Predictive Nomogram of the in-Hospital Mortality of Patients with Cardiogenic Shock

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Research

Keywords: cardiogenic shock, in-hospital mortality, nomogram, prognostication

Posted Date: February 9th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-200242/v1>

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Abstract

Background

Despite advances in treatment, the mortality rates of patients with cardiogenic shock (CS) remain high. The aim of this study was to develop a risk-predictive model for in-hospital mortality in patients admitted to the cardiac care unit (CCU) because of CS.

Methods

This retrospective study enrolled 509 adult patients who received inotropic support at the emergency room with subsequent admission to the CCU from January 2017 to December 2019. Patients with out-of-hospital cardiac arrest, inotrope use for conduction disorders, and non-CS were excluded. A total of 246 patients were analyzed using multiple logistic regression.

Results

A history of coronary artery disease (OR 3.44), multiple inotropic use (OR 17.70), ejection fraction less than 40% (OR 0.27), longer cardiopulmonary resuscitation (CPR) duration (OR 1.11), albumin infusion (OR 4.66), and renal replacement therapy (OR 3.08) were associated with higher in-hospital mortality. These factors were used to develop a risk-predictive nomogram. A receiver operating characteristic (ROC) curve was drawn using scores from 0 to 198.5 (area under the curve [AUC] = 0.92), and the cut-off score of 65 was identified. The model accurately predicted mortality (AUC = 0.81) in a validation set of 68 patients, with a sensitivity of 81% and a specificity of 74%.

Conclusion

Factors were used to develop a highly accurate risk-predictive nomogram for the in-hospital mortality of patients with CS, which may aid physicians in making prognoses.

Background

Cardiogenic shock (CS) is the most severe form of acute heart failure.¹ It can be described as a state of ineffective cardiac output, which results in clinical and biochemical manifestations of inadequate tissue perfusion.^{1,2} CS is a leading cause of mortality after myocardial infarction (MI) and complicates up to 10% of cases of acute myocardial infarction (AMI).³ It is more common in patients with ST-elevation myocardial infarctions (STEMI) than in those with non-ST-elevation myocardial infarctions (NSTEMI).^{3,4} Despite advances in treatment options, CS mortality remains high at approximately 35 to 50 percent.^{1,3,5}

Several risk scores that help predict short-term mortality have been established. The 'SHould we emergently revascularize Occluded coronaries for Cardiogenic shock?' (SHOCK) trial score had a large registry (n = 1217) and emphasized the importance of early coronary revascularization in MI patients with shock.⁶ The SHOCK measure employs a two-stage process to identify variables that can predict short-

term mortality, including age, shock on admission, evidence of end-organ hypoperfusion, anoxic brain damage, systolic blood pressure, prior coronary artery bypass grafting (CABG), noninferior MI, creatinine level, stroke work, and left ventricular ejection fraction (LVEF) of less than 28%.⁶ The model had an area under the curve (AUC) of 0.74 but has not been validated using an independent data set.⁶

The Intra-aortic Balloon Pump in Cardiogenic Shock II (IABP-SHOCK II) trial is the largest randomized trial to date (n = 480); however, only patients with MI were included.⁷ Similar to the SHOCK trial, age and creatinine were included in the risk score, among other factors, such as prior stroke, glucose level, blood lactate level, and thrombolysis in myocardial infarction (TIMI) flow grading.⁷ The model had a fair predictive performance (AUC = 0.79).⁷ Furthermore, internal validation using data from the IABP-SHOCK II registry patients (AUC = 0.79) and external validation based on the CardShock population (AUC = 0.73) were performed.⁷

The CardShock study is by far the largest prospective, observational study (n = 219) to include patients with all etiologies of CS.⁸ Age, previous MI or CABG, reduced LVEF, high lactate level, and confusion at presentation (presence of systemic hypoperfusion) were also used as predictors of mortality, as were acute coronary syndrome (ACS) etiology and estimated glomerular filtration rate (eGFR).⁸ This model had a good predictive power (AUC = 0.85) and the IABP-SHOCK II trial patients were used for external validation (AUC = 0.71).⁸

