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ORIGINAL RESEARCH

Mortality risk scores in acute cardiogenic pulmonary edema: a comparative study

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Abstract

Background: Acute cardiogenic pulmonary edema (ACPE) is a life-threatening clinical condition frequently associated with unplanned hospital admissions and recurrent emergency department visits. Several prognostic risk scores have been developed to predict early mortality in patients with ACPE. This study aimed to compare the discriminative performance of established risk scores and to determine the most applicable tool for clinical use, as early identification of high-risk patients may support timely and effective management. **Methods**: In this single-center retrospective cohort study, 508 patients diagnosed with ACPE and admitted to a tertiary care hospital between January 2023 and January 2024 were included. Four prognostic scores, the SABIHA (systolic blood pressure, age, blood urea nitrogen, intubation, heart rate, and anemia) score, the Three Interventions in Cardiogenic Pulmonary Oedema (3CPO) trial score, the Prognostic Risk Score (PRS), and the Pulmonary Edema Prognostic Score (PEPS), were calculated for each patient. The primary outcome was 30-day all-cause mortality. Discriminative ability was assessed using receiver operating characteristic (ROC) curve analysis. Additionally, multivariable logistic regression was conducted to identify independent predictors of mortality. **Results**: The SABIHA score demonstrated the highest discriminative performance, with an area under the curve (AUC) of 0.855 (95% confidence interval (CI): 0.808–0.903, $p < 0.001$). The optimal cutoff value for the SABIHA score was 2.5, yielding a sensitivity of 70% and specificity of 88%. In comparison, the AUC for the 3CPO score was 0.701 (95% CI: 0.808–0.903, $p < 0.001$). The SABIHA score significantly outperformed the PRS, PEPS, and 3CPO scores ($p < 0.001$, DeLong's test). **Conclusions**: Among the evaluated prognostic tools, the SABIHA score exhibited superior predictive accuracy for 30-day mortality in patients with ACPE. By integrating age, vital signs, laboratory parameters, and intubation status, the SABIHA score may facilitate early identification of high-risk patients, thereby supporting more informed clinical decision-making and improved patient outcomes.

Keywords

Heart failure; Pulmonary edema; Mortality; Risk score

1. Introduction

Acute cardiogenic pulmonary edema (ACPE) is a life-threatening condition that results from elevated cardiac filling pressures and is associated with a high risk of mortality [1, 2], requiring prompt identification and early intervention as delays in management can lead to rapid clinical deterioration. Therefore, early risk stratification is crucial for guiding treatment decisions and optimizing outcomes in patients presenting with ACPE [3].

In recent years, clinical risk scoring systems have been increasingly developed to predict short-term mortality in patients with ACPE [4] to support clinicians by providing an objective assessment of patient prognosis at an early stage. Most scoring systems incorporate a combination of clinical parameters, such as age and vital signs, which are readily available at presentation [5]. Others include laboratory findings or indicators of disease severity, such as the need for intubation, which may become available later in the clinical course [6–8]. Despite the proliferation of these scoring models, their routine use in clinical settings remains limited. Many have not been widely adopted, and few are referenced in current heart failure management guidelines [3–9], partly due to the lack of validation across diverse populations and the absence of direct comparisons between existing models. As a result, there is an ongoing need to evaluate their accuracy, generalizability, and practical applicability in real-world clinical environments. Thus, identifying the most reliable prognostic score for use in the emergency department could significantly improve clinical decision-making, and timely recognition of high-risk pa-

tients. This could not only facilitate appropriate care escalation but could also help reduce unnecessary hospital admissions, thereby minimizing the burden on healthcare resources [10].

The present study, therefore, aimed to address this gap by comparing the performance of several established risk scores for predicting short-term mortality in patients with ACPE. The goal was to identify the score with the highest predictive accuracy and clinical utility, particularly in the emergency care setting.

2. Materials and methods

2.1 Study setting

This retrospective cohort study was conducted in the emergency department of a high-volume tertiary care hospital, which receives approximately 850,000 patient visits annually. The study included patients who presented with ACPE between 01 January 2023, and 01 January 2024. Ethical approval was obtained from the local ethics committee prior to study initiation (approval number: AEŞH-BADEK-2025-0211; approval date: 12 February 2025). All patient data were anonymized and treated with full confidentiality. Informed consent was not required due to the retrospective design of the study.

2.2 Inclusion and exclusion criteria

The diagnosis of ACPE was established based on the 2021 European Society of Cardiology (ESC) guidelines. Diagnostic criteria included the presence of at least two of the following clinical features: acute respiratory distress, marked tachypnea (respiratory rate $>$25 breaths/min), use of accessory respiratory muscles or abdominal paradoxical breathing, auscultatory findings such as wheezing, third heart sound, orthopnea, and signs of respiratory failure defined by oxygen saturation (SpO_2) $<$90% on room air. Additionally, supporting data included arterial blood gas values indicating Partial Pressure of Arterial Oxygen (PaO_2) $<$60 mmHg, Partial Pressure of Arterial Carbon Dioxide ($PaCO_2$) $>$45 mmHg, or a PaO_2/Fraction of Inspired Oxygen (FiO_2) ratio $<$300 mmHg. Radiological and imaging criteria comprised evidence of pulmonary congestion on chest radiography or computed tomography, multiple B-lines on lung ultrasound (defined as $\geq$3 B-lines in at least two zones of each hemithorax), increased total lung water and altered pulse contour on thermodilution analysis, echocardiographic findings indicative of elevated filling pressures (*e.g.*, E/E′ $>$15), and significantly elevated natriuretic peptide levels (B-type Natriuretic Peptide (BNP) $>$400 pg/mL or N-terminal (NT)-proBNP $>$900 pg/mL) [3].

Patients aged 18 years or older who were diagnosed with ACPE in the emergency department were considered eligible for inclusion. The study exclusion criteria comprised patients with ST Segment (ST)-elevation myocardial infarction, dialysis-dependent individuals, those with concomitant terminal illnesses, and patients with incomplete prognostic data.

