation involved drawing a perpendicular line from each factor axis to intersect with the points axis on the nomogram. The resulting aggregate score could then be matched with the total score scale for interpretation purposes.

3.3. Model evaluation and clinical application

Calibration curve analysis indicated a high level of agreement between the nomogram's predictions and the actual pathological requirements for TT in both cohorts (Fig. 6 A, B), demonstrating an almost perfect fit. ROC analyses were conducted on the radiomics nomogram to predict the need for TT in both cohorts. The AUC values for the training and testing groups were 0.854 (95% confidence interval [CI]: 0.822–0.886) for the training cohort and 0.865 (95% CI: 0.817–0.913) for the testing cohort, respectively (Fig. 7 A, B). Furthermore, DCA revealed that the nomogram provided a greater net advantage in predicting the necessity of the TT compared to the "treat-all or treat-none" approach across most risk thresholds (Fig. 8 A, B).

4. Discussion

The clinical nomogram developed in this study provided medical professionals with a potential tool to evaluate the necessity of TT in patients with SABI. By potentially aiding healthcare professionals in making well-informed decisions regarding the use of the TT, this tool has the potential to enhance the personalization of tailored treatment strategies. Our novel model encompassed six parameters, all of which were standard clinical features routinely observed in health assessments. Importantly, ROC analysis revealed an AUC of 0.865 (95% CI: 0.817–0.913), highlighting the model's commendable discriminative and calibration capabilities. Furthermore, DCA demonstrated the substantial net clinical benefit of the model in both the training and validation cohorts.

TT is a common and effective technique for airway management that can be performed at any stage during hospitalization. Approximately 10–15% of general ICU patients undergo TT, while this percentage increases to between 15 and 35% for NSICU patients [15]. In our study, almost 33% of NSICU patients required TT, aligning with previous findings. The advantages of TT include reduced airway resistance, improved airway compliance, and decreased nursing intensity. The predictive model we have developed was aimed to assess the necessity for tracheotomy in patients. Considering that tracheal intubation can serve as a viable alternative in many cases,

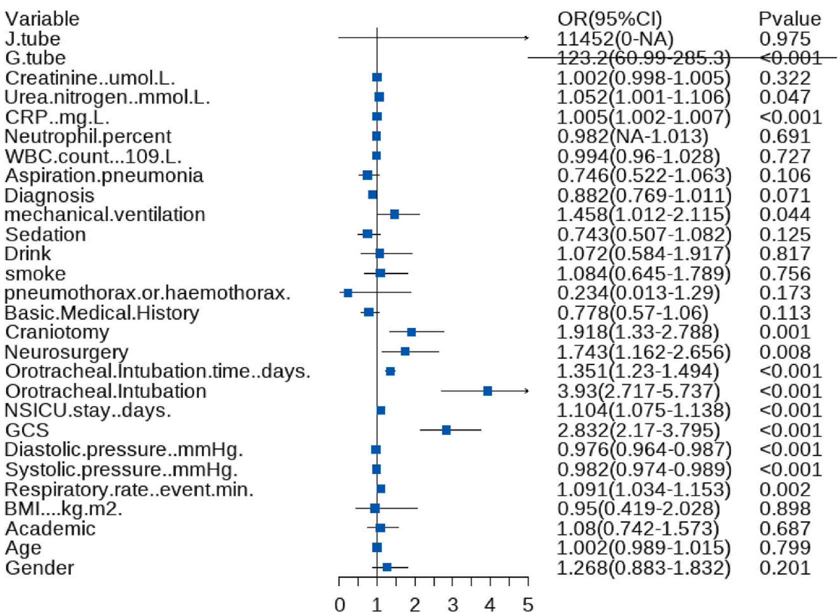

Fig. 2. A forest plot illustrating the all of characteristics identified by univariate logistic regression analyses.