A comparative study of these risk scores revealed modest prognostic accuracy, which indicated the need for novel methods of risk prediction.⁹ Furthermore, these scores were largely based on Western populations, and their applicability to different populations had not been tested.⁹ Zhang et al. developed a predictive model of the risk of developing CS in Chinese patients; however, the primary outcome was not mortality and the population was limited to patients with AMI, instead of those with the entire spectrum of related etiologies.¹⁰ The predictive factors included age, sex, body mass index (BMI), Killip class, mean arterial pressure (MAP), heart rate, previous coronary disease, the outcome of thrombolytic therapy, and MI location.¹⁰

The patient characteristics included in the aforementioned models were mostly from the medical history and biochemistry results. The variance in these risk factors illustrates the heterogeneity of CS presentations. Furthermore, a patient's clinical course is often nonlinear, and thus factors throughout their hospitalization should be explored.¹¹ Therefore, this study aimed to develop a risk-predictive model of in-hospital mortality for patients with CS based on their medical history, examination results, and interventions throughout hospitalization to aid physicians in their clinical management and to improve patients' prognoses.

Materials And Methods

Study population

This retrospective study was approved by the Institutional Review Board of National Taiwan University Hospital (NTUH). This study was conducted in the NTUH, a 2500-bed tertiary hospital with 110,000 annual emergency room (ER) visits. NTUH is located in Taipei City, Taiwan, which has a population density of approximately 10,000 people/km².¹²

This study enrolled 509 nontraumatic adult patients (≥ 20 years old) who received inotropic support at the ER, and had subsequent admission to the cardiac care unit (CCU) from January 2017 to December 2019. After the exclusion of 105 patients who had out-of-hospital-cardiac-arrest (OHCA), 48 who received inotropic support for bradycardia and conduction system disorders, and 110 patients with non-cardiogenic shock (obstructive, hypovolemic, distributive shock), 246 patients were included in this study to develop the predictive model (Fig. 1).

Another set of 163 patients with the same inclusion criteria who visited the ER from January to August 2020 were enrolled as the validation set (sFigure 1). Patients who presented with OHCA ($n = 35$), conduction disorders ($n = 18$), and non-cardiogenic shock ($n = 42$) were excluded. A validation set of 68 patients was thus used to determine the model's diagnostic accuracy.

Data collection and variable definitions

The primary outcome of this study was to predict the in-hospital mortality of patients with cardiogenic shock. The following information were collected from the individual medical records: age, sex, body mass index (BMI), smoking history, alcohol intake, preexisting comorbidities, laboratory exams, electrocardiogram (ECG) characteristics, chest X-ray findings, echocardiogram findings, medications administered, clinical management, discharge diagnosis, and length of hospital stay. The imaging and laboratory exams nearest to the shock time at the ER were recorded.

Medications and clinical management provided at the ER and throughout the hospitalization were recorded. Inotropic use was defined as the administration of dopamine, norepinephrine bitartrate, epinephrine, vasopressin, or dobutamine to achieve hemodynamic stability. Cases were recorded either as using only a single inotrope or multiple inotropic agents (two or more). Patients who did not require any supplemental oxygen, nasal cannula, oxygen mask, or nonrebreathing mask were classified as requiring low respiratory support; whereas patients who required bilevel positive airway pressure (BiPAP), high flow oxygen therapy, or endotracheal intubation were classified as having high respiratory support.

Transcutaneous pacing (TCP) refers to the noninvasive mode of temporary pacing by applying pads to the chest, whereas pacemaker implantation refers to the invasive method of inserting either temporary or permanent pacing devices. Fluid challenge is the infusion of more than 250 mL of a crystalloid to the patient when shock was noted, before administration of any inotropic agent or other interventions. Component transfusion during hospitalization involved the administration of either packed red blood cells, platelets, fresh frozen plasma, or cryoprecipitate. The use of mechanical circulatory support devices include extracorporeal membrane oxygenation (ECMO) or intra-aortic balloon pump (IABP) insertion.

Cardiopulmonary resuscitation (CPR) was performed on patients with cardiac arrest at the ER or during hospitalization until spontaneous circulation (ROSC) was achieved or an ECMO device was attached. Emergent coronary angiography (CAG) was performed within 24 hours of shock. CABG and renal replacement therapy (RRT) at the ER or during hospitalization were documented. RRT encompassed patients who received dialysis, sustained low-efficiency dialysis (SLED), or continuous veno-venous hemofiltration (CVVH) after manifesting symptoms of fluid overload, respiratory distress, or severe electrolyte imbalance.

