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ARTICLE

Influencing Factors of Postoperative Mechanical Ventilation Weaning Outcomes in Acute Stanford Type A Aortic Dissection: A Single-Center Retrospective Study

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Abstract

Aims/Background Patients with acute Stanford type A aortic dissection (ATAAD) face particularly high risks of prolonged mechanical ventilation and weaning failure due to the combined effects of surgical trauma, systemic inflammation, and multi-organ involvement. However, current weaning predictors are primarily derived from general cardiac surgery populations, leaving ATAAD-specific evidence limited. This study investigated the factors influencing postoperative mechanical ventilation weaning outcomes in ATAAD patients and constructed a prediction model.

Methods We retrospectively analyzed 120 postoperative ATAAD patients requiring mechanical ventilation at Nanjing First Hospital between January 2020 and March 2022. Patients were categorized into a weaning success group (n = 79) and a weaning failure group (n = 41) based on their weaning outcomes. Clinical variables were compared between groups, and multivariate logistic regression analysis was performed to identify independent predictors of weaning failure. Multicollinearity was assessed using variance inflation factors (VIFs). A nomogram prediction model was developed, and its performance was evaluated using the C-index, receiver operating characteristic (ROC) curve analysis, calibration plots, and decision curve analysis (DCA).

Results Multivariate logistic regression identified a history of chronic obstructive pulmonary disease (COPD) ($p = 0.002$), a history of kidney disease ($p = 0.002$), increased intraoperative blood loss ($p = 0.037$), elevated postoperative 24-hour serum creatinine (Scr) ($p < 0.001$), and elevated brain natriuretic peptide (BNP) levels ($p = 0.009$) as independent risk factors for weaning failure from mechanical ventilation in ATAAD patients. An increased respiratory rate ($p = 0.003$) was a protective factor. Multicollinearity testing revealed that VIF values for all six variables were <5 (1.018–1.050), indicating no significant collinearity. The nomogram model demonstrated good discrimination (C-index = 0.806, 95% confidence interval [CI]: 0.752–0.859; with an area under the curve [AUC] = 0.80 (95% CI: 0.72–0.88, $p < 0.001$), with a sensitivity of 92.13% and specificity of 67.86%. The calibration curve showed strong agreement with the ideal model. DCA indicated a significant net clinical benefit at thresholds above 0.2, confirming the clinical utility of the model.

Conclusion Mechanical ventilation weaning failure is a frequent and clinically significant complication after ATAAD surgery. Its risk is associated with a history of COPD, a history of kidney disease, intraoperative blood loss, postoperative Scr, BNP, and respiratory rate. The constructed nomogram accurately predicts weaning outcomes, offering valuable support for individualized risk assessment and clinical decision-making in ATAAD patients.

Key words: aortic dissection; artificial respiration; ventilator weaning; nomograms

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Introduction

Acute Stanford type A aortic dissection (ATAAD), a highly challenging emergency in cardiovascular medicine, poses a serious threat to the life and health of patients due to its rapid onset, swift progression, and poor prognosis (Pitts et al, 2023). ATAAD is a life-threatening condition that requires prompt diagnosis, typically confirmed through advanced imaging modalities. Its pathogenesis is complex, with tears in the aortic media allowing blood to enter and form a true-false lumen, severely compromising aortic structure and function. Without timely and effective treatment, mortality remains extremely high (Luehr et al, 2023; Liu et al, 2023). Currently, surgery is the primary treatment for ATAAD. Procedures such as aortic root replacement, ascending aortic replacement, or total aortic arch replacement repair the diseased aorta, restore its anatomy and physiological function, and significantly improve patient prognosis (Arabkhani et al, 2023; Biancari et al, 2023; Tian et al, 2023). However, following surgery, many patients experience impaired respiratory function due to anesthesia, surgical trauma, pain, and systemic inflammatory responses, necessitating mechanical ventilation support to maintain adequate oxygenation and ventilation (Ding et al, 2024).

Mechanical ventilation effectively improves respiratory and oxygenation status, reduces cardiac workload, and stabilizes circulation, creating favorable conditions for postoperative organ recovery (Wang et al, 2024). However, as a temporary supportive intervention, it must ultimately be discontinued to facilitate further recovery (Zhao et al, 2024). In clinical practice, some patients experience difficulty or failure in weaning from mechanical ventilation (Yuanxi et al, 2024; Diaz-Castrillon et al, 2024; Yu et al, 2024), leading to prolonged hospitalization, increased medical costs, and complications such as ventilator-associated pneumonia and respiratory muscle fatigue, which adversely affect rehabilitation and prognosis. Although several studies have explored factors influencing weaning outcomes, most have focused on common conditions such as chronic obstructive pulmonary disease or cardiogenic pulmonary edema (Liao et al, 2024; Gursel, 2005; Amado-Rodríguez et al, 2022), with limited and inconclusive evidence specifically addressing ATAAD patients. Given their complex postoperative condition and the involvement of multiple organ systems, particularly cardiovascular and respiratory functions, weaning outcomes in ATAAD patients may be influenced by a range of factors, including baseline comorbidities, intraoperative management, postoperative complications, and quality of nursing care (Lin et al, 2022; Xie et al, 2022). A deeper understanding of these factors holds significant clinical value for improving weaning success rates and overall prognosis in this population.

