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Risk factors for cardiogenic shock incidence and mortality after acute myocardial infarction: a systematic review and meta-analysis

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Abstract

Background Cardiogenic shock (CS) is a serious complication of acute myocardial infarction (AMI), which could lead to severe health loss. This systematic review aimed to analyze the risk factors related to the incidence and poor outcomes of cardiogenic shock after acute myocardial infarction (AMI-CS), including in-hospital death, 30-day death and 1-year death.

Methods Original studies were systematically searched in PubMed and Embase up to November 2022. The summary odds ratio (OR) and 95% confidence interval (CI) of all studies were acquired based on a random effect model or fixed effect model. Subgroup analyses were conducted according to the study design, followed by sensitive analyses. The protocol was registered on PROSPERO (registration number: CRD42023466123).

Results There are 25 studies enrolled, including 12 cross-sectional studies, ten retrospective cohort studies, and three case-control studies. The pooled results reveal that female sex (OR, 1.10; 95% CI, 1.09-1.11), advanced age (OR, 1.06; 95% CI, 1.03-1.09), smoking (OR, 1.36; 95% CI, 1.26-1.45), diabetes (OR, 1.45; 95% CI, 1.08-1.82), and ST-segment elevation myocardial infarction (STEMI; OR, 1.99; 95% CI, 1.34-2.63) are significantly associated with the development of AMI-CS. Among these factors, all except smoking increase the risk of in-hospital death among AMI-CS patients. Advanced age (OR, 1.08; 95% CI, 1.04-1.12) and diabetes (OR, 1.77; 95% CI, 1.25-2.29) have negative impacts on 30-day death, while advanced age (OR, 2.10; 95% CI, 1.70-2.50) and STEMI (OR, 1.55; 95% CI, 1.15-1.95) are associated with 1-year death.

Conclusions Our findings highlight the significance of risk factors in predicting the incidence and prognosis of AMI-CS. Early identification and targeted interventions for individuals with these risk factors could potentially help prevent the occurrence of AMI-CS and improve patient outcomes.

Plain Language Summary

Heart failure after a heart attack poses considerable threats to the health of patients with high incidence rate and increased death. However, identification of the key risk factors involved in heart failure after a heart attack remains unknown. This systematic review article compiles findings from current research on heart failure following a heart attack to examine patterns between groups and determine potential risk factors. We find that risk factors include female sex, advanced age, smoking, diabetes, and a severe heart attack with complete blockage. All these factors, except smoking, increase the risk of in-hospital death. These findings highlight the need for preventative care for individuals with these risk factors to prevent mortality.

Cardiogenic shock (CS), inadequate end-organ perfusion due to primary cardiac dysfunction, is a serious complication in acute myocardial infarction (AMI). The massive health loss of cardiogenic shock after acute myocardial infarction (AMI-CS) imposes an immense burden on individuals, communities, and health systems, although prior studies reported that the incidence rate of CS in AMI is relatively low, ranging from 2.7 to 10%[1]. It is noticed that patients with AMI-CS have higher likelihood of rehospitalization, 19% of whom are readmitted at 30 days and 59% at one year[2,3]. The

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in-hospital mortality rate of AMI-CS is approximately 60%, which is considerably higher than that of AMI patients without CS (1.8%)[4,5]. Furthermore, more than half of AMI-CS patients (58.1%) died in the first year of diagnosis[4]. Over the recent years, these undesirable outcomes remained unchanged and resulted in health disparities between AMI-CS and AMI only[4].

In order to improve health outcomes, it is necessary to identify the risk factors for AMI-CS. Many studies have tried to evaluate these risk factors, which include sociodemographic factors[1,4,6–8], such as female sex and older age, behavioral factors[8,9], such as smoking, hypertension, and diabetes, and medical factors[7,8,10], such as history of comorbidity and clinical characteristics of AMI. However, most of these studies are conducted in a specific setting and their results are inconsistent, resulting in that it is hard to draw a definitive conclusion on the risk factors of AMI-CS. A meta-analysis is essential to synthesize the current evidence and increase the statistical power.

Therefore, we conducted a systematic review and meta-analysis aiming to estimate the risk factors of AMI-CS incidence and death. Through the identification of the risk factors, AMI population at high risk can receive protective intervention to prevent CS occurrence and subsequently poor outcomes.

This study reveal that female sex, advanced age, smoking, diabetes, and STEMI are associated with the development of AMI-CS. Except smoking, the other four factors increase the risk of mortality during hospitalization among AMI-CS patients. Advanced age and diabetes have negative effects on 30-day outcome, while advanced age and STEMI on 1-year outcome. These finding highlight the importance of early identification and targeted interventions for individuals with these risk factors to prevent the occurrence of AMI-CS and improve patient outcomes.

Methods

Literature search

This review was conducted in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines[11], and the study protocol was registered on PROSPERO (registration number: CRD42023466123).

A systematic search of PubMed and Embase was performed to identify all the related studies published prior to November 23, 2022. The following keywords and/or corresponding medical subject heading terms were used: acute myocardial infarction; cardiogenic shock; prevalence; incidence; epidemiology; and risk factor. The details for search strategies of databases can be found in Supplementary Table 1.

Types of participants

Patients were diagnosed with AMI complicating CS (ICD-9-CM codes or ICD-10-CM codes), including those with CS on admission or developed CS subsequently during hospitalization. AMI could be ST-segment elevation myocardial infarction (STEMI), non-ST segment elevation myocardial infarction (NSTEMI), and unstable angina (UA).