Discharge diagnoses were recorded based on the judgement of attending physicians. Cases of STEMI, NSTEMI, and post-MI complications were classified as ACS; heart failure, valvular heart conditions, and myocarditis were classified as acute decompensated heart failure (ADHF); different types of cardiomyopathy (stress, restrictive, hypertrophic, dilated, ischemic) were classified as cardiomyopathy; tachyarrhythmia and bradyarrhythmia were classified as arrhythmia; CS with sepsis or pneumonia were classified as CS with septic complications; and cardiac tamponade, aortic dissection, and pulmonary hypertension were considered as other causes of CS.

Statistical analyses

Results were presented using frequencies for categorical variables and medians with ranges for continuous variables. Group comparisons of outcomes were performed using Fisher's exact or Pearson's chi-squared test for categorical variables and the Mann-Whitney U test for continuous variables. From the training set, 31 independent variables with significant associations ($p < 0.05$) in the univariate analysis were included in the forward multiple logistic regression analysis ($p < 0.05$ for inclusion and > 0.1 for elimination) to identify the predictors of in-hospital mortality. The selected variables were further used to develop a risk-prediction nomogram to predict in-hospital mortality. A receiver operating characteristic (ROC) curve was drawn using the total scores from the training set and the Youden Index was used to determine the cut-off value for predicting mortality in patients with CS. Patients from the validation set were scored using the nomogram and to test the model's diagnostic accuracy. The predicted mortality was then compared with the observed mortality.

All statistical analyses were performed using IBM SPSS Statistics for Windows, version 16 (IBM Corp, Armonk, NY, USA) and R statistical software version 4.0.2 was used to construct the nomogram.

Results

Clinical characteristics

A comparison of the characteristics of patients in the training set is presented in Table 1. The median age was 70 years and the majority of patients were men (60.16%). In-hospital mortality for patients with CS was at 26.83%. Coronary artery disease, heart failure, cardiomyopathy, and renal disease were determined to be higher in the patients who did not survive to discharge, whereas dyslipidemia was more frequent in the patients who survived. Patients who died during hospitalization were observed to have higher levels

of lactic acid, hemoglobin, platelet, international normalized ratio (INR), creatinine, and pro B-type natriuretic peptide (pro-BNP). A higher heart rate and longer QRS duration on ECG findings were also observed in patients who did not survive to discharge. Chest X-rays revealing lung edema were more frequent in patients who survived, whereas pleural effusion was observed more frequently in those who did not survive. Echocardiograms with LVEF lower than 40%, pericardial effusion, and valvular heart conditions were also observed more frequently in patients who failed to survive.

Table 1
Baseline characteristics and examination results of training set

Survival to Discharge				
	Total Patients	Survived	Non-survived	p-value
	N = 246	N = 180 (73.17%)	N = 66 (26.83%)	
Age (years)	70 (75)	70.5 (69)	69.50 (75)	0.566
Sex (male)	148 (60.16%)	104 (57.78%)	44 (66.67%)	0.207
BMI (kg/m ²)	23.75 (28.94)	24.23 (28.94)	22.50 (17.50)	0.013
Smoking	51 (20.73%)	39 (21.67%)	12 (18.18%)	0.550
Alcoholism	9 (3.66%)	5 (2.78%)	4 (6.06%)	0.224
Comorbidities				
Hypertension	128 (52.03%)	96 (53.33%)	32 (48.48%)	0.500
Diabetes mellitus	90 (36.59%)	62 (34.44%)	28 (42.42%)	0.250
Dyslipidemia	68 (27.64%)	56 (31.11%)	12 (18.18%)	0.045
Old MI	10 (4.07%)	8 (4.44%)	2 (3.03%)	0.619
CAD	78 (31.71%)	49 (27.22%)	29 (43.94%)	0.013
Heart failure	65 (26.42%)	38 (21.11%)	27 (40.91%)	0.002
Arrhythmia	69 (28.05%)	47 (26.11%)	22 (33.33%)	0.264
Cardiomyopathy	25 (10.16%)	14 (7.78%)	11 (16.67%)	0.041
Renal disease	37 (15.04%)	22 (12.22%)	15 (22.73%)	0.041
ESRD	24 (9.76%)	17 (9.44%)	7 (10.61%)	0.786
CVA	29 (11.79%)	25 (13.89%)	4 (6.06%)	0.092
Malignancy	32 (13.01%)	24 (13.33%)	8 (12.12%)	0.802
Laboratory exams				
pH value	7.35 (0.77)	7.35 (0.77)	7.31 (0.66)	0.062
Lactic acid (mmol/L)	3.38 (16.51)	3.05 (16.51)	5.26 (16.14)	0.000

