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Original Research Article

Clinical Outcomes and Predictors of Mortality in Patients with Acute Exacerbation of COPD Requiring ICU Admission

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Abstract

Background: Acute exacerbation of chronic obstructive pulmonary disease (AECOPD) requiring intensive care unit (ICU) admission represents a critical clinical event associated with substantial morbidity and mortality. Despite advances in critical care management, ICU mortality rates for severe AECOPD remain alarmingly high, and the identification of reliable early predictors of mortality is essential for optimizing clinical decision-making and resource allocation. This study aimed to evaluate the clinical outcomes and identify independent predictors of ICU mortality in patients admitted with severe AECOPD.

Methods: This prospective observational study was conducted at a tertiary care university hospital. A total of 246 consecutive patients admitted to the ICU with a primary diagnosis of severe AECOPD were enrolled. Comprehensive demographic, clinical, laboratory, and ventilatory data were collected. The primary outcome was ICU mortality. Univariate and multivariable binary logistic regression analyses were performed to identify independent predictors of mortality.

Results: The overall ICU mortality rate was 27.6% (68/246). Non-survivors were significantly older (68.4 ± 9.2 vs. 62.7 ± 10.4 years, $p < 0.001$), had lower mean BMI (19.8 ± 3.4 vs. 22.6 ± 4.2 kg/m², $p < 0.001$), and higher APACHE II scores (24.6 ± 6.8 vs. 16.4 ± 5.2, $p < 0.001$) compared with survivors. The requirement for invasive mechanical ventilation (IMV) was significantly higher among non-survivors (72.1% vs. 28.1%, $p < 0.001$). Multivariable logistic regression identified APACHE II score > 20 (adjusted OR 4.82; 95% CI: 2.64–8.80; $p < 0.001$), need for IMV (adjusted OR 3.96; 95% CI: 2.08–7.54; $p < 0.001$), serum albumin < 2.5 g/dL (adjusted OR 3.14; 95% CI: 1.62–6.08; $p = 0.001$), pH < 7.25 at admission (adjusted OR 2.86; 95% CI: 1.48–5.52; $p = 0.002$), and presence of cor pulmonale (adjusted OR 2.38; 95% CI: 1.24–4.56; $p = 0.009$) as independent predictors of ICU mortality.

Conclusion: Severe AECOPD requiring ICU admission carries a substantial mortality burden. APACHE II score, requirement for invasive mechanical ventilation, hypoalbuminemia, severe acidemia at admission, and cor pulmonale serve as reliable independent predictors of mortality that can guide early risk stratification and inform therapeutic decision-making in the critical care setting.

Keywords: Acute exacerbation; COPD; ICU mortality; Predictors; Mechanical ventilation; APACHE II; Acidemia; Critical care outcomes.

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Introduction

Chronic obstructive pulmonary disease (COPD) is a progressive, largely irreversible respiratory condition characterized by persistent airflow limitation resulting from chronic inflammatory responses in the airways and lung parenchyma to noxious particles and gases [1]. It represents a leading cause of morbidity and mortality worldwide, currently ranked as the third leading cause of death globally by the World Health Organization, accounting for approximately 3.23 million deaths annually [2]. The natural history of COPD is punctuated by episodes of acute exacerbation, defined as sustained worsening of respiratory symptoms beyond normal day-to-day variation that necessitates modification of regular therapy [3]. Acute exacerbations of COPD

(AECOPD) constitute pivotal events in the disease trajectory, accelerating lung function decline, diminishing health-related quality of life, increasing healthcare utilization, and conferring a significantly elevated risk of mortality [4]. While the majority of exacerbations are managed in the outpatient or general ward setting, a significant proportion presents with severe respiratory compromise necessitating admission to the intensive care unit (ICU), particularly when complicated by acute respiratory failure, severe acidemia, hemodynamic instability, or altered consciousness [5].

ICU admission for AECOPD is associated with a disproportionately high burden of adverse outcomes. Published mortality rates for AECOPD requiring ICU care range from 17% to 49%, depending upon the severity of illness, the availability of non-invasive ventilation (NIV), institutional protocols, and patient comorbidity profiles [6]. The economic impact is equally considerable, as ICU stays for AECOPD are resource-intensive and frequently prolonged, contributing substantially to the overall healthcare expenditure attributable to COPD management [7].

