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Original Article

Risk factors and predictive model for weaning failure in elderly patients with chronic obstructive pulmonary disease and type II respiratory failure

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Abstract: Objective: To identify factors associated with failed weaning from mechanical ventilation in elderly patients with chronic obstructive pulmonary disease (COPD) and type II respiratory failure. Method: This retrospective study included 210 patients treated at the Fourth Affiliated Hospital of Soochow University from April 2021 to April 2024. Patients were divided into a modeling group (n = 147) and a validation group (n = 63) in a 7:3 ratio. Univariate and multivariate logistic regression analyses were performed to determine risk factors for weaning failure. A risk prediction model was developed based on the multivariate results using the glm function and visualized as a nomogram with the rms package. The model's predictive performance was evaluated using receiver operating characteristic (ROC) curves. Results: Multivariate analysis identified elevated N-terminal pro-brain natriuretic peptide (NT-proBNP), low 25-hydroxyvitamin D_3 [25(OH)D_3], high rapid shallow breathing index, longer COPD disease duration, and higher Acute Physiology and Chronic Health Evaluation II (APACHE II) scores as independent risk factors (all $P < 0.05$). The area under the ROC curve (AUC) for predicting weaning failure was 0.802 in the modeling group and 0.824 in the validation group, indicating good predictive accuracy. Conclusion: NT-proBNP, 25(OH)D_3, rapid shallow breathing index, COPD duration, and APACHE II score are key predictors of mechanical ventilation weaning failure in elderly COPD patients with type II respiratory failure. The developed model demonstrates robust predictive value and may aid clinical decision-making.

Keywords: Elderly, chronic obstructive pulmonary disease, type II respiratory failure, mechanical ventilation, weaning failure, risk factors

Introduction

Chronic obstructive pulmonary disease (COPD) poses a significant global public health challenge, with its disease burden continuing to rise [1]. Recent epidemiological studies indicate that the global prevalence of COPD among individuals aged 40 years and older has reached 11.7%, with Asia bearing a particularly heavy burden due to high smoking rates and severe air pollution [2]. Acute exacerbations of COPD (AECOPD) are a major contributor to mortality. Approximately 30% of patients with type II respiratory failure require mechanical ventilation, and the weaning failure rate remains high at 25%-40% [3]. This high failure rate is largely due to the multisystem involvement in these patients: airflow limitation and dynamic hyperinflation increase respiratory muscle workload, while comorbid cardiopulmonary conditions - such as right heart failure and pulmonary hypertension - further complicate weaning [4, 5].

Although mechanical ventilation can temporarily correct respiratory failure, prolonged use increases the risk of complications, including ventilator-associated pneumonia (VAP) and diaphragmatic dysfunction. Patients ventilated for more than seven days face a 3.2-fold higher risk of weaning failure, and those who fail weaning have a significantly higher in-hospital mortality rate than those who succeed (38.5% vs. 12.7%) [6]. Clinicians must balance the risks of premature weaning, which can lead to respiratory and circulatory collapse, against delayed weaning, which raises infection risk. Current guidelines mainly rely on the rapid shallow breathing index (RSBI) and blood gas analysis,

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yet the impact of comorbidities (e.g., diabetes, heart failure) and nutritional deficiencies (e.g., hypoproteinemia) in elderly COPD patients is still insufficiently characterized [7, 8].

This study systematically evaluates a prediction model for weaning failure in elderly COPD patients with type II respiratory failure at our hospital. By integrating indicators of multi-organ function, ventilation parameters, and complications, this model provides a risk stratification tool to guide clinical decisions. This work addresses gaps in evidence specific to elderly patients in existing guidelines, offering practical value for reducing re-intubation rates and improving outcomes.

Materials and methods

Case selection

This retrospective study included 210 patients with COPD and type II respiratory failure who were admitted to the Fourth Affiliated Hospital of Soochow University between April 2021 and April 2024. Patients were divided into a modeling group (n = 147) and a validation group (n = 63) at a ratio of 7:3. All patients required tracheal intubation and mechanical ventilation. This study was approved by the Ethics Committee of the Fourth Affiliated Hospital of Soochow University.