This study employed a retrospective design to comprehensively analyze factors influencing postoperative mechanical ventilation weaning outcomes in ATAAD patients, addressing the gap in this high-risk population, which is underrepresented in previous weaning research. While earlier studies predominantly examined general cardiac surgery or chronic pulmonary disease, the unique pathophysiological challenges of ATAAD, including systemic inflammatory responses, multi-organ involvement, and distinct surgical trauma patterns, necessitate tailored predictive approaches. Our study aimed to identify key factors that may affect weaning outcomes and provide a scientific basis for developing personalized weaning strategies. A retrospective design was strategically chosen for three reasons: (1) immediate access to high-quality clinical data from our institutional ATAAD registry (2018–2022), ensuring comprehensive outcome capture; (2) the need for preliminary exploration of novel predictors in this specific population before conducting resource-intensive prospective studies; and (3) ethical appropriateness for initial investigations in a high-mortality cohort. Ultimately, this study aimed to provide a useful reference for optimizing postoperative management in ATAAD patients and improving the overall quality of medical care.

Methods

Participants

We retrospectively analyzed all 120 consecutive cases of postoperative mechanical ventilation in ATAAD patients admitted to Nanjing First Hospital between January 2020 and March 2022. Sample size estimation was based on the events per variable (EPV) principle (Peduzzi et al, 1996). Following the recommended statistical guideline of EPV = 9, preliminary analysis identified six risk factors associated with weaning failure after ATAAD surgery. According to Trouillet et al (2009), the rate of postoperative weaning failure in cardiac surgery patients is approximately 48%. Thus, the minimum sample size was calculated as $9 \times 6 \div 48\%$ $\approx$ 113 patients. Ultimately, this study enrolled 120 patients, fulfilling statistical requirements.

Inclusion criteria: (1) age $\geq$18 years; (2) postoperative mechanical ventilation time >24 hours; (3) completion of a standardized spontaneous breathing trial (SBT) using either a T-piece or pressure support ventilation (PSV $\leq$8 cmH_2O) for 30–120 minutes, with predefined pass criteria (respiratory rate $\leq$35/minute, peripheral arterial oxygen saturation (SpO_2) $\geq$90% on fraction of inspired oxygen (FiO_2) $\leq$0.4, hemodynamic stability [heart rate (HR) <140 bpm, systolic blood pressure (SBP) 90–160 mmHg] (Fan et al, 2017), and no signs of distress; (4) clinical readiness for weaning (hemodynamic stability, mental clarity, adequate cough reflex, and arterial oxygen partial pressure (PaO_2)/FiO_2 $\geq$150 mmHg) with standardized sedation interruption [richmond agitation-sedation scale (RASS) score $\geq$1] (Ely et al, 2003) and analgesia management (visual analog scale <4) (Gélinas, 2016) before the SBT.

Exclusion criteria: (1) presence of myasthenia gravis, severe cardiovascular/cerebrovascular diseases, or uncontrolled respiratory distress precluding weaning; (2) diaphragm paralysis or injury; (3) psychiatric disorders hindering effective communication; (4) interruption of mechanical ventilation for non-clinical reasons; (5) planned sequential non-invasive mechanical ventilation or high-flow oxygenation after the release from invasive mechanical ventilation; (6) perinatal status; (7) absence of protocolized physical therapy (e.g., early mobilization, inspiratory muscle training) during the weaning process.

The study was approved by the Medical Ethics Committee of Nanjing First Hospital (approval number: KY20220425-05) and conducted following the principles outlined in the Declaration of Helsinki. All patients underwent ATAAD surgery and provided written informed consent.

Data Collection

Collected data included: (1) Preoperative basic data: Gender, age, body mass index (BMI), smoking status, history of hypertension, diabetes, chronic obstructive pulmonary disease (COPD), and kidney disease. (2) Perioperative treatment data: mechanical ventilation time, cardiopulmonary bypass time, operative duration, and intraoperative blood loss. (3) Postoperative variables: 24-hour postoperative body temperature, heart rate, respiratory rate, systolic blood pressure, diastolic blood pressure, left ventricular ejection fraction (LVEF), pH, lactate, arterial carbon dioxide partial pressure ($PaCO_2$), arterial oxygen partial pressure/fraction of inspired oxygen (PaO_2/FiO_2), tidal volume, hemoglobin (Hb), alanine aminotransferase (ALT), serum creatinine (Scr), procalcitonin (PCT), cardiac troponin I (cTnI), and brain natriuretic peptide (BNP).