2.3 Data collection

Patient data were obtained from the hospital's electronic information system. For consistency, only the first admission for each patient was considered, while subsequent admissions of patients with recurrent episodes of ACPE were excluded. Each patient was therefore evaluated only once. A structured data collection form was used to record comprehensive clinical information, including demographic characteristics, medical history, initial clinical presentation, vital signs, laboratory values, administered treatments, and performed procedures. For patients with multiple presentations to the emergency department for ACPE, only the data corresponding to the initial visit were included in the analysis. To enhance data reliability, two emergency medicine physicians independently reviewed and verified all included cases.

2.4 ACPE management

Management of ACPE in the emergency department followed the current clinical guidelines. Initial treatment consisted of continuous positive airway pressure (CPAP) to provide oxygen support, along with standard pharmacologic therapy including intravenous nitrates and loop diuretics. For patients presenting with hypotension and signs of impaired perfusion, vasopressor agents were administered. In cases where patients failed to respond to treatment within the first two hours or showed no improvement with noninvasive ventilation, invasive mechanical ventilation was initiated. Simultaneously, the underlying cause of ACPE was investigated and treated accordingly to ensure targeted management.

2.5 Score calculation methods

Four prognostic scores were selected for evaluation based on their clinical relevance, availability of required parameters, and previous use in cohorts with similar characteristics. These included the SABIHA score (systolic blood pressure, age, blood urea nitrogen, intubation, heart rate, and anemia), the Three Interventions in Cardiogenic Pulmonary Oedema (3CPO) trials score, the Prognostic Risk Score (PRS), and the Pulmonary Edema Prognostic Score (PEPS). Each score was calculated for all patients included in the study.

PRS was calculated as follows: 1 $\times$ anemia ($<$13.0 g/dL in men or $<$12.0 g/dL in women) + 2 $\times$ (cTnI/T elevation) + 1 $\times$ [BNP 500 to $<$1500 pg/mL (NT-proBNP 2500 to $<$7500 pg/mL)] or 2 $\times$ [BNP $\geq$1500 (NT-proBNP $\geq$7500) pg/mL] + 3 $\times$ (QRS Complex (QRS) fraction of electrocardiogram $<$55%) + 1 $\times$ (angiotensin converting enzyme inhibitor/angiotensin receptor blocker (ACEI/ARB) not used) [7].

The QRS fraction was determined by calculating the ratio of the sum of R-wave amplitudes across the 12 Electrocardiogram (ECG) leads (ΣR) to the sum of the absolute values of total QRS amplitudes (ΣQRS), expressed as a percentage: (ΣR/ΣQRS) $\times$ 100%.

PEPS was computed as follows: 1 $\times$ (acute myocardial infarction) + 1 $\times$ (heart rate $>$115 beats/minute) + 1 $\times$ (systolic blood pressure $\leq$130 mmHg) + 1 $\times$ (white blood cell count $>$11,500/mm^3) [6].

The 3CPO score was calculated using the following equa-

tion: 1 × (failure to obey commands) + 1 × (age >75 years) + 1 × (systolic blood pressure ≤140 mmHg) [5].

The SABIHA score was derived as follows: 1 × (systolic blood pressure <110 mmHg) + 1 × (age ≥75 years) + 1 × (blood urea nitrogen (BUN) ≥33 mg/dL) + 1 × (need for invasive mechanical ventilation + 1 × (pulse ≥110) + 1 × (presence of anemia) [8].

In addition to the score-specific variables, other collected data included demographic information, comorbidities, laboratory findings (*e.g.*, white blood cell count, hemoglobin, platelet count, lymphocyte and neutrophil counts, BUN, creatinine, sodium, potassium, troponin, NT-proBNP, and lactate dehydrogenase), use of invasive or noninvasive mechanical ventilation, emergency department readmissions due to ACPE within three months, emergency department outcomes (discharge, hospitalization or death), and 30-day mortality.

2.6 Outcomes

The primary endpoint of this study was all-cause mortality within 30 days following admission. The secondary endpoint was readmission to the emergency department with a diagnosis of ACPE within three months of the initial presentation.

2.7 Sample size

The required sample size estimation was conducted using the Sample Size Estimation in Diagnostic Accuracy Studies tool [11], and the calculations were based on the highest reported sensitivity and specificity values from previous studies evaluating similar prognostic models [5, 8]. Assuming a power of 90% and a Type I error rate of 5%, and based on the reported accuracy rates of 86% and 78%, the required minimum sample size was determined to be 498 patients.

2.8 Statistical analysis

All statistical analyses were performed using R (version 4.4.1) and SPSS (version 27, IBM Corp., Armonk, NY, USA). The Shapiro-Wilk test was used to evaluate the normality of continuous variables. Group comparisons were conducted using either Student's *t*-test or the Mann-Whitney U test, depending on the normality of distribution. Categorical variables were compared using the chi-squared test or Fisher's exact test, as appropriate.

To assess model discrimination, Tjur's R^2 was calculated as a measure of the explained variance. Receiver operating characteristic (ROC) curve analyses were performed to evaluate the discriminatory power of each scoring model, and the area under the curve (AUC) was computed. Comparisons of AUCs across models were conducted using DeLong's test. The optimal cutoff value for each score was determined using Youden's index, and corresponding sensitivity and specificity values were reported with 95% confidence intervals.

Multivariable logistic regression models were constructed to identify independent predictors of 30-day mortality. Variables were selected based on their statistical significance in univariable analyses and clinical relevance. An iterative variable selection approach was used, whereby predictors were added or removed stepwise to maximize model performance. Comparative evaluation of model fit was conducted using information-theoretic criteria, including Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC), with lower values indicating better fit. Additionally, AIC weights, corrected AIC (AICc) weights, and BIC weights were calculated to estimate the probability of each model being the best among the candidate models. Prediction error was quantified using the root mean square error (RMSE), and performance metrics were used to rank models. Model calibration was assessed using the Hosmer-Lemeshow goodness-of-fit test. Multicollinearity was evaluated using the variance inflation factor (VIF), with a threshold of >10 indicating significant collinearity. The final model was selected based on a combination of statistical performance, goodness-of-fit, and clinical interpretability to ensure robustness and generalizability of the results. Statistical significance was set a p-value <0.05.