Inclusion criteria: (1) Diagnosis of COPD according to established guidelines [9]; (2) Diagnosis of type II respiratory failure as defined in Internal Medicine [10]; (3) Meeting weaning readiness criteria: marked improvement of COPD condition, adequate oxygenation [pH > 7.30, fraction of inspired oxygen (FiO_2) < 0.35, arterial partial pressure of oxygen (PaO_2) > 50 mmHg], stable hemodynamics, absence of dynamic myocardial ischemia or significant hypotension, preserved spontaneous breathing and cough reflex; (4) Age ≥ 60 years; (5) Systolic blood pressure between 90-160 mmHg without dependence on vasoactive drugs; (6) Duration of mechanical ventilation ≥ 48 hours; (7) Complete clinical records available for analysis.

Exclusion criteria: (1) Malignant tumors; (2) Interstitial lung disease; (3) Other respiratory diseases (e.g., asthma, tuberculosis); (4) Severe dysfunction of the heart, liver, or kidneys; (5) Immunodeficiency; (6) Respiratory failure due to other causes; (7) Chest deformity, pneumothorax, diaphragmatic paralysis, or abdominal drainage; (8) Primary neuromuscular diseases; (9) Uncontrolled sepsis, pulmonary fungal infection, or drug-resistant bacterial infection; (10) Severe electrolyte imbalance; (11) Acute coronary syndrome or uncontrolled heart failure within the past week.

Weaning method and criteria for success or failure

Weaning method: A spontaneous breathing trial (SBT) was performed under low-level pressure support ventilation: the pressure support level was set at 7 cm H_2O with an FiO_2 of 30%, and the trial duration was 120 minutes. Thirty minutes into the SBT, the respiratory frequency (f) and tidal volume (Vt) were measured to calculate the RSBI. Patients were closely monitored throughout, with arterial blood gas analysis performed before and after the trial.

Criteria for successful or failed weaning: Arterial blood gas criteria: SpO_2 > 90%, PaO_2 > 60 mmHg, pH > 7.32, $PaCO_2$ increase < 10 mmHg.

Hemodynamic criteria: Heart rate (HR) < 120-140 beats/min or change < 20%; systolic blood pressure (SBP) > 90 mmHg and < 180 mmHg or SBP change < 20%; respiratory rate (RR) < 35 breaths/min or change < 50%.

Clinical criteria: The patient remains conscious, without dyspnea, discomfort, sweating, or need for assisted ventilation. If these criteria are met 120 minutes after the SBT, extubation is performed. Absence of re-intubation within 48 hours is defined as successful weaning; re-intubation within this period is considered weaning failure.

Data collection

As a retrospective study, relevant data were extracted from the hospital's electronic medical record system and clinical assessment records.

Observation indicators

Collected variables included: Clinical data: sex, age, BMI, diabetes, hypertension, smoking history, COPD duration, mechanical ventilation duration, oxygenation index, Acute Physiology and Chronic Health Evaluation II (APACHE II) score, and RSBI. Laboratory data: Within 6

Table 1. Comparison of clinical data between the modeling and validation groups

Clinical data	the Modeling Group (n = 147)	the Validation Group (n = 63)	t/χ^2	*P*
Gender				
Male	93	39	0.035	0.852
Female	54	24		
Age (years)				
> 75	85	33	0.531	0.466
60-75	62	30		
BMI (kg/m^2, $\bar{x} \pm s$)	22.83 ± 2.50	22.76 ± 3.02	0.174	0.862
Diabetes [n (%)]	25 (17.01)	9 (14.29)	0.241	0.624
Hypertension [n (%)]	28 (19.05)	14 (22.22)	0.278	0.598
Smoking history [n (%)]	57 (38.78)	25 (39.68)	0.015	0.902
Mechanical ventilation time (d, $\bar{x} \pm s$)	9.87 ± 3.08	9.69 ± 3.11	0.387	0.699
COPD course (years, $\bar{x} \pm s$)	10.65 ± 2.15	10.97 ± 2.03	1.005	0.316
Respiratory rate (times/min, $\bar{x} \pm s$)	17.95 ± 3.10	17.35 ± 2.95	1.304	0.194
Oxygenation index (mmHg, $\bar{x} \pm s$)	277.56 ± 35.64	270.69 ± 40.62	1.227	0.221
APACHE II scores (scores, $\bar{x} \pm s$)	14.59 ± 3.41	15.03 ± 4.61	0.767	0.444
Shallow rapid breathing index [times/(min·L), $\bar{x} \pm s$]	78.69 ± 15.62	80.22 ± 13.49	0.677	0.499
WBC ($\times 10^9$/L, $\bar{x} \pm s$)	14.30 ± 2.70	13.89 ± 2.93	0.983	0.327
PLT ($\times 10^9$/L, $\bar{x} \pm s$)	208.58 ± 37.69	211.02 ± 48.95	0.392	0.696
Hb (g/L, $\bar{x} \pm s$)	117.60 ± 13.64	114.50 ± 16.76	1.406	0.161
CRP (mg/L, $\bar{x} \pm s$)	12.29 ± 4.61	11.85 ± 3.47	0.679	0.498
$25(OH)D_3$ (nmol/L, $\bar{x} \pm s$)	16.08 ± 4.57	16.68 ± 3.97	0.906	0.366
NT-proBNP (pg/ml, $\bar{x} \pm s$)	327.69 ± 108.95	317.86 ± 96.52	0.619	0.536

