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Original Article

Risk factors and prediction model for sleep disorders in respiratory critically ill patients after intensive care unit transfer

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Abstract: Objective: To investigate the risk factors for sleep disorders in respiratory critically ill patients after ICU transfer to general wards and to construct a reliable predictive model for early identification of high-risk patients and guide targeted interventions. Methods: This retrospective observational study included 102 patients with respiratory failure, multiple organ dysfunction, or severe pneumonia treated at a tertiary hospital between June 2022 and June 2025. Sleep disorders were assessed using the Pittsburgh Sleep Quality Index (PSQI; scores >7 as the cutoff) within one month after ICU transfer. Risk factors were screened using Lasso regression and multivariable logistic regression. A nomogram prediction model was constructed and validated through receiver operating characteristic (ROC) curve analysis, Hosmer-Lemeshow goodness-of-fit test, bootstrap validation (1000 resamples), and decision curve analysis (DCA) to assess clinical applicability. Results: Sleep disorders occurred in 37.3% (38/102) of patients. Four independent risk factors were identified: tracheotomy (OR=4.65, 95% CI: 1.11-19.51, P=0.036), sepsis (OR=4.26, 95% CI: 1.32-13.72, P=0.015), prolonged ICU stay (OR=1.72, 95% CI: 1.09-2.72, P=0.020), and increased APACHE II score (OR=1.20, 95% CI: 1.04-1.39, P=0.013). The nomogram demonstrated favorable discrimination (AUC=0.80, 95% CI: 0.71-0.89) and calibration (Hosmer-Lemeshow P=0.065; bootstrap validation showed 79.4% of resampled datasets with good fit). At the optimal cutoff, sensitivity, specificity, and positive predictive value were 0.62, 0.84, and 0.87, respectively. DCA indicated a positive net benefit when the predicted risk threshold exceeded 10%. Conclusion: Tracheotomy, sepsis, prolonged ICU stay, and higher APACHE II score at ICU discharge are independent risk factors for post-ICU sleep disorders. The validated nomogram provides a clinically applicable tool for early risk stratification, facilitating targeted preventive interventions to improve post-ICU recovery.

Keywords: Intensive care unit, respiratory critically ill, sleep disorder, risk factors

Introduction

The Intensive Care Unit (ICU) is a special hospital department for the management of critically ill patients [1], providing close monitoring and active treatment to improve survival and prognosis. However, as patients stabilize and are transferred out of the ICU, a new set of complications may emerge [2, 3]. Among these, sleep disorders represent a common and clinically significant issue that cannot be ignored [4, 5]. Post-intensive care syndrome (PICS) refers to new or worsening physical, cognitive, and psychological impairments following ICU treatment [6]. Sleep disturbances are increasingly recognized as a prevalent syndrome of PICS [7]. Patients who have been in ICU exhibits symptoms of insomnia, reduced sleep quality, and other sleep-related problems after transfer to general wards. Such disorders not only affect rest and recovery but may also exacerbate other PICS-related symptoms, including cognitive and psychological dysfunction [8]. Consequently, a comprehensive investigation of risk factors associated with sleep disorders in respiratory critically ill ICU patients following transfer - particularly those with respiratory failure, multiple organ dysfunction, or severe pneumonia - and the development of a reliable risk prediction model, are of paramount importance for optimizing patient management, improving therapeutic outcomes, and facilitating patients' overall recovery.

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At present, research on sleep disorders has primarily focused on the general population and patients with specific diseases [9]. For instance, Sochal et al. reported that sleep deprivation significantly affect immune function, manifesting as elevated granulocyte and leukocyte levels [10]. Damsgaard et al. found that sleep disorders were significantly associated with a markedly increased risk of short-term dementia in a large 40-year cohort study, suggesting that sleep disorders may be one of the early symptoms of dementia [11]. While sleep disorders have been extensively characterized in general ICU survivors and specific populations such as postcardiac surgery or post-trauma patients, the unique sleep-related pathophysiology of respiratory critically ill patients remains inadequately explored. Respiratory ICU patients face distinctive challenges, including ventilator-induced sleep fragmentation, chronic hypoxia-related hyperarousal, and the psychological burden of dyspnea - factors that are less prominent in other ICU populations. Despite this, in-depth investigation into sleep disorders among respiratory critically ill patients following ICU transfer is still lacking. ICU patients with respiratory failure or severe pneumonia often undergo intensive intervention during their hospitalization, including frequent vital sign monitoring, mechanical ventilation, and the use of sedative and analgesic drugs [12]. These special therapeutic experiences contribute to the complex pathophysiology of post-ICU sleep disorders, which involves interactions among physiological, psychological, and environmental factors. At the physiological level, prolonged mechanical ventilation may alter breathing patterns and impair respiratory muscle function, predisposing patients to respiratory-related sleep disorder after ICU discharge [13]. Additionally, circadian rhythm disruption due to continuous light and noise in the ICU interferes with intrinsic biological clock regulation, contributing to sleep disorders [14]. In terms of psychological factors, critically ill patients often experience fear and anxiety in ICU, and this psychological trauma may persist after transfer to general wards.