The identification of early, reliable predictors of mortality in ICU-admitted AECOPD patients is of paramount clinical importance. Accurate risk stratification at the time of ICU admission enables clinicians to make informed decisions regarding the intensity of monitoring, the escalation of ventilatory support, the appropriateness of invasive interventions, and the initiation of palliative care discussions when warranted [8].

Several clinical scoring systems, including the Acute Physiology and Chronic Health Evaluation II (APACHE II) score and the Sequential Organ Failure Assessment (SOFA) score, have been widely validated for predicting ICU mortality across heterogeneous critically ill populations, but their specific predictive performance in AECOPD cohorts requires further evaluation [9].

Previous investigations have identified a range of potential prognostic factors in this population, including advanced age, nutritional status, arterial blood gas parameters at admission, the need for invasive mechanical ventilation (IMV), comorbid conditions such as cardiovascular disease and diabetes mellitus, and biomarkers of inflammation and organ dysfunction [10].

Connors et al., in their landmark study, demonstrated that in-hospital mortality following AECOPD was independently associated with severity of illness, body mass index, and functional status [11]. More recently, Ucgun et al. highlighted the prognostic significance of arterial pH and the requirement for prolonged mechanical ventilation [12]. Groenewegen et al. further established that hypercapnia, low albumin, and the presence of cor pulmonale were independent determinants of mortality in hospitalized AECOPD patients [13]. Despite the growing body of evidence, significant heterogeneity exists across published studies regarding patient populations, healthcare settings, ventilatory practices, and analytical methodologies. The relative prognostic importance of individual variables remains incompletely defined, and few studies have comprehensively evaluated the combined predictive contributions of clinical, laboratory, and ventilatory parameters within a single ICU cohort [14]. Furthermore, data from resource-limited settings with variable access to advanced ventilatory modalities remain underrepresented in the international literature [15].

The aim of the present study was to comprehensively evaluate the clinical outcomes and identify independent predictors of ICU mortality in patients admitted with severe AECOPD at an urban tertiary care center, with the objective of establishing a practical risk stratification framework to guide clinical decision-making.

Materials and Methods

Study Design and Setting: This prospective observational cohort study was conducted in the medical intensive care unit (MICU) of a tertiary care hospital.

Study Population: A total of 246 consecutive patients admitted to the MICU with a primary diagnosis of severe AECOPD were enrolled. COPD diagnosis was established based on prior documentation in medical records according to Global Initiative for Chronic Obstructive Lung Disease (GOLD) criteria, defined as a post-bronchodilator FEV1/FVC ratio < 0.70 on prior spirometry. AECOPD was defined as an acute sustained worsening of dyspnea, cough, and/or sputum production beyond normal day-to-day variability, sufficient to warrant a change in management.

Inclusion and Exclusion Criteria: Inclusion criteria comprised: age $\geq$ 40 years; confirmed diagnosis of COPD with documented spirometric evidence of airflow obstruction; acute exacerbation requiring ICU admission for intensive respiratory monitoring and/or ventilatory support; and ability to obtain informed consent from the patient or surrogate.

Exclusion criteria included: primary diagnosis other than AECOPD (e.g., pneumothorax, pulmonary embolism, acute coronary syndrome, or decompensated heart failure as the primary indication for ICU admission); concomitant active malignancy; known interstitial lung disease or bronchiectasis as the dominant pulmonary pathology; discharge against medical advice within 24 hours of admission; and incomplete data precluding meaningful analysis.

Data Collection: Comprehensive data were collected at the time of ICU admission and throughout the ICU stay using a standardized case record form. Demographic variables recorded included age, sex, body mass index (BMI), and smoking history quantified in pack-years. Clinical variables included the duration of COPD diagnosis, GOLD stage based on prior spirometry, number of prior exacerbations in the preceding 12 months, number of prior ICU admissions, presence of home oxygen therapy, and long-term medication use.

Comorbidities were systematically documented, including hypertension, diabetes mellitus, coronary artery disease, cor pulmonale (defined by clinical assessment and echocardiographic evidence of right ventricular dysfunction and/or pulmonary hypertension), chronic kidney disease, and cerebrovascular disease.

