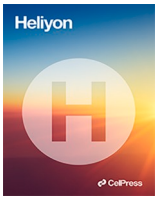
Heliyon 10 (2024) e34070

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon



Research article

Cardiac arrest and cardiogenic shock complicating ST-segment elevation myocardial infarction in China: A retrospective multicenter study

Shao-shuai Liu [a], Juan Wang [b,*], Hui-qiong Tan [c,d,**], Yan-min Yang [b], Jun Zhu [b]

[a] *Department of Cardiology, Qilu Hospital (Qingdao), Cheeloo College of Medicine, Shandong University, 758 Hefei Road, Qingdao, Shandong, 266035, China*
[b] *Emergency Center, Fuwai Hospital, National Center for Cardiovascular Disease, National Clinical Research Center of Cardiovascular Diseases, Chinese Academy of Medical Science and Peking Union Medical College, Beijing, 100037, China*
[c] *Intensive Care Center, Fuwai Hospital, National Center for Cardiovascular Diseases, National Clinical Research Center of Cardiovascular Diseases, Chinese Academy of Medical Sciences and Peking Union Medical College, Beijing, 100037, China*
[d] *Intensive Care Center, Fuwai Hospital, Chinese Academy of Medical Sciences and Peking Union Medical College, Shenzhen, 518057, China*

ARTICLE INFO

Keywords:
All-cause death
Cardiac arrest
Cardiogenic shock
Major adverse cardiac event
ST-Segment elevation myocardial infarction

ABSTRACT

Background: Data on the effect of cardiac arrest (CA), cardiogenic shock (CS), and their combination on the prognosis of Chinese patients with ST-segment elevation myocardial infarction (STEMI) are limited. The present study sought to evaluate the clinical outcomes of STEMI complicated by CA and CS, and to identify the risk factors for CA or CS.

Methods: This study included 7468 consecutive patients with STEMI in China. The patients were divided into 4 groups (CA + CS, CA only, CS only, and No CA or CS). The endpoints were 30-day all-cause death and major adverse cardiovascular events. A Cox proportional hazards regression analysis was performed.

Results: CA, CS, and their combination were noted in 332 (4.4 %), 377 (5.0 %), and 117 (1.6 %) among all patients. During the 30-day follow-up, 817 (10.9 %) all-cause deaths and 964 (12.9 %) major adverse cardiovascular events occurred, and the incidence of all-cause mortality (3.6 %, 62.3 %, 74.1 %, 83.3 %) and major adverse cardiovascular events (5.4 %, 67.1 %, 75.0 %, and 87.2 %) significantly increased in the No CA or CS, CS only, CA only, and CA + CS groups, respectively. In the multivariate Cox regression models, compared with the No CA or CS group, the CA + CS, CA, and *CS*-only groups were associated with an increased risk of all-cause death and major adverse cardiovascular events. Patients with CA + CS had the highest risk of all-cause death (hazard ratio [HR], 25.259 [95 % confidence interval (CI) 19.221–33.195]) and major adverse cardiovascular events (HR 19.098, 95%CI 14.797–24.648).

Conclusions: CA, CS, and their combination were observed in approximately 11 % of Chinese patients with STEMI, and were associated with increased risk for 30-day mortality and major adverse cardiovascular events in Chinese patients with STEMI.

* Corresponding author. Emergency Center, National Center for Cardiovascular Disease, Fuwai Hospital, Chinese Academy of Medical Science and Peking Union Medical College, Beijing, 100037, China.
** Corresponding author. Intensive Care Center, Fuwai Hospital, Chinese Academy of Medical Sciences and Peking Union Medical College, Shenzhen, 518057, China.
E-mail addresses: wangjuan@fuwai.com (J. Wang), tanhq163@163.com (H.-q. Tan).

https://doi.org/10.1016/j.heliyon.2024.e34070
Received 13 March 2024; Received in revised form 24 June 2024; Accepted 3 July 2024
Available online 6 July 2024

1. Introduction

Cardiac arrest (CA) and cardiogenic shock (CS) are the most life-threatening complications of acute myocardial infarction (AMI), occurring in approximately 5–10 % of all hospital admissions and collectively contributing to over 60–80 % of deaths due to AMI [1–3]. In particular, for patients with ST-segment elevation myocardial infarction (STEMI), a national database from the United States identified that 30 % of admissions for STEMI with either CS or CA exhibited the concurrent presence of both conditions [2,4]. Concomitant CS was present in 43%–51 % of patients with STEMI and CA, according to data obtained from contemporary registries [5,6]. The 2019 expert consensus statement on the classification of CS by the Society of Cardiovascular Angiography and Intervention (SCAI) highlighted the additional risk predicted by CA in CS, referring to it as a "risk modifier" in each phase of CS [7]. The presence of CA exacerbates the condition of patients with CS and has been linked to higher mortality rates in every SCAI shock states [8]. CA frequently occurs following STEMI-CS due to ventricular tachycardia (VT) or ventricular fibrillation (VF) [9], which are major contributors to mortality in CS [10]. The increased incidence of ventricular arrhythmias in patients with STEMI accounts for the elevated risk of CA [11]. Despite considerable pathophysiological similarities, approximately half of patients with CS experience CA, while approximately two-thirds of patients with CA develop CS [12].

Previous studies have shown that patients with STEMI complicated by CA or CS have a very high mortality rate and poor prognosis [2,12]. However, the risk factors for the early and timely identification of CA or CS in hospitals among patients with STEMI are limited. The effect of concurrent CA and CS on the prognosis of Chinese patients with STEMI, particularly regarding all-cause mortality and major adverse cardiac events (MACEs), remains unclear. Using a large database, we aimed to assess the clinical outcomes associated with STEMI complicated by CA and CS, and to identify the risk factors predisposing patients to CA or CS.

2. Methods

2.1. Study design and patient selection

This was a retrospective, multicenter study with 7510 consecutive patients diagnosed with acute STEMI within 12 h of symptom onset. The study was conducted between June 2001 and July 2004 across 274 medical centers located in China. This study was a secondary analysis, and the diagnostic and exclusion criteria for acute STEMI have been described previously [13,14]. The study protocols were approved by the ethics committees of Fuwai Hospital and all participating centers and adhered to the principles outlined in the Declaration of Helsinki. Written informed consent was obtained from all the enrolled patients.