3. Results

Between 01 January 2023, and 01 January 2024, a total of 539 patients were admitted to the emergency department with a diagnosis of ACPE. Of them, 31 patients were excluded based on the predefined exclusion criteria. As a result, 508 patients were included in the final analysis (Fig. 1).

The mean age of the patients included in the study was 73 ± 12.2 years, and 257 patients (51%) were female. Among the total cohort, 75 patients (15%) died within 30 days, and 89 patients (17%) were readmitted to the emergency department with a diagnosis of ACPE within three months of their initial presentation. The detailed demographic data, vital signs, laboratory results, electrocardiographic characteristics, ventilation strategies, hospitalization status, and mortality outcomes are summarized in Table 1.

When survivors and non-survivors were compared, several significant differences were observed between the two groups. Systolic blood pressure and white blood cell count were significantly lower in non-survivors, particularly among those who arrived by ambulance. In addition, non-survivors had significantly higher levels of blood urea nitrogen (BUN), creatinine, potassium, NT-proBNP, troponin, and lactate dehydrogenase (LDH) compared to survivors. Furthermore, the proportion of patients with a QRS fraction greater than 55%, the use of angiotensin II receptor blockers (ARBs), and the presence of altered mental status differed significantly between survivors and non-survivors. A detailed comparison of clinical and laboratory characteristics between these two groups is presented in Table 2.

When the predictive performance of the PRS, PEPS, 3CPO, and SABIHA scores was compared among patients with ACPE, the SABIHA score demonstrated the highest discriminatory ability, with an AUC of 0.855 (95% CI: 0.808–0.903, $p < 0.001$). The optimal cutoff value for the SABIHA score was 2.5, yielding a sensitivity of 70% and a specificity of 88%, indicating strong predictive power. In comparison, the 3CPO score yielded an AUC of 0.701 (95% CI: 0.808–0.903, $p < 0.001$), with an optimal cutoff of 1.5 and corresponding sensitivity and specificity of 66% and 63%, respectively. The AUC values for all evaluated scores

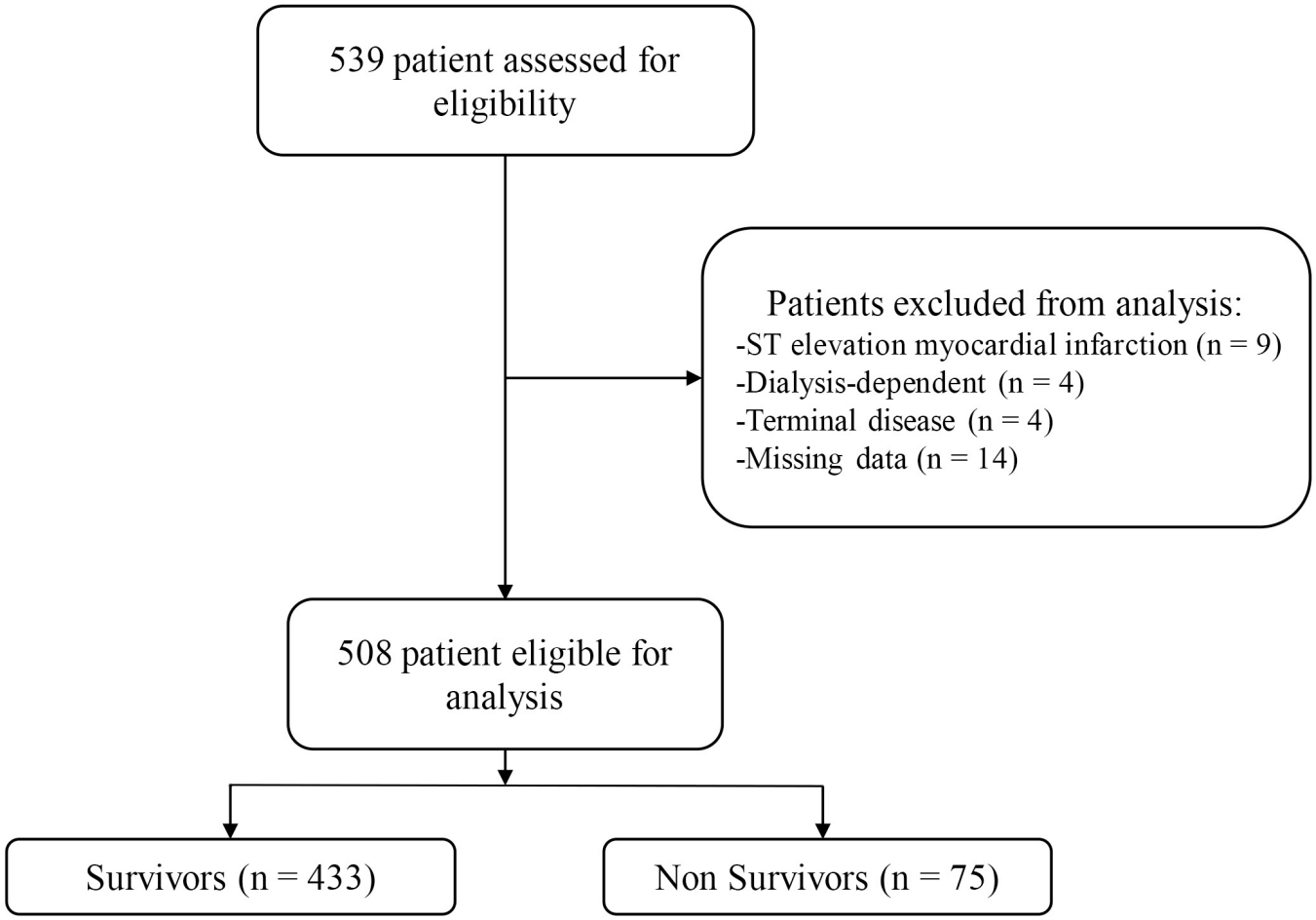

FIGURE 1. Patient flow diagram. ST: ST segment.

