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Risk factors influencing the prognosis of patients with acute myocardial infarction and cardiogenic shock undergoing extracorporeal membrane oxygenation therapy

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Abstract

Background Patients with acute myocardial infarction (AMI) complicated by cardiogenic shock (CS) face high mortality rates. Extracorporeal Membrane Oxygenation (ECMO) therapy offers critical support in these cases, yet identifying factors that influence patient outcomes is crucial for improving survival rates.

Methods This retrospective study included 63 patients with AMI and CS who underwent ECMO therapy at our institution from January 2020 to December 2023. Patients were categorized into survivors ($n=33$) and non-survivors ($n=30$) based on 30-day outcomes. Data collected included demographics, clinical history, hemodynamic and biomarker parameters, and treatment details such as time from symptom onset to percutaneous coronary intervention (PCI) and the use of intra-aortic balloon pump (IABP). Logistic regression models and ROC curve analysis were used to evaluate the predictive value of various factors.

Results Non-survivors had significantly higher arterial blood lactate levels (8.0 [6.2, 11.0] mmol/L vs. 4.8 [3.0, 8.5] mmol/L, $p=0.015$) and required more intensive vasoactive support, as indicated by higher Vasoactive-Inotropic Scores (VIS) (130 [IQR: 105, 175] vs. 100 [IQR: 60, 115], $p=0.016$). They also experienced longer delays from symptom onset to PCI (15.5 [IQR: 11.0, 20.5] hours vs. 9.5 [IQR: 7.0, 12.0] hours, $p=0.001$). The prevalence of left main coronary artery disease (33.3% vs. 12.1%, $p=0.013$) and triple vessel disease (36.7% vs. 9.1%, $p=0.002$) was higher in non-survivors. ROC analysis identified arterial blood lactate (AUC = 0.6909), time from onset to PCI (AUC = 0.7667), and VIS (AUC = 0.703) as significant predictors of prognosis. Logistic regression showed that arterial blood lactate (OR = 1.884, $p=0.039$), VIS (OR = 1.122, $p=0.033$), and time from onset to PCI (OR = 108.271, $p=0.039$) were significantly associated with worse outcomes.

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Conclusions Elevated arterial blood lactate, prolonged time to PCI, and higher VIS could be important predictors of poor outcomes in AMI-CS patients undergoing ECMO therapy. Timely intervention, including rapid revascularization and effective management of metabolic disturbances, might be key to improving survival.

Keywords Acute myocardial infarction, Cardiogenic shock, Extracorporeal membrane oxygenation, Prognosis, Risk factors

Introduction

Acute myocardial infarction (AMI) remains a significant global health challenge, with an in-hospital mortality rate ranging from 15 to 25%, despite advancements in medical interventions [1, 2]. The advancement of AMI may result in cardiogenic shock (CS), a severe consequence marked by insufficient tissue perfusion stemming from cardiac failure [3, 4]. In critical situations, swift and efficient response is crucial to mitigate negative consequences and enhance patient survival.

The introduction of extracorporeal membrane oxygenation (ECMO) therapy has signified a transformative change in the treatment approach for patients suffering from acute myocardial infarction complicated with cardiogenic shock [5, 6]. Veno-arterial (V-A) ECMO provides temporary mechanical circulatory support, aimed at restoring hemodynamic stability and enhancing oxygen delivery. While it supports cardiac output, it also increases afterload, which can lead to elevated myocardial workload and potentially exacerbate infarct expansion in the setting of AMI. As such, careful management of afterload and myocardial oxygen demand is crucial during V-A ECMO support [5, 7]. The application of ECMO is fundamental in the modern treatment of AMI-related CS, providing critical support to patients with poor prognoses. ECMO enhances tissue perfusion through temporary circulatory support, facilitating myocardial repair and potentially preventing irreparable organ damage, thereby improving overall outcomes [8, 9].

