Mortality in cardiogenic shock patients receiving mechanical circulatory support: a network meta-analysis

Qun Zhang1,2,3,4, Yu Han1,2,3,4, Shukun Sun1,2,3,4, Chuanxin Zhang1,2,3,4, Han Liu1,2,3,4, Bailu Wang5 and Shujian Wei1,2,3,4*

Abstract

Objective: Mechanical circulatory support (MCS) devices are widely used for cardiogenic shock (CS). This network meta-analysis aims to evaluate which MCS strategy offers advantages.

Methods: A systemic search of PubMed, EMBASE, and the Cochrane Central Register of Controlled Trials was performed. Studies included double-blind, randomized controlled, and observational trials, with 30-day follow-ups. Paired independent researchers conducted the screening, data extraction, quality assessment, and consistency and heterogeneity assessment.

Results: We included 39 studies (1 report). No significant difference in 30-day mortality was noted between venoarterial extracorporeal membrane oxygenation (VA-ECMO) and VA-ECMO plus Impella, Impella, and medical therapy. According to the surface under the cumulative ranking curve, the optimal ranking of the interventions was surgical venting plus VA-ECMO, medical therapy, VA-ECMO plus Impella, intra-aortic balloon pump (IABP), Impella, Tandem Heart, VA-ECMO, and Impella plus IABP. Regarding inhospital mortality and 30-day mortality, the forest plot showed low heterogeneity. The results of the node-splitting approach showed that direct and indirect comparisons had a relatively high consistency.

Conclusions: IABP more effectively reduce the incidence of 30-day mortality compared with VA-ECMO and Impella for the treatment of CS.

Keywords: Cardiogenic shock, Mechanical circulatory support, Venoarterial extracorporeal membrane oxygenation, intra-aortic balloon pump, Impella, Tandem heart

Introduction

Cardiogenic shock (CS) is a state of low cardiac output and hypoperfusion that is highly associated with organ damage [1]. The progress made in the field of mechanical circulatory support (MCS) has led to considerable changes in the management and treatment of CS; however, CS remains associated with a certain degree of mortality [2]. In clinical practice, venoarterial extracorporeal membrane oxygenation (VA-ECMO) has been frequently used to treat CS caused by different aetiologies such as postcardiotomy shock, acute myocardial infarction (AMI), end-stage heart failure, and acute myocarditis [1, 3–7].

CS continues to be associated with high rates of mortality and morbidity, causing a therapeutic challenge for clinicians [1, 8–10]. Although the mortality of CS patients may decrease over time, the short-term
mortality rate remains 35–40% [11–13]. The main cause of CS is myocardial infarction (MI) [11]. Nevertheless, even after active treatment, there is a high mortality rate, so it is particularly important to reduce short-term mortality [11, 14]. MCS has achieved considerable advances in the treatment of CS and MCS has a theoretical basis for the treatment of CS. Moreover, this treatment has been accepted by clinicians. Therefore, the purpose of this study was to evaluate the in-hospital mortality and 30-day mortality of CS patients who underwent MCS treatment, to provide the best intervention strategy for clinicians.

Methods
This network meta-analysis (NMA) complies with the Preferred Reporting Items of Systematic Reviews and Meta-Analyses (PRISMA) guidelines [15]. All aspects involved in this study were independently conducted by at least two researchers.

Inclusion criteria
Study types: Studies included double-blind, randomized controlled, and observational trials, with 30-day follow-ups.