Eligibility criteria

Studies included in the meta-analysis should meet the following eligibility criteria: (1) original articles, including observational studies (e.g., cross-sectional, cohort and case-control studies), or experimental studies (e.g., randomized controlled study, RCT); (2) studies investigating the risk factors of AMI-CS occurrence and mortality; (3) studies reporting estimates of odds ratio (OR), relative ratio (RR), or hazard ratio (HR) with their corresponding 95% confidence interval (CI); (4) published in the English language.

Risk factors

Based on the previous evidence and guidelines[3,10,12,13], risk factors analyzed in this review included: female sex, advanced age, smoking, hypertension, diabetes, and STEMI. Smoking referred to both the status of ever smoking or current smoking. The definitions of other risk factors were mainly similar across studies and did not require extra description.

Outcomes

Primary outcome was the incidence of AMI-CS on admission and/or during the hospital. Secondary outcomes were AMI-CS mortality, including in-hospital death, 30-day death, and 1-year death. The 30-day death and 1-year death were defined as the all-cause death that occurred during the first month and first year after hospital discharge, respectively.

Study screening

Two researchers independently examined the eligibility of the studies identified through our search. First, all titles and abstracts were screened to determine relevance and adherence to the inclusion criteria. Then, full text screening was conducted to determine the ultimate included studies. Any disagreement between the two researchers during the screening process was resolved by reaching a consensus, and a third reviewer was consulted if necessary.

Data extraction

Data were extracted as follows: authors, publication year, study location (country in which the study was performed), study design, study period, number of cases (both total AMI and AMI-CS), prevalence rate of CS, and related risk factors.

Evaluation of research quality

The Newcastle-Ottawa Quality Assessment Scale (NOS) was used to assess the research quality for retrospective cohort, and case-control studies, which focuses on three domains: selection of study population, comparability between groups, and ascertainment of outcome (for cohort studies) and exposure (for case-control studies)[14]. An NOS score 7-9 indicated high quality of study, score 4–6 indicated moderate quality of study, and scores <4 indicated low quality of study. The Agency for Healthcare Research and Quality (AHRQ) methodology checklist was used to evaluate the quality of cross-sectional studies[15], which considers 11 items for quality assessment. Studies with scores 8-11, 4–7, and 0–3 were graded to be of high quality, moderate quality, and low quality, respectively. Any disagreement was resolved by reaching a consensus, and a third reviewer was consulted if necessary. For details of the assessment tools, see Supplementary Data 1–3.

Statistics and reproducibility

Data were pooled if at least two studies reported the same outcomes and study factors. The odds ratio (OR) and their 95% confidence interval (95% CI) were calculated to assess the pooled effect size, and P value < 0.05 was considered to be statistically significant. As for female's OR, when a study reported the OR of the male group, we computed the OR of the female by taking the reciprocal of the OR of the male. Some studies estimated the effect of age on the outcomes of interest by considering age as a continuous variable, while some considering age as a categorical variable. In this case, we extracted the OR of the last age group.

The Q test and I^2 statistic were applied to estimate heterogeneity. If there was substantial heterogeneity (Q test < 0.1 or I^2 > 50%) across studies, a random effect model (DerSimonian-Laird method) was used; otherwise, a fixed effect model (Inverse-Variance method) was applied. We performed meta-analysis irrespective of the statistical heterogeneity (I^2 statistic), but we attempted to explore possible reasons for variability by conducting subgroup analysis or sensitive analysis, and to interpret the degree of heterogeneity.

Subgroup analysis was performed according to the study design (cross-sectional, retrospective cohort, and case-control studies) when there was substantial heterogeneity (Q test<0.1 or I^2 > 50%) and sufficient studies (at least two studies in each group).

We performed sensitive analysis, repeating the meta-analysis, to assess the robustness of our conclusions and the effect of computed data on the

pooled results, in which we excluded studies reporting the results of univariate analysis, unadjusted analysis, and opposite group (the male). That is, data only resulted from multivariate analysis controlling covariables was included in sensitive analysis. In all the sensitive analysis for age, we additionally excluded studies that reported the OR of age considering it as a categorical variable.

If there were more than 10 studies, a funnel plot was generated to explore possible publication bias; otherwise, we applied Egger's regression test. All statistical analyses and tests were performed by STATA 17.0 (StataCorp, College Station, TX).

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Results

Study selection

Figure 1 shows the process of study identification and selection. A total of 705 articles were identified through electronic literature search (152 records through PubMed, and 553 records through Embase). After removing duplicates ($n = 54$), the titles and abstracts of 651 articles were screened. Then, 51 articles were assessed through full texts, among which 26 articles were excluded for specific reasons. Finally, 25 articles[1,4,6–8,10,16–34] met the eligibility criteria and were included in the meta-analysis.

Study characteristics

The main characteristics of the 25 studies included are summarized in Supplementary Data 4. There were 12 cross-sectional, ten retrospective cohort, and three case-control studies, among which ten studies were from North America, 13 studies from Europe, one study from Asia, and one study were from multiple continents involving North America, South America, Europe, and Oceania. A total of 19 studies were considered to be high-quality, and 6 studies were moderate-quality.

Risk factors of AMI-CS development

The incidence rate of AMI-CS ranged from 5.1% (Spain) to 8.5% (America) according to the latest studies[16,17], while there was no certain trend in the incidence rate of AMI-CS over the past 20 years, varying between 2.7% and 10%.