TABLE 1. Demographic and clinical characteristics of the study population.

Variables		n (%) or Mean ± SD/Median (IQR)
Age, yr*		73 (±12.2)
Gender†		
	Male	251 (49)
	Female	257 (51)
Admission Type†		
	Walk-in	212 (42)
	Ambulance	296 (58)
SBP, mmHg*		132 (±30)
DBP, mmHg*		78 (±16)
MAP, mmHg‡		94 (84–106)
HR, bpm*		91 (±20)
SpO_2, %‡		84 (81–86)
Shock Index‡		0.678 (0.556–0.848)
WBC, $\times 10^9$/L‡		9.4 (7.1–12.5)
Hgb, g/dL*		11.9 (±2.3)
PLT, $\times 10^9$/L‡		242.0 (184–311)
Lymphocyte, $\times 10^9$/L‡		1.29 (0.84–2.1)

TABLE 1. Continued.

Variables		n (%) or Mean ± SD/Median (IQR)
Neutrophile, $\times 10^9$/L‡		6.7 (5.1–9.7)
BUN, mg/dL‡		55 (38–83)
Creatinine (Cr), mg/dL‡		1.17 (0.93–1.66)
Na, mmol/L*		136 (±5.5)
K, mmol/L*		4.6 (±0.8)
Trop, ng/mL‡		36.3 (16.1–70.7)
NT-proBNP, pg/mL‡		4650 (1983–11,215)
LDH‡		271.5 (223–384)
Anemi (yes)†		218 (43)
Trop (positive)†		368 (72)
BNP, pg/mL†		
	<2500	202 (40)
	2500–7500	147 (29)
	>7500	159 (31)
AMI (yes)†		31 (6)
QRS fraction >55%†		66 (13)
ARB use†		59 (11)
Mental status†		
	Normal	458 (90)
	Poor	50 (10)
MV, NIMV†		
	None	376 (74)
	MV	85 (17)
	NIMV	47 (9)
PRS*		3.3 (±1.8)
PEPS‡		2 (1–2)
3CPO‡		1 (1–2)
SABIHA‡		2 (2–1)
Hospitalization (admitted)†		251 (49)
Length of hospital stay, days‡		0 (0–7)
Hospital admission in 3 months (yes)†		89 (17)
30-day Mortality†		
	Survivor	433 (85)
	Death	75 (15)

**: mean ± standard deviation; †: number of patients (percentage); ‡: median days (25–75 percentile).*
SBP: systolic blood pressure; DBP: diastolic blood pressure; MAP: mean arterial pressure; HR: heart rate; WBC: white blood cell count; Hgb: hemoglobin; PLT: platelet; BUN: blood urea nitrogen; LDH: lactate dehydrogenase; AMI: acute myocardial infarction; ARB: angiotensin II receptor blocker; MV: mechanical ventilation; NIMV: non-invasive mechanical ventilation; SpO_2: Peripheral Capillary Oxygen Saturation; NT: N-terminal; BNP: B-type Natriuretic Peptide; QRS: QRS Complex; PRS: Prognostic Risk Score; PEPS: Pulmonary Edema Prognostic Score; 3CPO: Three Interventions in Cardiogenic Pulmonary Oedema; SABIHA: systolic blood pressure, age, blood urea nitrogen, intubation, heart rate, and anemia; SD: Standard Deviation; IQR: Interquartile Range.

TABLE 2. Comparison of demographic and clinical characteristics between survivors and non-survivors of acute cardiogenic pulmonary edema.

Variables	Death (n = 75)	Survivor (n = 433)	*p*
Age, yr*	72 (±13)	73 (±12)	0.700
Gender†			
Male	45 (18)	206 (82)	0.040*
Female	30 (12)	227 (88)	
Admission type†			
Walk-in	14 (7)	198 (93)	<0.001*
Ambulance	61 (21)	235 (79)	
Hospitalization†			
Admitted	63 (25)	188 (85)	<0.001*
Non-admitted	12 (5)	245 (95)	
Length of hospital stay, days‡	5 (1–15)	0 (0–6)	<0.001*
SBP, mmHg*	108 (±24)	136 (±27)	<0.001*
DBP, mmHg*	65 (±15)	80 (±15)	<0.001*
MAP, mmHg‡	80 (69–93)	96 (87–108)	<0.001*
HR, bpm*	97 (±23)	90 (±19)	0.010*
SpO_2, %‡	82 (80–86)	84 (81–86)	0.020*
Shock Index‡	0.8907 (0.6720–1.1821)	0.6607 (0.5441–0.7910)	<0.001
WBC, $\times 10^9$/L‡	12.38 (9.55–17.89)	8.9 (7.0–11.9)	<0.001
Hgb, g/dL*	12.1 (±2.5)	11.8 (±2.3)	0.360
PLT, $\times 10^9$/L‡	231 (171–323)	244 (186–310)	0.480
Lymphocyte, $\times 10^9$/L‡	1.26 (0.81–2.06)	1.31 (0.84–2.10)	0.660
Neutrophile, $\times 10^9$/L‡	9.88 (7.47–13.51)	6.40 (4.87–8.93)	<0.001*
BUN, mg/dL‡	80 (60–140)	51 (36–77)	<0.001
Creatinine (Cr), mg/dL‡	1.6 (1.1–2.4)	1.12 (0.8–1.5)	<0.001
Na, mmol/L*	134 (±7.8)	136 (±4.9)	0.040*
K, mmol/L*	5.0 (±1.0)	4.5 (0.7)	<0.001*
Trop, ng/mL‡	61.4 (28.6–154.5)	32.3 (15.3–60.1)	<0.001*
NT-proBNP, pg/mL‡	7018 (3508–15,259)	4101 (1864–9755)	<0.001*
LDH‡	329 (240–477)	267 (217–352)	0.010*
Anemi (yes)†	31 (14)	187 (85)	0.760
Trop (positive)†	61 (17)	307 (83)	0.060
BNP†			
<2500	19 (10)	183 (90)	0.010*
2500–7500	23 (16)	124 (84)	
>7500	33 (21)	126 (79)	
AMI†			
No	69 (15)	408 (85)	0.450
Yes	6 (19)	25 (81)	

TABLE 2. Continued.