Note: BMI: body mass index. COPD: Chronic obstructive pulmonary disease. APACHE II: Acute Physiological and Chronic health scores. WBC: White blood cell count. PLT: Platelet count. Hb: Hemoglobin. CRP: C-reactive protein. $25(OH)D_3$: 25-hydroxyvitamin D_3. NT-proBNP: N-terminal brain natriuretic peptide precursor.

hours before SBT, peripheral venous blood was drawn to measure white blood cell count (WBC), platelet count (PLT), hemoglobin (Hb), C-reactive protein (CRP), 25-hydroxyvitamin D_3 [$25(OH)D_3$], and N-terminal pro-brain natriuretic peptide (NT-proBNP).

Statistical analysis

Statistical analyses were conducted using SPSS 27.0. Continuous variables were expressed as mean ± standard deviation (SD) and compared using the t-test. Categorical variables were presented as percentages and compared using the chi-square test. A two-tailed *P*-value < 0.05 was considered statistically significant. Univariate and multivariate Logistic regression analyses were performed to identify factors associated with weaning failure. The predictive value of the model for weaning failure was analyzed using the ROC curve. Nomogram models, calibration curves and the decision curve analysis (DCA) were constructed and analyzed using R language.

Results

Comparison of clinical data between the modeling and validation groups

There were no significant differences between the modeling and validation groups in terms of gender, age, BMI, diabetes, hypertension, smoking history, mechanical ventilation duration, COPD disease duration, respiratory rate, APACHE II score, RSBI, WBC, PLT, Hb, CRP, $25(OH)D_3$, and NT-proBNP (all P > 0.05), as shown in **Table 1**.

Comparison of clinical data between the failed and successful weaning groups

Among the 147 patients in the modeling group, 39 patients (26.53%) failed weaning and were classified as the failed weaning group, while the remaining 108 patients were classified as the successful weaning group. Compared to the successful group, the failed group had significantly longer mechanical ventilation duration,

Table 2. Comparison of clinical data between successful and failed weaning groups