The prognosis of patients facing the dual problems of AMI and CS receiving ECMO therapy depends on a complex interaction of demographic, clinical, and procedural factors. A comprehensive understanding of these variables is essential for risk classification, treatment optimization, and prognosis evaluation [10, 11]. This paper embarks on a comprehensive exploration of the heterogeneous spectrum of risk factors that exert influence on the prognosis of individuals grappling with AMI and CS undergoing ECMO therapy. Through an exhaustive delineation of these factors, clinicians can refine risk stratification paradigms, tailor therapeutic regimens, and ultimately enhance clinical outcomes.

Methods

Study design

A thorough retrospective analysis was conducted at our hospital to identify the risk variables affecting the prognosis of patients diagnosed with AMI and CS who received ECMO therapy. The probe extended from January 2020 to December 2023. This study involved a cohort of 63 patients who received ECMO therapy for acute myocardial infarction complicated by cardiogenic shock. According to the 30-day prognosis, patients were categorized into two separate groups: survivors ($n = 33$) and non-survivors ($n = 30$). All participants granted informed consent before their enrollment in the study. Informed permission was secured from all participants or their legal representatives. The research received approval from the hospital's ethical committee and was conducted in compliance with the Declaration of Helsinki and pertinent recommendations. All data was anonymised to safeguard confidentiality and protect participant privacy.

Inclusion and exclusion criteria

Inclusion Criteria: This study encompasses individuals diagnosed with AMI, validated by clinical and electrocardiographic evidence, who also exhibit CS. Furthermore, patients who received ECMO therapy for the treatment of AMI complicated by CS qualify for inclusion. Participants must be at least 18 years old, and complete medical records, including clinical data, laboratory tests, and imaging examinations, must be accessible for analysis.

Exclusion Criteria: Patients with a history of CKD stage 4 or higher necessitating renal replacement therapy, significant irreversible neurological impairments, or brain death before the commencement of ECMO are excluded from the study. Furthermore, individuals with terminal cancers or end-stage organ failure that prevent significant recovery, contraindications to ECMO therapy such as active hemorrhagic disorders, severe irreversible respiratory failure, or irreversible multi-organ dysfunction, as well as those who received ECMO therapy for reasons other than acute myocardial infarction complicated by cardiogenic shock, are also excluded.

Diagnostic criteria for cardiogenic shock

In this study, CS was diagnosed based on the following four criteria. All patients were classified as being in the typical or more severe stages of CS:

1. Hemodynamic Criteria [12–14] (any one of the following):

1) Systolic Blood Pressure (SBP) < 90 mmHg or Mean Arterial Pressure (MAP) < 60 mmHg, requiring

pharmacological or mechanical support to maintain target blood pressure.
2) Cardiac Index (CI) < 2.2 $L \cdot min^{-1} \cdot m^{-2}$
3) Pulmonary Capillary Wedge pressure (PCWP) > 15 mmHg
4) Right atrial pressure (RAP)/PCWP ratio ≥ 0.8
5) Pulmonary artery pulsatility index (PAPi) < 1.85
6) Cardiac Power Output (CPO) ≤ 0.6 W.

2. Biomarker Criteria [15] (any one of the following):

1) Blood lactate ≥ 2 mmol/L, indicating tissue hypoperfusion
2) Creatinine (cr) level doubled or glomerular filtration rate (GFR) decreased by > 50%, indicating renal impairment
3) Elevated liver function tests (e.g., transaminases)
4) Increased Brain Natriuretic Peptide (BNP) levels, indicating cardiac dysfunction.

3. Physical examination Criteria (any one of the following) [16]:

1) General malaise, with pallor, mottled or dusky skin, and cold, clammy skin
2) Signs of volume overload, such as widespread rales and Killip class III or IV heart failure.
3) Requirement for bilevel positive airway pressure (BPAP) or mechanical ventilation
4) Urine output < 30 mL/h, indicating inadequate renal perfusion.

4. Clinical presentation Criteria [12, 13]:

1) Evidence of tissue hypoperfusion necessitating interventions beyond volume resuscitation, such as inotropic support, vasopressors, or mechanical circulatory support.
2) Relative hypotension, typically presenting as classic shock with MAP ≤ 60 mmHg and inadequate perfusion.