According to the summary effect sizes, the predictors of AMI-CS incidence included female sex, advanced age, smoking, diabetes, and STEMI (Table 1). Five studies examined the sex effect on AMI-CS incidence were included[10,18,21,25,26], which all were cross-sectional studies. The pooled OR for female was 1.10 (95% CI, 1.09–1.11; $P < 0.001$), with a low heterogeneity across studies ($P = 0.32$, $I^2 = 14.92\%$). As is also the case with smoking, the pooled OR was 1.36 (95% CI, 1.26–1.45; $P < 0.001$), with a low heterogeneity across studies ($P = 0.68$; $I^2 = 0.00\%$). In the sensitive analysis for studies related to female, the heterogeneity was further decreased to 0.00% ($P = 0.55$), demonstrating a consistent (OR, 1.10; 95% CI, 1.09–1.11; $P < 0.001$) (Fig. 1).

Although negative effects were observed in the meta-analysis of studies focusing on advanced age (OR, 1.06; 95% CI, 1.03–1.09; $P < 0.001$), diabetes (OR, 1.45; 95% CI, 1.08–1.82; $P < 0.001$), and STEMI (OR, 1.99; 95% CI, 1.34–2.63; $P < 0.001$), there was substantial heterogeneity across studies, with I^2 statistics of 97.25% ($P < 0.001$), 74.29% ($P = 0.02$), and 96.77% ($P < 0.001$), respectively (Table 1). After performing subgroup analysis by

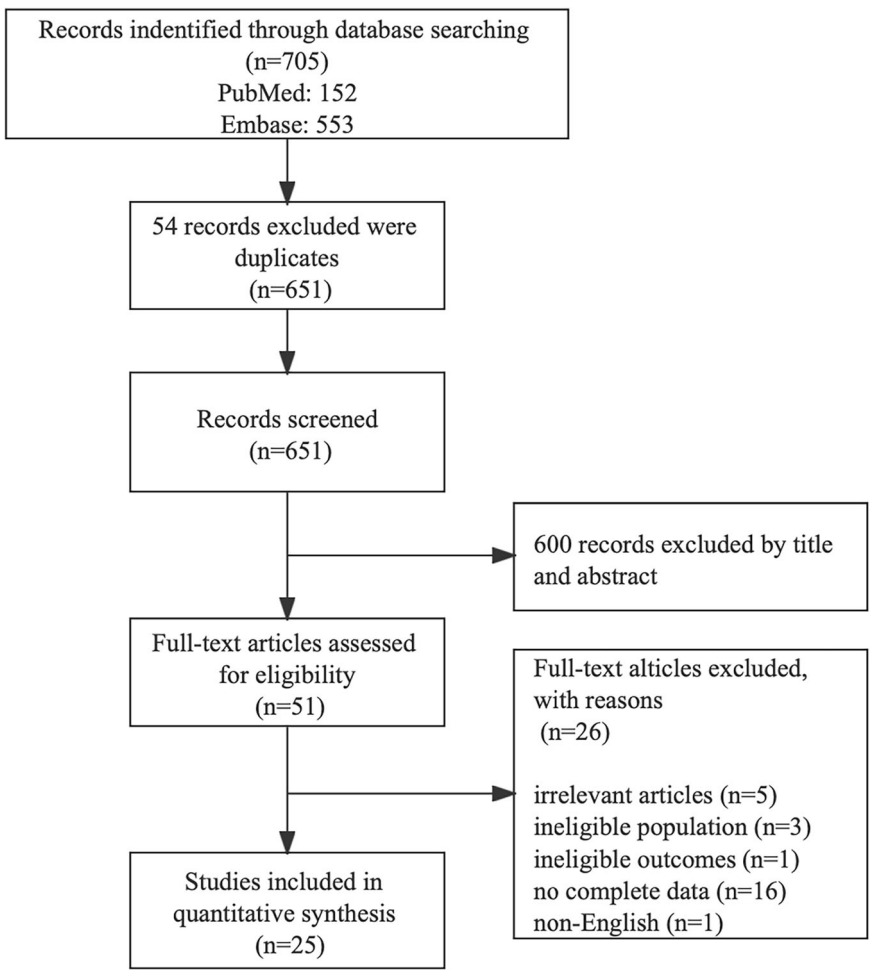

Fig. 1 | Flowchart for study selection. The diagram illustrates the procedure followed to identify the eligible studies. Studies were excluded in each critical screening step based on the eligibility criteria.

Table 1 | Meta-analysis results of the associations between the risk factors and outcomes of interest