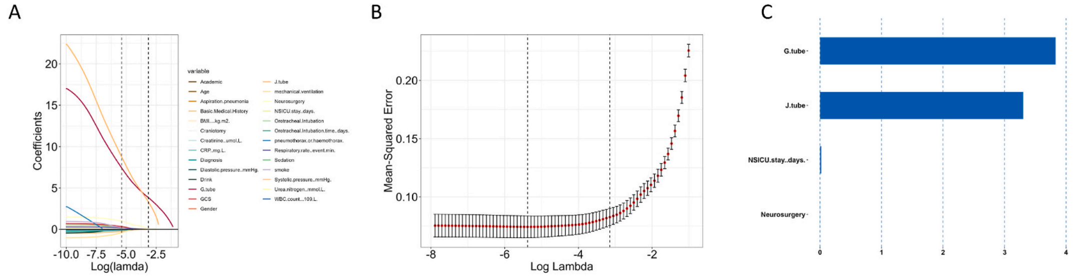

Fig. 3. Tuning parameter selection using the LASSO regression in the training cohort. (A) LASSO coefficient profiles of the clinical features. (B) The optimal penalization coefficient lambda was generated in the LASSO via 10-fold cross-validation. The lambda value of the 1-fold mean square error for the training cohort was given. (C) A plot illustrating the positive characteristics identified by LASSO.

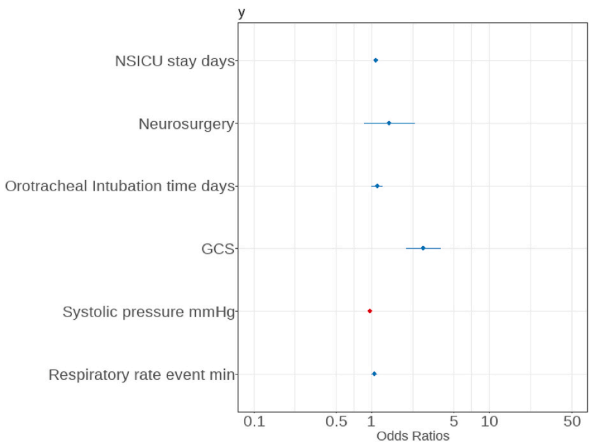

Fig. 4. A forest plot illustrating the positive characteristics identified by multivariate logistic regression analyses.

it is suggested to employ the predictive model during hospitalization.

Numerous studies support the benefits of early TT, such as shortened ventilation duration [16], decreased sedative usage, and reduced respiratory complications, particularly in patients with prolonged mechanical ventilation [15–18]. This procedure has even demonstrated a mortality benefit in some cases. Additionally, accumulated evidences have emphasized the ability of early TT to reduce the occurrences of ventilator-associated pneumonia, facilitate effective breathing, lower medical costs, and decrease hospital mortality rates [11,19]. TT is typically employed in patients requiring prolonged mechanical ventilation, facing difficulty with extubation [20], or in need of long-term care. Early anticipation and detection of patients who might necessitate TT could facilitate prompt administration of respiratory assistance and potentially enhance prognosis. Hence, it is imperative to ascertain the risk factors and necessity for TT, given its potential advantages.

Hemorrhagic stroke patients often exhibit higher rates of TT compared to non-neurological patients [10]. Factors such as reduced consciousness, typically measured using the GCS, have been correlated with TT, particularly in NSICUs [10,21]. Notably, low levels of consciousness, indicative of severe brain injury, have been associated with increased rates of TT [10]. Thus, we found that the GCS score and neurosurgery were superior predictors for TT. Additionally, SABI frequently triggers sympathetic overdrive in patients, potentially disrupting normal breathing patterns, as evidenced by occurrences of hyperpnea. Central neurogenic hyperventilation often originates from diencephalic injuries or malfunctions [22]. The elevated respiratory rate emerged as a significant predictor for TT in our study.

Meanwhile, patients who exhibit excessively high respiratory rates typically require sedative treatments to protect their respiratory capabilities. Besides, delirium is a common condition that occurs after SABI-induced injuries, potentially stemming from a hyper-adrenergic state following trauma [23,24]. In clinical practice, sedation is also used as a therapy [25]. Neurosurgical patients often experience varying degrees of consciousness disturbance when sedatives are administered [18]. A considerable portion of these patients necessitate prolonged utilization of mechanical ventilation, highlighting the justification for opting for tracheostomy tube (TT) when extubation is considered impracticable.