Data presented as no. (%) or as median (range).

BMI, body mass index; CAD, coronary artery disease; CVA, cerebrovascular accident; ESRD, end-stage renal disease; INR, international normalized ratio; LVEF, left ventricular ejection fraction; old MI, old myocardial infarction; pro-BNP, pro B-type natriuretic peptide; VHD, valvular heart disease.

Survival to Discharge				
Hemoglobin (g/dL)	12.70 (15.50)	13.10 (15.50)	11.80 (12.30)	0.021
Platelet (K/uL)	203 (746)	210 (746)	183 (396)	0.040
INR	1.08 (9.10)	1.06 (2.99)	1.27 (9.08)	0.000
Total bilirubin (mg/dL)	0.88 (41.16)	0.81 (11.91)	1.18 (41.16)	0.064
Creatinine (mg/dL)	1.65 (20.60)	1.50 (20.60)	2.20 (16.30)	0.001
Sodium (mmol/L)	134 (50.00)	134.5 (31.00)	132 (50.00)	0.015
Potassium (mmol/L)	4.4 (6.1)	4.3 (5.6)	4.5 (5.90)	0.552
Troponin T (ng/L)	85.93 (9994.98)	54.09 (9994.98)	162.1 (9991.84)	0.000
pro-BNP (pg/mL)	4932 (34970.32)	3470 (34970.32)	13415 (43942.19)	0.000
ECG characteristics				
HR (bpm)	83 (216)	78 (216)	94 (122)	0.003
QRS duration (ms)	102 (230)	100 (156)	116 (230)	0.013
Chest X-ray				
Cardiomegaly	161 (65.45%)	117 (65.00%)	44 (66.67%)	0.808
Lung edema	44 (17.89%)	39 (21.67%)	5 (7.58%)	0.011
Pleural effusion	69 (28.05%)	44 (24.44%)	25 (37.88%)	0.038
Echocardiogram				
LVEF < 40%	82 (33.33%)	47 (26.11%)	35 (53.03%)	0.000
LVEF ≥ 40%	164 (66.67%)	133 (73.89%)	31 (46.97%)	
Pericardial effusion	31 (12.60%)	13 (7.22%)	18 (27.27%)	0.000
VHD	120 (48.78%)	78 (43.33%)	42 (63.64%)	0.005
Data presented as no. (%) or as median (range).				
BMI, body mass index; CAD, coronary artery disease; CVA, cerebrovascular accident; ESRD, end-stage renal disease; INR, international normalized ratio; LVEF, left ventricular ejection fraction; old MI, old myocardial infarction; pro-BNP, pro B-type natriuretic peptide; VHD, valvular heart disease.				

Patients who did not survive had received albumin infusion, multiple inotropic agents, and heparin more frequently. These patients also more frequently required high respiratory support, pacemaker implantation, mechanical circulatory support devices, CABG surgery, component transfusion, and RRT.

Among patients with cardiac arrest following CS, resuscitation efforts were longer for patients who did not survive than for those who did.

The discharge diagnosis classification indicated that ACS was perceived as the main etiology of CS, followed by ADHF, arrhythmia, cardiomyopathy, CS with septic complication, and other causes. Patients with CS complicated by arrhythmia and septic complications had higher rates of survival than those who did not. Patients who did not survive had significantly longer CCU stays (Table 2).