	No. of studies	Heterogeneity		Effect size		*P* value of Egger test
		P value	I^2 (%)	OR (95% CI)	*P* value	
AMI-CS development						
Female	5	0.32	14.92	1.10 (1.09–1.11)	1.08 × 10^–15	0.28
Advanced age	7	4.62 × 10^–14	97.25	1.06 (1.03–1.09)	1.01 × 10^–14	1.00 × 10^–4
Smoking	2	0.68	0.00	1.36 (1.26–1.45)	1.23 × 10^–18	–
Hypertension	4	6.23 × 10^–13	96.17	1.40 (0.74-2.06)	3.63 × 10^–5	0.53
Diabetes	3	0.02	74.29	1.45 (1.08–1.82)	1.87 × 10^–14	0.22
STEMI	4	2.56 × 10^–14	96.77	1.99 (1.34–2.63)	1.97 × 10^–9	0.74
In-hospital death						
Female	7	0.06	50.69	1.16 (1.13–1.18)	8.19 × 10^–12	0.32
Advanced age	9	1.00 × 10^–20	99.96	1.85 (1.69–2.01)	4.17 × 10^–12	0.30
Smoking	1	–	–	–	–	–
Hypertension	2	8.34 × 10^–10	97.35	1.00 (0.81–1.18)	1.08 × 10^–16	–
Diabetes	3	2.80 × 10^–3	82.93	1.08 (1.00–1.17)	3.82 × 10^–18	0.35
STEMI	2	0.80	0.00	1.57 (1.52–1.62)	1.08 × 10^–19	–
30-day death						
Female	4	0.01	76.21	1.26 (0.88–1.64)	5.75 × 10^–11	0.27
Advanced age	6	1.21 × 10^–6	94.14	1.08 (1.04–1.12)	1.65 × 10^–15	1.00 × 10^–3
Smoking	3	0.01	80.01	1.07 (0.48–1.67)	4.15 × 10^–4	0.69
Hypertension	4	0.01	73.65	1.02 (0.82–1.21)	4.49 × 10^–14	0.47
Diabetes	3	0.01	80.60	1.77 (1.25–2.29)	3.14 × 10^–11	0.19
STEMI	3	1.13 × 10^–10	95.52	2.11 (0.72–3.51)	3.00 × 10^–3	0.30
1-year death						
Female	4	2.55 × 10^–6	87.56	1.08 (0.84–1.33)	4.87 × 10^–8	0.51
Advanced age	3	1.21 × 10^–12	99.30	2.10 (1.70–2.50)	1.02 × 10^–12	0.40
Smoking	2	4.00 × 10^–4	91.95	1.44 (0.05–2.83)	0.04	–
Hypertension	0	–	–	–	–	–
Diabetes	0	–	–	–	–	–
STEMI	2	0.04	75.60	1.55 (1.15–1.95)	4.04 × 10^−14	–

AMI acute myocardial infarction, *AMI-CS* cardiogenic shock after acute myocardial infarction, *CI* confidence interval, *CS* cardiogenic shock, *OR* odds ratio, *STEMI* ST-segment elevation myocardial infarction.

study design (six cross-sectional studies)[4,7,10,18,25,26], the pooled effect also presented advanced age as a risk factor, but the high heterogeneity still existed (Supplementary Table 2). However, a reduction in heterogeneity was observed after sensitive analysis ($P = 1.00$; $I^2 = 0.00\%$), indicating the correlation between advanced age and AMI-CS incidence (OR, 1.03; 95% CI, 1.03–1.03; $P < 0.001$) (Fig. 2). As for STEMI, we did not find a large reduction in heterogeneity ($P < 0.001$; $I^2 = 93.04\%$) through sensitive analysis, but the pooled effect remained the same direction (OR, 2.12; 95% CI, 1.68-2.58; $P < 0.001$) (Supplementary Table 3).

Four studies were pooled to assess the effect of hypertension[7,10,25,26], and it was found that there was no significant association between hypertension and AMI-CS incidence (OR, 1.04; 95% CI, 0.74–2.06; $P < 0.001$) (Table 1).

Risk factors of AMI-CS in-hospital death

Quantitative synthesis was performed for studies related to all factors but smoking, as only one included study[28] examined the effect of smoking on the in-hospital death of AMI-CS (Table 1). The results revealed that there were correlations between AMI-CS in-hospital death and female, advanced age, diabetes, and STEMI. The overall OR of female was 1.16 (95% CI, 1.13–1.18; $P < 0.001$), with a high heterogeneity ($P = 0.06$; $I^2 = 97.25\%$). Subgroup analysis of female showed major reductions in heterogeneity across both cross-sectional studies[17,18] ($P = 1.00$; $I^2 = 0.00\%$) and retrospective cohort studies[28,30–32] ($P = 0.40$; $I^2 = 0.00\%$), with negative effect sizes (cross-sectional: OR, 1.16; 95% CI, 1.15–1.17; retrospective cohort: OR, 1.15; 95% CI, 1.12–1.19) (Supplementary Table 2). Sensitive analysis demonstrated a consistent (OR, 1.16; 95% CI, 1.15–1.17; $P = 0.06$; heterogeneity, $P = 0.63$; $I^2 = 0.00\%$) (Fig. 3).

The negative pooled effects were also observed in advanced age (OR, 1.85; 95% CI, 1.69–2.01; $P < 0.001$), and diabetes (OR, 1.08; 95% CI, 1.00–1.17; $P < 0.001$), but with substantial heterogeneity across studies, with I^2 statistics of 99.96% ($P < 0.001$) and 82.93% ($P < 0.001$), respectively (Table 1). After performing subgroup analysis and sensitive analysis for studies investigating advanced age, considerable heterogeneity was still noticed, whereas the direction of effect size remained the same (OR, 1.08; 95% CI, 1.05–1.11; $P < 0.001$) (Fig. 2). With a low heterogeneity across studies ($P = 0.80$; $I^2 = 0.00\%$), STEMI increased the risk of in-hospital death among AMI-CS patients (OR, 1.57; 95% CI, 1.52–1.62; $P < 0.001$). Again, there was no significant association between hypertension and AMI-CS in-hospital death (OR, 1.00; 95% CI, 0.81–1.18; $P < 0.001$) (Table 1).