Anatomically, brain injuries can compromise various critical regions responsible for breathing, ranging from the cortex to the pons and medulla [22]. Severe SABI can disrupt protective airway reflexes, leading to potential aspiration of oral and respiratory secretions [5]. It is usually attributed to decreased alertness rather than direct damage to the brainstem. Stroke patients often struggle with respiratory and swallowing difficulties, with approximately a quarter requiring ventilatory support [26,27]. Critically ill neurological patients with compromised brain functions generally require mechanically assisted ventilation and intubation. Extended orotracheal

Table 2
Results of univariate and multivariate logistic regression analyses.

characteristics	Univariate Analysis				Multivariate Analysis			
	β coefficient	**OR**	**95% CI**	**P-value**	**β coefficient**	**OR**	**95% CI**	**P-value**
Gender	0.238	1.268	1.268 (0.883–1.832)	0.201				
Age	0.002	1.002	1.002 (0.989–1.015)	0.799				
Academic	0.077	1.08	1.08 (0.742–1.573)	0.687				
BMI	−0.051	0.95	0.95 (0.419–2.028)	0.898				
Respiratory rate	0.087	1.091	1.091 (1.034–1.153)	0.002	0.188	1.207	1.206 (1.045–1.419)	0.016
Systolic pressure	−0.018	0.982	0.982 (0.974–0.989)	< 0.001	−0.028	0.972	0.972 (0.955–0.987)	0.001
Diastolic pressure	−0.025	0.976	0.976 (0.964–0.987)	< 0.001				
GCS	1.041	2.832	2.832 (2.17–3.795)	< 0.001	0.753	2.123	2.123 (1.063–4.290)	0.033
NSICU stay days	0.099	1.104	1.104 (1.075–1.138)	< 0.001	0.132	1.141	1.140 (1.064–1.236)	0.001
Orotracheal Intubation	1.369	3.93	3.93 (2.717–5.737)	< 0.001				
Orotracheal Intubation time days.	0.301	1.351	1.351 (1.23–1.494)	< 0.001	−0.162	0.85	0.850 (0.729–0.996)	0.039
Neurosurgery	0.556	1.743	1.743 (1.162–2.656)	0.008	1.603	4.969	4.969 (1.895–13.79)	0.001
Craniotomy	0.651	1.918	1.918 (1.33–2.788)	0.001				
Basic Medical History	−0.251	0.778	0.778 (0.57–1.06)	0.113				
pneumothorax or haemothorax.	−1.452	0.234	0.234 (0.013–1.29)	0.173				
smoke	0.081	1.084	1.084 (0.645–1.789)	0.756				
Drink	0.07	1.072	1.072 (0.584–1.917)	0.817				
Sedation	−0.296	0.743	0.743 (0.507–1.082)	0.125				
mechanical ventilation	0.377	1.458	1.458 (1.012–2.115)	0.044	−0.735	0.48	0.479 (0.175–1.208)	0.133
Diagnosis	−0.126	0.882	0.882 (0.769–1.011)	0.071				
Aspiration pneumonia	−0.293	0.746	0.746 (0.522–1.063)	0.106				
WBC count (109/L)	−0.006	0.994	0.994 (0.96–1.028)	0.727				
Neutrophil percent	−0.018	0.982	0.982(NA-1.013)	0.691				
CRP (mg/L)	0.005	1.005	1.005 (1.002–1.007)	< 0.001	−0.005	0.995	0.995 (0.989–1.000)	0.063
Urea nitrogen (mmol/L)	0.051	1.052	1.052 (1.001–1.106)	0.047	−0.075	0.928	0.927 (0.843–1.015)	0.109
Creatinine (umol/L)	0.002	1.002	1.002 (0.998–1.005)	0.322				
G-tube	4.814	123.204	123.2 (60.99–285.3)	< 0.001	31.511	48413886826013.3	48413 (1.982–3.462)	0.976
J-tube	16.254	11452698.805	11452 (0-NA)	0.975	50.864	1.23057165502149E+022	1.230 (2.437-Inf)	0.996