Table 2
Clinical management and diagnosis classification of training set

Survival to Discharge				
	Total Patients	Survived	Non-survived	p-value
	N = 246	N = 180 (73.17%)	N = 66 (26.83%)	
Medications				
Bronchodilator	94 (38.21%)	62 (34.44%)	32 (48.48%)	0.045
Albumin	117 (47.56%)	64 (35.56%)	53 (80.30%)	0.000
Diuretic	156 (63.41%)	112 (62.22%)	44 (66.67%)	0.521
Inotrope use				
Single inotrope	104 (42.28%)	101 (56.11%)	3 (4.55%)	0.000
Multiple inotropes	142 (57.72%)	79 (43.89%)	63 (95.45%)	
NTG	70 (28.46%)	55 (30.56%)	15 (22.73%)	0.228
Aspirin	124 (50.41%)	97 (53.89%)	27 (40.91%)	0.071
P2Y12 inhibitors	117 (47.56%)	90 (50.00%)	27 (40.91%)	0.206
Heparin	148 (60.16%)	97 (53.89%)	51 (77.27%)	0.001

Data presented as no. (%) or as median (range).

ACS, acute coronary syndrome; ADHF, acute decompensated heart failure; CABG, coronary artery bypass grafting; CAG, coronary angiography; CCU, cardiac care unit; CPR, cardiopulmonary resuscitation; MCS, mechanical circulatory support devices; NTG, nitroglycerin; PCI, percutaneous coronary intervention; RRT, renal replacement therapy; TCP, transcutaneous pacing.

Survival to Discharge

Clinical management				
Respiratory support				
Low	99 (40.24%)	93 (51.67%)	6 (9.09%)	0.000
High	147 (59.76%)	87 (48.33%)	60 (90.90%)	
TCP	42 (17.07%)	35 (19.44%)	7 (10.61%)	0.103
Pacemaker implantation	72 (29.27%)	62 (34.44%)	10 (15.15%)	0.003
Fluid challenge	97 (39.43%)	68 (37.78%)	29 (43.94%)	0.381
Component transfusion	135 (54.88%)	79 (43.89%)	56 (84.85%)	0.000
MCS	60 (24.39%)	26 (14.44%)	34 (51.52%)	0.000
CPR	44 (17.89%)	18 (10.00%)	26 (39.39%)	0.000
CPR duration, median (range), m	14.5 (69)	4 (31)	29 (69)	0.000
Emergent CAG	119 (48.37%)	93 (51.67%)	26 (39.39%)	0.088
PCI	76 (63.87%)	59 (63.44%)	17 (65.38%)	0.291
CABG	16 (6.50%)	7 (3.89%)	9 (13.64%)	0.006

Data presented as no. (%) or as median (range).

ACS, acute coronary syndrome; ADHF, acute decompensated heart failure; CABG, coronary artery bypass grafting; CAG, coronary angiography; CCU, cardiac care unit; CPR, cardiopulmonary resuscitation; MCS, mechanical circulatory support devices; NTG, nitroglycerin; PCI, percutaneous coronary intervention; RRT, renal replacement therapy; TCP, transcutaneous pacing.

Survival to Discharge				
RRT	72 (29.27%)	29 (16.11%)	43 (65.15%)	0.000
Discharge diagnosis classification				
ACS	79 (32.11%)	61 (33.89%)	18 (27.27%)	0.325
ADHF	76 (30.89%)	50 (27.78%)	26 (39.39%)	0.081
Cardiomyopathy	15 (6.10%)	10 (5.56%)	5 (7.58%)	0.557
Arrhythmia	56 (22.76%)	49 (27.22%)	7 (10.61%)	0.006
Septic complication	9 (3.66%)	3 (16.67%)	6 (9.09%)	0.006
Others	11 (4.47%)	7 (3.89%)	4 (6.06%)	0.465
CCU stay, median (range), d	5 (127)	4 (89)	14 (127)	0.000
Hospital stay, median (range), d	12 (192)	11.50 (189)	13 (128)	0.580
Data presented as no. (%) or as median (range).				
ACS, acute coronary syndrome; ADHF, acute decompensated heart failure; CABG, coronary artery bypass grafting; CAG, coronary angiography; CCU, cardiac care unit; CPR, cardiopulmonary resuscitation; MCS, mechanical circulatory support devices; NTG, nitroglycerin; PCI, percutaneous coronary intervention; RRT, renal replacement therapy; TCP, transcutaneous pacing.				