Given the complexity and severity of sleep disorders in respiratory critically ill patients after ICU transfer, there is an urgent need to identify risk factors. The aim of this study was to elucidate the primary risk factors for sleep disorders in this particular patient population and to develop a scientifically validated risk prediction model. Such a model can assist healthcare professionals in early identification of high-risk patients and facilitate targeted preventive measures. Importantly, this research highlights the clinical significance of post-ICU sleep disorders, offering guidance to enhance quality of life and recovery, and inform both clinical practice and future scientific investigations.

Participants and methods

Research subject

This retrospective observational study included 114 respiratory critically ill patients (e.g., with respiratory failure, multiple organ dysfunction, or severe pneumonia) treated at the Affiliated Hospital of Xuzhou Medical University between June 2022 to June 2025, identified through medical record review. Of them, 12 patients were excluded due to not meeting the inclusion criteria, as detailed in **Figure 1**. Finally, 102 patients were included in the analysis.

Inclusion criteria: (a) Age ≥18 years; (b) ICU stay ≥24 hours; (c) successful transfer to general ward after stabilization. Exclusion criteria: (a) significant sleep disturbance prior to ICU admission; (b) inability to complete the survey due to language or cognitive impairment; (c) pre-existing primary sleep disorders (e.g., obstructive sleep apnea, restless legs syndrome, narcolepsy, chronic insomnia), severe psychiatric disorders with prominent sleep symptoms, active malignancy with nocturnal symptoms, or neurodegenerative diseases affecting sleep architecture; (d) direct transfer to other specialized wards for continuous life support treatment; (e) incomplete clinical data. Missing data were handled using complete case analysis; patients with incomplete data for any of the study variables were excluded.

Patients were divided into two groups based on the occurrence of sleep disorders after ICU transfer: the sleep disorder group (SD group; n=38) and the non-sleep disorder group (NSD group; n=64). The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the Affiliated Hospital of Xuzhou Medical University.

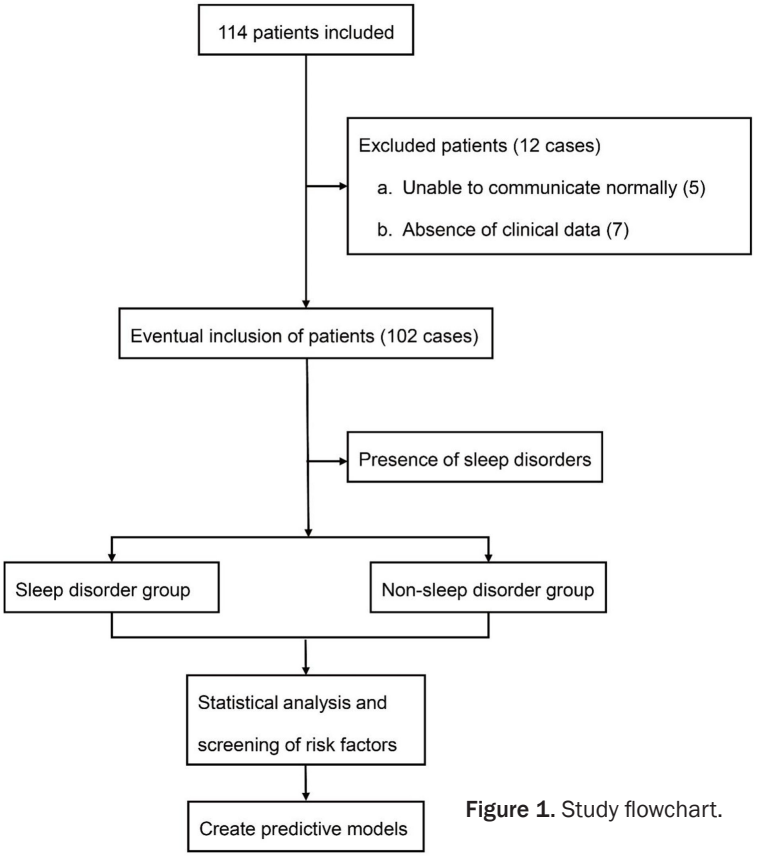

Figure 1. Study flowchart.

Sample size calculation

The sample size was determined based on the rule of 10-20 events per variable (EPV) for multivariable logistic regression. Anticipating four independent predictors in the final model, a minimum of 40 sleep disorder events were required. The anticipated prevalence of sleep disorders (35-40%) was derived from previous studies in general ICU survivors [15]. Assuming this prevalence, 100-120 total patients were targeted. The final sample of 102 patients (38 sleep disorder events) yielded an EPV ratio of 9.5:1, approaching the recommended threshold.