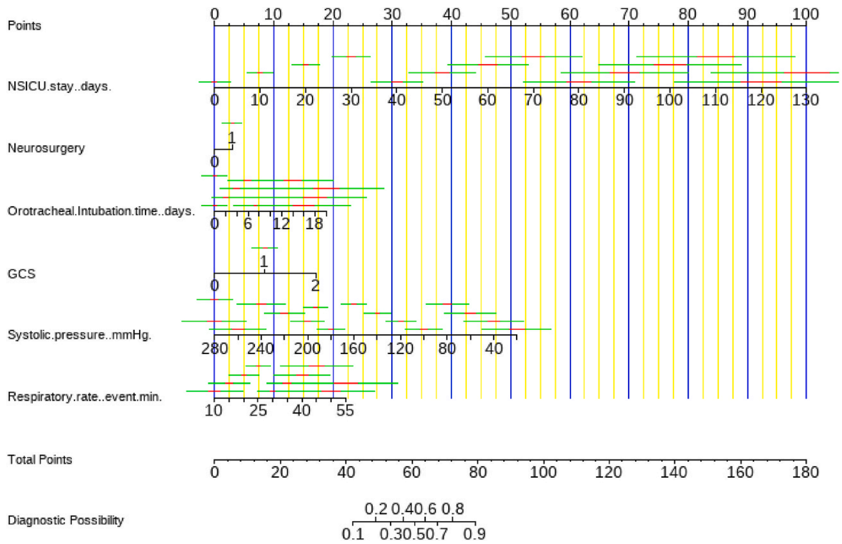

Fig. 5. Clinical-radiomics nomogram based on LASSO regression and multivariate logistic regression analysis for the prediction of need of tracheostomy in SABI patients.

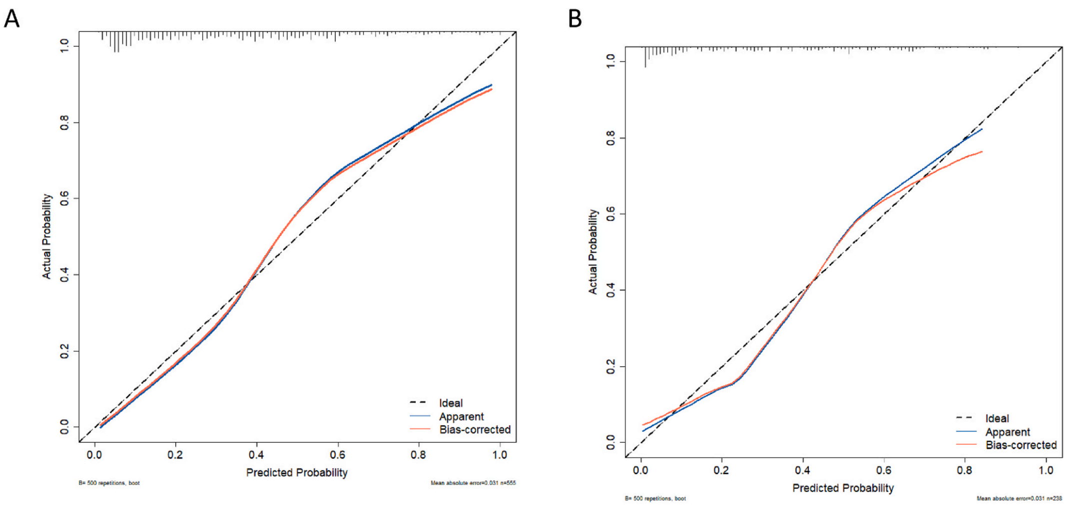

Fig. 6. ROC curves for the assessment of discrimination performance of the clinical nomogram. ROC, receiver operating characteristic. (A) , the training set; (B), the validation set. (bootstrap replicates = 500 times).

intubation can exacerbate pulmonary infections and mortality rates, issues that can be mitigated by TT [11].

In NSICUs, respiratory deterioration can originate from pneumonia or secondary factors such as brain edema or infarctions [22]. Healthy adults produce significant daily airway secretions, which may contain harmful substances and pathogens. The effective removal of these secretions in critically ill patients is vital to prevent bronchial and lung infections [28]. Airway secretion retention often results from weakened cough strength, underscoring the importance of enhanced respiratory care. It can be postulated that patients lacking mucociliary oscillation require strengthened respiratory care interventions, such as repositioning, chest percussion, and sputum suction. These procedures can strongly stimulate the patient, inducing an abnormal rise in blood pressure. Elevated blood pressure has been linked to such respiratory care, suggesting its potential as a predictor for TT. The mechanism behind airway secretion retention often involves environmental and disease-related factors.