After hospitalization, the patients received treatment according to the clinical guidelines relevant to the study period and local healthcare standards for managing STEMI. This includes reperfusion therapy, such as primary percutaneous coronary intervention (PCI) or thrombolytic therapy. In the present study, 42 patients were excluded because of incomplete data; 7468 patients were included in the final analysis.

2.2. Data collection and laboratory measurements

Baseline patient information collected on admission included sex, age, weight, blood pressure (BP), heart rate, Killip class, location of myocardial infarction, cardiovascular history (myocardial infarction [MI], hypertension, heart failure [HF], diabetes mellitus [DM], and stroke), reperfusion therapy (PCI and thrombolysis), and medications. The admission TIMI risk score (TRS) was calculated according to established criteria [15].

2.3. Definitions and study endpoints

CA was defined as ventricular fibrillation, pulseless ventricular tachycardia, or pulseless clinical situations characterized by pulseless electrical activity or bradycardia necessitating cardiopulmonary resuscitation and/or emergency defibrillation. CS was defined as the presence of systolic arterial hypotension ($<$90 mmHg) persisting for $>$30 min, accompanied by signs of hypoperfusion, unresponsiveness to fluid titration, and the need for intravenous inotropic therapy and/or mechanical support devices to maintain BP.

The patients were categorized into four groups based on the presence of CA and CS: CA + CS, CA only, CS only, and No CA or CS. All patients were followed up for 30 days using various methods such as conducting interviews at the clinic, making phone calls to patients or their relatives, and reviewing medical records. The primary endpoint of the present study was all-cause death within 30 days of enrollment, and secondary endpoint was MACEs. MACEs were assessed as a composite endpoint, including all-cause mortality, recurrent myocardial infarction, stroke, and major bleeding. The evaluation of these endpoint events was performed by proficient research personnel who were unaware of the study objectives.

2.4. Statistical analysis

Data are presented as means (standard deviation, SD) for continuous variables and frequency (percentage) for categorical variables. Group comparisons were performed using analysis of variance for continuous variables and Pearson's chi-square test for categorical variables. Endpoint estimates were obtained using the Kaplan-Meier method, and differences were evaluated using the log-rank test. Univariate and multivariate Cox proportional hazards models with clustered standard errors were used for endpoint analysis. In the

multivariate analyses, established risk factors and variables (P-value = 0.05) were subsequently included. The adjusted hazard ratios (HRs) and their corresponding 95 % confidence intervals (CIs) were calculated with reference to the reference group, for which the HR was considered to be 1. All statistical tests were conducted as two-sided. Statistical significance was set at $P < 0.05$. significant. Statistical analyses were performed using the SPSS software (version 26.0; IBM Corporation, New York, NY, USA) and GraphPad Prism 9.0 (GraphPad Software, Boston, MA, USA).

3. Results

3.1. Baseline characteristic

A total of 7468 patients with a primary STEMI diagnosis and complete data were included in this study. The mean (SD) age of all patients was 62.66 (11.87) years. Among the 7468 patients, CA, CS, and both were noted in 332 (4.4 %), 377 (5.0 %), and 117 (1.6 %) patients, respectively. Compared with the no CA or CS groups, patients who experienced CA and CS were older and had lower body weight, lower BP, higher heart rate, and a higher proportion of female patients. The proportion of patients with Killip class ≥ III was much higher in both CA + CS and CS only groups, the same trend in TRS. The presence of CS, either alone or in combination with CA, was associated with a higher incidence of prior heart failure, stroke, and diabetes (Table 1).

3.2. Baseline treatment

Reperfusion therapy was administered to 4781 patients (64.0 %), including thrombolysis in 3921 patients (52.5 %) and primary PCI in 860 patients (11.5 %). Patients with CA or CS were less likely to receive primary PCI than patients without CA or CS; In terms of medications treatment, the proportional of patients receive antiplatelet therapy, β-blockers, statins, angiotensin-converting enzyme inhibitors (ACEI)/angiotensin receptor antagonists (ARB), nitrates and calcium channel blockers (CCB) were lower in group CA and CS, CS only and CA only, while antiarrhythmic medications and diuretics were higher in these groups (Table 1).

Table 1
Baseline characteristics of STEMI admissions stratified by CA and CS.