Data collection

Data were collected from the hospital medical record system and patient questionnaire surveys. Basic demographic information was collected, including age, sex, smoking history, alcohol consumption, hypertension, diabetes, and hyperlipidemia. Clinical data included medications (sedatives, analgesics, and vasoactive agents), treatment (tracheotomy, surgical treatment, mechanical ventilation, and invasive procedures), adverse events (sepsis, hypoxemia, abnormal blood pressure, and abnormal blood glucose), length of ICU stay, Charlson Comorbidity Index (CCI), and Acute Physiology and Chronic Health Evaluation II (APACHE II) scores.

The APACHE II score is a tool for assessing the severity of illness in critically ill patients [16]. It integrates acute physiological measurements and chronic health status, encompassing 12 parameters (body temperature, mean arterial pressure, pH, serum sodium, serum potassium, serum creatinine, Glasgow Coma Scale, respiratory rate, oxygenation, age, and chronic health status). Each parameter was scored according to the degree of abnormality, producing a total score ranging from 0 to 71, with higher scores indicating more severe illness. The CCI assess comorbidity burden and predicts long-term mortality risk by considering the presence and severity of 19 common chronic diseases, with higher scores indicating a higher burden of co-morbidities [17].

Evaluation of sleep disorders

Sleep disorders were assessed using the Pittsburgh Sleep Quality Index (PSQI) at a fixed time point of 7 days (±2 days) after ICU transfer. This timing was selected to capture early-onset sleep disturbances while allowing sufficient recovery from acute illness for valid self-reporting. All patients completed a single evaluation at this designated time. For in patients, assessments were conducted via bedside interview; for those discharged, evaluations were performed by trained investigators through telephone follow-up using a standardized questionnaire protocol. A PSQI score >7 was used to define the presence of sleep disorders [18]. The fixed assessment timing ensured consistency across all enrolled patients and mini-

mized temporal bias in the classification of sleep disorders.

Statistical analysis

Continuous variables conforming to a normal distribution were presented as mean ± standard deviation (SD) and compared between groups using the independent samples t-test. Continuous variables not conforming to a normal distribution were presented as median (interquartile range, IQR) and compared between groups using Mann-Whitney U test. Categorical variables were described as frequencies and percentages, and compared using the chi-square (χ^2) test.

Lasso regression was used for initial variable selection. Coefficients of independent variables were penalized by varying values of λ, with the minimum λ (0.036) chosen to balance the mean squared error and the regularization term. Variables with non-zero coefficients at this λ were considered potential independent risk factors and included in a multivariable logistic regression model to assess their independent association with sleep disorders. Odds ratios (ORs) and 95% confidence intervals (CIs) were calculated. Covariance diagnostics was performed to exclude multicollinearity among variables (variance inflation factor, VIF<5).

Independent risk factors identified by multivariate logistic regression analyses were incorporated into a nomogram predictive model for post-ICU sleep disorders. The nomogram assigned scores to each risk factor, and the total score was used to estimate the probability of developing sleep disorders. Binary logistic regression was used to examine multiplicative interactions among variables. In the interaction analysis, continuous variables were dichotomized at their median values.

Model discrimination was assessed by receiver operating characteristic (ROC) curves and area under the curve (AUC). Model calibration was evaluated using calibration plots and the Hosmer-Lemeshow goodness-of-fit test. Bootstrap validation (1000 resamples) was performed to assess model stability. Decision curve analysis (DCA) was used to evaluate clinical utility. In addition, predictive accuracy, sensitivity, specificity, positive predictive value, and negative predictive value were calculated at the optimal cutoff to further assess the diagnostic performance of the model.

Results

Comparison of patients' general characteristics

A total of 102 respiratory critically ill patients were included in this study, of whom 38 (37.25%) had sleep disorders. The mean age was 58.20±5.99 years, with no significant difference between the SD and NSD groups (P= 0.146) (**Table 1**). In addition, there were no significant differences between the two groups in terms of sex composition, smoking or alcohol consumption history, hypertension, diabetes, or hyperlipidemia.

Comparison of clinical characteristics

The SD group had higher percentages of patients receiving analgesics (89.47% vs. 71.88%, P=0.037), undergoing tracheotomy (23.68% vs. 7.81%, P=0.024), and requiring mechanical ventilation (92.11% vs. 75.00%, P=0.032), and a higher incidence of sepsis (42.11% vs. 21.88%, P=0.030) than the NSD group (**Table 2**). The proportion of patients with CCI>1 was significantly higher in the SD group than that in the NSD group (57.89% vs. 35.94). In addition, the duration of ICU stay (4 days vs. 3 days, P<0.001) and APACHE II score (14 vs. 12, P<0.001) were significantly higher in the SD group than those in the NSD group.

Screening for risk factors using lasso regression

The coefficients of the independent variables were separately compressed by Lasso regression at different λ levels. Both λ.min (0.036) and λ.1se (0.018) were evaluated. At λ.1se, four variables (tracheotomy, sepsis, ICU stay, and APACHE II score) were retained, while at λ.min, seven variables were retained. The minimum λ (0.036) was used to balance the mean square error and the regularization term. Under this cut-off value, seven variables with non-zero coefficients were screened as potential risk factors: analgesic use, tracheotomy, ICU length of stay, mechanical ventilation, sepsis, APACHE II score, and co-morbidity index (**Figure 2**).