Some researchers proposed that TT could contribute to a shorter duration of ICU stay [16]. Nevertheless, our study findings suggested that TT might actually prolonged the length of ICU stay. In accordance with our results, the brain injury-induced immunosuppression syndrome initiated after acute brain injury and ischemia has been recognized in animal models [31]. It was mediated by intense activation of the hypothalamic-pituitary axis and the sympathetic nervous system. Almost 40% of patients undergoing craniotomy develop at least one infection [32,33]. Elevated catecholamine levels and subsequent suppressed immune function may increase the risk of infection. In addition, anesthesia and mechanical ventilation required for surgery further heighten the risk of

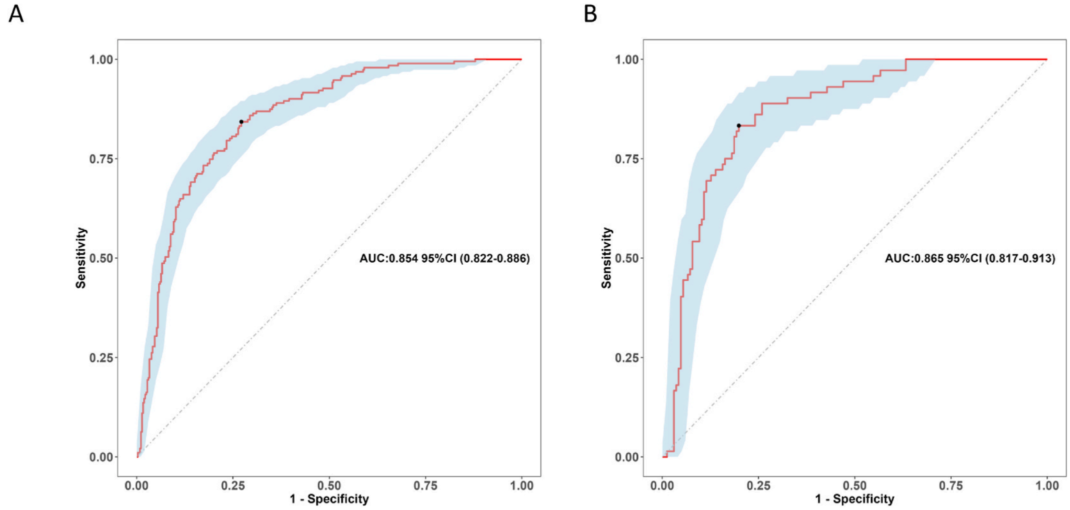

Fig. 7. Calibration curve analysis for the clinical-radiomics nomogram in the training set （A）and the validation set(B).

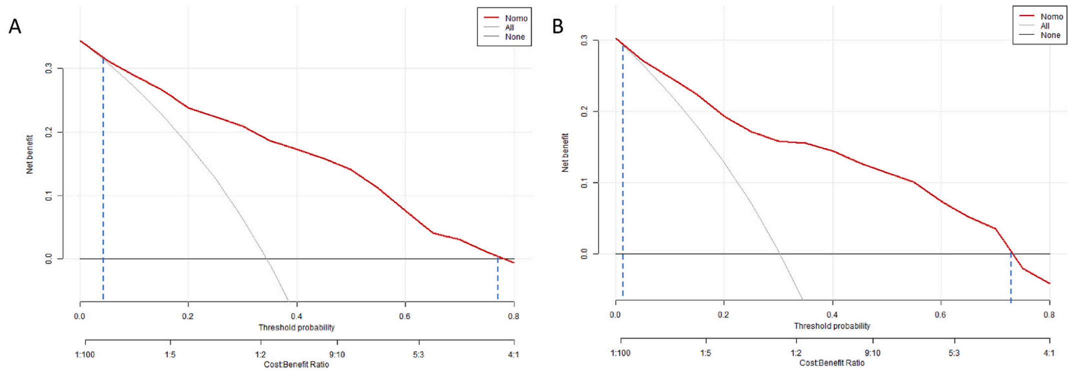

Fig. 8. Decision curve analysis of the clinical nomogram.（A）, the training set; (B), the validation set. The decision curve shows that when the threshold probability of an individual falls within 5%–78%, using this model to predict the necessity of tracheostomy provides greater benefits compared to employing either the treat-all or the treat-none method.

ventilator-associated pneumonia and impaired lung compliance [34].