Clinical data	Failed Weaning Group (n = 39)	Successful Weaning Group (n = 108)	t/χ^2	*P*
Gender				
Male	25	68	0.016	0.899
Female	14	40		
Age (years)				
> 75	23	62	0.029	0.865
60-75	16	46		
BMI (kg/m^2, $\bar{x} \pm s$)	23.17 ± 2.29	22.71 ± 3.01	0.867	0.387
Diabetes [n (%)]	8 (20.51)	17 (15.74)	0.462	0.497
Hypertension [n (%)]	10 (25.64)	18 (16.67)	1.497	0.221
Smoking history [n (%)]	20 (51.28)	37 (34.26)	3.497	0.062
Mechanical ventilation time (d, $\bar{x} \pm s$)	11.67 ± 3.31	9.22 ± 2.69	4.577	0.000
COPD course (years, $\bar{x} \pm s$)	13.42 ± 2.41	9.65 ± 1.97	9.636	0.000
Respiratory rate (times/min, $\bar{x} \pm s$)	18.21 ± 2.98	27.56 ± 3.35	15.366	0.000
Oxygenation index (mmHg, $\bar{x} \pm s$)	269.84 ± 36.60	280.35 ± 33.21	1.648	0.102
APACHE II scores (scores, $\bar{x} \pm s$)	16.03 ± 3.17	14.07 ± 3.82	2.866	0.005
Shallow rapid breathing index [times/(min·L), $\bar{x} \pm s$]	85.62 ± 13.97	76.19 ± 16.01	3.256	0.001
WBC ($\times 10^9/L$, $\bar{x} \pm s$)	13.97 ± 3.16	14.42 ± 2.56	0.882	0.379
PLT ($\times 10^9/L$, $\bar{x} \pm s$)	198.79 ± 39.60	212.12 ± 30.28	2.164	0.032
Hb (g/L, $\bar{x} \pm s$)	112.30 ± 15.42	119.51 ± 12.96	2.828	0.005
CRP (mg/L, $\bar{x} \pm s$)	13.86 ± 3.79	11.72 ± 4.81	2.510	0.013
$25(OH)D_3$ (nmol/L, $\bar{x} \pm s$)	13.57 ± 3.94	16.99 ± 4.72	4.043	0.000
NT-proBNP (pg/ml, $\bar{x} \pm s$)	361.25 ± 110.51	315.57 ± 98.49	2.403	0.018

Note: BMI: body mass index. COPD: Chronic obstructive pulmonary disease. APACHE II: Acute Physiological and Chronic health scores. WBC: White blood cell count. PLT: Platelet count. Hb: Hemoglobin. CRP: C-reactive protein. $25(OH)D_3$: 25-hydroxyvitamin D_3. NT-proBNP: N-terminal brain natriuretic peptide precursor.

Table 3. Multivariate logistic regression analysis of factors affecting failed extraction

Important factors	β	S.E	χ^2	*P*	OR	95% CI
NT-proBNP	2.351	0.724	10.545	0.001	10.496	2.539-43.382
$25(OH)D_3$	-1.976	0.633	9.745	0.002	0.139	0.040-0.479
Shallow Fast Breathing Index	1.791	0.610	8.620	0.003	5.995	1.814-19.818
COPD course	1.558	0.594	6.880	0.009	4.749	1.483-15.214
APACHE II scores	1.482	0.577	6.597	0.010	4.402	1.421-13.639

Note: NT-proBNP: N-terminal brain natriuretic peptide precursor. $25(OH)D_3$: 25-hydroxyvitamin D_3. COPD: Chronic obstructive pulmonary disease. APACHE II: Acute Physiological and Chronic health scores. WBC: White blood cell count.

longer COPD disease course, higher APACHE II scores, higher RSBI, higher CRP, lower $25(OH)D_3$ levels, and higher NT-proBNP levels (all $P < 0.05$), as shown in **Table 2**.

Multivariate logistic regression analysis of risk factors for weaning failure

A multivariate logistic regression analysis was performed on variables that were significant in the univariate analysis. The results indicated that NT-proBNP, $25(OH)D_3$, RSBI, COPD disease duration, and APACHE II score were independent risk factors for weaning failure (all $P < 0.05$), as detailed in **Table 3**.

Construction of the nomogram model

A binary logistic regression model was constructed using the glm function, and a nomogram was developed and visualized using the rms package, as shown in **Figure 1A**.