Establishment and management of ECMO

This study utilized the veno-arterial ECMO (VA-ECMO) modality. Cannulation was executed through femoral vein and femoral artery cutdown or percutaneous puncture. A distal perfusion cannula was introduced into the superficial femoral artery on the same side as the femoral artery cannulation to preserve distal limb perfusion.

Flow Management: ECMO flow was modified based on the level of support needed for existing heart function.

Anticoagulation Management: Standard heparin anticoagulation was employed. active coagulation time (ACT) and active partial thromboplastin time (APTT) were assessed, and dosages were modified according to variations in these metrics, as well as occurrences of bleeding and thrombotic events.

Vasoactive-inotropic score (VIS)

The VIS [17] is a standardized approach for quantifying the extent of circulatory support from various vasoactive drugs and assessing the patient's status. The VIS score is computed utilizing the accompanying formula: VIS = Dopamine dosage (μg·kg^-1·min^-1) + Dobutamine dosage (μg·kg^-1·min^-1) + 100 × Epinephrine dosage (μg·kg^-1·min^-1) + 100 × Norepinephrine dosage (μg·kg^-1·min^-1) + 10,000 × Vasopressin dosage (U·kg^-1·min^-1) + 10 × Milrinone dosage (μg·kg^-1·min^-1). This scoring method enables the consistent measurement of various vasoactive drugs used by patients, hence assisting in the study of their effects on circulatory support and patient hemodynamics.

Data collection

Clinical data from two patient groups were collected, including gender, age, body mass index (BMI), and medical history (smoking history, coronary artery disease, diabetes mellitus, hypertension, hyperlipidemia, cerebrovascular disease). Additionally, acute physiology and chronic health evaluation II (APACHE II) scores [18] and VIS [17] were recorded (at the time of ICU admission). The worst auxiliary examination indicators within 24 h prior to ECMO initiation were also documented, including arterial blood lactate levels, white blood cell count (WBC), cardiac troponin I (cTnI), alanine transferase (ALT), total bilirubin (TBil), creatinine (Cr), left ventricular ejection fraction (LVEF), and the ratio of early diastolic mitral valve blood flow peak velocity to early diastolic mitral annular velocity (E/e'). Time from onset to percutaneous coronary intervention (PCI) was noted, along with coronary angiography results: involvement of the left anterior descending artery, circumflex artery, right coronary artery, presence of triple vessel disease, and left main coronary artery disease. Additionally, the use of intra-aortic balloon pump (IABP) support and continuous renal replacement therapy (CRRT) was documented.

Statistical analysis

Statistical analyses were performed utilizing SPSS version 26.0. Continuous variables with a normal distribution were represented as mean ± standard deviation ($x \pm s$), whereas those with a non-normal distribution were denoted as median (interquartile range) [M (QL, QU)]. T-tests or Mann-Whitney U tests were utilized as appropriate. Categorical variables were characterized by frequencies (percentages), while chi-square tests were utilized for binary variables. Logistic regression models

Table 1 Comparison of demographics and medical history between survivors and non-survivors in Acute myocardial infarction complicated by cardiogenic shock

Parameter	Survivors (33 cases)	Non-survivors (30 cases)	χ^2 / t / Z value	*P* value
Body Mass Index (BMI, kg/m^2, x ± s)	25.9 ± 3.7	23.8 ± 3.2	1.364	0.058
Age (years, x ± s)	54.6 ± 10.2	59.8 ± 11.2	-1.89	0.059
Cerebrovascular Disease [n (%)]	1 (3.0)	3 (10.0)	1.176	0.278
Smoking [n (%)]	14 (42.4)	10 (33.3)	0.798	0.372
Coronary Artery Disease [n (%)]	4 (12.1)	6 (20.0)	0.743	0.389
Hypertension [n (%)]	10 (30.3)	12 (40.0)	0.67	0.413
Hyperlipidemia [n (%)]	2 (6.1)	3 (10.0)	0.248	0.618
Male [n (%)]	24 (72.7)	20 (66.7)	0.223	0.637
Diabetes Mellitus [n (%)]	9 (27.3)	7 (23.3)	0.163	0.687
APACHE II Score (points, x ± s)	23.8 ± 5.7	25.5 ± 8.2	-0.839	0.402
Vasoactive-Inotropic Score (VIS, points, M (QL, QU))	100 (60, 115)	130 (105, 175)	-2.012	0.016