Participants: Patients included adults and children diagnosed with CS. CS diagnostic criteria have been debated over the years. Clinicians established the presence of CS by combining evidence of end-organ dysfunction and abnormal haemodynamic parameters. Most patients were diagnosed based on some combination of the following diagnostic criteria: (I) severe hypotension with systolic blood pressure (BP) < 80–90 mmHg for at least 30 min, the mean BP decreases by 30 mmHg or more from baseline, and vasoactive medications are needed to maintain the systolic BP above 90 mmHg in spite of sufficient fluid resuscitation; (II) elevated biventricular filling pressures with pulmonary capillary wedge pressure (PCWP) exceeding 15 mmHg and central venous pressure above 10 mmHg; (III) significantly reduced cardiac index (< 1.8 L/min/m² or < 2.2 L/min/m² with haemodynamic support); (IV) low mixed venous blood oxygen saturation signalling increased peripheral oxygen extraction due to hypoperfusion [13, 16].

Interventions: The interventions for CS included Tandem Heart (Cardiac Assist, Pittsburgh, PA, USA) plus Impella, medical therapy, VA-ECMO plus intra-aortic balloon pump (IABP), Tandem Heart, IABP, Impella, VA-ECMO, VA-ECMO plus Impella, Impella plus IABP, and Surgical Venting plus VA-ECMO.

Retrieval strategy
To identify relevant clinical trials, we searched PubMed, EMBASE, and the Cochrane Central Register of Controlled Trials. To expand the number of included studies, the search terms “cardiogenic shock” and “mechanical circulatory support” were used. The researchers screened the literature according to the inclusion criteria of this study. After two researchers determined that an article satisfied the preliminary inclusion criteria by reading the title and abstract, the researchers proceeded to read the full text independently to finally determine whether the article met the inclusion criteria. When differences were noted, the two researchers discussed the inclusion qualification of the article until they reached an agreement. If no agreement could be reached, a third researcher acted as an arbitrator to determine whether the article met the inclusion criteria. The reference lists of all included studies were also screened to examine relevant articles and discover other related published and unpublished research. To minimize publication bias, clinical trial registries (ClinicalTrials.gov [http://clinicaltrials.gov/]) were searched. Any discrepancies in the selected papers were resolved by consensus.

Data extraction and clinical outcome
A data extraction form was used by two pairs of reviewers to extract data independently and duplicate them. The name of the project or the last name of the first author, the time of publication, study design, setting, aetiology of CS, and interventions (VA-ECMO plus IABP, IABP, VA-ECMO, medical therapy, VA-ECMO plus Impella, percutaneous left ventricular (LV) assist devices (PLVADs)) were extracted. We considered “no MCS used” described by the study authors as “medical therapy” and extracted quantitative data from the studies. The number of patients who died in the hospital, those who died within 30 days, and the total number of patients receiving treatment were extracted. The primary outcomes were in-hospital mortality and 30-day mortality.

Meta-analysis methods and quality assessment
Using fixed-effects models [17], a Bayesian NMA was conducted using netmeta [18]. The NMA was used to estimate the relative effectiveness of all interventions for the primary outcomes by using a fixed-effects model combined with direct and indirect evidence. The model assumes that the between-study heterogeneity parameters and frequency theory methods of the whole network are common. We conducted NMA using the package netmeta in R software (Version 4.0.3, http://www.r-project.org/). The design-by-treatment test (global) and the node-splitting approach were used to perform a statistical evaluation of consistency. The Bayesian analyses estimated rank probabilities. The probability of each treatment obtaining each possible rank is shown by their relative effects. Odds ratios (ORs) and 95% confidence
intervals (CIs) were used to evaluate the efficacy of various MCS equipment for adverse clinical events. To visualize heterogeneity, prediction intervals were used in the forest plots for the primary outcomes. We assessed network heterogeneity by the I² statistic. I² > 50% indicated higher heterogeneity. The fixed-effects model was used first. When I² was > 50%, a random-effects model was used for statistical analysis. Subgroup analysis was performed to explore the causes of heterogeneity. Sensitivity analysis was performed by omitting each study to evaluate the reliability and stability of all studies. The methodological quality of the included articles was assessed according to the Cochrane Risk of Bias criteria [19]. CINeMA grades the confidence for the results of each intervention comparison as high, moderate, low, or very low. The statistical analyses in this NMA were performed using a combination of R software (Version 4.0.3, http://www.r-project.org/), STATA statistical software (version 16; StataCorp, College Station, Texas, USA), and Review Manager software (Version 5.3; Copenhagen; The Nordic Cochrane Center; The Cochrane Collaboration, 2014).