Mechanical Ventilation Weaning Indicators and Weaning Outcome Definition

Criteria for weaning readiness included improvement or partial resolution of the underlying disease, absence of excessive airway secretions, strong cough reflex, stable hemodynamic status, stable overall clinical and metabolic conditions, respiratory rate $\leq$35 breaths/minute, positive end-expiratory pressure (PEEP) $\leq$8 cmH_2O, oxygenation index (PaO_2/FiO_2) $\geq$150 mmHg, and no significant respiratory acidosis. Weaning failure was defined as the need for re-intubation within 48 hours after extubation, unplanned initiation of non-invasive ventilation or high-flow oxygen therapy, or death (Griffiths et al, 2019). Weaning success was defined as sustained extubation without meeting any failure criteria for 48 hours. Based on these outcomes, patients were classified into a weaning success group (n = 79) and a weaning failure group (n = 41) (Fig. 1).

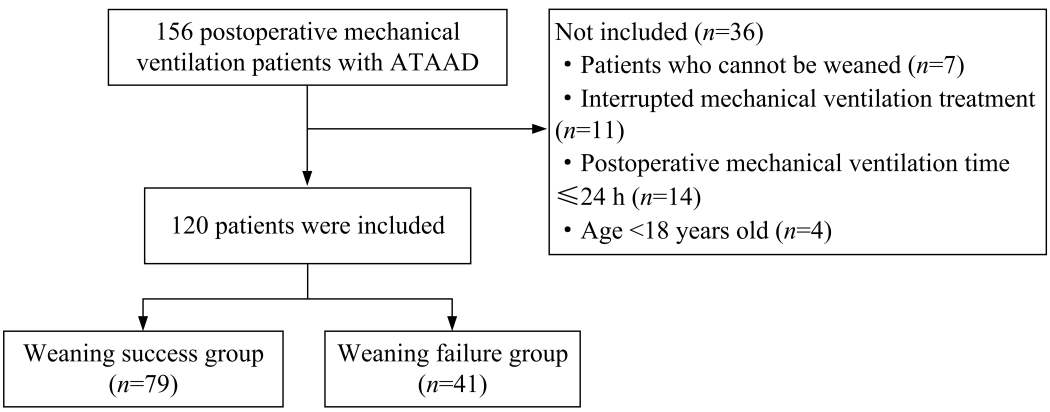

Fig. 1. Flow diagram of patient selection. The flow diagram was created using Microsoft Visio 2024 (version 2408, Microsoft Corporation, Redmond, WA, USA). ATAAD, acute Stanford type A aortic dissection.

Statistical Analysis

Statistical analyses were conducted using SPSS version 23.0 (IBM Corporation, Armonk, NY, USA). Continuous variables were assessed for normality using the Shapiro-Wilk test. Normally distributed data were expressed as mean ± standard deviation (SD) and compared between groups using independent-sample *t*-tests. Categorical variables were expressed as frequencies (%) and compared using the Pearson chi-square test or continuity correction test, where appropriate. Multivariate logistic regression analysis was conducted to identify factors associated with mechanical ventilation weaning failure in ATAAD patients. Multicollinearity among influencing factors was assessed using the variance inflation factor (VIF) analysis, with VIF <5 indicating no significant collinearity.

A predictive nomogram model was constructed using R software (Version 3.4.3, R Core Team, Auckland, New Zealand). Internal validation was performed via bootstrap resampling with 1000 iterations, and the concordance index (C-index) was calculated to evaluate model discrimination. Receiver operating characteristic (ROC) curves were constructed to evaluate the discrimination of the model, and calibration plots were used to evaluate the model calibration. Decision curve analysis (DCA) was performed to evaluate the net clinical benefit of the model. A *p*-value < 0.05 was considered statistically significant.

Results

Clinical Data

Among the 41 patients with weaning failure, outcomes within 48 hours post-extubation included reintubation in 19 cases (46.3%), non-invasive ventilation in 8 cases (19.5%), high-flow oxygen therapy in 13 cases (31.7%), and death in 1 case (2.4%). Compared with the weaning success group, the weaning failure group had significantly higher rates of COPD history (21.95% *vs*. 6.33%, $p = 0.026$) and kidney disease history (19.51% *vs*. 5.06%, $p = 0.029$). They also exhibited greater intraoperative blood loss (1430.72 ± 233.73 mL *vs*. 1301.77 ± 214.03 mL, $p = 0.003$), higher Scr levels (112.97 ± 31.92 µmol/L *vs*. 89.67 ± 26.14 µmol/L, $p < 0.001$), and elevated BNP levels (820.37 ± 82.65 pg/mL *vs*. 772.68 ± 91.64 pg/mL, $p = 0.006$) at 24 hours postoperatively. In contrast, their postoperative respiratory rate was significantly lower in the weaning failure group than that in the weaning success group (13.27 ± 1.76 *vs*. 14.58 ± 1.89 breaths/minute, $p < 0.001$) (Table 1).

Multivariate Logistic Regression Analysis

Variables with statistically significant differences in Table 1 were included as independent variables, and postoperative mechanical ventilation weaning outcomes (success = 0, failure = 1) were set as dependent variables in a multivariate logistic regression model. Results showed that history of COPD (odds ratio [OR] = 15.639, 95% confidence interval [CI]: 2.828–86.495, $p = 0.002$), history of kidney disease (OR = 12.221, 95% CI: 2.447–61.043, $p = 0.002$), increased intraoperative blood loss (OR = 1.002, 95% CI: 1.000–1.005, $p = 0.037$), elevated Scr levels (OR = 1.042, 95% CI: 1.021–1.065, $p < 0.001$), and increased BNP levels (OR=1.009,

Table 1. Comparison of clinical characteristics between weaning success and failure groups [mean ± SD, *n* (%)].