Variables	Death (n = 75)	Survivor (n = 433)	*p*
QRS fraction			
<55%	55 (12)	387 (88)	<0.001*
>55%	20 (30)	46 (70)	
ARB use†	21 (35)	38 (64)	<0.001*
Consciousness†			
Poor	38 (76)	12 (24)	<0.001
Normal	37 (8)	421 (92)	
Mechanical Ventilation†			
Non	0 (0)	376 (100)	
MV	75 (88)	10 (12)	<0.001*
NIMV	0 (0)	47 (100)	
PRS*	4.3 (±2)	3.1 (±1.7)	<0.001*
PEPS	2 (1–2.5)	2 (1–2)	<0.001*
3CPO‡	2 (1–2)	0 (1–1)	<0.001*
SABIHA‡	3 (2–4)	1 (1–2)	<0.001*

**: mean ± standard deviation; †: number of patients (percentage); ‡: median days (25–75 percentile).*
SBP: systolic blood pressure; DBP: diastolic blood pressure; MAP: mean arterial pressure; HR: heart rate; Hgb: hemoglobin; PLT: platelet; BUN: blood urea nitrogen; LDH: lactate dehydrogenase; AMI: acute myocardial infarction; ARB: angiotensin II receptor blocker; MV: mechanical ventilation; NIMV: non-invasive mechanical ventilation; SpO_2: Peripheral Capillary Oxygen Saturation; WBC: white blood cell count; NT: N-terminal; BNP: B-type Natriuretic Peptide; QRS: QRS Complex; PRS: Prognostic Risk Score; PEPS: Pulmonary Edema Prognostic Score; 3CPO: Three Interventions in Cardiogenic Pulmonary Oedema; SABIHA: systolic blood pressure, age, blood urea nitrogen, intubation, heart rate, and anemia.

in predicting 30-day mortality are summarized in Table 3. The SABIHA score significantly outperformed the PRS, PEPS and 3CPO scores in terms of discriminatory power ($p < 0.001$, DeLong's test), while no significant differences were observed between the PRS, PEPS, and 3CPO scores. A detailed statistical comparison of AUC differences is presented in Table 4, and the ROC curves of all four scoring systems are illustrated in Fig. 2.

When patients who died within 30 days were excluded from the analysis, the predictive performance of the scoring systems for hospital readmission was found to be limited. The AUC for the SABIHA score was 0.515, indicating no meaningful discriminatory power. Similarly, the AUC values for the PRS, 3CPO and PEPS scores were 0.543, 0.559 and 0.490, respectively, suggesting that none of these scoring systems effectively predict the risk of readmission. The corresponding ROC curves for hospital readmission outcomes are shown in Fig. 3.

The final multivariable logistic regression model exhibited strong explanatory capability, as reflected by a Nagelkerke R^2 value of 0.565, indicating that approximately 56.5% of the variance in 30-day mortality was accounted for by the included predictors. Model calibration was evaluated using the Hosmer-Lemeshow goodness-of-fit test, which produced a non-significant result ($\chi^2 = 6.048$, $df = 8$, $p = 0.642$), suggesting good concordance between observed outcomes and predicted probabilities. The model converged successfully, with a −2 Log Likelihood value of 218.514. All variables included in the final model were selected based on their statistical significance in univariable analyses and their clinical relevance. The results of the logistic regression analyses are presented in Table 5.

4. Discussion

The diagnosis and initial management of ACPE are typically performed in the emergency department. However, early identification of patients at high risk of mortality and determining which low-risk patients can be safely discharged after treatment remain significant clinical challenges. In this study, we compared several prognostic scoring systems used to predict mortality in patients admitted to the emergency department with a diagnosis of ACPE, aiming to identify the most accurate and clinically applicable model. Among the evaluated scores, the SABIHA score, recently introduced by Toprak *et al.* [8], demonstrated superior predictive performance in our cohort compared to the 3CPO score, the PRS, and the PEPS. The SABIHA score, which achieved an AUC of 0.855 in our study, demonstrated strong predictive performance. It comprises six variables, systolic blood pressure, age, blood urea nitrogen, intubation status, heart rate, and anemia, that are readily available in the emergency department and can be used

TABLE 3. Performance of prognostic scores in predicting 30-day mortality: AUC, sensitivity, specificity, and predictive values.

Variables	AUC	95% CI		*p*	Best threshold	Sensitivity	Specificity	PPV	NPV
		Lower	Upper						
PRS	0.664	0.596	0.733	<0.001	4.5	0.45	0.79	0.27	0.89
PEPS	0.647	0.580	0.714	<0.001	1.5	0.73	0.47	0.19	0.91
3CPO	0.701	0.808	0.903	<0.001	1.5	0.66	0.63	0.24	0.91
SABIHA	0.855	0.808	0.903	<0.001	2.5	0.70	0.88	0.51	0.94

AUC: area under the curve; CI: confidence interval; PPV: positive predictive value; NPV: negative predictive value; PRS: Prognostic Risk Score; PEPS: Pulmonary Edema Prognostic Score; 3CPO: Three Interventions in Cardiogenic Pulmonary Oedema; SABIHA: systolic blood pressure, age, blood urea nitrogen, intubation, heart rate, and anemia.

TABLE 4. Pairwise comparison of AUCs for prognostic scores using DeLong's test.

Scores	AUC difference	*Z*	*p*
PRS-SABIHA	0.664–0.855	−5.5244	<0.001
PEPS-SABIHA	0.648–0.855	−6.3468	<0.001
3CPO-SABIHA	0.701–0.855	−4.7674	<0.001
3CPO-PRS	0.701–0.664	0.7697	0.440
3CPO-PEPS	0.701–0.648	1.4166	0.150
PRS-PEPS	0.664–0.647	0.37647	0.700

AUC: area under the curve; PRS: Prognostic Risk Score; PEPS: Pulmonary Edema Prognostic Score; 3CPO: Three Interventions in Cardiogenic Pulmonary Oedema; SABIHA: systolic blood pressure, age, blood urea nitrogen, intubation, heart rate, and anemia.