Risk factors of AMI-CS 30-day death

The predictors of 30-day death among AMI-CS patients were advanced age (OR, 1.08; 95% CI, 1.04–1.12; $P < 0.001$) and diabetes (OR, 1.77; 95% CI,

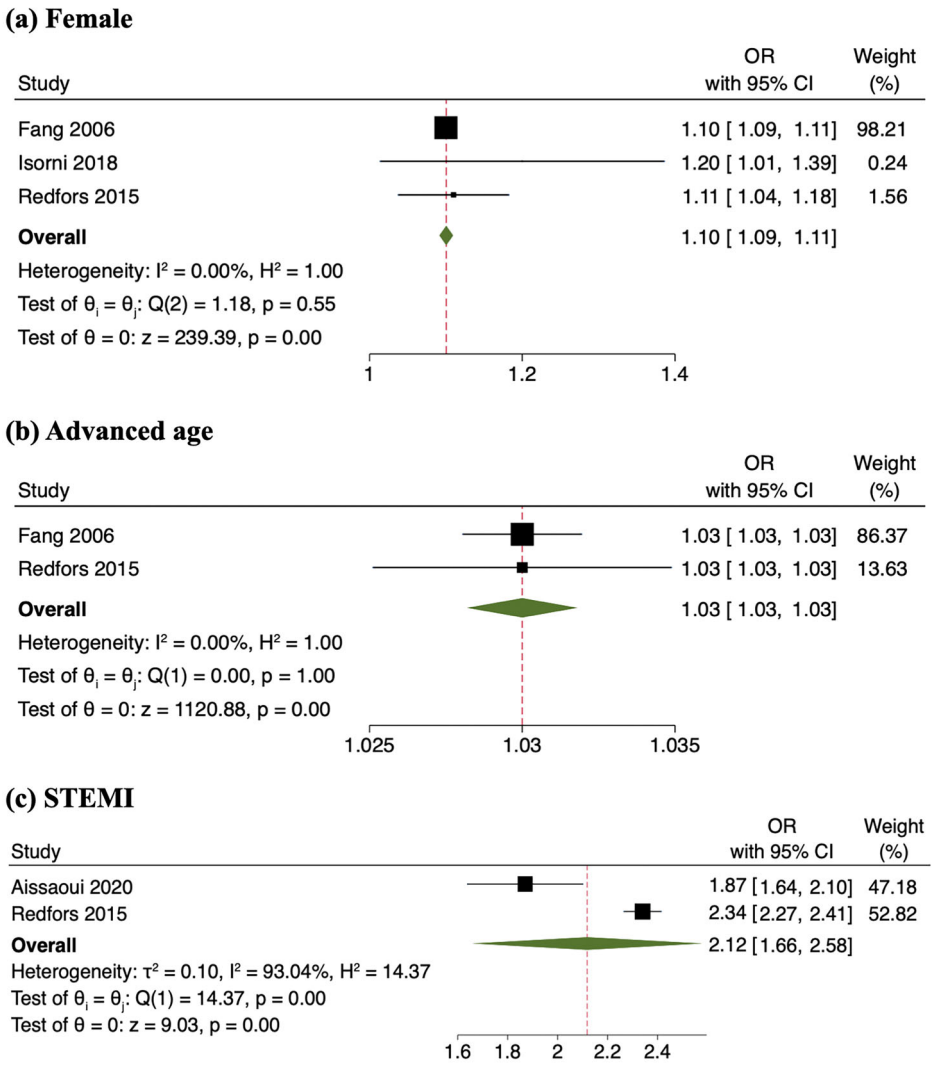

Fig. 2 | Forest plot of sensitive analysis for the association between female, advanced age, and STEMI and AMI-CS development. a Sensitive analysis for the association between female and AMI-CS development. **b** Sensitive analysis for the association between advanced age and AMI-CS development. **c** Sensitive analysis for the association between STEMI and AMI-CS development. The random- effects model was used to estimate the pooled effect of female, advanced age and STEMI on reducing the risk of AMI-CS development. The green diamond shape and the red dotted line show the effect size (odds ratio with 95% confidence interval) in each group, while the lateral tips of the diamond represent the confidence interval. The square shapes in individual study suggests the effect size estimate, while the bigger the shape, the larger the sample size and the reverse is true. AMI-CS cardiogenic shock after acute myocardial infarction, CI confidence interval, OR odds ratio, STEMI ST-segment elevation myocardial infarction.

1.25–2.29; $P < 0.001$), but there were high heterogeneities (Table 1). Sensitive analysis yielded a considerable reduction in heterogeneity across studies related to age (I^2 statistics from 94.14% to 57.99%), and a slight reduction in heterogeneity across studies related to diabetes (I^2 statistics from 95.52% to 81.51%), and the pooled effects were still consistent with the initial analysis (Fig. 4), indicating a robustness of the results.

Other factors, female, smoking, STEMI, were proved to have no significant associations with AMI-CS 30-day death. To be noted, sensitive analysis for studies focusing on hypertension showed that AMI-CS patients with hypertension were at lower risk of 30-day death than those without hypertension (Supplementary Table 3).