Table 2 Comparison of Auxiliary examinations between survivors and non-survivors in Acute myocardial infarction complicated by cardiogenic shock

Parameter	Survivors (33 cases)	Non-survivors (30 cases)	χ^2 / t / Z value	*P* value
Arterial Blood Lactate (mmol/L)	4.8 (3.0, 8.5)	8.0 (6.2, 11.0)	-2.489	0.015
Creatinine (Cr, μmol/L)	115.5 (90.0, 156.0)	140.0 (95.0, 180.0)	-1.722	0.085
Total Bilirubin (TBil, μmol/L)	11.0 (8.0, 21.0)	15.3 (11.0, 29.0)	-1.701	0.089
White Blood Cell Count (×10^9/L)	13.7 (12.3, 16.5)	15.8 (13.0, 18.5)	-1.549	0.121
Cardiac Troponin I (cTnI, μg/L)	4.5 (1.8, 40.5)	42.0 (4.0, 59.0)	-1.103	0.27
Potassium (K+, mmol/L)	4.4 (4.0, 4.9)	4.5 (4.0, 5.0)	-0.752	0.452
Alanine Transferase (ALT, U/L)	80.9 (35.0, 180.0)	75.2 (30.1, 190.0)	0.523	0.601

were employed to examine the risk factors influencing the outcome of individuals with acute myocardial infarction complicated by cardiogenic shock. Receiver operating characteristic (ROC) curves were generated to evaluate the predictive significance of each risk factor for the prognosis of AMI-CS patients. All hypotheses were two-tailed, and a p-value threshold of under 0.05 was utilized to determine statistical significance.

Results

Comparison of demographics and medical history between survivors and non-survivors

The comparison between survivors and non-survivors in AMI complicated by CS is shown in Table 1. There was a trend towards a higher mean body mass index (BMI) in survivors (25.9 ± 3.7) compared to non-survivors (23.8 ± 3.2), but this difference did not reach statistical significance ($p = 0.058$). Similarly, there was a trend towards younger age in survivors (54.6 ± 10.2 years) compared to non-survivors (59.8 ± 11.2 years), though this difference also did not reach statistical significance ($p = 0.059$). The prevalence of cerebrovascular disease was 3.0% in survivors and 10.0% in non-survivors ($p = 0.278$), and the prevalence of hypertension was 30.3% in survivors and 40.0% in non-survivors ($p = 0.413$). The VIS was significantly higher in non-survivors, with a median of 130 (IQR: 105, 175) compared to 100 (IQR: 60, 115) in survivors ($p = 0.016$). APACHE II scores were higher in non-survivors (25.5 ± 8.2) compared to survivors (23.8 ± 5.7), but the difference was not statistically significant ($p = 0.402$).

Comparison of Auxiliary examinations in Acute myocardial infarction complicated by cardiogenic shock

The comparison of auxiliary examinations between survivors and non-survivors in AMI complicated by CS is shown in Table 2. Non-survivors had significantly higher arterial blood lactate levels (8.0 [6.2, 11.0] mmol/L) compared to survivors (4.8 [3.0, 8.5] mmol/L) ($p = 0.015$). There were no significant differences between the two groups in terms of creatinine ($p = 0.085$), total bilirubin ($p = 0.089$), white blood cell count ($p = 0.121$), cardiac troponin I ($p = 0.27$), potassium ($p = 0.452$), or alanine transferase ($p = 0.601$) levels (Table 2).