Variable	Weaning success group (n = 79)	Weaning failure group (n = 41)	t/χ^2	p-value
Gender			0.534	0.465
Male	61 (77.22)	34 (82.93)		
Female	18 (22.78)	7 (17.07)		
Age (years)	52.19 ± 9.42	51.67 ± 9.21	0.289	0.773
BMI (kg/m^2)	24.38 ± 2.36	24.51 ± 2.27	0.290	0.772
Smoking status			0.653	0.419
No	54 (68.35)	25 (60.98)		
Yes	25 (31.65)	16 (39.02)		
Hypertension			1.214	0.271
No	16 (20.25)	5 (12.20)		
Yes	63 (79.75)	36 (87.80)		
Diabetes			0.003	0.954
No	73 (92.41)	37 (90.24)		
Yes	6 (7.59)	4 (9.76)		
History of COPD			4.966	0.026
No	74 (93.67)	32 (78.05)		
Yes	5 (6.33)	9 (21.95)		
History of kidney disease			4.759	0.029
No	75 (94.94)	33 (80.49)		
Yes	4 (5.06)	8 (19.51)		
Mechanical ventilation time (hour)	68.31 ± 11.09	71.85 ± 11.74	1.625	0.107
Cardiopulmonary bypass time (minute)	278.63 ± 35.87	280.59 ± 38.62	0.277	0.783
Operation time (minute)	548.71 ± 50.96	553.96 ± 55.47	0.519	0.605
Intraoperative blood loss (mL)	1301.77 ± 214.03	1430.72 ± 233.73	3.033	0.003
Temperature (°C)	37.45 ± 0.76	37.50 ± 0.72	0.348	0.729
Heart rate (bpm)	91.08 ± 11.54	89.72 ± 10.16	0.637	0.525
Respiratory rate (breaths/minute)	14.58 ± 1.89	13.27 ± 1.76	3.685	<0.001
Systolic blood pressure (mmHg)	147.56 ± 10.16	145.28 ± 9.87	1.177	0.241
Diastolic blood pressure (mmHg)	78.43 ± 8.01	77.09 ± 7.62	0.883	0.379
LVEF (%)	63.49 ± 4.02	62.76 ± 3.78	0.963	0.338
pH	7.45 ± 0.15	7.43 ± 0.12	0.739	0.461
Lactate (mmol/L)	1.47 ± 0.32	1.36 ± 0.28	1.861	0.065
$PaCO_2$ (mmHg)	39.68 ± 3.02	40.79 ± 3.16	1.880	0.063
PaO_2/FiO_2 (mmHg)	200.68 ± 39.17	199.24 ± 37.46	0.194	0.847
Tidal volume (mL)	567.96 ± 110.28	572.38 ± 109.85	0.209	0.835
Hb (g/L)	87.98 ± 7.24	89.12 ± 6.73	0.838	0.404
ALT (U/L)	26.12 ± 7.65	28.41 ± 7.96	1.534	0.128
Scr (µmol/L)	89.67 ± 26.14	112.97 ± 31.92	4.288	<0.001
PCT (ng/mL)	0.67 ± 0.21	0.61 ± 0.19	1.532	0.128
cTnI (ng/mL)	2.18 ± 0.67	1.98 ± 0.49	1.690	0.094
BNP (pg/mL)	772.68 ± 91.64	820.37 ± 82.65	2.793	0.006

Abbreviations: BMI, body mass index; COPD, chronic obstructive pulmonary disease; LVEF, left ventricular ejection fraction; $PaCO_2$, arterial carbon dioxide partial pressure; PaO_2, arterial oxygen partial pressure; FiO_2, fraction of inspired oxygen; Hb, hemoglobin; ALT, alanine aminotransferase; Scr, serum creatinine; PCT, procalcitonin; cTnI, cardiac troponin I; BNP, brain natriuretic peptide; SD, standard deviation.

Table 2. Multivariate logistic regression analysis of predictors of postoperative mechanical ventilation weaning failure in ATAAD patients.

Variable	β	*SE*	Wald χ^2	*p*-value	OR (95% CI)
History of COPD	2.750	0.873	9.929	0.002	15.639 (2.828–86.495)
History of kidney disease	2.503	0.821	9.305	0.002	12.221 (2.447–61.043)
Intraoperative blood loss	0.002	0.001	4.363	0.037	1.002 (1.000–1.005)
Respiratory rate	–0.421	0.144	8.576	0.003	0.656 (0.495–0.870)
Scr	0.042	0.011	15.074	$<$0.001	1.042 (1.021–1.065)
BNP	0.009	0.003	6.783	0.009	1.009 (1.002–1.015)
Constant	–9.967	3.947	6.375	0.012	0.000

Abbreviations: COPD, chronic obstructive pulmonary disease; Scr, serum creatinine; BNP, brain natriuretic peptide; CI, confidence interval; OR, odds ratio; SE, standard error.