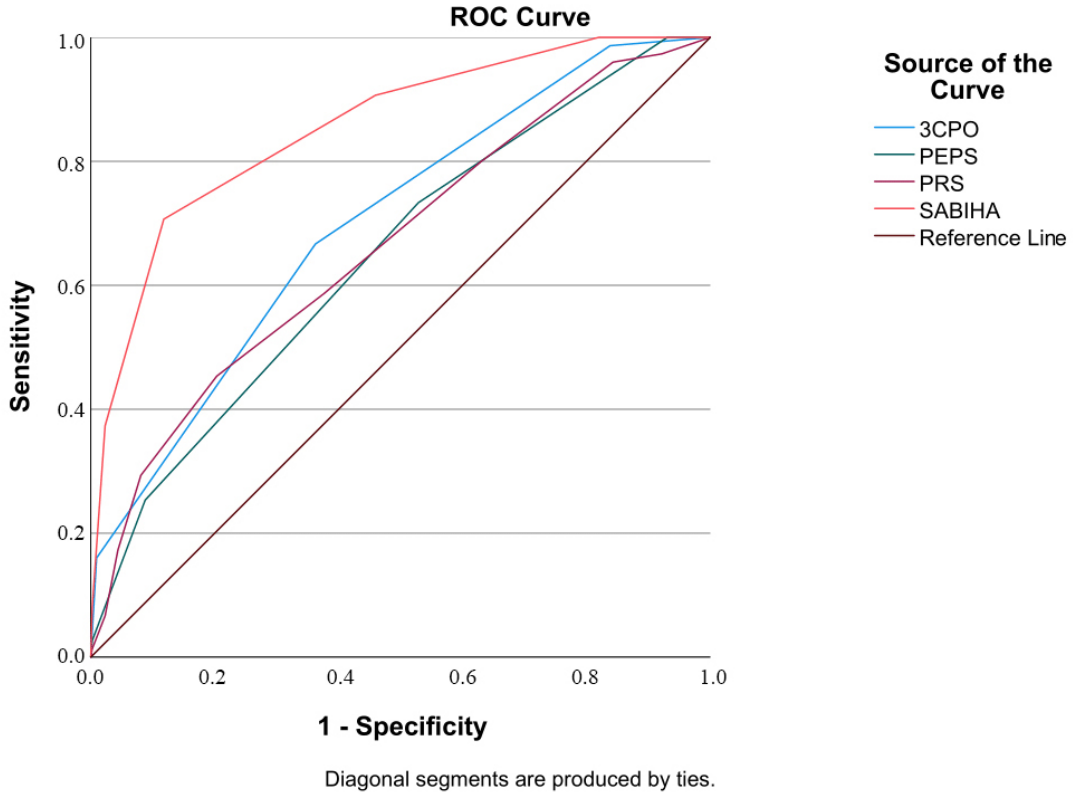

FIGURE 2. Receiver operating characteristic (ROC) curve analysis comparing the predictive performance of different scoring systems (SABIHA, PRS, PEPS and 3CPO) for 30-day mortality in patients with acute cardiogenic pulmonary edema. PRS: Prognostic Risk Score; PEPS: Pulmonary Edema Prognostic Score; 3CPO: Three Interventions in Cardiogenic Pulmonary Oedema; SABIHA: systolic blood pressure, age, blood urea nitrogen, intubation, heart rate, and anemia.