Severe brain injury also impairs the protective airway reflexes, leading to aspiration of oral and respiratory secretions. Patients in ICUs for extended durations typically exhibit deteriorated overall health, making them susceptible to infections [21]. It could be attributed to stress ulcers, poor gastrointestinal function, malnutrition, especially for patients with SABI [38] and respiratory muscle fatigue [39]. Actually, SABI patients often enter a hypercatabolic state in an attempt to repair neuronal damage. Malnutrition in critically ill patients can be accompanied with endocrine dysfunction, multiorgan failure, impaired immunity, and increased mortality. Many SABI patients experience swallowing difficulties and may require mechanical ventilation, making enteral nutrition the preferred method of nutritional support, especially within the first 24–48 h [35]. During treatment, a gastrostomy tube (G-tube) or jejunostomy tube (J-tube) is often inserted to provide necessary nutrients and meet caloric requirements [12]. We calculated that the G-tube is typically placed within 3 days, while the J-tube is placed within 7 days. The placement of these tubes has been recommended to reduce the incidence of infections, improve feeding tolerance, and decrease reflux [37]. Early enteral nutrition has been shown to significantly decrease mortality, the risk of metabolic imbalances, pressure ulcer formation, and hepatobiliary dysfunction in SABI patients [36]. The placement of G-tubes and J-tubes can reflect the condition of the patient. Patients in poor conditions often have compromised airway mucosal barriers, immune function, and lung compliance [29,30]. ICU-acquired infections are another contributing factor [40]. Our results revealed that longer stays in the ICU were associated with a poorer overall body status, thereby compromising both the body's resistance and its ability to repair damage caused by pathogenic bacteria [41,42]. It further increased the need for TT procedures. Patients with unstable respiratory status and intensive nursing care requirements face challenges in regular departments and are at significant risk of suffocation due to retained airway secretions if not detected in time. Prolonged use of mechanical ventilation and longer stays in the NSICU have led to an increase in TT procedures. Furthermore, physicians' predictions about patients' conditions and their confidence in the likelihood of prolonged NSICU stays are influential factors driving the implementation of TT for patient safety during extended periods of artificial airway and respiratory support.

This study proposed a clinical nomogram involving both clinical features and biomarkers to provide personalized evaluations for the necessity of TT among SABI patients in NSICUs. Although previous studies have discussed whether pneumonia was a predictor for TT [28,43], our results suggest that it did not play a significant role. Our model may aid clinicians in categorizing NSICU patients, facilitating early identification of high-risk TT cases and endorsing proactive and tailored treatments. The individual SABI types appears to be insignificant in predicting the need for TT, highlighting the role of overall respiratory weakness rather than pneumonia in such determinations.

Our research had several limitations. As a single-center retrospective study with a potentially limited sample size, it may introduce selection bias. Additionally, some patients may refuse surgery due to disease severity or financial constraints, indicating that patient selection in our study might introduce potential bias. Moreover, not all influencing factors were considered, underscoring the need for future comprehensive studies. When assessing changes in physiological indicators such as respiratory rate, blood pressure, and blood cell count, we relied on extreme values within a specific time frame to indicate disease severity. However, it is important to note that relying solely on extreme values may not accurately reflect the patient's condition.

5. Conclusion

In summary, our innovative model holds the potential to facilitate the identification of risk factors for TT in SABI patients within the NSICU, thereby assisting clinicians in making timely decisions regarding TT. In future, prospective large-scale multicenter cohort study would be necessary to further refine and update this clinical decision-making system.

Ethics statement

The studies involving human participants were reviewed and approved by the Ethics Committee of Affiliated People's Hospital of Jiangsu University (Approval Number:K-20230129-W) .

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Data availability statement

The data we have gathered has not been stored in a publicly accessible repository. Any or all of the data, models, or code that back up the conclusions of this research can be obtained from the corresponding author upon making a reasonable inquiry.

CRediT authorship contribution statement

Liqin Gao: Writing – original draft, Data curation. **Yafen Chang:** Data curation. **Siyuan Lu:** Software, Data curation. **Xiyang Liu:** Data curation. **Xiang Yao:** Data curation. **Wei Zhang:** Writing – review & editing. **Eryi Sun:** Writing – review & editing, Writing – original draft, Software, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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