95% CI: 1.002–1.015, $p = 0.009$) were independent risk factors for weaning failure. Conversely, a higher respiratory rate (OR = 0.656, 95% CI: 0.495–0.870, $p = 0.003$) served as a protective factor (Table 2).

Multicollinearity Test

Multicollinearity testing revealed that the VIF for the six predictors of postoperative extubation outcomes in ATAAD patients were all close to 1, ranging from 1.018 to 1.050, indicating no evidence of multicollinearity among these variables.

Construction of a Nomogram Prediction Model

Using history of COPD, history of kidney disease, intraoperative blood loss, respiratory rate, Scr, and BNP at 24 hours postoperatively as predictors, a nomogram model was constructed for predicting the postoperative mechanical ventilation weaning outcomes in ATAAD patients (Fig. 2). For example, one patient with no history of COPD (0 points) or kidney disease (0 points), intraoperative blood loss (22.30 points), respiratory rate (62.07 points), Scr (23.88 points), and BNP (11.05 points) achieved a total score of 119.30 points, corresponding to a 72.16% risk of weaning failure (indicated by the pink arrow in Fig. 2). Internal validation with bootstrap resampling (1000 iterations) produced an optimism-corrected C-index of 0.806 (95% CI: 0.752–0.859, $p < 0.001$), indicating robust predictive performance of the model.

Evaluation of the Predictive Efficacy of the Nomogram Model

The nomogram model demonstrated strong predictive performance, with an area under the curve (AUC) of 0.80 (95% CI: 0.72–0.88, $p < 0.001$), sensitivity of 92.13%, and specificity of 67.86%, confirming good discrimination (Fig. 3). Calibration curve analysis showed close agreement with the ideal reference line, with a calibration slope of 0.89 (Fig. 4). DCA indicated a substantial net benefit when the threshold probability exceeded 0.2, further supporting the clinical utility of the model (Fig. 5).

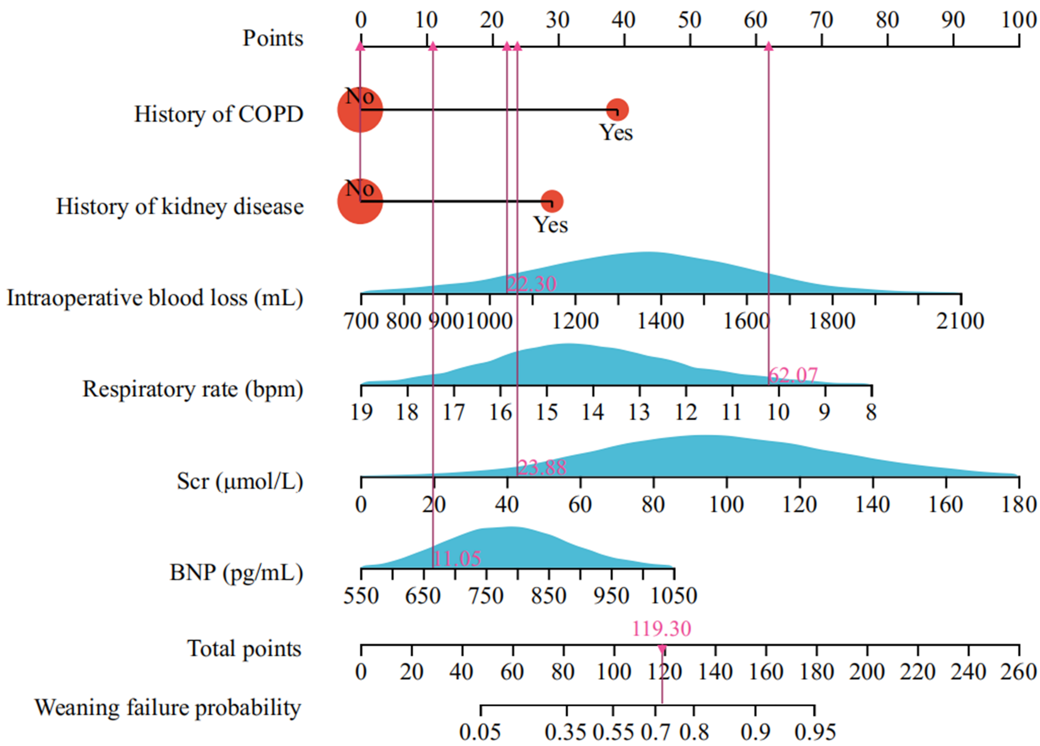

Fig. 2. Nomogram model for predicting postoperative mechanical ventilation weaning outcomes in ATAAD patients. The pink arrow illustrates a clinical example of calculating individual weaning failure risk. Abbreviations: COPD, chronic obstructive pulmonary disease; Scr, serum creatinine; BNP, brain natriuretic peptide.