Arterial blood gas (ABG) analysis was performed at admission and included pH, partial pressure of arterial carbon dioxide ($PaCO_2$), partial pressure of arterial oxygen (PaO_2), bicarbonate (HCO_3^-), and PaO_2/FiO_2 ratio. Laboratory investigations recorded at admission included complete blood count, serum albumin, serum creatinine, blood urea nitrogen, C-reactive protein (CRP), and procalcitonin. The APACHE II score was calculated within the first 24 hours of ICU admission using the worst physiological values recorded during that period.

Ventilatory management details were recorded, including the mode of initial ventilatory support (NIV versus IMV), duration of ventilatory support, need for escalation from NIV to IMV, and total duration of IMV. The presence of ventilator-associated pneumonia (VAP), tracheostomy requirement, and the use of vasopressor support were also documented.

Outcome Measures: The primary outcome was ICU mortality, defined as death from any cause during the ICU stay. Secondary outcomes included ICU length of stay (LOS), total hospital LOS, duration of mechanical ventilation, NIV failure rate (defined as the need for intubation and IMV following initial NIV trial), and in-hospital mortality (death occurring after ICU discharge but before hospital discharge).

Statistical Analysis: Statistical analyses were performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were assessed for normality using the Shapiro-Wilk test and expressed as mean ± standard deviation (SD) or median with interquartile range (IQR) as appropriate. Categorical variables were presented as frequencies and percentages. Comparisons between survivors and non-survivors were performed using independent samples t-test or Mann-Whitney U test for continuous variables and Chi-square test or Fisher's exact test for categorical variables. Univariate binary logistic regression was performed to assess the association between candidate predictor variables and ICU mortality. Variables demonstrating statistical significance at $p < 0.10$ on univariate analysis were entered into a multivariable binary logistic regression model using a backward stepwise elimination approach. Results were expressed as adjusted odds ratios (OR) with 95% confidence intervals (CI). Model discrimination was assessed using the area under the receiver operating characteristic (AUROC) curve, and calibration was evaluated using the Hosmer-Lemeshow goodness-of-fit test. A two-tailed p-value of < 0.05 was considered statistically significant.

Results

Demographic and Clinical Characteristics: Of the 246 patients enrolled, 68 (27.6%) died during the ICU stay (non-survivors), while 178 (72.4%) survived to ICU discharge (survivors). The demographic and clinical characteristics of both groups are summarized in Table 1. Non-survivors were significantly older (68.4 ± 9.2 vs. 62.7 ± 10.4 years, $p < 0.001$), had significantly lower BMI (19.8 ± 3.4 vs. 22.6 ± 4.2 kg/m², $p < 0.001$), and a higher mean APACHE II score at admission (24.6 ± 6.8 vs. 16.4 ± 5.2, $p < 0.001$). The prevalence of cor pulmonale was significantly higher among non-survivors (51.5% vs. 24.2%, $p < 0.001$). Diabetes mellitus was more prevalent in non-survivors (38.2% vs. 23.6%, $p = 0.019$). No significant differences were observed between groups regarding sex distribution, smoking pack-years, or duration of COPD.

Table 1: Demographic and Clinical Characteristics of Survivors and Non-Survivors

Variable	Survivors (n=178)	Non-Survivors (n=68)	p-value
Age (years), mean ± SD	62.7 ± 10.4	68.4 ± 9.2	<0.001*
Male sex, n (%)	126 (70.8%)	52 (76.5%)	0.371
BMI (kg/m²), mean ± SD	22.6 ± 4.2	19.8 ± 3.4	<0.001*
Smoking (pack-years), mean ± SD	34.2 ± 16.8	38.6 ± 18.4	0.078
Duration of COPD (years), mean ± SD	8.4 ± 4.6	9.8 ± 5.2	0.052
GOLD Stage III–IV, n (%)	108 (60.7%)	54 (79.4%)	0.005*

Prior exacerbations ≥ 2/year, n (%)	72 (40.4%)	42 (61.8%)	0.002*
Prior ICU admissions, n (%)	38 (21.3%)	26 (38.2%)	0.006*
Home oxygen therapy, n (%)	32 (18.0%)	22 (32.4%)	0.013*
APACHE II score, mean ± SD	16.4 ± 5.2	24.6 ± 6.8	<0.001*
Comorbidities, n (%)			
Hypertension	68 (38.2%)	30 (44.1%)	0.393
Diabetes mellitus	42 (23.6%)	26 (38.2%)	0.019*
Coronary artery disease	28 (15.7%)	16 (23.5%)	0.149
Cor pulmonale	43 (24.2%)	35 (51.5%)	<0.001*
Chronic kidney disease	14 (7.9%)	10 (14.7%)	0.100