Table 1. Comparison of baseline characteristics between the two groups

Variables	Total (n=102)	NSD group (n=64)	SD group (n=38)	Statistic	*P*
Age, Mean ± SD	58.20 ± 5.99	57.53 ± 5.82	59.32 ± 6.16	t=-1.46	0.146
Sex, n (%)				χ^2=0.10	0.752
Female	45 (44.12)	29 (45.31)	16 (42.11)		
Male	57 (55.88)	35 (54.69)	22 (57.89)		
Smoking, n (%)				χ^2=0.17	0.679
No	67 (65.69)	43 (67.19)	24 (63.16)		
Yes	35 (34.31)	21 (32.81)	14 (36.84)		
Drinking, n (%)				χ^2=0.38	0.535
No	63 (61.76)	41 (64.06)	22 (57.89)		
Yes	39 (38.24)	23 (35.94)	16 (42.11)		
Hypertension, n (%)				χ^2=0.04	0.834
No	55 (53.92)	34 (53.12)	21 (55.26)		
Yes	47 (46.08)	30 (46.88)	17 (44.74)		
Diabetes, n (%)				χ^2=0.04	0.833
No	79 (77.45)	50 (78.12)	29 (76.32)		
Yes	23 (22.55)	14 (21.88)	9 (23.68)		
Hyperlipemia, n (%)				χ^2=0.06	0.807
No	71 (69.61)	44 (68.75)	27 (71.05)		
Yes	31 (30.39)	20 (31.25)	11 (28.95)		

Note: ICU, intensive care unit; SD, sleep disorder; NSD, non-sleep disorder.

Table 2. Comparison of clinical characteristics between the two groups

Variables	Total (n=102)	NSD group (n=64)	SD group (n=38)	Statistic	*P*
Sedative, n (%)				χ^2=0.32	0.571
No	19 (18.63)	13 (20.31)	6 (15.79)		
Yes	83 (81.37)	51 (79.69)	32 (84.21)		
Analgesic, n (%)				χ^2=4.37	0.037
No	22 (21.57)	18 (28.12)	4 (10.53)		
Yes	80 (78.43)	46 (71.88)	34 (89.47)		
Vasoactive drug, n (%)				χ^2=0.29	0.588
No	16 (15.69)	11 (17.19)	5 (13.16)		
Yes	86 (84.31)	53 (82.81)	33 (86.84)		
Tracheotomy, n (%)				χ^2=5.07	0.024
No	88 (86.27)	59 (92.19)	29 (76.32)		
Yes	14 (13.73)	5 (7.81)	9 (23.68)		
Surgical treatment, n (%)				χ^2=0.24	0.624
No	38 (37.25)	25 (39.06)	13 (34.21)		
Yes	64 (62.75)	39 (60.94)	25 (65.79)		
Mechanical ventilation, n (%)				χ^2=4.60	0.032
No	19 (18.63)	16 (25.00)	3 (7.89)		
Yes	83 (81.37)	48 (75.00)	35 (92.11)		
Invasive treatment, n (%)				χ^2=0.10	0.747
No	26 (25.49)	17 (26.56)	9 (23.68)		
Yes	76 (74.51)	47 (73.44)	29 (76.32)		
Sepsis, n (%)				χ^2=4.70	0.030
No	72 (70.59)	50 (78.12)	22 (57.89)		
Yes	30 (29.41)	14 (21.88)	16 (42.11)		

Hypoxemia, n (%)				χ^2=0.67	0.412
No	72 (70.59)	47 (73.44)	25 (65.79)		
Yes	30 (29.41)	17 (26.56)	13 (34.21)		
Abnormal blood pressure, n (%)				χ^2=0.21	0.645
No	62 (60.78)	40 (62.50)	22 (57.89)		
Yes	40 (39.22)	24 (37.50)	16 (42.11)		
Abnormal blood sugar, n (%)				χ^2=0.20	0.654
No	67 (65.69)	41 (64.06)	26 (68.42)		
Yes	35 (34.31)	23 (35.94)	12 (31.58)		
CCI, n (%)				χ^2=4.66	0.031
0	57 (55.88)	41 (64.06)	16 (42.11)		
≥1	45 (44.12)	23 (35.94)	22 (57.89)		
ICU stay, M (Q_1, Q_3)	4.00 (3.00, 5.00)	3.00 (3.00, 4.00)	4.00 (3.25, 5.00)	Z=-3.34	<0.001
APACHE II score, M (Q_1, Q_3)	13.00 (10.00, 15.00)	12.00 (10.00, 14.00)	14.00 (12.00, 16.75)	Z=-3.36	<0.001

Note: ICU, intensive care unit; SD, sleep disorder; NSD, non-sleep disorder; CCI, Charlson Comorbidity Index; APACHE II, Acute Physiology and Chronic Health Evaluation II.