Discussion

This single-center retrospective study investigated postoperative mechanical ventilation weaning outcomes in patients with ATAAD. We identified six independent predictors of weaning failure: history of COPD (OR = 15.639), history of kidney disease (OR = 12.221), increased intraoperative blood loss (OR = 1.002), elevated postoperative Scr levels (OR = 1.042), and elevated BNP levels (OR = 1.009), while an increased respiratory rate was protective (OR = 0.656). These findings provide clinically meaningful insights into the mechanisms underlying mechanical ventilation weaning challenges and related complications in ATAAD patients after surgery.

In this study, a history of COPD and kidney disease was identified as a significant risk factor for weaning failure from postoperative mechanical ventilation in ATAAD patients. Elevated Scr levels at 24 hours postoperatively also contributed to an increased risk. Patients with COPD frequently exhibit chronic airway inflammation and impaired pulmonary function, predisposing them to postoperative pulmonary infections, respiratory muscle fatigue, and impaired gas exchange (Li et al, 2024), which may complicate ventilatory support withdrawal. Similarly, a history of kidney disease and elevated Scr levels suggests insufficient renal functional reserve. After major surgeries such as ATAAD repair, reduced renal capacity to regulate metabolite clearance and water-electrolyte homeostasis exacerbates systemic

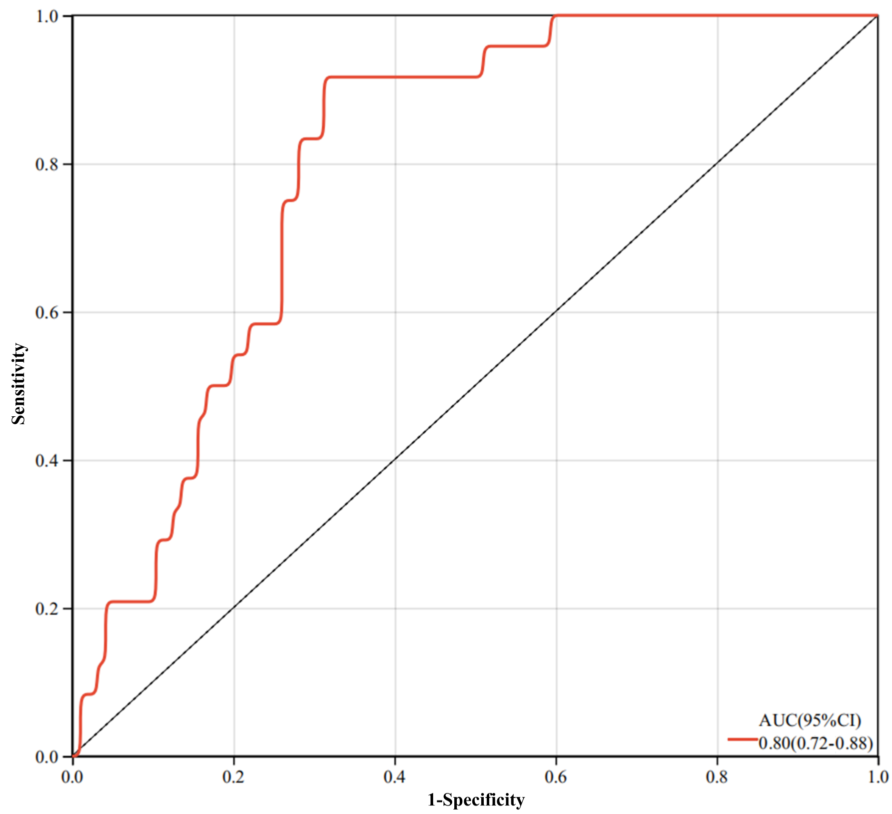

Fig. 3. Receiver operating characteristic (ROC) curve of the nomogram model. Abbreviation: AUC, area under the curve.

inflammation, impede respiratory recovery, and increase the difficulty of weaning off the ventilator (Ren et al, 2015; Zong et al, 2020). Consistent with these findings, Rahimi et al (2023) also reported that a history of COPD, kidney disease, and elevated postoperative Scr are risk factors for prolonged mechanical ventilation in cardiovascular surgery patients. Therefore, in ATAAD patients with comorbid COPD, thorough preoperative pulmonary function assessment and enhanced postoperative respiratory management, such as early respiratory rehabilitation and optimized analgesic strategies to minimize respiratory depression, may improve weaning success. For patients with preexisting kidney disease, close postoperative monitoring of renal function is warranted, and early initiation of continuous renal replacement therapy may help maintain internal homeostasis. Additionally, our study confirmed that a higher respiratory rate at 24 hours postoperatively was a protective factor against weaning failure, consistent with the findings by Rahimi et al (2023). This may indicate that these patients possess a better compensated respiratory drive and relatively preserved respiratory muscle function, facilitating more effective gas exchange and promoting ventilator liberation.