Comparison of coronary angiography results and treatment in Acute myocardial infarction complicated by cardiogenic shock

The comparison of coronary angiography results and treatment between survivors and non-survivors in AMI complicated by CS is shown in Table 3. Non-survivors had a significantly longer time from onset to PCI, with a median of 15.5 (IQR: 11.0, 20.5) hours compared to 9.5 (IQR: 7.0, 12.0) hours in survivors ($p = 0.001$). The prevalence of left main coronary artery disease was higher in non-survivors (33.3% vs. 12.1%, $p = 0.013$), as was

Table 3 Comparison of coronary angiography results and treatment between survivors and non-survivors in Acute myocardial infarction complicated by cardiogenic shock

Parameter	Survivors (33 cases)	Non-survivors (30 cases)	χ^2 / t / Z value	*P* value
Time from Onset to PCI (hours)	9.5 (7.0, 12.0)	15.5 (11.0, 20.5)	-3.271	0.001
Left Main Coronary Artery Disease [n (%)]	4 (12.1)	10 (33.3)	5.194	0.013
Triple Vessel Disease [n (%)]	3 (9.1)	11 (36.7)	6.011	0.002
Intra-aortic Balloon Pump [n (%)]	4 (12.1)	8 (26.7)	2.539	0.014
Right Coronary Artery [n (%)]	7 (21.2)	10 (33.3)	1.529	0.217
Circumflex Artery [n (%)]	13 (39.4)	15 (50.0)	0.78	0.378
Left Anterior Descending Artery [n (%)]	20 (60.6)	18 (60.0)	0.002	0.967
Continuous Renal Replacement Therapy [n (%)]	13 (39.4)	12 (40.0)	0.002	0.967

Table 4 Logistic regression analysis of factors influencing prognosis in AMI complicated by CS

Variable	β Value	χ^2 Value	OR Value	95% CI	*P* Value
Arterial Blood Lactate (mmol/L)	0.634	4.319	1.884	1.021–3.471	0.039
Vasoactive-Inotropic Score (VIS)	0.722	3.977	1.122	0.103–1.054	0.033
Time from Onset to PCI (hours)	4.716	4.272	108.271	1.317–8,785.791	0.039
Left Main Coronary Artery Disease [n (%)]	1.309	1.119	3.709	0.317–49.212	0.219
Triple Vessel Disease [n (%)]	1.822	1.188	5.865	0.272–115.391	0.275
Intra-aortic Balloon Pump [n (%)]	-1.486	0.798	0.226	0.009–5.890	0.372

the prevalence of triple vessel disease (36.7% vs. 9.1%, $p = 0.002$). The use of intra-aortic balloon pump was more common in non-survivors (26.7% vs. 12.1%, $p = 0.014$). There were no significant differences between the two groups regarding the involvement of the right coronary artery ($p = 0.217$), circumflex artery ($p = 0.378$), left anterior descending artery ($p = 0.967$), or the use of continuous renal replacement therapy ($p = 0.967$).

Predictors of prognosis in Acute myocardial infarction complicated by cardiogenic shock

The logistic regression analysis revealed several factors associated with prognosis in patients with AMI complicated by CS (Table 4). Elevated arterial blood lactate levels were significantly associated with prognosis (OR = 1.884, 95% CI: 1.021–3.471, $p = 0.039$). The VIS also had a significant impact on prognosis (OR = 1.122, 95% CI: 0.103–1.054, $p = 0.033$). A longer time from symptom onset to PCI was associated with worse prognosis (OR = 108.271, 95% CI: 1.317–8,785.791, $p = 0.039$). No significant associations were found between prognosis and the presence of left main coronary artery disease ($p = 0.219$), triple vessel disease ($p = 0.275$), or the use of IABP ($p = 0.372$).

3.5 Predictive Value of Arterial Blood Lactate, Time from Onset to PCI, and Vasoactive-Inotropic Score for Prognosis in Acute Myocardial Infarction Complicated by Cardiogenic Shock.

Arterial blood lactate demonstrated significant predictive value for prognosis in AMI complicated by CS (AUC = 0.6909). Time from symptom onset to PCI also emerged as a significant prognostic factor, with an AUC of 0.7667. The VIS showed predictive value for prognosis (AUC = 0.703). Higher lactate levels, longer time from onset to PCI, and elevated VIS scores were associated with worse outcomes (Fig. 1).