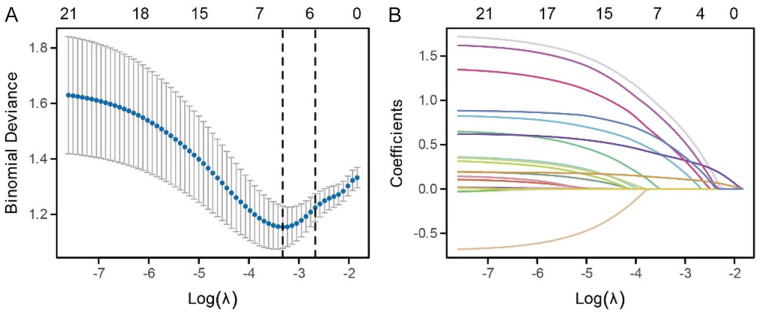

Figure 2. Lasso regression analysis. A. Variation diagram of the optimum penalty coefficient λ; B. Regression coefficient trajectory diagram.

Multivariate logistic regression and collinear diagnosis

Multivariate logistic regression analysis showed that tracheotomy (OR=4.65, P=0.036), prolonged stay in ICU (OR=1.72, P=0.020), associated sepsis (OR=4.26, P=0.015), and higher APACHE II score (OR=1.20, P=0.013) were independent risk factors for sleep disorders after ICU transfer (**Table 3**; **Figure 3**). Collinearity diagnostics indicated no multicollinearity among these variables (VIF<5). Interaction analyses were performed to examine potential effects of age and sex on these associations, and no significant interactions were observed (**Table 4**).

Construction of a nomogram model

The four selected variables were incorporated into a nomogram predictive model. With the occurrence of sleep disorders as the dependent variable and the four risk factors (tracheotomy, ICU length of stay, sepsis, and APACHE II score) as independent variables. The constructed nomogram model is shown in **Figure 4**.

Differentiation, calibration, and clinical utility of the model

The ROC curve of the predictive model demonstrated an AUC of 0.80 (95% CI: 0.71-0.89), indicating good discriminative ability (**Figure 5A**). Calibration analysis showed no significant difference between observed and predicted probabilities (Hosmer-Lemeshow P=0.065), suggesting good model fit (**Figure 5B**). Bootstrap validation (1000 iterations) confirmed model stability, with 79.4% of resampled datasets demonstrating good fit (P>0.05). DCA indicated that the predictive model provided a positive net benefit when the risk threshold exceeded 10%, supporting its clinical applicability (**Figure 5C**).

Diagnostic performance of the model

At the optimal cut-off value, the predictive accuracy, sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of the combined indicators were 0.71 (95% CI: 0.61-0.79), 0.62 (95% CI: 0.51-0.74), 0.84 (95% CI: 0.73-0.96), 0.87 (95% CI: 0.77-0.97), and 0.57 (95% CI: 0.44-0.70), respectively (**Table 5**). All individual performance indicators exceeded 65%, further confirming the model's reliability in risk prediction.

Table 3. Logistic regression analysis of factors associated with post-ICU sleep disorder

Characteristics	Total (N)	Univariate analysis		Multivariate analysis		
		Odds Ratio (95% CI)	*P* value	Odds Ratio (95% CI)	*P* value	VIF
Analgesic	102					
No	22	Reference		Reference		
Yes	80	3.33 (1.03-10.72)	0.044	2.39 (0.59-9.68)	0.223	1.04
Tracheotomy	102					
No	88	Reference		Reference		
Yes	14	3.66 (1.13-11.92)	0.031	4.65 (1.11-19.51)	0.036	1.10
ICU stay	102	1.85 (1.25-2.74)	0.002	1.72 (1.09-2.72)	0.020	1.06
Mechanical ventilation	102					
No	19	Reference		Reference		
Yes	83	3.89 (1.05-14.38)	0.042	3.11 (0.68-14.21)	0.143	1.09
Sepsis	102					
No	72	Reference		Reference		
Yes	30	2.60 (1.08-6.23)	0.033	4.26 (1.32-13.72)	0.015	1.18
APACHE II score	102	1.22 (1.08-1.39)	0.002	1.20 (1.04-1.39)	0.013	1.03
CCI	102					
0	57	Reference		Reference		
≥1	45	2.45 (1.08-5.58)	0.033	2.76 (0.96-7.93)	0.059	1.13

Note: OR, odds ratio; CI, confidence interval; VIF, variance inflation factor; ICU, intensive care unit; APACHE II, Acute Physiology and Chronic Health Evaluation II; CCI, Charlson Comorbidity Index.