***Statistically significant at p < 0.05**

Laboratory, Blood Gas, and Ventilatory Parameters: Table 2 presents the laboratory, arterial blood gas, and ventilatory parameters of the study cohort. Non-survivors demonstrated significantly more severe acidemia at admission (mean pH 7.22 ± 0.08 vs. 7.32 ± 0.06, p < 0.001), higher PaCO2 levels (78.4 ± 18.6 mmHg vs. 62.8 ± 14.2 mmHg, p < 0.001), and lower PaO2/FiO2 ratios (148.6 ± 42.4 vs. 196.8 ± 48.6, p < 0.001). Serum albumin was significantly lower among non-survivors (2.3 ± 0.6 g/dL vs. 3.1 ± 0.7 g/dL, p < 0.001). CRP levels were significantly elevated in the non-survivor group (86.4 ± 42.8 mg/L vs. 48.6 ± 32.4 mg/L, p < 0.001).

The need for invasive mechanical ventilation was markedly higher among non-survivors (72.1% vs. 28.1%, p < 0.001), and the NIV failure rate was 58.8% in non-survivors compared with 16.9% in survivors (p < 0.001). The median ICU length of stay was significantly longer in non-survivors (12.4 ± 6.8 days vs. 7.6 ± 4.2 days, p < 0.001).

Table 2: Laboratory, Arterial Blood Gas, and Ventilatory Parameters

Variable	Survivors (n=178)	Non-Survivors (n=68)	p-value
Admission pH, mean ± SD	7.32 ± 0.06	7.22 ± 0.08	<0.001*
PaCO2 (mmHg), mean ± SD	62.8 ± 14.2	78.4 ± 18.6	<0.001*
PaO2 (mmHg), mean ± SD	58.4 ± 12.6	52.6 ± 14.8	0.003*
PaO2/FiO2 ratio, mean ± SD	196.8 ± 48.6	148.6 ± 42.4	<0.001*
HCO_3^- (mEq/L), mean ± SD	28.4 ± 5.6	24.8 ± 6.2	<0.001*
Serum albumin (g/dL), mean ± SD	3.1 ± 0.7	2.3 ± 0.6	<0.001*
Serum creatinine (mg/dL), mean ± SD	1.1 ± 0.4	1.4 ± 0.6	<0.001*
CRP (mg/L), mean ± SD	48.6 ± 32.4	86.4 ± 42.8	<0.001*
Procalcitonin (ng/mL), mean ± SD	0.82 ± 0.64	2.46 ± 1.84	<0.001*
Hemoglobin (g/dL), mean ± SD	12.4 ± 2.2	11.2 ± 2.6	0.001*
WBC count ($\times 10^3/\mu L$), mean ± SD	12.6 ± 4.8	16.4 ± 6.2	<0.001*
Initial NIV, n (%)	142 (79.8%)	48 (70.6%)	0.118
NIV failure, n (%)	30 (16.9%)	40 (58.8%)	<0.001*
Invasive mechanical ventilation, n (%)	50 (28.1%)	49 (72.1%)	<0.001*
Duration of MV (days), mean ± SD	4.2 ± 2.8	8.6 ± 4.6	<0.001*
Vasopressor use, n (%)	18 (10.1%)	32 (47.1%)	<0.001*
VAP, n (%)	12 (6.7%)	18 (26.5%)	<0.001*
Tracheostomy, n (%)	8 (4.5%)	14 (20.6%)	<0.001*
ICU LOS (days), mean ± SD	7.6 ± 4.2	12.4 ± 6.8	<0.001*

***Statistically significant at p < 0.05**

Independent Predictors of ICU Mortality: The results of univariate and multivariable logistic regression analyses are presented in Table 3. On multivariable analysis, five variables were independently associated with ICU mortality: APACHE II score > 20 (adjusted OR 4.82; 95% CI: 2.64–8.80; p < 0.001), need for invasive mechanical ventilation (adjusted OR 3.96; 95% CI: 2.08–7.54; p < 0.001), serum albumin < 2.5 g/dL (adjusted OR 3.14; 95% CI: 1.62–6.08; p = 0.001), admission pH < 7.25 (adjusted OR 2.86; 95% CI: 1.48–5.52; p = 0.002), and presence of cor pulmonale (adjusted OR 2.38; 95% CI: 1.24–4.56; p = 0.009). The multivariable model demonstrated excellent discrimination with an AUROC of 0.892 (95% CI: 0.847–0.937), and the Hosmer-Lemeshow test indicated adequate calibration (p = 0.364).