Risk factors of AMI-CS 1-year death

Meta-analysis was conducted for studies related to female, advanced age, smoking and STEMI as there were enough data only for these four factors (Table 1). The results showed that advanced age (OR, 2.10; 95% CI, 1.70–2.50; $P < 0.001$), and STEMI (OR, 1.55; 95% CI, 1.15–1.95; $P < 0.001$) increased the risk of AMI-CS death during the first year after hospital discharge. After performing subgroup analysis and sensitive analysis for studies focusing on age, we observed a considerable reduction in heterogeneity (I^2 statistics from 99.30 to 14.25%) (Supplementary Table 2 and Fig. 5). The overall results and the direction of the effect seem not to be affected by the data from univariate analysis, unadjusted analysis or computation, and we considered the results of the analyses robust.

Discussion

There were increasing studies on the risk factors of AMI-CS, but they were merely conducted in a single setting with small sample sizes, and their results were not consistent so that the conclusion from these studies should be further verified. In addition, clinical trials, such as the Culprit Lesion Only PCI versus Multivessel PCI in Cardiogenic Shock (CULPRIT-SHOCK) trials and the Intraaortic Balloon Pump in Cardiogenic Shock (IABP-SHOCK II) trials, that were mainly conducted in European countries[35–37]. These studies mainly investigated the prognosis impact of different treatments or complications on the AMI-CS. This study synthesized previous evidence to systematically analyze the correlations between patient-related factors and AMI-CS. In order to increase the reliability and robustness of the results, we performed subgroup analysis and sensitive analysis when there was enough data.

According to the analysis, the independent risk factors of (1) AMI-CS incidence were: female sex, advanced age, smoking, diabetes, and STEMI; (2) AMI-CS in-hospital death were: female sex, advanced age, diabetes, and STEMI; (3) AMI-CS 30-day death were: advanced age and diabetes; (4) AMI-CS 1-year death were: advanced age and STEMI.

As revealed in our analysis, women, older age, smoking, diabetes and STEMI are related to an increasing risk of AMI-CS. The underlying reason for this result could be a low awareness of cardiovascular risk. The Should We Emergently Revascularize Occluded Coronaries In Cardiogenic Shock? (SHOCK) trial and registry, a study on the association of coronary artery revascularization for AMI-CS patients, demonstrated that a median (IQR)

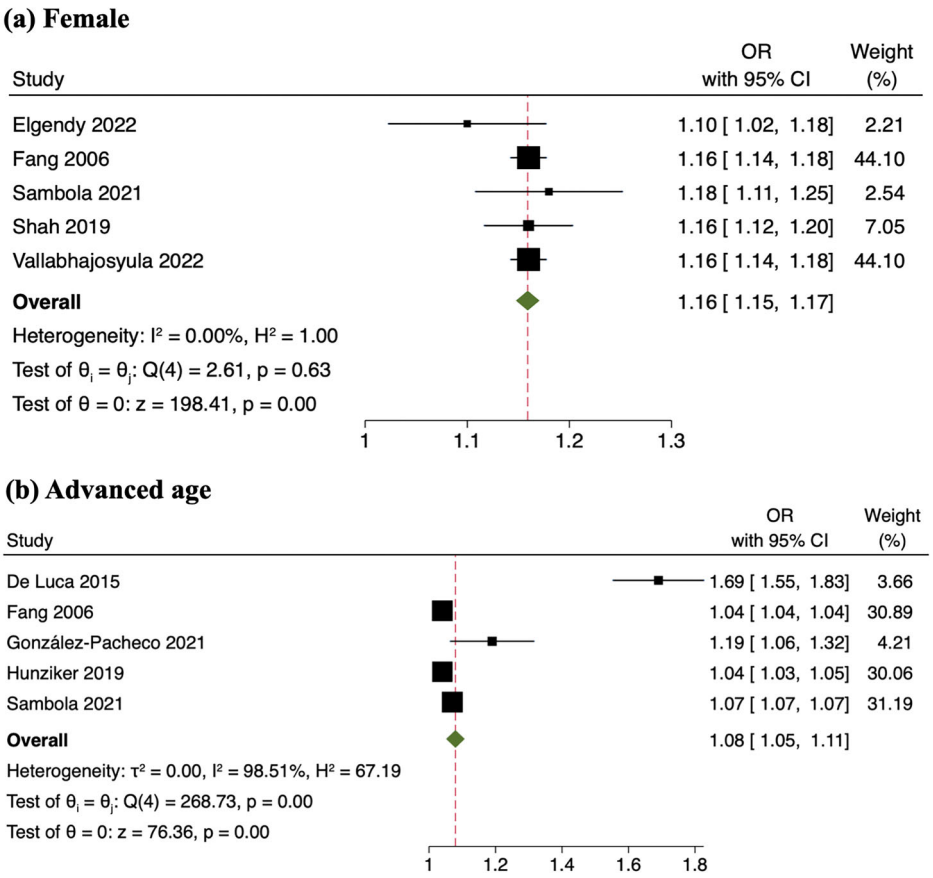

Fig. 3 | Forest plot of sensitive analysis for the association between female and advanced age and in-hospital death among AMI-CS patients. a Sensitive analysis for the association between female and in-hospital death. **b** Sensitive analysis for the association between advanced age and in-hospital death. The random- effects model was used to estimate the pooled effect of female and advanced age on reducing the risk of AMI-CS in-hospital death. The green diamond shape and the red dotted line show the effect size (odds ratio with 95% confidence interval) in each group, while the lateral tips of the diamond represent the confidence interval. The square shapes in individual study suggests the effect size estimate, while the bigger the shape, the larger the sample size and the reverse is true. AMI-CS cardiogenic shock after acute myocardial infarction, CI confidence interval, OR odds ratio.