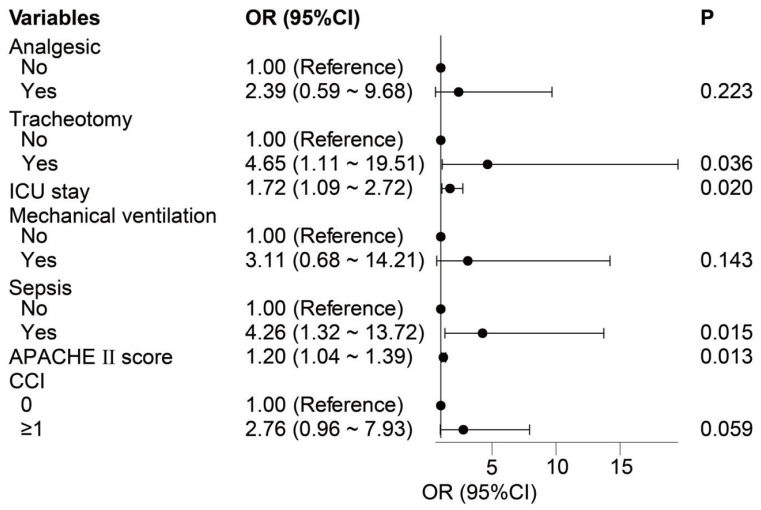

Figure 3. Forest plot of the multivariate logistic regression model. Note: OR, odds ratio; CI, confidence interval; ICU, intensive care unit; APACHE II, Acute Physiology and Chronic Health Evaluation II; CCI, Charlson Comorbidity Index.

Discussion

This study aimed to identify risk factors for sleep disorders in respiratory critically ill ICU patients following transfer to general wards and to construct a reliable predictive model. Univariate analysis revealed that analgesic use, tracheotomy, mechanical ventilation, sepsis, CCI, ICU length of stay, and APACHE II scores might influence the occurrence of sleep disorders. Subsequent Lasso regression and multifactorial logistic regression analyses identified tracheotomy, sepsis, prolonged ICU stay, and elevated APACHE II score as independent risk factors. Based on these findings, a nomogram predictive model was constructed, demonstrating satisfactory discrimination and calibration, with potential clinical applicability.

Tracheostomy is a common invasive procedure in the ICU, with the aim of improving ventilation and oxygenation [19]. However, the procedure of tracheostomy and its subsequent care process can induce substantial psychological and physical stress [20]. Patients undergoing tracheotomy often experience pain, discomfort, and communication difficulties, which contribute to sleep disturbances [21]. Moreover,

Table 4. Interaction analysis of risk factors with age and sex

Risk factor	Main effect	P for interaction	
	OR (95% CI)	Age (≥60 years)	Sex (Male)
Tracheotomy	3.66 (1.13-11.92)	0.990	0.989
Sepsis	2.60 (1.08-6.23)	0.829	0.260
ICU stay (≥4 days)	4.00 (1.26-12.72)	0.405	0.585
APACHE II score (≥13 points)	3.59 (1.52-8.48)	0.681	0.563

Note: OR, odds ratio; CI, confidence interval; ICU, intensive care unit; APACHE II, Acute Physiology and Chronic Health Evaluation II.

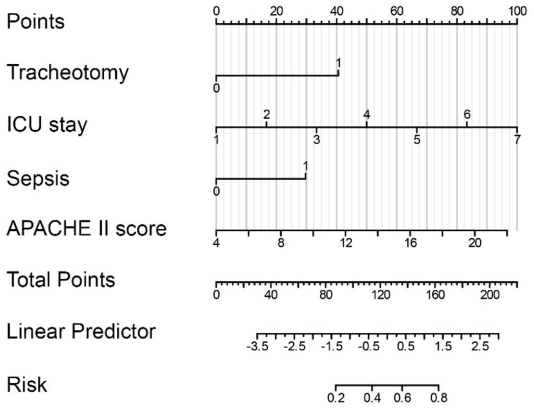

Figure 4. Nomogram predictive model. Note: ICU, intensive care unit; APACHE II, Acute Physiology and Chronic Health Evaluation II.

the long adaptation and recovery after tracheotomy may exacerbate anxiety and psychological stress, further impairing sleep. These findings highlight the importance of careful sleep monitoring in patients undergoing tracheotomy, as well as interventions such as pain management and psychological support.

Sepsis, a severe systemic infection frequently associated with systemic inflammatory response syndrome (SIRS) [22, 23], is common in critically ill patients with respiratory disease, particularly those with severe pneumonia or respiratory failure. In this study, sepsis was identified as an independent risk factor for the development of post-ICU sleep disorders. Several mechanisms may underlie this association. Lipopolysaccharide, a common mediator in gram-negative sepsis [24], has been shown to disrupt both rapid eye movement (REM) and non-REM sleep [25]. Electroencephalogram (ECG) studies in septic patients have demonstrated mixed-frequency, low-amplitude waves with intermittent θ and δ activity [26, 27]. Melatonin, a hormone secreted by the pineal gland, is primarily secreted during nocturnal hours, with its secretion rhythm exhibiting a close correlation to the circadian rhythm [28]. Melatonin plays a pivotal role in the regulation of the sleep-wake cycle. As demonstrated in earlier research, the circadian rhythm of melatonin secretion in sepsis patients is frequently disrupted, leading to a weakened or abolished rhythmicity [29]. In addition, Tiruvoipati et al. reported that ICU patients with sepsis usually present with a reduction or even loss of the REM sleep and speculated that it may be related to the administration of high doses of opioids [30]. Therefore, early recognition and treatment of sepsis, as well as comprehensive care during the recovery process, are essential to improving sleep quality of patients.