	All patients N=7468	CA + CS N=117	CA Only N=332	CS Only N=377	No CA or CS N=6642	P value
Age(SD), years	62.7(11.9)	69.2(10.3)	66.4(12.0)	68.5(10.2)	62.0(11.8)	<0.001
Female, n(%)	2175(29.1)	50(42.7)	134(40.4)	164(43.5)	1827(27.5)	<0.001
Weight(SD), Kg	66.6(11.8)	63.4(11.9)	65.0(12.6)	61.7(11.4)	67.0(11.7)	<0.001
SBP(SD), mmHg	125.7(26.6)	102.2(33.7)	120.4(29.5)	97.4(37.2)	127.9(24.4)	<0.001
DBP(SD), mmHg	78.5(17.0)	63.8(23.1)	75.6(19.7)	61.4(24.7)	79.8(15.4)	<0.001
Heart rate(SD), bpm	77.5(18.8)	86.5(29.6)	80.0(20.0)	81.5(27.5)	77.0(17.8)	<0.001
Killip class						<0.001
I	6094(81.6)	41(35.0)	254(76.5)	147(39.0)	5652(85.1)	
II	1009(13.5)	22(18.8)	60(18.1)	68(18.0)	859(12.9)	
≥III	365(4.9)	54(46.2)	18(5.4)	162(43.0)	131(2.0)	
TRS(SD)	4.23(2.43)	7.42(2.87)	5.06(2.62)	7.06(2.83)	3.97(2.23)	<0.001
Anterior STE or LBBB, n(%)	3983(53.3)	70(59.8)	191(57.5)	189(50.1)	3533(53.2)	0.115
Previous myocardial infarction, n(%)	592(7.9)	13(11.1)	28(8.4)	28(7.4)	523(7.9)	0.594
Previous heart failure, n(%)	200(2.7)	6(5.1)	14(4.2)	17(4.5)	163(2.5)	0.008
Hypertension, n(%)	3019(40.4)	47(40.2)	140(42.2)	135(35.8)	2697(40.6)	0.278
Diabetes, n(%)	838(11.2)	17(14.5)	54(16.3)	60(15.9)	707(10.6)	<0.001
Previous stroke, n(%)	705(9.4)	12(10.3)	42(12.7)	54(14.3)	597(9.0)	0.001
Reperfusion therapy						
Thrombolytic therapy, n(%)	3921(52.5)	61(52.1)	177(53.3)	202(53.6)	3481(52.4)	0.961
Primary PCI, n(%)	860(11.5)	4(3.4)	20(6.0)	17(4.5)	819(12.3)	<0.001
Medications						
Inotropic, n(%)	428(5.7)	98(83.8)	0(0)	330(87.5)	0(0)	<0.001
Antiplatelet therapy, n(%)	7201(96.4)	102(87.2)	305(91.9)	336(89.1)	6458(97.2)	<0.001
β-blockers, n(%)	4579(61.3)	39(33.3)	148(44.6)	137(36.3)	4255(64.1)	<0.001
Statins, n(%)	5307(71.1)	58(49.6)	184(55.4)	188(49.9)	4877(73.4)	<0.001
ACEI/ARB, n(%)	5339(71.5)	45(38.5)	187(56.3)	159(42.2)	4948(74.5)	<0.001
Nitrate, n(%)	6847(91.7)	86(73.5)	299(90.1)	282(74.8)	6180(93.1)	<0.001
CCB, n(%)	946(12.7)	7(6.0)	39(11.7)	19(5.0)	881(13.3)	<0.001
Antiarrhythmic medications, n(%)	1477(19.8)	79(67.5)	163(49.1)	142(37.7)	1093(16.5)	<0.001
Diuretics, n(%)	1914(25.6)	60(48.7)	104(31.3)	215(57.0)	1538(23.2)	<0.001

CA, cardiac arrest; CS, cardiogenic shock; STEMI, ST-segment elevation myocardial infarction; SD, standard deviation; SBP, systolic blood pressure; DBP, diastolic blood pressure; TRS, TIMI risk score; STE, ST-segment elevation; LBBB, left bundle branch block; PCI, percutaneous coronary intervention; ACEI, angiotensin-converting enzyme inhibitors; ARB, angiotensin receptors blockers; CCB, calcium channel blocker.

3.3. Clinical outcomes and risk factor for death and MACEs

During the 30-day follow-up, 817 (10.9 %) all-cause deaths and 964 (12.9 %) MACEs occurred. Compared to STEMI admissions without CA or CS (30-day mortality 3.6 %, and MACEs incidence 5.4 %), the 30-day all-cause mortality was significant higher in the other groups, i.e. CA + CS (83.8 %), CA only (71.4 %), and CS only (62.3 %) ($P < 0.001$), and the MACEs also significant higher in CA + CS (87.2 %), CA only (75.0 %) and CS only (67.1 %) groups ($P < 0.001$) (Fig. 1).

Kaplan-Meier curves depicting 30-day mortality and MACEs were analyzed using the log-rank test, which revealed statistically significant differences among the groups ($P < 0.001$). Notably, the CA + CS group exhibited a significantly higher cumulative mortality rate than the other groups (Fig. 2A). Similarly, the CA + CS group demonstrated significantly higher cumulative MACEs within the 30-day period than the other groups (Fig. 2B).

Table 2 shows factors associated with 30-day mortality and MACEs based on multivariate Cox regression models, the CA + CS, CA only and CS only groups all associated with increased risk of all-cause death and MACEs. After adjustment, 30-day mortality risk in STEMI survivors was greatest in patients with CA + CS group. Patients with CA + CS (HR 25.259 [95%CI 19.221–33.195]), CA only (HR 25.385, 95 % CI 20.846–30.912]), CS only (HR 14.487, 95 % CI 11.624–18.055]) had significant higher all-cause mortality compared with No CA or CS group (all $P < 0.001$). Similarly, after multivariate adjustment, and the risk for MACEs also significant higher in CA + CS group (HR 19.098, 95%CI 14.797–24.648), CA only (HR 17.155, 95%CI 14.348–20.511), CS only (HR 11.351, 95% CI 9.295–13.862) compared with the No CA or CS group (all $P < 0.001$) (Table 2).

Furthermore, advanced age, female sex, lower SBP, higher diastolic blood pressure (DBP), faster heart rate, and diuretic use were found to correlate with an increased risk of all-cause mortality and MACEs. Conversely, the treatment with PCI, antiplatelets, statins, β-blockers, and ACEI/ARB demonstrated an association with a decreased risk of all-cause mortality and MACEs, as indicated in Table 2.

3.4. Risk factors for CA or CS

Fig. 3 shows the multivariate Cox regression model identified independent risk factors for 30-day CA or CS, the results showed that older age, faster heart rate, Killip class ≥ III, antiarrhythmic medications were independent risk factors for 30-day CA (Fig. 3A). And risk factors for CS, the results showed that older age, lower weigher and SBP, Killip class ≥ II, antiarrhythmic medications and diuretic were independent risk factors for 30-day CS (Fig. 3B).

4. Discussion

In this study, we evaluated the 30-day clinical outcomes of CA and CS in Chinese patients with STEMI and found several results: (1) CA, CS, and their combination are common in Chinese patients with STEMI, with a prevalence of 4.4 %, 5.0 %, and 1.6 %, respectively. (2) Patients with STEMI with CA, CS, CA + CS groups were associated with significantly higher 30-day mortality, which was present in 71.4 %, 62.3 %, and 83.8 % of patients, respectively, and MACEs, CA 75.0 %, CS 67.1 %, and CA + CS 87.2 %, respectively. (3) After adjusting for potential confounders, the CA + CS, CA only, and CS only groups were associated with a higher risk of all-cause death and MACEs. (4) and we also found that advanced age, female sex, faster heart rate were risk factors for all-cause death and MACEs. (5) Risk factors independently associated with CA or CS in patients with STEMI included advanced age, Killip class ≥ III, and antiarrhythmic medications.