Post-hoc power analysis using weighted method

A post-hoc power analysis was conducted to evaluate the statistical power of our study. Utilizing the weighted method, the overall power of the study was determined to be 0.84, indicating a strong ability to detect significant effects across all analyses. This power estimate reflects the contributions of each individual analysis, with weights applied based on sample size, effect size, and statistical power. The result suggests that the study is adequately powered to reliably identify meaningful associations across the examined variables.

Discussion

AMI complicated by CS (AMI-CS) is a life-threatening condition with high mortality, requiring intensive interventions like ECMO to support hemodynamics and facilitate recovery [19, 20]. The prognosis of AMI-CS patients on ECMO is influenced by various factors, including the severity of the infarction, hemodynamic status, comorbidities, and the timeliness of intervention [21, 22], highlighting the complexity of optimizing treatment outcomes [23, 24]. This study provides novel insights into the prognostic factors influencing outcomes in AMI complicated by CS and treated with ECMO. We identified elevated arterial lactate, prolonged time to PCI, and the VIS as significant predictors of mortality, highlighting the importance of early revascularization and optimal hemodynamic management. Our findings underscore the clinical utility of these biomarkers and scores in

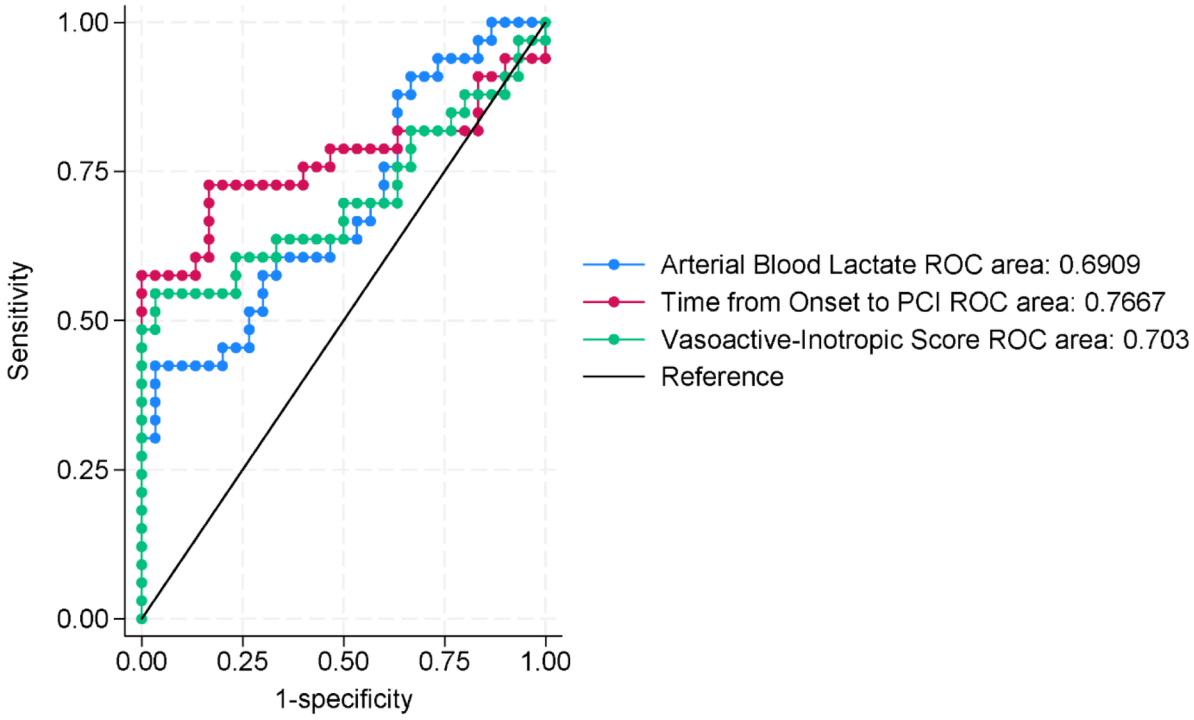

Fig. 1 Receiver operating characteristic curves for predicting prognosis in patients with acute myocardial infarction complicated by cardiogenic shock using arterial blood lactate, time from onset to percutaneous coronary intervention, and vasoactive-inotropic score

predicting patient outcomes, offering potential for personalized therapeutic strategies and improving prognosis in critically ill AMI-CS patients.