time from AMI symptom onset to CS onset is 6.2 (1.7–20.1) hours, while 74.1% of AMI patients would develop CS during the first 24 h after AMI[5]. However, women are less likely to receive timely revascularization and antithrombotic therapy, which can be attributed to older age, higher prevalence of comorbidities, and higher risk of bleeding[6,38,39], resulting in prolonged myocardial ischemia with a higher risk of CS, or lower use of invasive therapy which in turn can increase the risk of CS[40]. STEMI patients, among whom the frequency of CS is approximately 30% greater than NSTEMI[16], LV infraction that more occurs in STEMI are proven to be correlated with greater risk of CS[33,41]. On the basis of most clinical investigations, CS mainly results from severe left ventricular (LV) dysfunction due to AMI[42].

Patients with the risk factors of AMI-CS appear to be more susceptible to poor outcomes. Given the unencouraging facts of female patients that are stated above[5,6,38–40], it is explainable, to some extent, that female sex is correlated to short-term death. Of note, older age could result in poor prognosis irrespective of the observation time, which can be attributable to a greater burden of comorbidities, more severe coronary disease, and more unfavorable hemodynamic status[10,25]. Diabetes, for example, is more common in the older, which was also verified as a risk factor of patient death in our study. In addition, SHOCK trial suggested a lower rate of invasive therapy among the elderly with AMI-CS[8]. As for STEMI, previous studies suggested the association between higher in-hospital mortality and worse thrombolysis in myocardial infarction (TIMI) flow at the end of the procedure[16]. Furthermore, STEMI patients complicated by CS (STEMI-CS) tend to be older and have more than one comorbidity[43,44]. A greater burden of atherosclerotic coronary disease is also seen in STEMI-CS patients. For instance, chronic total occlusion (CTO) is nearly 4- to 10-fold higher in STEMI-CS than STEMI without CS (1 CTO: 23% in STEMI-CS vs. 6% in STEMI without CS; >1 CTO: 5% in STEMI-CS vs. 0.5% in)[33]. Thus, patients with STEMI-CS might be at higher risk of death.

CS is a fatal complication of AMI that contributes to approximately 60% of death at hospitals[5], and 40% of death at 30 days, and 60% of death at one year[4,5,45]. Early recognizing patients at high risk might give room for early aggressive therapy to prevent this condition and hereby reduce its serious consequences. Our findings reinforce the urgent for an initial examination of the associated factors for AMI-CS, such as patient's sociodemographic characteristics, comorbid conditions, and type of acute infarction. Education is required to alert AMI patients to the potential of the CS incidence as well as to remind paramedics of the prompt recognition of vulnerable population and predictive interventions for this condition during AMI treatment. Additionally, immediate revascularization should be taken into consideration when managing a patient with AMI-CS as it is the only therapy to decline death in CS[45], which was identified by a randomized trial and further supported by data from a long-term follow-up study[46,47].

This systematic review has several limitations. First, meta-analysis for some factors, such as female sex and age, used generated data or selected data. We described the necessity for this in the method section and performed sensitive analysis in the hope of ruling out the impact on the results. In general, the generated data and selected data had no influence on the robustness of the conclusion. Second, there were high heterogeneity across studies that might be resulted from different study design, geographic location, time periods, and so forth. Although we attempted to address it by conducting subgroup analysis, the source of heterogeneity was identified only for limited studies. Third, considering the all-cause death as measure indicator is likely to amplify the effect of CS on AMI. Last, the lack of adequate studies keeps us from conducting data synthesis to identify possible predictors of AMI-CS, such as clinical characteristics, laboratory results, and treatment characteristics. Failure to detection cannot eliminate a negative effect or vice versa. Thus, it is warranted to conduct well-designed prospective studies, such as RCT and cohort studies that are particularly