CA and CS are the most life-threatening complications of STEMI, and our study showed that the 30-day CA, CS, and their combined incidence in Chinese patients with STEMI was 4.4 %, 5.0 %, and 1.6 %, respectively. An increasing number of studies have reported the prevalence and incidence of CA or CS in patients with AMI, the prevalence or incidence have slightly difference. Vallabhajosyula et al. found that among 163,071 patients with AMI from 2010 to 2018, CA only, CS only and CA + CS were noted in 5.0 %, 4.0 % and 2.4 %, respectively [16]. Omer et al. analyzed 4500 patients with STEMI between 2003 and 2014 and noted that 4.1 % of patients with STEMI

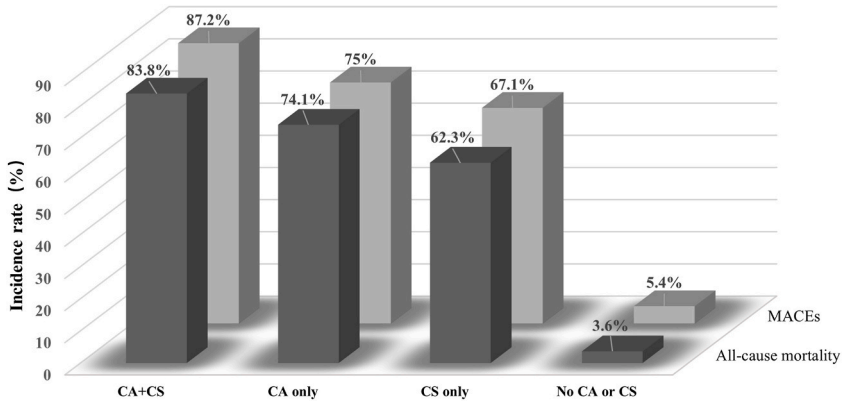


Fig. 1. Incidence of endpoints stratified by CA and CS.

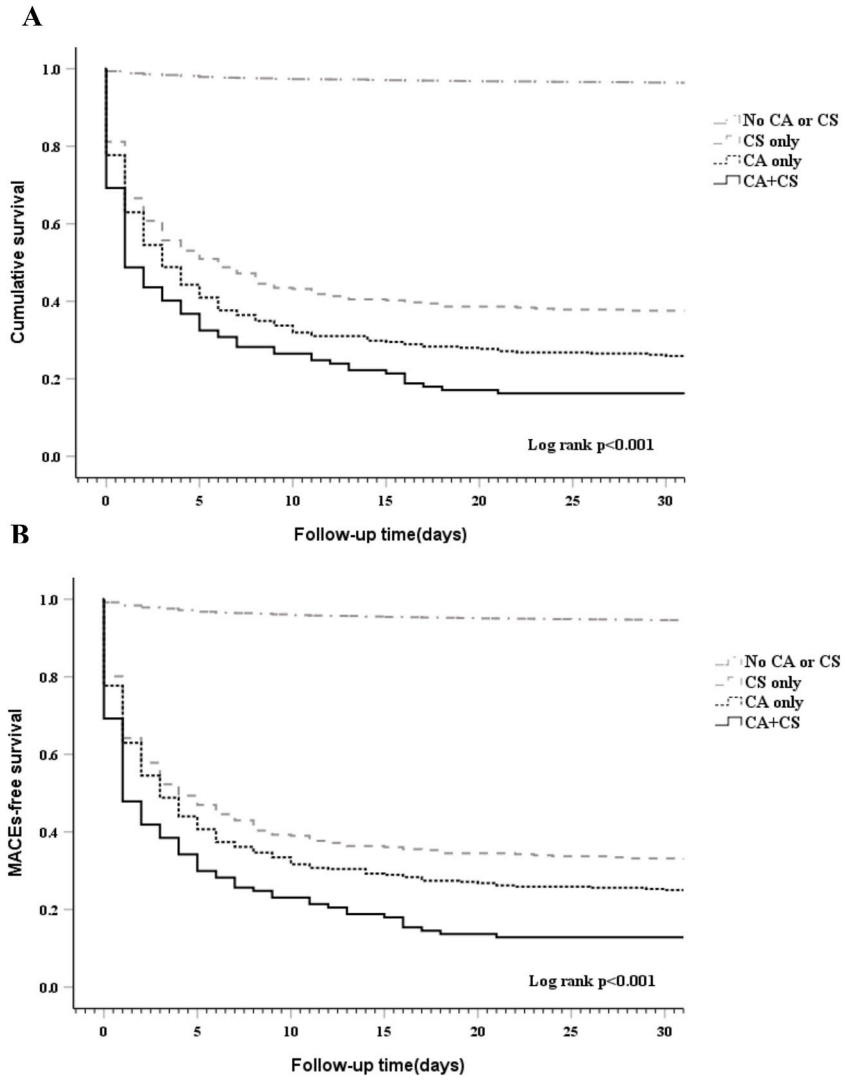


Fig. 2. Kaplan-Meier curves for 30-day all-cause mortality and MACEs stratified by CA and CS A: All-cause death; B: MACEs.

had concomitant CA and CS [17]. A study from the United States included 4320117 adult patients with STEMI between 2000 and 2017; either CA or CS were present in 15 % of all admissions, and CS and CA co-existed in nearly 3 % of admissions [2].

Patients with STEMI with CA and CS present a heightened risk profile, with the mortality rate surpassing that of patients with CA or CS alone. This cohort exhibited the highest in-hospital mortality and represented the most critically ill subgroup, resulting in markedly worse outcomes [3]. Similar to our study, patients with STEMI in the CA + CS, CA only, and CS only groups had significantly higher 30-day mortality and MACEs. After adjusting for potential confounders, CA + CS, CA only, and CS only were significantly associated with all-cause mortality and MACEs. Omer et al. demonstrated that patients with STEMI with CS and CA simultaneously presented with 44 % in-hospital mortality [17]. A study from the United States showed that mortality from CS + CA in the STEMI population remained high at 66.8 % in 2000 and 48.1 % in 2017 [2]. Another study from Argentine analyzed 6122 patients with STEMI between 2015 and 2022; the overall in-hospital mortality of patients with CS and CA at presentation was 79.3 % [18].