Prolonged ICU stay was identified as an independent risk factor for sleep disorders in this study. The ICU environment is characterized by continuous noise, light, and frequent medical interventions, all of which can disrupt patients' circadian rhythms and sleep quality [31]. Studies have shown that prolonged exposure to such environment may alter the biological clock, adversely affecting sleep [32]. Moreover, respiratory critically ill patients often present with severe and complex condition, including persistent respiratory failure and multiple organ dysfunction, which, in combination with prolonged ICU stay, can further compromise sleep quality and increase the risk of sleep disorders. As a result, optimizing the ICU environment, reducing unnecessary interventions, and implementing early rehabilitation may help improve sleep quality and overall patient outcome.

Elevated APACHE II score was also identified as an independent risk factor. Higher APACHE II score usually reflects greater illness severity and frequently associated with multiple compli-

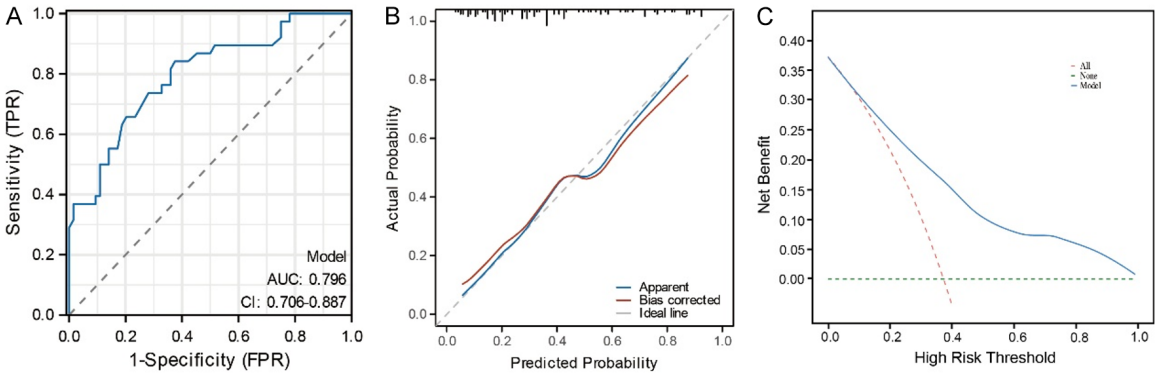

Figure 5. Validation of predictive models. A. ROC curve analysis; B. Calibration curve analysis; C. Decision curve analysis. Note: ROC, receiver operating characteristic; AUC, area under the curve.

Table 5. Diagnostic performance of each risk factor and their joint application

Type	Accuracy (95% CI)	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)	cut off
Joint index	0.71 (0.61-0.79)	0.62 (0.51-0.74)	0.84 (0.73-0.96)	0.87 (0.77-0.97)	0.57 (0.44-0.70)	0.287
Tracheotomy	0.67 (0.57-0.76)	0.92 (0.86-0.99)	0.24 (0.10-0.37)	0.67 (0.57-0.77)	0.64 (0.39-0.89)	0.486
Sepsis	0.65 (0.55-0.74)	0.78 (0.68-0.88)	0.42 (0.26-0.58)	0.69 (0.59-0.80)	0.53 (0.35-0.71)	0.419
ICU stay	0.70 (0.60-0.78)	0.83 (0.74-0.92)	0.47 (0.31-0.63)	0.73 (0.62-0.83)	0.62 (0.44-0.80)	4.5
APACHE II score	0.69 (0.59-0.77)	0.70 (0.59-0.82)	0.66 (0.51-0.81)	0.78 (0.67-0.88)	0.57 (0.42-0.71)	13.5

Note: CI, confidence interval; PPV, positive predictive value; NPV, negative predictive value; ICU, intensive care unit; APACHE II, Acute Physiology and Chronic Health Evaluation II.

cations and organ dysfunction [33]. In respiratory critically ill patients, elevated APACHE scores often correlate with the severity of respiratory failure, hypoxemia, or the need for advanced respiratory support. These conditions directly affect physiological stability and may exacerbate psychological stress and anxiety, consequently impairing sleep. Moreover, patients with elevated APACHE II scores may necessitate prolonged ICU treatment and rehabilitation, further increasing the likelihood of developing sleep disorders [34]. Consequently, it is imperative to prioritize close sleep monitoring and the provision of personalized care for patients with high APACHE II scores.