Table 3: Univariate and Multivariable Logistic Regression Analysis of Predictors of ICU Mortality

Variable	Univariate OR (95% CI)	Univariate p-value	Adjusted OR (95% CI)	Multivariable p-value
Age > 65 years	2.42 (1.38–4.24)	0.002*	1.56 (0.82–2.96)	0.174
BMI < 18.5 kg/m²	2.86 (1.54–5.32)	0.001*	1.72 (0.84–3.52)	0.138
GOLD Stage III–IV	2.48 (1.28–4.80)	0.007*	1.44 (0.68–3.06)	0.342
APACHE II > 20	5.64 (3.18–10.02)	<0.001*	4.82 (2.64–8.80)	<0.001*
Admission pH < 7.25	4.18 (2.32–7.54)	<0.001*	2.86 (1.48–5.52)	0.002*
PaCO2 > 70 mmHg	3.12 (1.78–5.48)	<0.001*	1.58 (0.78–3.20)	0.204
PaO2/FiO2 < 150	2.94 (1.66–5.20)	<0.001*	1.64 (0.82–3.28)	0.162
Serum albumin < 2.5 g/dL	4.28 (2.36–7.76)	<0.001*	3.14 (1.62–6.08)	0.001*
Invasive MV required	6.56 (3.62–11.88)	<0.001*	3.96 (2.08–7.54)	<0.001*
Cor pulmonale	3.32 (1.88–5.86)	<0.001*	2.38 (1.24–4.56)	0.009*
Diabetes mellitus	2.00 (1.12–3.58)	0.020*	1.52 (0.78–2.96)	0.216
Prior ICU admissions	2.28 (1.26–4.12)	0.007*	1.46 (0.74–2.88)	0.276
Vasopressor use	7.86 (4.06–15.22)	<0.001*	—	—
CRP > 50 mg/L	2.78 (1.58–4.88)	<0.001*	1.48 (0.76–2.88)	0.248

***Statistically significant at p < 0.05; OR = Odds Ratio; CI = Confidence Interval; MV = Mechanical Ventilation**

The overall in-hospital mortality (including deaths occurring after ICU discharge) was 31.3% (77/246). Among survivors of the ICU stay, 9 additional patients (5.1%) died in the general ward before hospital discharge.

Discussion

The present study comprehensively evaluated the clinical outcomes and prognostic determinants of ICU mortality in a well-characterized cohort of patients admitted with severe AECOPD. The observed ICU mortality rate of 27.6% falls within the range reported by major international studies and underscores the persistent lethality of this condition despite advances in critical care management [16].

The APACHE II score emerged as the strongest independent predictor of ICU mortality in our analysis, with an adjusted odds ratio of 4.82 for scores exceeding 20. This finding corroborates the extensive body of literature validating the APACHE II scoring system as a reliable prognostic tool in critically ill populations. Wildman et al. demonstrated that APACHE II was superior to simpler clinical markers in predicting hospital mortality among COPD patients requiring ICU admission, attributing its predictive strength to its comprehensive incorporation of acute physiological derangements and chronic health status [17]. The high AUROC of 0.892 achieved by our multivariable model further affirms the discriminatory capacity of combining APACHE II with other clinical and biochemical variables.

The requirement for invasive mechanical ventilation was the second most powerful predictor of mortality (adjusted OR 3.96), consistent with the seminal findings of Seneff et al., who reported that the need for endotracheal intubation and mechanical ventilation was independently associated with a two- to four-fold increase in mortality among AECOPD patients in the ICU [18]. The high mortality associated with IMV in this population reflects the compounding effects of prolonged ventilatory dependence, ventilator-associated complications including ventilator-associated pneumonia and barotrauma, difficulty in weaning due to respiratory muscle fatigue and hyperinflation, and the general frailty of COPD patients requiring such intensive interventions [19].