The results of multivariate logistic regression analysis in this study indicated that increased intraoperative blood loss and elevated postoperative 24-hour BNP levels were significant risk factors for weaning failure from mechanical ventilation in ATAAD patients. Although the odds ratio (OR) per mL of blood loss was 1.002, which may initially appear trivial, its clinical relevance becomes evident

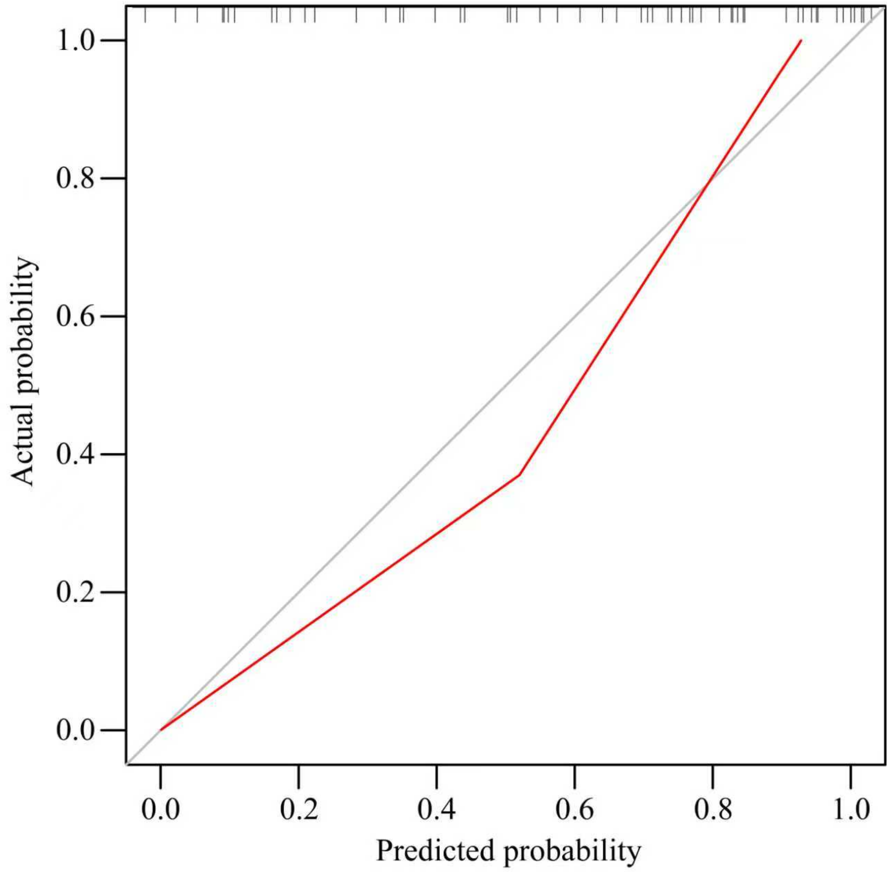

Fig. 4. Calibration curve of the nomogram model. The red line represents the calibration curve, while the grey line indicates the ideal reference line, demonstrating agreement between predicted and observed outcomes.

when considering the cumulative effects across several hundred milliliters. In our study, average intraoperative blood loss was significantly greater in the weaning failure group than in the success group (1430.72 $\pm$ 233.73 mL *vs.* 1301.77 $\pm$ 214.03 mL). This notable difference underscores that even small per-milliliter increases can accumulate into a meaningful risk factor for weaning failure when considering total intraoperative loss. Substantial blood loss can lead to hypovolemia and inadequate organ perfusion while also triggering systemic inflammatory and coagulation cascades, resulting in microcirculatory dysfunction and organ injury, thereby impairing postoperative respiratory recovery (Woldendorp et al, 2023) and increasing the risk of weaning failure.

In ATAAD patients, postoperative myocardial ischemia, cardiac tamponade, or surgical trauma may further compromise cardiac function (Acharya and Mariscalco, 2023). Elevated BNP levels reflect increased ventricular wall stress, which can adversely impact pulmonary circulation and gas exchange (Bhagat, 2024). Moreover, elevated BNP may indicate volume overload, further exacerbating respiratory dysfunction (Chen et al, 2024). Xie et al (2024) demonstrated that intraoperative blood loss $\geq$650 mL and postoperative BNP $\geq$806 pg/mL were associated with prolonged extubation after cardiac surgery. Similarly, Bratt et al (2024) reported that patients undergoing ATAAD surgery with major intraoperative bleeding had a sig-

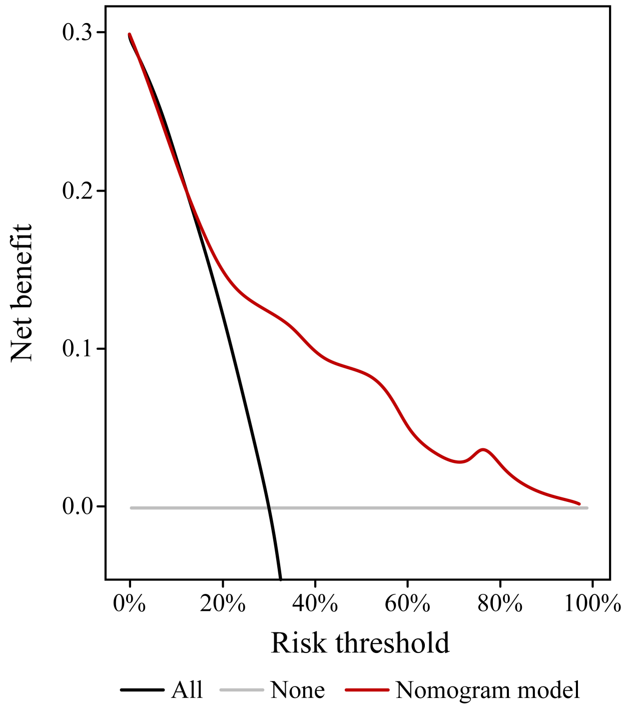

Fig. 5. Decision curve analysis (DCA) curve of the nomogram model.