These differences in prevalence and mortality may be explained by the different definitions of CA and CS, study population characteristics, time period of evaluation, medical care level, and proportion of PCI treatment in the contemporary era. The 30-day mortality in our cohort was much higher than that reported in other studies, which may be due to the lower proportion of patients undergoing primary PCI and temporary mechanical circulatory supportive treatment in the early 2000s. The intra-aortic balloon pump (IABP) is an important treatment for patients with AMI, with a low rate of use in the early 2000s, which slightly increased in 2010 but decreased in 2015 [19]. The IABP-SHOCK II trial conducted in 2013 demonstrated the clinical effect of IABP, which did not reduce the 30-day and 12-months all-cause mortality among patients undergoing early revascularization for AMI complicated by CS [20]. The widespread use of other temporary mechanical circulatory supports was not associated with improved outcomes in patients with AMI with CA and CS, and trials or observational data that failed to demonstrate improved patient outcomes using different types of

Table 2
Predictors of all-cause mortality and MACEs by multivariate Cox analysis.

	All-cause mortality		MACEs	
	HR (95%CI)	P value	HR (95%CI)	P value
No CA or CS	1		1	
CS Only	14.487(11.624–18.055)	<0.001	11.351(9.295–13.862)	<0.001
CA Only	25.385(20.846–30.912)	<0.001	17.155(14.348–20.511)	<0.001
CS and CA	25.259(19.221–33.195)	<0.001	19.098(14.797–24.648)	<0.001
Age	1.032(1.024–1.040)	<0.001	1.030(1.023–1.037)	<0.001
Female	1.222(1.036–1.442)	0.017	1.232(1.057–1.435)	0.007
SBP	0.995(0.991–1.000)	0.037	0.996(0.992–1.000)	0.043
DBP	1.010(1.004–1.018)	0.003	1.010(1.003–1.016)	0.003
Heart rate	1.012(1.009–1.015)	<0.001	1.010(1.007–1.013)	<0.001
Stroke			1.277(1.066–1.531)	0.008
Primary PCI	0.408(0.266–0.625)	<0.001	0.602(0.436–0.831)	0.002
Antiplatelet	0.748(0.590–0.948)	0.016	0.690(0.551–0.865)	0.001
β-blockers	0.752(0.643–0.879)	<0.001	0.808(0.701–0.932)	0.003
Statins	0.708(0.608–0.826)	<0.001	0.747(0.649–0.860)	<0.001
ACEI/ARB	0.645(0.549–0.757)	<0.001	0.681(0.588–0.790)	<0.001
Nitrate	0.784(0.637–0.965)	0.022	0.839(0.680–1.021)	0.080
Diuretics	1.236(1.056–1.446)	0.008	1.273(1.102–1.470)	0.001

MACEs, major adverse cardiovascular events; HR, hazards ratio; CI, confidence interval; CA, cardiac arrest; CS, cardiogenic shock; SBP, systolic blood pressure; DBP, diastolic blood pressure; PCI, percutaneous coronary intervention; ACEI, angiotensin-converting enzyme inhibitors; ARB, angiotensin receptors blockers.

short-term supportive treatment devices [21]. This persistently high mortality in these severely affected patients occurred despite improvements in prehospital care and increases in the utilization of supportive treatment and revascularization over time, managing these patients continues to be a challenging task that requires the expertise of skilled multidisciplinary teams, who must closely monitor and frequently evaluate management strategies.

Furthermore, our study showed that older age, female sex, faster heart rate, and higher blood glucose levels were the risk factors for mortality and MACEs. Age is a well-known continuous risk factor for adverse outcomes in patients with AMI with CS and was highlighted in the seminal shock trial, IABP-SHOCK II trial, and subsequent risk scores [22]. Other studies have also shown that female sex and older age are predictors of higher in-hospital mortality in high-risk subgroups such as those with STEMI-CS presentation [18,23,24]. A faster heart rate and higher blood glucose levels are also independent predictors of 30-day mortality among patients with AMI with concomitant CS [25,26]. However, in our study, antiplatelet, β-blocker, ACEIs and statin usage were found inversely correlated with 30-day mortality and MACEs. The favorable effects of β-blockers and ACEIs have already been reported in severe patients requiring inotrope treatment [27,28]. Previous studies already conformed β-blockers may mitigate the harmful effects of catecholamines in patients experiencing shock [29,30]. However, administration of these medications may pose challenges for individuals with low BP. Considering the observational nature of our study, it is probable that both β-blockers and ACEIs were predominantly prescribed to patients with less severe initial hemodynamic characteristics. A study conducted using data from the Korean AMI registry examined the correlation between early statin administration and patient outcomes in individuals with CS and AMI who underwent revascularization, after adjustment for confounding factors, it was observed that early statin use was linked to a decreased risk of mortality within 30 days [31].

For risk factors associated with CA or CS among patients with STEMI, our study shows that older age, Killip class $\geq$ III, and antiarrhythmic therapy. Previous studies showed that STEMI and CA used to identify as features associated with a higher risk of CS during hospitalization following AMI [19,32]. Another study showed that STEMI is an independent predictor of CA [33]. Older age is a common risk factor for death; other studies have also demonstrated that age is an independent predictor of CA or CS among patients with STEMI [18,19,34]. A grading of deteriorating cardiac function like Killip class $\geq$ III remain one of the strongest predictor of CS in the setting of STEMI [35,36]. Previous studies have shown that prophylactic treatment with antiarrhythmic drugs is not beneficial, and may even be harmful [9]. Identifying these risk factors could offer valuable support for risk stratification and aid in clinical decision making for patients with STEMI. It is helpful to take active intervention measures to improve the prognosis of patients and reduce the mortality of patients with STEMI.