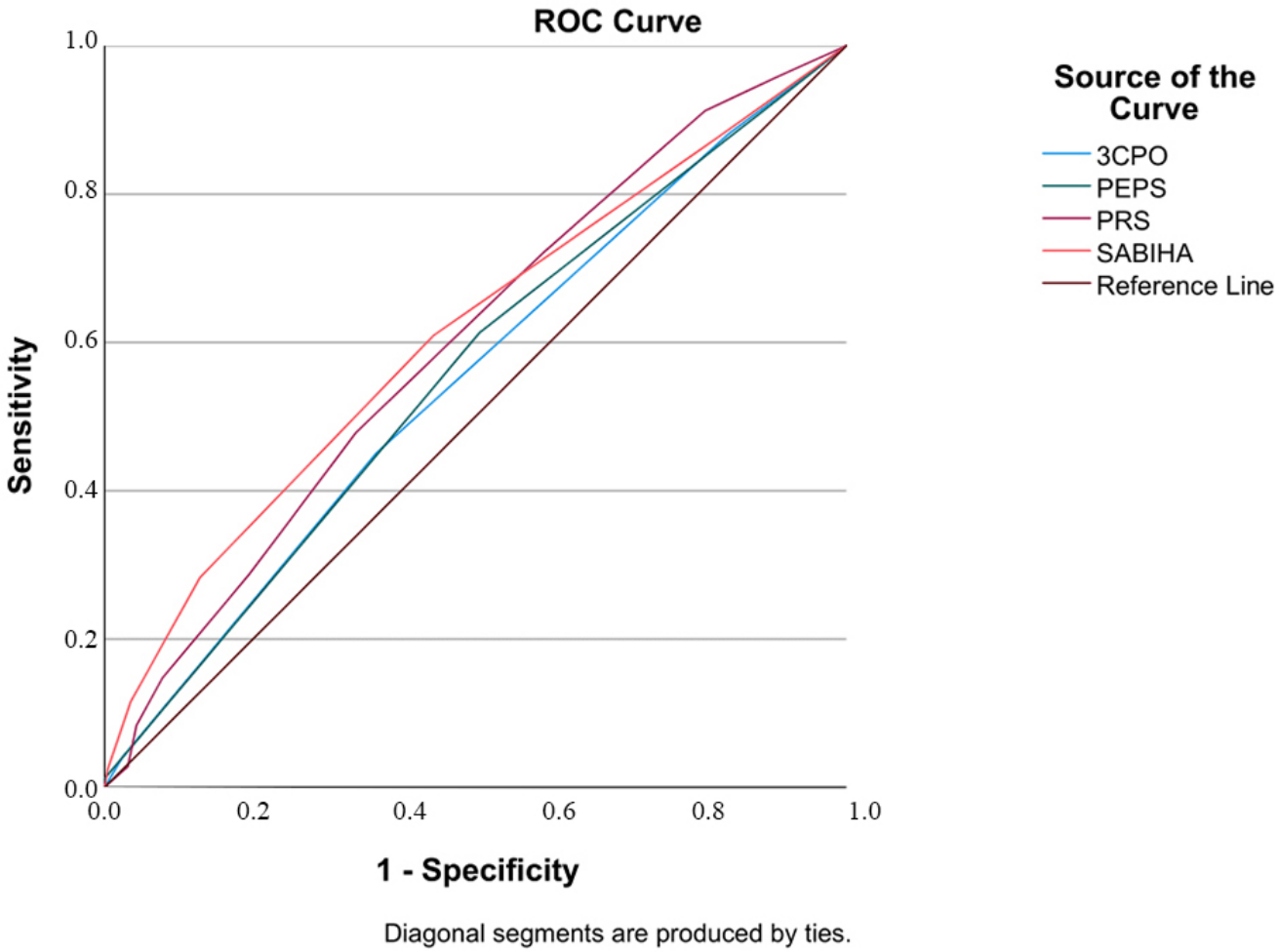

FIGURE 3. Receiver operating characteristic (ROC) curve analysis comparing the predictive performance of different scoring systems (SABIHA, PRS, PEPS and 3CPO) for 3-month hospital readmission among patients who survived the initial 30-day period. PRS: Prognostic Risk Score; PEPS: Pulmonary Edema Prognostic Score; 3CPO: Three Interventions in Cardiogenic Pulmonary Oedema; SABIHA: systolic blood pressure, age, blood urea nitrogen, intubation, heart rate, and anemia.

TABLE 5. Univariable and multivariable logistic regression analysis of clinical and laboratory variables associated with 30-day mortality in patients with acute cardiogenic pulmonary edema.

Variables	Univariable analysis		Multivariable analysis		
	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value	Wald
Age >75 yr	0.996 (0.977–1.016)	0.706			
Sex (male)	1.653 (1.004–2.722)	0.040	1.563 (0.782–3.121)	0.206	1.59
Admission type (ambulance)	3.671 (1.993–6.762)	<0.001	1.809 (0.829–3.947)	0.137	1.21
SBP, mmHg*	0.952 (0.940–0.965)	<0.001			
DBP, mmHg*	0.936 (0.918–0.954)	<0.001			
MAP, mmHg‡	0.932 (0.914–0.949)	<0.001	0.964 (0.939–0.990)	0.008	7.07
HR, bpm*	1.017 (1.005–1.029)	0.005			
SpO_2, %‡	0.964 (0.929–1.000)	0.052			
Shock Index‡	23.826 (9.750–58.221)	<0.001	3.715 (0.811–17.019)	0.090	2.85
WBC, $\times 10^9$/L‡	1.145 (1.090–1.203)	<0.001	1.056 (0.994–1.121)	0.070	3.12
Hgb, g/dL*	1.049 (0.947–1.164)	0.359			
PLT, $\times 10^9$/L‡	1.000 (0.998–1.002)	0.911			
Lymphocyte, $\times 10^9$/L‡	1.111 (0.937–1.317)	0.226			

TABLE 5. Continued.

Variables	Univariable analysis		Multivariable analysis		
	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value	Wald
Neutrophile, $\times 10^9$/L‡	1.159 (1.097–1.223)	<0.001			
BUN, mg/dL‡	1.017 (1.011–1.022)	<0.001	1.010 (1.002–1.019)	0.010	5.7
Creatinine (Cr), mg/dL‡	1.432 (1.178–1.740)	<0.001			
Na, mmol/L*	0.943 (0.904–0.983)	0.006			
K, mmol/L*	2.102 (1.551–2.847)	<0.001	1.096 (0.774–1.848)	0.420	0.65
Trop, ng/mL‡	1.001 (1.000–1.002)	0.009	1.001 (1.000–1.002)	0.080	3.00
Troponin (positive)	1.788 (0.965–3.313)	0.065			
NT-proBNP, pg/mL‡	1.000 (1.000–1.000)	<0.001			
LDH‡	1.003 (1.001–1.004)	0.003			
ARB use	4.042 (2.210–7.396)	<0.001			
Altered mental status	36.032 (17.349–74.833)	<0.001	16.81 (6.80–41.55)	<0.001	37.3
Hospitalization (no)	0.146 (0.77–0.279)	<0.001			
Length of hospital stay, (d)	1.041 (1.020–1.063)	<0.001			
Hospital admission in 6 months (yes)	0.053 (0.007–0.386)	0.004			

OR: odds ratio; CI: confidence interval; SBP: systolic blood pressure; DBP: diastolic blood pressure; MAP: mean arterial pressure; HR: heart rate; Hgb: hemoglobin; PLT: platelet count; BUN: blood urea nitrogen; Cr: creatinine; Na: sodium; K: potassium; Trop: troponin; LDH: lactate dehydrogenase; ARB: angiotensin II receptor blocker; MV: mechanical ventilation; NIMV: non-invasive mechanical ventilation; SpO_2: Peripheral Capillary Oxygen Saturation; WBC: Peripheral Capillary Oxygen Saturation; NT: N-terminal; BNP: B-type Natriuretic Peptide.

collectively to estimate mortality risk in patients with ACPE.

Timely and accurate evaluation of patients in the emergency department is essential, particularly in high-mortality conditions such as ACPE. Among the four scoring systems assessed in this study, the 3CPO score was the only one that could be calculated without requiring laboratory test results [5]. By comprising only three clinical variables, namely age, mental status, and systolic blood pressure, the 3CPO score offers the advantage of rapid application at the bedside. However, despite its practical utility, its discriminatory power was only moderate in our study (AUC = 0.701) and was notably lower than that of the SABIHA score. This difference may be explained by the broader range of clinically relevant parameters included in the SABIHA score. Unlike the 3CPO, the SABIHA score integrates six variables: age, systolic blood pressure, pulse rate, blood urea nitrogen, anemia, and the need for invasive mechanical ventilation. These parameters capture both the hemodynamic status and the severity of underlying organ dysfunction. This more comprehensive assessment likely accounts for the superior predictive performance of the SABIHA score and supports its use as a reliable tool for early risk stratification in patients with ACPE.