The comparison of demographic and medical history between survivors and non-survivors highlighted several trends that, although not reaching statistical significance, suggest potential areas for further investigation. Survivors exhibited a trend towards higher BMI and younger age, which may indicate that higher metabolic reserves or fewer comorbidities associated with younger age could offer a protective advantage [25, 26]. However, the lack of statistical significance underscores that BMI and age alone are insufficient predictors of outcomes without considering the multifaceted nature of acute presentations. Non-survivors demonstrated higher APACHE II scores and VIS, although the difference in APACHE II scores was not statistically significant. These findings indicate a more severe physiological derangement and greater need for hemodynamic support upon admission, reflecting the critical condition of non-survivors [27, 28]. Significantly elevated arterial blood lactate levels in non-survivors underscore lactate as a crucial marker of metabolic distress and tissue hypoperfusion. Elevated lactate levels signify a shift towards anaerobic metabolism due to inadequate oxygen delivery, correlating with the severity of shock and an increased risk of adverse outcomes. In contrast, other biomarkers such as creatinine, total bilirubin, white blood cell count, and cardiac troponin I did not show significant predictive value in this cohort. This suggests that while these markers are important for overall patient management, they may not directly influence short-term survival in severe CS [29, 30].

Significant differences in coronary anatomy and treatment interventions were observed between survivors and non-survivors. Non-survivors were more likely to have severe coronary artery disease, including left main and triple vessel disease, which likely exacerbates myocardial dysfunction and the clinical presentation of CS. The prolonged time from symptom onset to PCI in non-survivors underscores the critical importance of timely revascularization [31, 32]. Delays in PCI increase the risk of irreversible myocardial damage and mortality, highlighting the time-sensitive nature of coronary intervention in CS. Logistic regression analysis reinforced the prognostic significance of elevated arterial blood lactate, prolonged time to PCI, and higher VIS. Each of these factors independently predicted worse outcomes, emphasizing their utility in clinical risk stratification [33, 34]. Elevated lactate levels indicate severe metabolic distress and tissue hypoperfusion, while higher VIS reflects the need for intensive hemodynamic support, both of which are critical indicators of patient prognosis. Prolonged

ischemic time further signifies the extent of myocardial injury and the urgency required in managing AMI-CS patients. These predictors should be integrated into early evaluation protocols to identify high-risk patients who may benefit from more aggressive and tailored therapeutic approaches, thereby enhancing survival outcomes in this critically ill population.

Regarding the variable "coronary artery disease" in Table 1, we would like to clarify that all patients in our study were diagnosed with AMI, as outlined in the Inclusion Criteria. The "coronary artery disease" (CAD) variable refers to the presence of pre-existing coronary artery disease history in some patients, rather than indicating a diagnosis of CAD at the time of AMI admission. While the majority of patients had a history of CAD, a subset of the cohort was experiencing their first-ever AMI. This distinction was essential to capture the prior medical history of the patients accurately. Additionally, we conducted a post-hoc power analysis using the weighted method, which yielded an overall power of 0.84, indicating that our sample size is adequate to detect significant effects across all analyses. Although the use of IABP was significantly higher in non-survivors in our study ($p = 0.014$), logistic regression analysis did not identify IABP use as an independent predictor of poor prognosis ($p = 0.372$). This suggests that while IABP support is frequently required in patients with severe hemodynamic instability, it may not directly contribute to worse outcomes. Instead, its association with poor prognosis likely reflects more advanced disease stages and the necessity for intensive support, highlighting the complex nature of prognosis in patients with AMI complicated by CS.