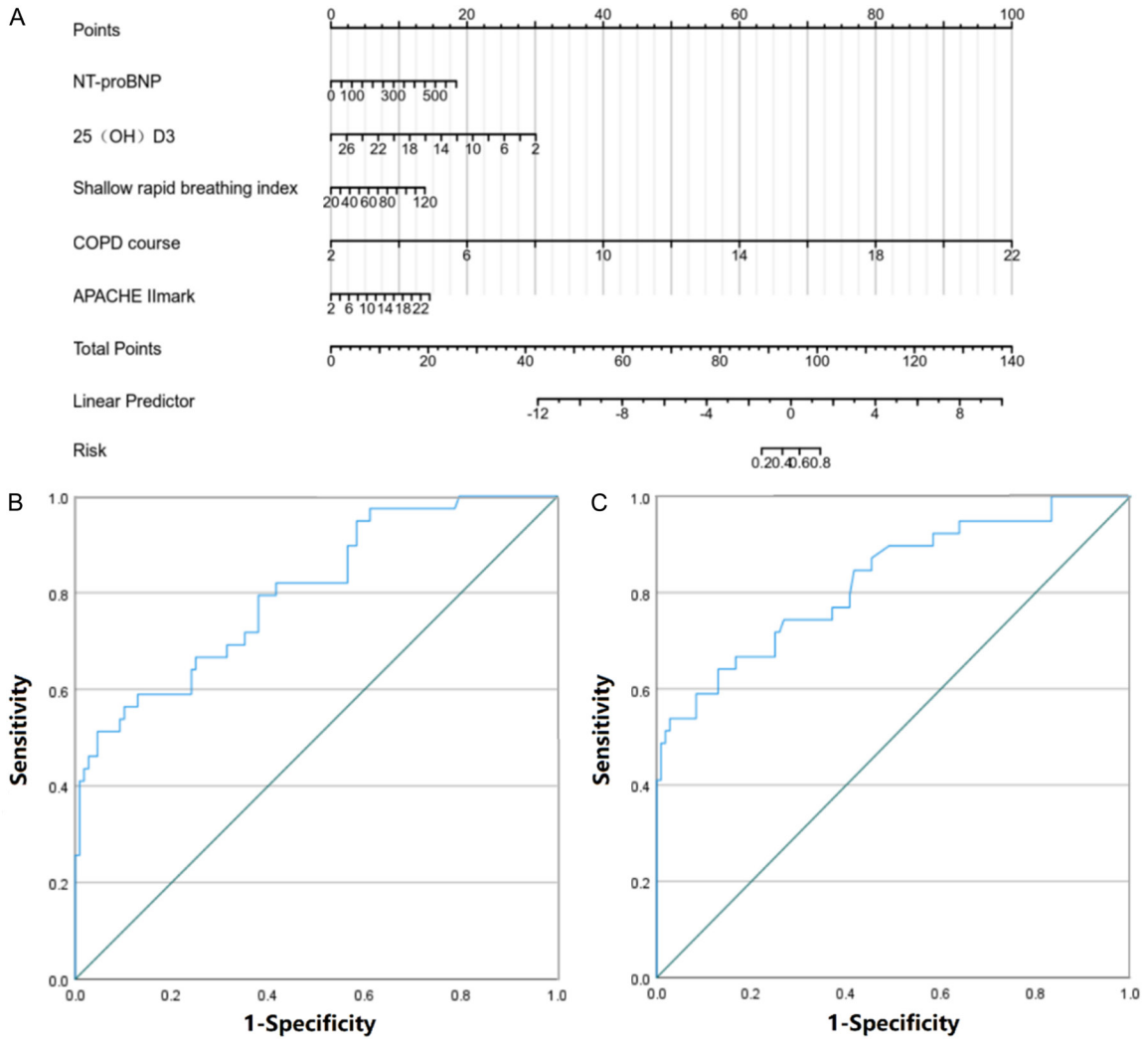

Figure 1. Construction of the nomogram model and ROC curve. A: Construction of the nomogram model. B: ROC curve analysis of the model's predictive value for failed weaning in the modeling group patients. C: ROC curve analysis of the model for predicting failure to decannulate patients in the validation group. Note: NT-proBNP: N-terminal brain natriuretic peptide precursor. 25(OH)D_3: 25-hydroxyvitamin D_3. COPD: Chronic obstructive pulmonary disease. APACHE II: Acute Physiological and Chronic health scores. WBC: White blood cell count.

ROC curve analysis of the model's predictive value in the modeling group

The predictive value of the model for weaning failure in the modeling group was evaluated using an ROC curve. The AUC was 0.802 ($P < 0.001$; 95% CI: 0.720-0.884), with a sensitivity of 51.30% and a specificity of 95.40%, as shown in **Figure 1B**. The calibration curve had a C-index of 0.937 (**Figure 2A**), and DCA indicated good clinical utility (**Figure 2B**).

ROC curve analysis of the model's predictive value in the validation group

In the validation group, the ROC curve showed an AUC of 0.824 ($P < 0.001$; 95% CI: 0.743-0.906), with a sensitivity of 64.10% and a specificity of 87.00%, as shown in **Figure 1C**. The calibration curve had a C-index of 0.957 (**Figure 3A**), and the DCA demonstrated good clinical benefit (**Figure 3B**).