When the scoring systems were evaluated for their ability to predict hospital readmission due to ACPE within three months, none demonstrated adequate performance. Notably, among the four scores examined, only the PRS was originally developed to include hospital readmission as an outcome measure [7]. However, our findings indicate that the predictive power of the PRS in this context was limited, with an AUC of 0.543, suggesting insufficient discriminatory ability. In our cohort, nearly half of the patients required hospitalization, and 17% were readmitted within three months. These findings imply that factors influencing both initial hospitalization and subsequent readmission extend beyond those captured by conventional risk scores. Specifically, variables not included in these models, such as racial or ethnic background, socioeconomic status, and medication adherence, may significantly impact the likelihood of readmission [12–14]. Since such factors are not incorporated into existing scoring systems, their exclusion may partly explain the limited readmission predictive accuracy observed. It has been suggested that identifying high-risk patients with heart failure and ensuring appropriate hospitalization may help reduce the incidence of serious adverse events [15].

The 3CPO score can be calculated using either a 3-point or a 7-point method, both of which rely on the same clinical variables but differ in the weighting coefficients assigned to each component. Previous analyses conducted on the same patient population have demonstrated that these two approaches exhibit comparable predictive performance for mortality. In the present study, we employed the simplified 3-point version of the 3CPO score rather than the original 7-point scale. This unweighted, integer-based format was selected due to its practicality and ease of use in the emergency setting. Nonetheless, we acknowledge that this simplification may limit direct comparability with studies utilizing the full 7-point version.

Despite this limitation, the predictive accuracy of both the 3CPO and SABIHA scores in our study was consistent with that reported in previous literature. Moreover, the 30-day mortality rate observed in our cohort aligns with those documented in comparable populations [6, 7, 16]. In our logistic regression analysis, variables independently associated with mortality included SBP, BUN, troponin, and altered mental

status. Among the components common to existing prognostic scores, SBP consistently emerged as a significant predictor of mortality in our cohort. This finding reinforces its importance in early risk assessment. Additionally, elevated BUN levels, previously identified as a marker of poor prognosis in ACPE, were strongly associated with mortality, consistent with earlier studies [17, 18].

Anemia, despite being a component of the SABIHA score, was not found to be a significant predictor of mortality in our analysis. Hemoglobin levels did not differ significantly between survivors and non-survivors, indicating that anemia may not have influenced short-term outcomes in our patient cohort, consistent with previous studies that have reported contradictory results regarding the prognostic value of hemoglobin in ACPE, with some showing no significant association between hemoglobin levels and mortality [6, 19]. Although anemia is considered a clinically important parameter in patients with cardiovascular disease, its prognostic role in ACPE remains uncertain. Given this inconsistency, further research is warranted to clarify the impact of anemia on outcomes in ACPE. Future studies should explore whether different hemoglobin thresholds may hold prognostic significance, preferably using large-scale, prospective cohorts designed to evaluate anemia as an independent risk factor.

To improve the generalizability of our findings, external validation in different populations is needed. Comparative evaluations of these scoring systems in independent cohorts, or through publicly available datasets, would provide stronger evidence regarding their applicability across diverse clinical settings.

5. Limitations

This study has several limitations. First, the retrospective design may have introduced inherent biases in data collection and is particularly susceptible to confounding factors, which could affect the internal validity of the findings.

Second, the study was conducted at a single center, which may limit the generalizability of the results. However, this limitation is somewhat mitigated by the fact that the study site is one of the two largest tertiary hospitals in the country, serving a broad and diverse patient population. Nonetheless, future research should consider multicenter designs to enhance external validity.

Third, the 3CPO score can be calculated using either a 3-point or a 7-point method. In this study, we used the simplified 3-point version, which prioritizes ease of use but may provide less precision than the full 7-point model. This methodological choice may have influenced the comparative performance of the score. Similarly, the PRS includes recombinant human brain natriuretic peptide (rhBNP) as a risk-enhancing variable. Although the developers of the score suggested a version that excludes rhBNP due to its limited availability in clinical practice, this variation may also have affected the score's predictive accuracy in our analysis.

Finally, although the study focused on four widely cited scoring systems (SABIHA, 3CPO, PRS and PEPS), other validated models for predicting mortality in ACPE were not included. We intentionally excluded scores based on subjective clinical judgments to reduce potential bias. Nevertheless, including a broader range of scoring systems may have yielded more comprehensive and generalizable insights.

6. Conclusions

In this study, none of the evaluated scoring systems (*i.e.*, SABIHA, 3CPO, PRS and PEPS) demonstrated adequate performance in predicting hospital readmission within three months in patients with ACPE. However, when used to predict 30-day mortality, the SABIHA score outperformed the other scoring models by showing good discriminatory power. A SABIHA score exceeding 2.5 points may be used to identify patients at increased risk of mortality. Given its simplicity and reliance on readily available clinical data, the SABIHA score may serve as a practical tool for early risk stratification in the emergency management of ACPE.

AVAILABILITY OF DATA AND MATERIALS

The data are available from the corresponding author upon request.

AUTHOR CONTRIBUTIONS

İŞ—performed Material preparation, and analysis; written the first draft of the manuscript. MŞ—performed Data collection. İŞ, MŞ—contributed to the study's conception and design. Both authors commented on previous versions of the manuscript. Both authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Approval was obtained from Ankara Etlik City Hospital Ethics Committee (Approval no: AEŞH-BADEK-2025-0211; date: 12 February 2025) and the need of informed consent was waived by Institutional Review Board of Etlik City Hospital. The data used in this study was anonymized before its use. We rigorously adhered to the ethical principles outlined in the Helsinki Declaration throughout the study.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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