5. Limitations

The current study has some limitations. First, owing to the restricted availability of medical resources during the early 2000s, only a small proportion of patients (13.5 %) underwent PCI in the present study, although it can effectively reduce the incidence of adverse events and is recommended as a first-line therapy, which may confound our results. Second, the data used in this study were derived from an observational design, rendering them susceptible to unmeasured confounding factors and selection biases. Consequently, we were able to establish associations, rather than causality, among baseline characteristics, treatment strategies, and outcomes. Third, the use of mechanical circulatory support devices other than the IABP was low in our program (<1 %) during the study period. Fourth, the enrollment period of our study spanning from June 2001 to July 2004 indeed reflects a significant time gap since the study was

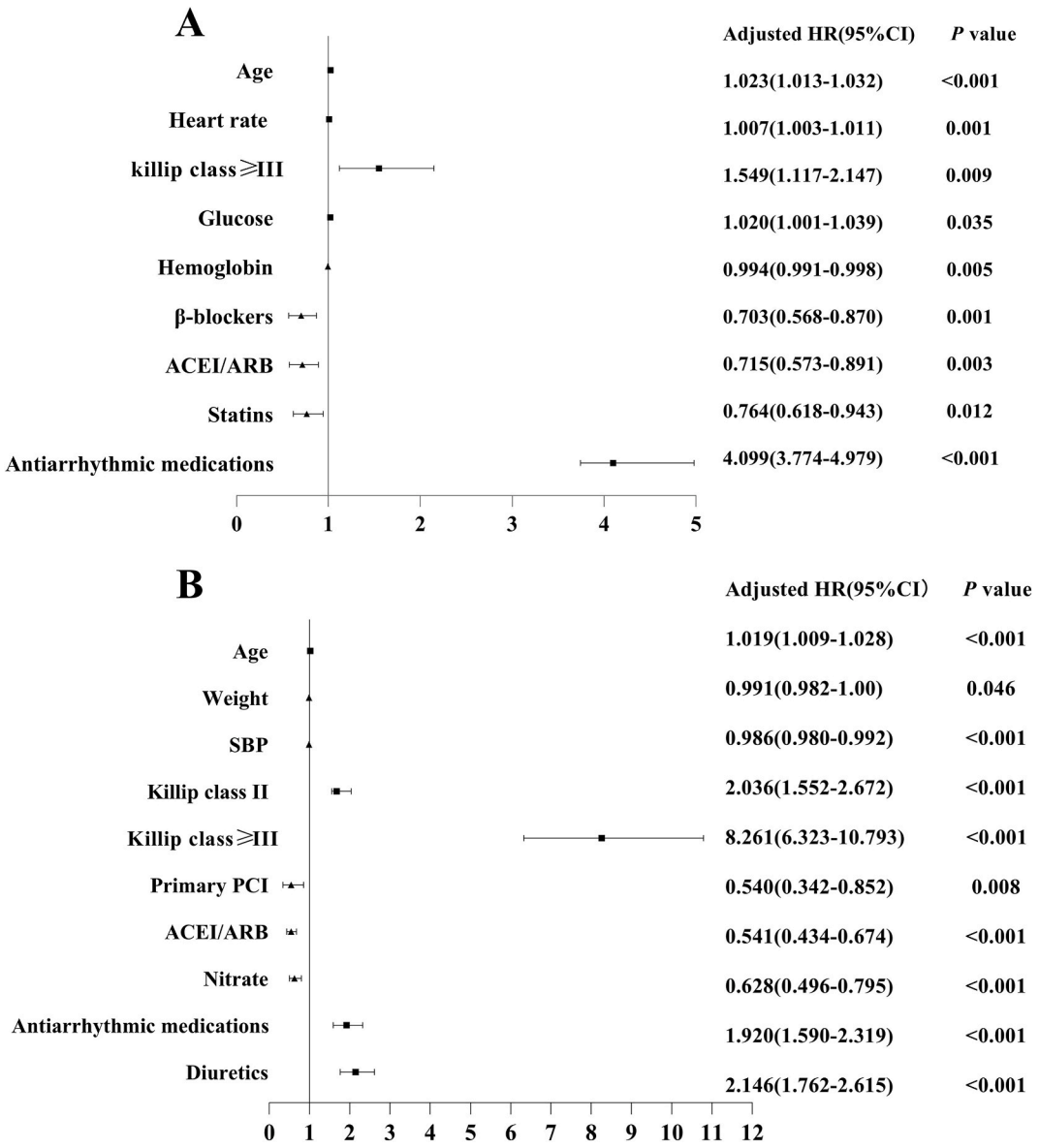


Fig. 3. Risk factors for A: CA, B: CS by multivariate Cox analysis.

conducted, however, despite the temporal gap, the study's findings are still relevant in identifying risk factors for CA and CS in STEMI patients. Finally, it is important to acknowledge that the generalizability of the study's outcomes is predominantly limited to Chinese patients. Therefore, large-scale, well-designed studies are required to confirm our findings.

6. Conclusions

The current study revealed that CA, CS, and their combination were observed in approximately 11 % of Chinese patients with STEMI and that these conditions were significantly associated with a higher risk of 30-day mortality and MACEs. These findings have important implications in the clinical management of these patients. However, further specialized investigations are warranted to explore the long-term implications of CA and CS, either alone or in combination, as understanding the interaction between CA and CS is crucial for improving the outcomes of this critically ill population.

Ethics statement and consent to participate

The study was approved by the ethics committee of Fuwai Hospital, Chinese Academy of Medical Science and Peking Union

Medical College (Approval Number: 2024–2358), and complied with the principles outlined in the Declaration of Helsinki. Written informed consent was obtained from all the patients.

Consent for publication

All data used in this study were obtained with proper authorization and consent from the participating hospitals.

Data availability statement

The datasets used and analyzed in the current study are available from the corresponding author (Juan Wang, Email: wangjuan@fuwai.com) upon reasonable request.

Funding

The present study was funded by the Special Foundation for the National Science and Technology Basic Research Program of China (No. 2018FY100606) and Funded by Qingdao Key Clinical Specialty Elite Discipline(No. QDZDZK-2022008).

CRediT authorship contribution statement

Shao-shuai Liu: Writing – original draft, Formal analysis. **Juan Wang:** Writing – review & editing, Visualization, Methodology, Formal analysis, Conceptualization. **Hui-qiong Tan:** Supervision, Funding acquisition. **Yan-min Yang:** Supervision, Funding acquisition, Data curation, Conceptualization. **Jun Zhu:** Investigation, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We are grateful to all the members for their contributions to this study.