Discussion

As the aging population grows, the number of elderly patients with COPD and type II respiratory failure is increasing each year. Mechanical ventilation remains a vital intervention for these patients, improving oxygenation and facilitating carbon dioxide elimination, thus meeting alveolar ventilation demands [11, 12]. However, prolonged mechanical ventilation significantly increases the risk of VAP. Therefore,

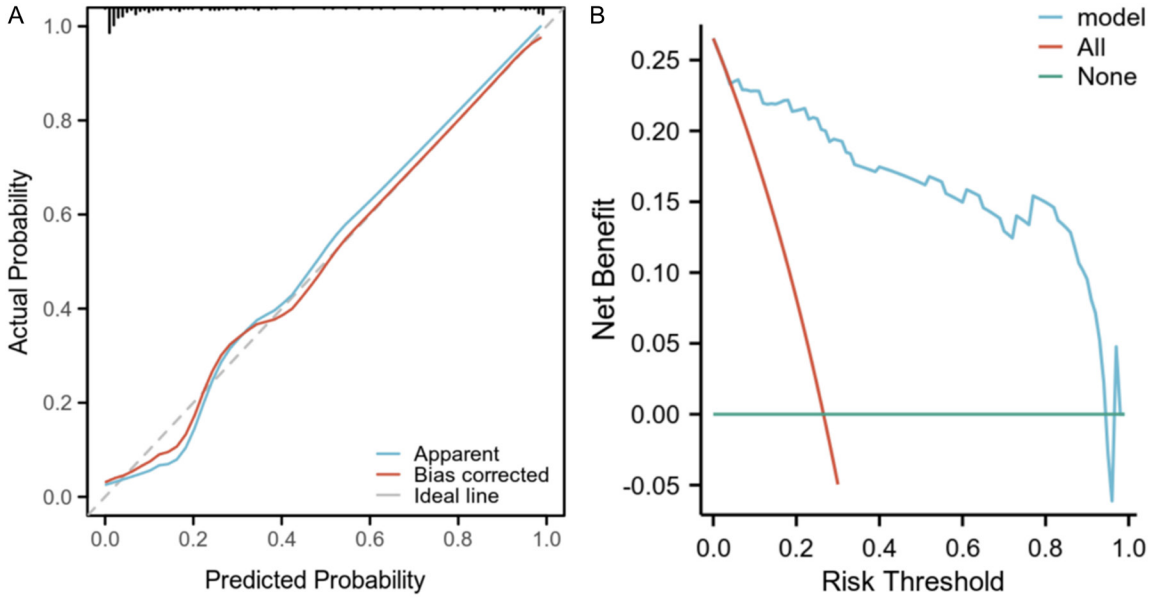

Figure 2. Calibration curve and DCA curve of the modeling group. A: Calibration curve of the modeling group. B: DCA curve of the modeling group.