Comparison with existing literature reveals both consistencies and unique insights. Regarding sepsis, our findings align with Tiruvoipati et al. [30], who reported that ICU patients with sepsis exhibit reduced REM sleep, potentially attributable to inflammatory cytokine-mediated disruption of sleep architecture. However, unlike previous studies that focused on general ICU populations, our study specifically highlights sepsis as an independent predictor in respiratory critically ill patients, where systemic inflammation and respiratory compromise may synergistically exacerbate sleep disturbances. For APACHE II scores, previous investigations in mixed ICU cohorts have demonstrated associations between illness severity and sleep quality, though effect sizes varied considerably. In our study, APACHE II score was identified as an independent risk factor (OR=1.20), consistent with the broader literature linking physiologic instability to post-ICU sleep disorders. Notably, tracheotomy emerged as a particularly strong predictor (OR=4.65) in our study, exceeding estimates reported in general ICU populations, likely reflecting the unique respiratory vulnerability and prolonged ventilator dependence in our study population. These comparisons suggest that while fundamental mechanisms of sleep disruption are shared across ICU subgroups, the relative importance and interactions of risk factors differ in respiratory critically ill patients, supporting the need for population-specific prediction models.

Based on the independent risk factors, a nomogram was constructed to predict the risk of sleep disorders after ICU transfer. The model demonstrated a sensitivity of 0.62, indicating

that it identifies approximately 62% of patients who will develop sleep disorders, and a higher specificity of 0.84, ensuring a low false-positive rate. This performance suggests that the model is most suited for screening, where identification of high-risk patients prompts proactive interventions, rather than serving as a definitive diagnostic tool. Clinically, we recommend applying the model at ICU discharge or within 24 hours of ward transfer to stratify patients into risk categories: those with predicted probabilities >28.7% (optimal cutoff) should receive enhanced monitoring, sleep hygiene optimization, and early psychological assessment; moderate-risk patients (10-28.7%) warrant standardized sleep education and scheduled follow-up; while low-risk patients (<10%) may receive routine care. This tiered approach allows efficient allocation of limited resources, focusing intensive interventions on the subset most likely to benefit. The modest sensitivity implies that some patients who will develop sleep disorders may be missed; therefore, clinicians should maintain vigilance for sleep complaints even among lower-risk individuals, particularly those with unmeasured risk factors such as pre-existing anxiety or chronic pain. Future studies should evaluate whether implementation of this risk-stratified protocol reduces the incidence of sleep disorder and improves recovery trajectories compared to uniform post-ICU care.

Still, this study has several limitations. First, although the sample size of 102 patients provided an acceptable EPV ratio for the final 4-variable model, the EPV of 9.5:1 is slightly below the conventional threshold of 10:1. This may lead to overfitting or unstable coefficient estimates in logistic regression models. Although our validation supports model robustness, the relatively small sample may limit the precision of confidence intervals and the generalizability of the findings. Future studies with larger sample sizes and higher EPV ratios (preferably ≥10:1 or higher) are needed to improve model stability and external validity. Future external validation in larger, multicenter cohorts is warranted to confirm these findings. Second, the current investigation focused only on short-term sleep disorders after ICU transfer, without assessing long-term outcomes. Future studies should investigate how sleep disorders affect long-term outcomes of patients discharged from the ICU. Third, mechanical ventilation and sedative/analgesic use were recorded as binary variables without detailed parameters. Attempts to extract these data from medical records were limited by two major factors: (1) the retrospective design spanning three years (2022-2025) resulted in inconsistent documentation practices, with many records lacking standardized ventilator settings or daily sedative titration logs; (2) for patients transferred from multiple ICU subunits, detailed medication records were often dispersed across different electronic medical record systems that were not fully integrated during the study period. Consequently, complete and reliable data were unavailable for most patients, precluding meaningful analysis. Prospective studies should collect detailed treatment parameters to elucidate their specific contributions to post-ICU sleep disorders. Fourth, objective sleep monitoring using polysomnography (PSG) or actigraphy was not employed in this study due to practical constraints of the retrospective design and clinical setting. PSG requires specialized equipment, trained technicians, and overnight hospitalization in a sleep laboratory, which were not consistently available for routine post-ICU monitoring. Furthermore, PSG testing may impose excessive burden on patients recovering from critical illness. The PSQI was selected as a validated and clinically feasible alternative that has been widely used in ICU survivor populations and demonstrates good correlation with objective sleep measures in critically ill patients [35]. Nevertheless, self-reported measures may be subject to recall bias and subjective interpretation.

Conclusion

This study comprehensively analyzed the risk factors for sleep disorders in respiratory critically ill ICU patients following transfer to general wards. Tracheotomy, sepsis, prolonged ICU stay, and elevated APACHE II score were identified as independent risk factors. A nomogram predictive model was constructed based on these factors, demonstrating satisfactory discrimination and calibration, indicating its potential clinical relevance. In clinical practice, this model can assist healthcare professionals in early identification of high-risk patients, enabling implementation of personalized nursing care and targeted interventions for patients with conditions such as tracheotomy or sepsis. By guiding risk-stratified management, the mo-

del can help reduce the incidence of post-ICU sleep disorders, promote patient recovery, standardize clinical workflows, improve care efficiency, and alleviate the burden on patients, families, and healthcare systems.

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Disclosure of conflict of interest

None.

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