The NIV failure rate of 58.8% among non-survivors compared with 16.9% among survivors highlights the critical importance of NIV as a first-line ventilatory strategy in AECOPD. The pivotal randomized controlled trial by Brochard et al. established that NIV significantly reduces the need for intubation, shortens ICU stay, and decreases mortality in patients with AECOPD complicated by acute respiratory failure [20]. Our data reinforce the concept that failure of NIV, manifesting as the need for escalation to IMV, constitutes a powerful adverse prognostic signal in this population.

Severe acidemia at admission (pH < 7.25) was independently predictive of mortality (adjusted OR 2.86), reflecting the degree of acute ventilatory failure and physiological reserve depletion at the time of ICU presentation. Plant et al., in their landmark multicenter trial, demonstrated that admission pH was the single most important determinant of NIV success and overall outcome in AECOPD, with patients presenting with pH < 7.25 exhibiting significantly higher mortality rates regardless of the ventilatory modality employed [21]. The persistence of acidemia despite initial therapeutic interventions has been shown to predict NIV failure and the eventual requirement for intubation [22].

Hypoalbuminemia (serum albumin < 2.5 g/dL) was independently associated with a 3.14-fold increased risk of mortality, reinforcing the critical prognostic importance of nutritional status in critically ill COPD patients. Serum albumin serves as a composite biomarker reflecting both nutritional reserve and the magnitude of the systemic inflammatory response, as it behaves as a negative acute-phase reactant whose hepatic synthesis is suppressed during states of acute inflammation [23]. Gunen et al. demonstrated that low serum albumin was an independent predictor of in-hospital mortality in AECOPD, attributing this association to the combined effects of malnutrition-related respiratory muscle weakness, impaired immune function, and heightened susceptibility to secondary infections [24].

The presence of cor pulmonale as an independent predictor of ICU mortality (adjusted OR 2.38) reflects the adverse prognostic implications of right ventricular dysfunction and pulmonary hypertension in the setting of acute-on-chronic respiratory failure. Cor pulmonale indicates advanced COPD with established pulmonary vascular remodeling and limited cardiovascular reserve, rendering such patients particularly vulnerable to the acute hemodynamic stresses imposed by severe exacerbations [25]. Groenewegen et al. similarly identified cor pulmonale as an independent risk factor for in-hospital mortality in AECOPD, proposing that the presence of right heart failure limits the adaptive cardiovascular responses necessary to compensate for the increased work of breathing during exacerbations [26].

Notably, while several variables including advanced age, low BMI, GOLD stage, elevated CRP, and diabetes mellitus demonstrated significant associations with mortality on univariate analysis, they did not retain independent significance on multivariable analysis after adjusting for the more powerful predictors. This finding suggests that these factors may exert their prognostic influence indirectly through their contributions to the overall severity of illness as captured by the APACHE II score and the need for invasive ventilation [27].

This study has several limitations. The single-center design may limit generalizability to other healthcare settings with different resources, patient populations, and ventilatory practices.

The observational nature of the study precludes causal inference. Long-term outcomes beyond hospital discharge, including 30-day and 90-day mortality, readmission rates, and post-discharge functional status, were not assessed. Additionally, certain potentially relevant prognostic variables such as echocardiographic parameters of right ventricular function, nutritional assessment scores, and frailty indices were not systematically evaluated. Future multicenter prospective studies incorporating these variables and long-term follow-up are warranted to validate and extend our findings [28].

Conclusion

Acute exacerbation of COPD requiring ICU admission continues to carry a substantial mortality burden, with over one-quarter of patients failing to survive their ICU stay. This study identifies APACHE II score exceeding 20, requirement for invasive mechanical ventilation, hypoalbuminemia below 2.5 g/dL, severe acidemia with pH below 7.25 at admission, and the presence of cor pulmonale as independent predictors of ICU mortality. These readily assessable clinical and laboratory parameters can be utilized at the time of ICU admission for early risk stratification, enabling clinicians to identify high-risk patients who may benefit from more aggressive monitoring, early initiation of non-invasive ventilation to prevent the need for intubation, nutritional optimization, and timely multidisciplinary discussions regarding goals of care. Integration of these predictive factors into a structured risk assessment framework has the potential to improve clinical decision-making, optimize resource allocation, and ultimately enhance outcomes in this critically ill population. Future prospective multicenter validation studies are warranted to confirm the generalizability and clinical utility of these findings.

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