The baseline characteristics, laboratory and imaging examinations, clinical management, and diagnosis classification of the validation set are presented in Supplemental Tables 1 and 2. The median age was 72 years and the majority of such patients were men (61.76%). The ratio of patients per characteristic in the validation set was comparable to those in the training set. ACS remained the most common etiology of CS, accounting for one-third of the cases.

Nomogram for in-hospital mortality

In the training set, 31 variables (dyslipidemia, coronary artery disease [CAD], heart failure, cardiomyopathy, renal disease, lactic acid, platelet, sodium, INR, creatinine, troponin, pro-BNP, heart rate, QRS duration, lung edema, pleural effusion, ejection fraction, pericardial effusion, valvular heart disease, bronchodilator use, albumin infusion, inotrope use, nitroglycerin use, heparin use, respiratory support, pacemaker implantation, component transfusion, MCS, CPR duration, CABG, and RRT) were identified from the univariate analysis and entered into the stepwise multiple logistic regression. A history of CAD (OR 3.44, 95% CI 1.25–9.47, $p = 0.017$), multiple inotropic use (OR 17.70, 95% CI 3.98–78.74, $p = 0.000$), reduced ejection fraction less than 40% (OR 0.27, 95% CI 0.11–0.69, $p = 0.006$), longer cardiopulmonary

resuscitation (CPR) duration (OR 1.11, 95% CI 1.03–1.19, $p = 0.004$), albumin infusion (OR 4.66, 95% CI 1.60–13.60, $p = 0.005$), and renal replacement therapy (OR 3.08, 95% CI 1.19–8.02, $p = 0.021$) remain associated with higher in-hospital mortality, and a risk-prediction nomogram was developed accordingly (Fig. 2). A ROC curve was drawn using scores ranging from 0 to 198.5 and the cut-off value to predict mortality was determined to be 65. The nomogram yielded a sensitivity of 92.42%, a specificity of 72.78%, and an AUC of 0.92 (95% CI 0.88–0.96) for the training set. Using the total scores from the validation set, with scores less than 65 deemed as survival to hospital discharge and scores more than 65 deemed as in-hospital mortality, the predicted mortalities were compared with the observed mortalities, which revealed a sensitivity of 81.25%, a specificity of 74%, and an AUC of 0.81 (95% CI 0.71–0.92; Fig. 3).

Discussion

In this retrospective observational study that used a training set of 246 patients, six factors (history of CAD, multiple inotropic use, ejection fraction of less than 40%, longer CPR duration, albumin infusion, and RRT) were associated with higher in-hospital mortality. A risk-predictive nomogram was developed and validated using another set of 68 patients. This model is based on simple parameters that account for not only characteristics that can be observed during the initial presentation but also clinical management decisions that can occur throughout the hospitalization period. This model exhibited a more favorable performance than the previously published models.

The SHOCK trial score identified a prior CABG among MI patients and the CardShock risk score identified prior MI or CABG and ACS etiologies as risk factors in the general population.^{6,8} Our findings did not indicate that a history of MI was a predictor of in-hospital mortality, whereas a history of CAD was. Furthermore, Wehner et al.¹³ reported that LVEF may have a U-shaped relationship with mortality. However, most studies demonstrated a relatively linear relationship, with lower LVEF being associated with a higher risk of death.^{14,15} Our risk-predictive nomogram, along with the SHOCK trial score and CardShock risk score, identified reduced ejection fraction as a predictor of mortality.^{6,8}

CS can manifest signs of end-organ hypoperfusion; therefore, the prevalence of acute kidney injury (AKI) is high among patients with CS and is a strong predictor of 90-day mortality.¹⁶ Patients who require RRT had higher in-hospital mortality than those with AKI who did not undergo dialysis.^{17,18} The SHOCK trial score and CardShock risk score included creatinine levels as a predictor of mortality while our multivariate analysis indicated that the need for RRT during hospitalization was a risk factor.^{6,8}