Abbreviations

CA	Cardiac arrest
CS	Cardiogenic shock
STEMI	ST-segment elevation myocardial infarction
AMI	Acute myocardial infarction
PCI	Percutaneous coronary intervention
VT	Ventricular tachycardia
VF	Ventricular fibrillation
MI	Myocardial infarction
HF	Heart failure
DM	Diabetes mellitus
MACEs	Major adverse cardiac events
TRS	TIMI risk score
ACEI	Angiotensin-converting enzyme inhibitors
ARB	Angiotensin receptor antagonists
CCB	Calcium channel blockers
IABP	Intra-aortic balloon pump
HRs	Hazard ratios
CIs	Confidence intervals

References

[1] S. Vallabhajosyula, S.M. Dunlay, A. Prasad, et al., Acute noncardiac organ failure in acute myocardial infarction with cardiogenic shock, J. Am. Coll. Cardiol. 73 (14) (2019) 1781–1791, https://doi.org/10.1016/j.jacc.2019.01.053.

[2] S. Vallabhajosyula, S.M. Dunlay, A. Prasad, et al., Cardiogenic shock and cardiac arrest complicating st-segment elevation myocardial infarction in the united states, 2000–2017, Resuscitation 1552020) 55-64, https://doi.org/10.1016/j.resuscitation.2020.07.022.

[3] S. Vallabhajosyula, S.R. Payne, J.C. Jentzer, et al., Long-term outcomes of acute myocardial infarction with concomitant cardiogenic shock and cardiac arrest, Am. J. Cardiol. 1332020) 15-22, https://doi.org/10.1016/j.amjcard.2020.07.044.

[4] S. Vallabhajosyula, J.C. Jentzer, A. Prasad, et al., Epidemiology of cardiogenic shock and cardiac arrest complicating non-st-segment elevation myocardial infarction: 18-year us study, ESC Heart Fail 8 (3) (2021) 2259–2269, https://doi.org/10.1002/ehf2.13321.

[5] M.C. Kontos, C.B. Fordyce, A.Y. Chen, et al., Association of acute myocardial infarction cardiac arrest patient volume and in-hospital mortality in the United States: insights from the national cardiovascular data registry acute coronary treatment and intervention outcomes network registry, Clin. Cardiol. 42 (3) (2019) 352–357, https://doi.org/10.1002/clc.23146.

[6] M.C. Kontos, B.M. Scirica, A.Y. Chen, et al., Cardiac arrest and clinical characteristics, treatments and outcomes among patients hospitalized with st-elevation myocardial infarction in contemporary practice: a report from the national cardiovascular data registry, Am. Heart J. 169 (4) (2015) 515–522, https://doi.org/10.1016/j.ahj.2015.01.010.

[7] D.A. Baran, C.L. Grines, S. Bailey, et al., Scai clinical expert consensus statement on the classification of cardiogenic shock: this document was endorsed by the american college of cardiology (acc), the american heart association (aha), the society of critical care medicine (sccm), and the society of thoracic surgeons (sts) in april 2019, Cathet. Cardiovasc. Interv. 94 (1) (2019) 29–37, https://doi.org/10.1002/ccd.28329.

[8] S.S. Naidu, D.A. Baran, J.C. Jentzer, et al., Scai shock stage classification expert consensus update: a review and incorporation of validation studies, J. Am. Coll. Cardiol. 79 (9) (2022) 933–946, https://doi.org/10.1016/j.jacc.2022.01.018.

[9] K. Zeppenfeld, J. Tfelt-Hansen, M. de Riva, et al., Esc guidelines for the management of patients with ventricular arrhythmias and the prevention of sudden cardiac death, Eur. Heart J. 43 (40) (2022) 3997–4126, https://doi.org/10.1093/eurheartj/ehac262, 2022.

[10] S. Vallabhajosyula, S.H. Patlolla, D. Verghese, et al., Burden of arrhythmias in acute myocardial infarction complicated by cardiogenic shock, Am. J. Cardiol. 125 (12) (2020) 1774–1781, https://doi.org/10.1016/j.amjcard.2020.03.015.

[11] J.J. Liang, E.A. Fender, Y.M. Cha, R.J. Lennon, A. Prasad, G.W. Barsness, Long-term outcomes in survivors of early ventricular arrhythmias after acute st-elevation and non-st-elevation myocardial infarction treated with percutaneous coronary intervention, Am. J. Cardiol. 117 (5) (2016) 709–713, https://doi.org/10.1016/j.amjcard.2015.12.002.

[12] S. Vallabhajosyula, D. Verghese, T.D. Henry, et al., Contemporary management of concomitant cardiac arrest and cardiogenic shock complicating myocardial infarction, Mayo Clin. Proc. 97 (12) (2022) 2333–2354, https://doi.org/10.1016/j.mayocp.2022.06.027.

[13] S. Wu, Y.M. Yang, J. Zhu, et al., Impact of glycemic gap on 30-day adverse outcomes in patients with acute st-segment elevation myocardial infarction, Atherosclerosis 3602022) 34-41, https://doi.org/10.1016/j.atherosclerosis.2022.10.003.

[14] Y.M. Yang, J. Zhu, H.Q. Tan, et al., Clinical characteristics and management of patients with st segment elevation myocardial infarction in China: survey of 7510 cases], Zhonghua Yixue Zazhi 85 (31) (2005) 2176–2182 (article in Chinese).

[15] D.A. Morrow, E.M. Antman, A. Charlesworth, et al., Timi risk score for st-elevation myocardial infarction: a convenient, bedside, clinical score for risk assessment at presentation: an intravenous npa for treatment of infarcting myocardium early ii trial substudy, Circulation 102 (17) (2000) 2031–2037, https://doi.org/10.1161/01.cir.102.17.2031.

[16] S. Vallabhajosyula, S.R. Payne, J.C. Jentzer, et al., Use of post–acute care services and readmissions after acute myocardial infarction complicated by cardiac arrest and cardiogenic shock, Mayo Clin. Proc.: Innovations, Quality & Outcomes 5 (2) (2021) 320–329, https://doi.org/10.1016/j.mayocpiqo.2020.12.006.