nificantly higher incidence of requiring mechanical ventilation exceeding 48 hours compared to those without major bleeding, highlighting the link between intraoperative hemorrhage and prolonged ventilation. Therefore, dynamic monitoring of postoperative BNP levels and hemodynamic status, combined with optimized fluid management and cardiac support, may improve weaning outcomes.

Notably, several variables commonly associated with weaning outcomes in general critical care populations, including age, operative time, cardiopulmonary bypass time, hypertension, and diabetes, were not significantly different between groups in our cohort. Several factors may explain these divergent findings. First, the homogeneous nature of ATAAD surgery may reduce variability in operative or cardiopulmonary bypass times. Second, our strict inclusion criteria likely created a more uniform population, diminishing the influence of chronic conditions like hypertension. Third, the unique pathophysiology of ATAAD, characterized by a profound systemic inflammatory response, may overshadow the effects of chronic comorbidities in the immediate postoperative phase.

These findings should be interpreted considering the limitations associated with our study. The single-center design and modest sample size may have reduced statistical power to detect subtle associations with variables like diabetes. Additionally, the exclusion of high-risk patients (e.g., severe cerebrovascular disease) may have attenuated associations typically observed in more heterogeneous intensive care unit (ICU) populations. Future multicenter studies with larger cohorts are warranted to validate whether these “negative” findings persist across diverse clinical settings.

This study developed and validated a nomogram prediction model by integrating the identified risk factors, demonstrating good discriminative performance

(AUC = 0.80) and calibration. As a visual tool, the nomogram allows quantification of individual weaning failure risk, facilitating rapid assessment and the development of personalized intervention strategies by clinicians. For example, high-risk patients may benefit from enhanced respiratory management, optimized analgesia and sedation, delayed weaning attempts, or sequential weaning protocols to mitigate complications associated with weaning failure. The model exhibited high sensitivity (92.13%) but relatively lower specificity (67.86%), suggesting a stronger ability to reduce missed diagnoses in high-risk patients, though at the expense of increased false-positive predictions. Future research could enhance model specificity by increasing sample size or incorporating additional predictive variables.

This study has several limitations. First, its single-center retrospective design and relatively small sample size may introduce selection bias, underscoring the need for external validation through multicenter studies. Second, potential influencing factors, such as sedation strategies, variations in surgical techniques, and preoperative nutritional status, were not included in the analysis, which may limit the comprehensiveness of the model. Finally, the clinical utility of the nomogram model has not yet been validated through prospective studies.

Conclusion

Weaning failure from postoperative mechanical ventilation in ATAAD patients is closely associated with a history of COPD and kidney disease, increased intraoperative blood loss, and elevated postoperative levels of Scr and BNP, whereas a higher respiratory rate may reduce the risk. The nomogram model developed in this study demonstrates good predictive performance, offering a valuable tool for individualized risk assessment and supporting the optimization of postoperative respiratory management strategies to improve patient outcomes. Further prospective studies are warranted to validate the clinical utility of this model and explore additional potential influencing factors, thereby enabling more precise therapeutic approaches for ATAAD patients.

Key Points

- COPD and kidney disease history are the strongest predictors of weaning failure (OR = 15.639 and 12.221), highlighting the need for preoperative optimization and postoperative vigilance in these high-risk patients.
- Intraoperative blood loss and elevated postoperative BNP/Scr reflect multisystem involvement, indicating that combined cardiopulmonary-renal monitoring may improve weaning outcomes.
- Higher respiratory rate is a protective factor (OR = 0.656), potentially serving as a real-time marker of respiratory compensation capacity during weaning trials.
- The nomogram model (AUC = 0.80) provides individualized risk stratification, allowing clinicians to tailor mechanical ventilation weaning protocols based on quantified risk scores.

Availability of Data and Materials

All data included in this study are available from the corresponding author upon reasonable request.

Author Contributions

CP designed the study framework, established methodologies, and outlined experimental protocols to ensure research feasibility and rigor. SN led data collection and curation; YZ conducted formal statistical analysis and visualization to generate interpretable results. All authors contributed to drafting. SW refined the text through iterative revisions, ensuring logical flow and academic integrity. WC supervised progress, ensuring ethical compliance and resource management. ZQ validated methodologies and cross-verified key findings to guarantee robustness. All authors made substantial contributions to conception. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

The study was conducted following the principles of the Declaration of Helsinki and was approved by the Medical Ethics Committee of Nanjing First Hospital (approval number: KY20220425-05). Written informed consent was obtained from all participants.

Acknowledgement

Not applicable.

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Conflict of Interest

The authors declare no conflict of interest.

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