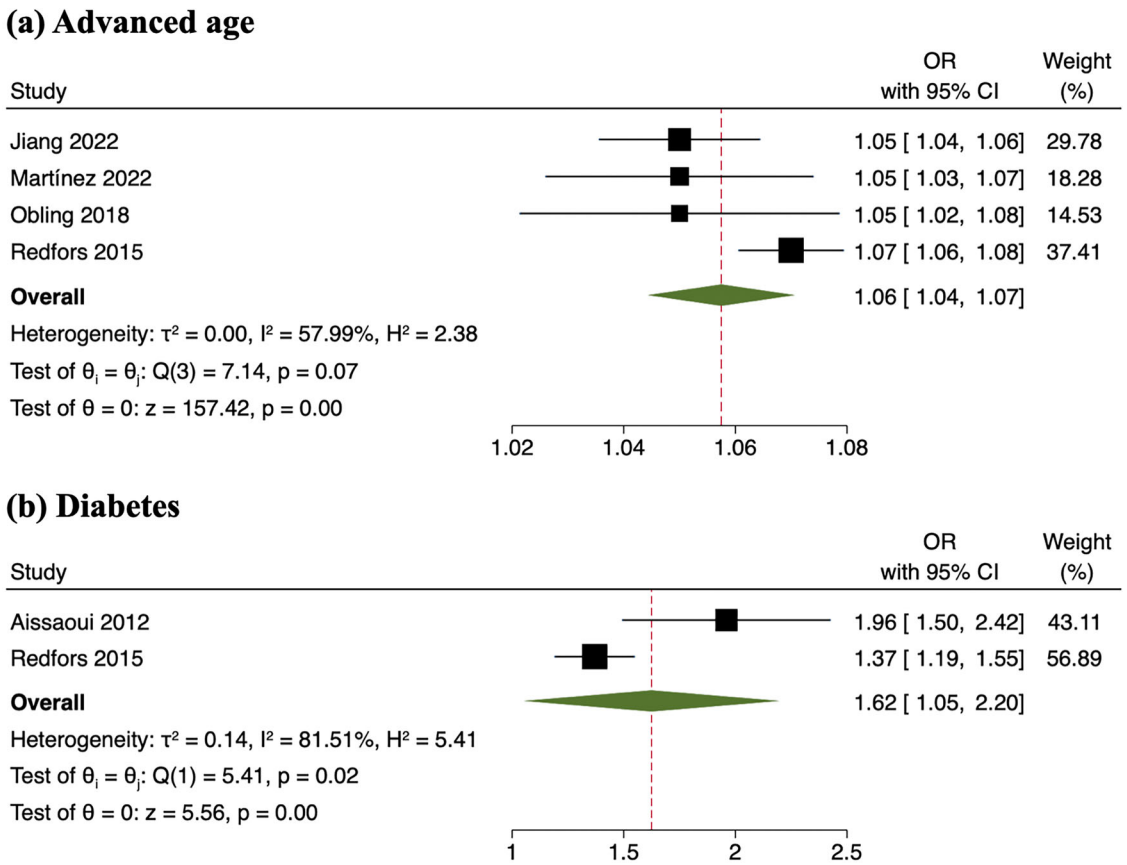

Fig. 4 | Forest plot of sensitive analysis for the association between advanced age and diabetes and 30-day death among AMI-CS patients. a Sensitive analysis for the association between advanced age and diabetes and 30-day death; **b** Sensitive analysis for the association between diabetes and diabetes and 30-day death. The random- effects model was used to estimate the pooled effect of advanced age and diabetes on reducing the risk of AMI-CS 30-day death. The green diamond shape and the red dotted line show the effect size (odds ratio with 95% confidence interval) in each group, while the lateral tips of the diamond represent the confidence interval. The square shapes in individual study suggests the effect size estimate, while the bigger the shape, the larger the sample size and the reverse is true. AMI-CS cardiogenic shock after acute myocardial infarction, CI confidence interval, OR odds ratio.

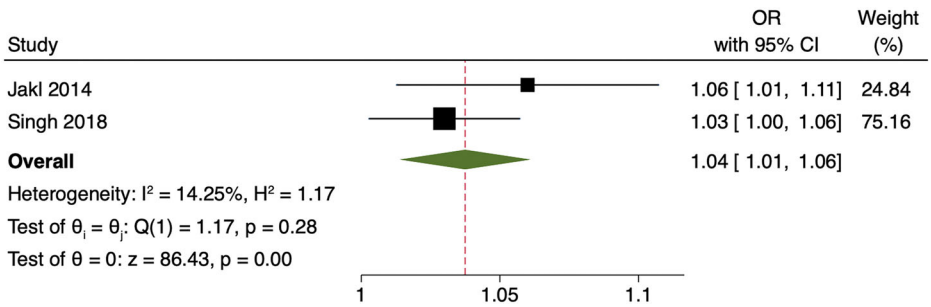

Fig. 5 | Forest plot of sensitive analysis for the association between advanced age and 1-year death among AMI-CS patients. The random- effects model was used to estimate the pooled effect of advanced age on reducing the risk of AMI-CS 1-year death. The green diamond shape and the red dotted line show the effect size (odds ratio with 95% confidence interval) in each group, while the lateral tips of the diamond represent the confidence interval. The square shapes in individual study suggests the effect size estimate, while the bigger the shape, the larger the sample size and the reverse is true. AMI-CS cardiogenic shock after acute myocardial infarction, CI confidence interval, OR odds ratio.

from low- and middle-income countries, to verify the influence of these risk factors on AMI-CS from a comprehensive perspective.

In conclusion, the quantitative analysis of all available studies suggests that female sex, advanced age, smoking, diabetes, and STEMI are associated with the development of AMI-CS. Except smoking, the other four factors increase the risk of mortality during hospitalization among AMI-CS patients. Advanced age and diabetes have negative effects on 30-day outcome, while advanced age and STEMI on 1-year outcome. Patients with these characteristics should be paid attention with the aim of reducing severe health loss caused by AMI-CS. Further research is warranted to develop specific strategies for risk stratification and management of this severe cardiovascular condition.

Data availability

All data used to produce this study was gathered from published studies. The key terms and search strategies built to retrieve studies are available in Supplementary Table 1. The list of included studies is available in Supplementary Data 4. The source data for Table 1 and Figs. 2–5 are available in

Supplementary Data 5. All other relevant data that support the findings of the study are available from the corresponding author upon reasonable request.

Code availability

The underlying code for this study is available at https://github.com/maimai1204/meta_code.git[48].

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Author contributions

Y.J. and M.M. developed the study concept and design. M.M., S.L. and K.H. contributed to study selection and data extraction. M.M. contributed to statistical analysis, data interpretation and manuscript writing. M.M., F.L. and S.C.S.Jr. provided critical comments. Z.-J.Z. provided critical revision of article for important intellectual content. All authors revised the manuscript and approved the final version.

Competing interests

The authors declare no competing interests.

Additional information

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