[17] M.A. Omer, J.M. Tyler, T.D. Henry, et al., Clinical characteristics and outcomes of stemi patients with cardiogenic shock and cardiac arrest, JACC Cardiovasc. Interv. 13 (10) (2020) 1211–1219, https://doi.org/10.1016/j.jcin.2020.04.004.

[18] Y. Castillo Costa, F. Delfino, V. Mauro, et al., Clinical characteristics and evolution of patients with cardiogenic shock in Argentina in the context of an acute myocardial infarction with st segment elevation. Data from the nationwide argen-iam-st registry, Curr. Probl. Cardiol. 48 (2) (2023) 101468, https://doi.org/10.1016/j.cpcardiol.2022.101468.

[19] N. Aissaoui, E. Puymirat, C. Delmas, et al., Trends in cardiogenic shock complicating acute myocardial infarction, Eur. J. Heart Fail. 22 (4) (2020) 664–672, https://doi.org/10.1002/ejhf.1750.

[20] H. Thiele, U. Zeymer, F.J. Neumann, et al., Intra-aortic balloon counterpulsation in acute myocardial infarction complicated by cardiogenic shock (iabp-shock ii): final 12 month results of a randomised, open-label trial, Lancet 382 (9905) (2013) 1638–1645, https://doi.org/10.1016/S0140-6736(13)61783-3.

[21] B. Schrage, K. Ibrahim, T. Loehn, et al., Impella support for acute myocardial infarction complicated by cardiogenic shock, Circulation 139 (10) (2019) 1249–1258, https://doi.org/10.1161/CIRCULATIONAHA.118.036614.

[22] J. Pöss, J. Köster, G. Fuernau, et al., Risk stratification for patients in cardiogenic shock after acute myocardial infarction, J. Am. Coll. Cardiol. 69 (15) (2017) 1913–1920, https://doi.org/10.1016/j.jacc.2017.02.027.

[23] S. Vallabhajosyula, S. Vallabhajosyula, S.M. Dunlay, et al., Sex and gender disparities in the management and outcomes of acute myocardial infarction–cardiogenic shock in older adults, Mayo Clin. Proc. 95 (9) (2020) 1916–1927, https://doi.org/10.1016/j.mayocp.2020.01.043.

[24] S. Vallabhajosyula, L. Ya Qoub, M. Singh, et al., Sex disparities in the management and outcomes of cardiogenic shock complicating acute myocardial infarction in the young, Circulation, Heart Fail. 13 (10) (2020), https://doi.org/10.1161/CIRCHEARTFAILURE.120.007154.

[25] L. Obling, M. Frydland, R. Hansen, et al., Risk factors of late cardiogenic shock and mortality in st-segment elevation myocardial infarction patients, Eur. Heart J.-Acute Cardiovasc. Care 7 (1) (2018) 7–15, https://doi.org/10.1177/2048872617706503.

[26] J. Pöss, J. Köster, G. Fuernau, et al., Risk stratification for patients in cardiogenic shock after acute myocardial infarction, J. Am. Coll. Cardiol. 69 (15) (2017) 1913–1920, https://doi.org/10.1016/j.jacc.2017.02.027.

[27] E. Gayat, A. Hollinger, A. Cariou, et al., Impact of angiotensin-converting enzyme inhibitors or receptor blockers on post-icu discharge outcome in patients with acute kidney injury, Intensive Care Med. 44 (5) (2018) 598–605, https://doi.org/10.1007/s00134-018-5160-6.

[28] X. Zhao, G. Zhao, M. Zhou, et al., Early acei/arb use and in-hospital outcomes of acute myocardial infarction patients with systolic blood pressure <100 mmhg and undergoing percutaneous coronary intervention: findings from the ccc-acs project, Front. Cardiovasc. Med. 92022) 1003442, https://doi.org/10.3389/fcvm.2022.1003442.

[29] M.N. Cocchi, J. Dargin, M. Chase, et al., Esmolol to treat the hemodynamic effects of septic shock: a randomized controlled trial, Shock 57 (4) (2022) 508–517, https://doi.org/10.1097/SHK.0000000000001905.

[30] A. Morelli, C. Ertmer, M. Westphal, et al., Effect of heart rate control with esmolol on hemodynamic and clinical outcomes in patients with septic shock: a randomized clinical trial, JAMA, J. Am. Med. Assoc. 310 (16) (2013) 1683–1691, https://doi.org/10.1001/jama.2013.278477.

[31] D.S. Sim, M.H. Jeong, K.H. Cho, et al., Effect of early statin treatment in patients with cardiogenic shock complicating acute myocardial infarction, Korean Circ. J. 43 (2) (2013) 100–109, https://doi.org/10.4070/kcj.2013.43.2.100.

[32] H.K. Siddiqi, E.M. Defilippis, D.W. Biery, et al., Mortality and heart failure hospitalization among young adults with and without cardiogenic shock after acute myocardial infarction, J. Card. Fail. (2022), https://doi.org/10.1016/j.cardfail.2022.08.012.

[33] A. Kumar, L. Zhou, C.P. Huded, et al., Prognostic implications and outcomes of cardiac arrest among contemporary patients with stemi treated with pci, Resusc. Plus 72021) 100149, https://doi.org/10.1016/j.resplu.2021.100149.

[34] S. van Diepen, J.N. Katz, N.M. Albert, et al., Contemporary management of cardiogenic shock: a scientific statement from the american heart association, Circulation 136 (16) (2017), https://doi.org/10.1161/CIR.0000000000000525.

[35] V. Auffret, Y. Cottin, G. Leurent, et al., Predicting the development of in-hospital cardiogenic shock in patients with st-segment elevation myocardial infarction treated by primary percutaneous coronary intervention: the orbi risk score, Eur. Heart J. 39 (22) (2018) 2090–2102, https://doi.org/10.1093/eurheartj/ehy127.

[36] V. Auffret, G. Leurent, M. Gilard, et al., Incidence, timing, predictors and impact of acute heart failure complicating st-segment elevation myocardial infarction in patients treated by primary percutaneous coronary intervention, Int. J. Cardiol. 2212016) 433-442, https://doi.org/10.1016/j.ijcard.2016.07.040.