Predictors identified in this study that were not a part of the other scoring systems were multiple inotropic use, longer CPR duration, and albumin infusion. Pharmacologic management with inotropic agents and vasopressors has become a cornerstone of hemodynamic support for patients with shock.¹⁹ Early diagnosis of CS and rapid initiation of therapy can greatly improve patient prognosis.¹⁹ However, inotropes and vasopressors are recommended for short-term treatment at minimum doses when deemed necessary in the absence of alternatives.²⁰ Studies have presented conflicting results regarding their

safety and overall benefits. Tarvasmäki et al.¹⁹ revealed that a combination of vasopressors such as levosimendan with noradrenaline was associated with a more favorable prognosis; however, adrenaline was associated with an increased mortality, whether administered alone or in combination. Other studies have reported that inotropic therapy is not associated with differences in mortality, and the additive effect does not reduce mortality in patients with heart failure.^{20, 21} The simultaneous administration of more than one inotropic agent to maintain hemodynamic stability was strongly associated with in-hospital mortality in our study.

Severe cases of CS often progress to cardiac arrest, thus requiring resuscitation efforts.²²

Vallabhajosyula et al.²³ reported that among STEMI patients, CS with cardiac arrest was associated with higher rates of noncardiac organ failure and subsequent in-hospital mortality compared with CS or arrest alone. In patients with cardiac arrest, a prolonged CPR duration is associated with a poorer prognosis, as demonstrated in our study.^{22, 24}

The infusion of albumin as a volume expander or as an alternative to using crystalloids for volume replacement is performed in patients with shock and severe sepsis; however, evidence that its use in critically ill patients improves survival is limited.^{25, 26} Although improvements in hemodynamic instability can be achieved with the administration of albumin, long-term benefits require further investigation.²⁵ Among patients with heart failure or ACS, hypoalbuminemia is correlated with higher overall illness severity and low levels of albumin can act as a frailty biomarker; therefore, it is consistently associated with higher mortality rates.²⁷ Our findings also indicated that patients who received albumin infusion were at risk of a less favorable prognosis.

Conclusion

The risk factors of a history of CAD, multiple inotropic use, ejection fraction less than 40%, longer CPR duration, albumin infusion, and RRT are associated with higher in-hospital mortality. A risk-predictive nomogram with high diagnostic accuracy was developed accordingly.

Limitations

Several limitations of this study should be considered. The retrospective nature of the study caused unavoidable selection bias toward patients with more severe conditions requiring more medical interventions. The small sample size may have resulted in nonsignificant differences between groups in some variables. Unrecognized confounding factors may also be present. This study is largely based on an Asian demographic and thus may be more applicable for similar populations. External validation was not performed for the predictive model. The availability of IABP and ECMO without Impella support may differ from the Western practices. As renal replacement therapy is usually not applied on the first day of hospitalization, this new score may not be useful for the initial evaluation of patients with CS; rather, it will be up to the physician's discretion as to the appropriate time to apply this score for prognostication.

purposes. Moreover, the primary outcome of this study was in-hospital mortality, and thus the prediction of long-term prognosis after discharge requires future investigation through well-designed studies.

Declarations

Ethics Approval and Consent to Participate

Not applicable

Consent for Publication

Not applicable

Availability of Data and Materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing Interests

The authors declare that there is no conflict of interest, including the relevant financial interests, activities, relationships, and affiliations.

Funding

None

Authors' Contributions

MST, CHH and WJC contributed to the study concept and design; YTT, MST, CCH, WJC, WTC, and JJL contributed to the acquisition of the data; YTT, MST, and CSH analyzed and interpreted the data; YTT and MST drafted the manuscript; CHH and WJC provided critical revision of the manuscript for important intellectual content; YTT and MST performed the statistical analysis; CHH and WJC supervised the study. All authors read and approved the final manuscript.

Acknowledgements

We would like to thank the Colleague Medical Research and Education Foundation for their support.

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Figures

Figure 1

Flowchart of patient enrolment in the training set. CCU, cardiac care unit; ER, emergency room; OHCA, out-of-hospital cardiac arrest.

Figure 2

Predictive nomogram of in-hospital mortality in patients with cardiogenic shock. CAD, coronary artery disease; CPR, cardiopulmonary resuscitation; EF, left ventricular ejection fraction.

Figure 3

ROC curves of training and validation sets. AUC, area under the curve; NPV, negative predictive value; PPV, positive predictive value; ROC, receiver operating characteristic.

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