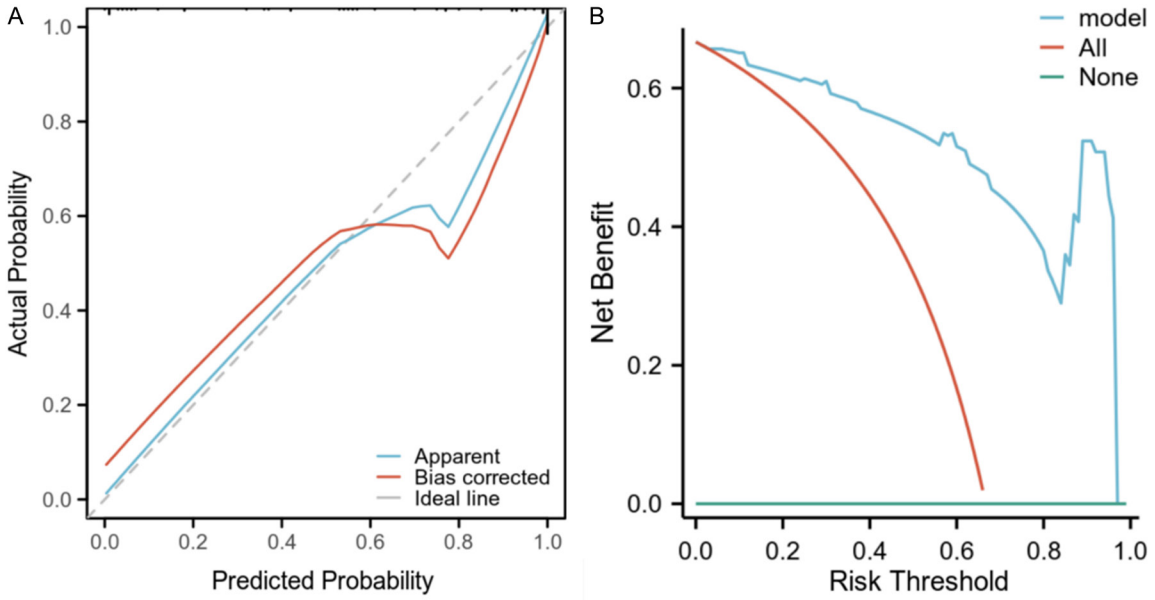

Figure 3. Calibration Curve and the decision curve analysis of the Verification Group. A: Calibration curve of the verification group. B: The decision curve analysis of the Verification group.

improving the success rate of extubation is crucial for reducing the incidence of VAP. Identifying risk factors for weaning failure and implementing targeted interventions are essential for optimizing patient outcomes [13, 14].

This study aimed to investigate the factors associated with mechanical ventilation weaning failure in elderly patients with COPD and type II respiratory failure and to develop a risk prediction model to aid early identification of high-risk patients. Univariate and multivariate logistic regression analyses identified NT-proBNP, 25(OH)D_3, RSBI, COPD disease duration, and APACHE II score as significant predictors of weaning failure. NT-proBNP is a cardiac biomarker reflecting cardiac load and function; elevated levels indicate increased

cardiac workload, which may lead to myocardial injury and complications such as heart failure, thus lowering extubation success rates [15, 16]. Elevated NT-proBNP may also suggest pulmonary hypertension, a known risk factor for weaning failure [17]. Prolonged mechanical ventilation leads to respiratory muscle disuse, atrophy, and functional decline, further compromising extubation success [18, 19].

$25(OH)D_3$, a key vitamin D metabolite, reflects vitamin D status and was found to be a protective factor against weaning failure. This may be due to vitamin D's immunomodulatory effects, which enhance systemic immunity and lower infection risk [20, 21]. Deficiency in vitamin D may worsen respiratory muscle atrophy, reducing weaning success [22-24]. The RSBI indicates respiratory muscle strength and endurance; higher RSBI values imply insufficient muscle function, increasing the likelihood of failed weaning [25-27]. As a progressive disease, COPD leads to gradual lung function decline, weakening respiratory muscles and reducing the probability of successful weaning [28, 29]. Longer COPD duration is associated with more severe disease and greater respiratory muscle impairment, further elevating weaning failure risk [30, 31].

The APACHE II score provides a comprehensive assessment of acute physiological status and chronic health conditions; higher scores reflect greater severity and reduced physiological reserve, increasing the risk of weaning failure [32-35]. Overall, these findings highlight the multifactorial nature of weaning failure in elderly COPD patients with type II respiratory failure, indicating that clinical interventions should address multiple systems rather than single parameters.

Based on the multivariate logistic regression results, a nomogram model was constructed using the rms package. ROC curve analysis showed an AUC of 0.802 in the modeling group and 0.824 in the validation group, demonstrating good predictive accuracy and stability for clinical application. Notably, this model is the first to incorporate cardiac biomarkers (NT-proBNP) and nutritional indicators ($25(OH)D_3$) into the weaning assessment system for COPD patients, emphasizing the importance of multi-organ interactions in weaning outcomes.

This study's single-center retrospective design and limited sample size may constrain the model's generalizability. Future research should expand sample sizes and include multi-center prospective studies to validate the model externally and enhance its clinical utility.

In conclusion, NT-proBNP, $25(OH)D_3$, RSBI, COPD disease duration, and APACHE II score are key predictors of weaning failure in elderly COPD patients with type II respiratory failure. The developed prediction model demonstrates strong predictive performance and offers practical value for guiding clinical decision-making in this population.

Disclosure of conflict of interest

None.

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