In the context of CS complicating AMI, several studies have explored the use of ECMO and its impact on survival outcomes, yet findings remain contentious. Kondo et al. [35]report on the variability in survival based on the cause of CS and the type of mechanical circulatory support (MCS) used. While their study provides important insights into cause-specific survival rates, it lacks focus on specific predictors within AMI-CS patients undergoing ECMO, which our study identifies as crucial for guiding clinical decisions. Notably, our findings underscore the significance of elevated arterial lactate, prolonged time to PCI, and high VIS as key prognostic factors for poor outcomes in this cohort, providing more actionable insights compared to the broader observations in Kondo's registry-based study. In contrast to Paddock's [36] systematic review and meta-analysis, which found no significant improvement in 30-day mortality with ECMO, our study suggests that early intervention, particularly timely revascularization and effective metabolic management, plays a vital role in improving short-term survival. While Paddock's analysis does not identify specific predictors like time to PCI or VIS, our research highlights their clinical importance, potentially offering a more targeted approach for enhancing 30-day survival outcomes. Lastly, Thiele's [37] multicenter trial found no benefit of ECLS in improving 30-day mortality in AMI-CS patients, questioning the role of early ECMO. However, our study adds a critical layer to this debate by emphasizing the significance of timing (e.g., time from onset to PCI) and metabolic parameters (e.g., arterial lactate and VIS) as potential predictors of survival, suggesting that prompt revascularization and metabolic correction could improve outcomes even in patients receiving ECMO. Thus, our study offers a more comprehensive and predictive framework for clinical decision-making in AMI-CS patients on ECMO therapy.

This study has several limitations. First, the retrospective design introduces potential selection bias, limiting causal inference. Although the sample size was adequate, as confirmed by post-hoc power analysis (power > 0.8), the single-center design may affect the generalizability of the results. Multicenter studies with larger cohorts are needed to validate these findings. Additionally, the absence of data on VA-ECMO flow rates represents a significant gap, as this parameter may influence outcomes; future studies should incorporate flow data for a more comprehensive assessment. Survival outcomes related to decannulation versus discharge were not explored and warrant further investigation. ECMO-related complications, such as increased afterload or delayed myocardial recovery, were not assessed and should be considered in future research. Longitudinal biomarker data, including lactate clearance and peak lactate levels, could provide valuable insights into their prognostic value and should be included in subsequent studies. Finally, while IABP use was associated with poorer outcomes, it was not identified as an independent predictor of mortality in our analysis, suggesting that potential confounding factors require further exploration. Future studies should employ real-time analytics and machine learning to refine prognostic prediction and enable personalized therapeutic strategies. Investigating the biological mechanisms linking elevated lactate levels and delayed PCI to increased mortality may reveal new therapeutic targets.

Conclusions

This study identifies arterial blood lactate, vasoactive-inotropic score, time from onset to PCI, left main coronary artery disease, triple vessel disease, and the use of an intra-aortic balloon pump as variables associated with mortality in patients with AMI-CS. Early implementation of ECMO, reduction of lactate levels, minimized use of vasopressors, and prompt PCI may improve outcomes for appropriately selected patients.

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Author contributions
The research and manuscript were developed with distinct contributions from each author. Guoying Zheng, Zhuoqian Xu, and Shuwen Yao were pivotal in conceptualizing the study. Data curation was managed by Guoying Zheng, Zhuoqian Xu, and Xiao Liu. The formal analysis was conducted by Guoying Zheng, Shuwen Yao, and Shuxiang Wang. Methodological planning was carried out by Guoying Zheng and Haitian Huang. Resources were coordinated by Guoying Zheng, Zhuoqian Xu, and Shuwen Yao. The software utilized in the study was handled by Guoying Zheng, Zhuoqian Xu, and Shuwen Yao. Guoying Zheng, Zhuoqian Xu, and Shuwen Yao drafted the original manuscript, and Yuanyuan Li reviewed and edited the final submission.

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Data availability
The datasets used and/or analyzed during the present study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This retrospective study was approved by the Ethics Committee of Huadu District People's Hospital of Guangzhou. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants involved in the study or from their legal guardians.

Consent for publication
Written informed consent for publication was obtained from all patients and/or their families included in this retrospective analysis.

Competing interests
The authors declare no competing interests.

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