Results

Study characteristics
A total of 4461 articles were retrieved by searching relevant online databases. Of these, 253 articles were eliminated due to duplication. By retrieving the references of previous meta-analyses, 26 additional articles met the inclusion criteria. After reading the title and abstract, 4158 articles were excluded and 50 were identified. Thereafter, 11 articles were removed after reading the full text. The flow chart of literature retrieval and reasons for article exclusion are shown in Fig. 1. Finally, we included 39 studies (including 1 report) in this NMA [11, 21–57]. The quality assessment of studies that met the inclusion criteria is summarized in Table 1. The study designs of all randomized controlled trials were of high quality according to the Cochrane Risk of Bias criteria.

Primary outcomes
Regarding in-hospital mortality, the results showed no significant differences between IABP and Impella, VA-ECMO plus IABP, Tandem Heart, and medical therapy (Fig. 2). According to the results of the SUCRA and cumulative ranking plots, the optimal ranking among the interventions was as follows: Tandem Heart or Impella, medical therapy, VA-ECMO plus IABP, PLVAD (Tandem Heart), IABP, Impella, VA-ECMO, IABP or VA-ECMO, VA-ECMO plus Impella, and Impella plus IABP (Additional file 1: Figures S2 and S3).

Based on the in-hospital mortality and mortality within 30 days, we constructed two network diagrams (Fig. 3). The contribution of each study to the indirect comparison of interventions is shown in Additional file 1: Figure S4. Regarding 30-day mortality, the results showed no significant differences between VA-ECMO and VA-ECMO plus Impella, Impella, and medical therapy. In addition, no significant differences were noted between IABP, Tandem Heart, Impella, and medical therapy (Fig. 2). According to the results of the SUCRA and cumulative ranking plots, the optimal ranking among the interventions was as follows: surgical venting plus VA-ECMO, medical therapy, VA-ECMO plus Impella, IABP, Impella, Tandem Heart, VA-ECMO, and Impella plus IABP (Additional file 1: Figures S2 and S3).

Heterogeneity and consistency
The forest plots showed that the heterogeneity of all results was low (Fig. 2). The results of the node-splitting approach showed relatively high consistency in direct and indirect comparisons (Fig. 4). P values were greater than 0.05. Density plots were used to judge the degree of convergence of the model. Additional file 1: Figure S5 demonstrates that the shape of the curve is close to a normal distribution. However, the intermediate value is far from “1”; the left side of the graph shows a better coincidence rate. In summary, the model had a good degree of fit.

Bias detection and evidence for the NMA graded by the CINeMA system
Regarding 30-day mortality, the funnel plot showed no significant bias in the included studies (Fig. 5). Given that

IABP with medical therapy, Impella plus VA-ECMO with Impella, VA-ECMO plus Impella with VA-ECMO, and VA-ECMO with Impella was compared in 3, 8, 4, 1, 11, 1, 6, and 5 articles, respectively. The characteristics of all studies that met the inclusion criteria are summarized in Table 1. The study designs of all randomized controlled trials were of high quality according to the Cochrane Risk of Bias criteria.
this NMA includes observational trials and double-blind, randomized controlled trials, the evidence level of comparison between some interventions is low according to the CINeMA system.

**Discussion**

Regarding 30-day mortality, the results of network comparison of VA-ECMO plus Impella versus VA ECMO, VA ECMO versus Impella, and IABP versus medical therapy showed high heterogeneity. Subsequently, sensitivity analysis was performed by omitting each study. Through sensitivity analysis, upon elimination of articles with a low-quality score, all results of the heterogeneity test showed low heterogeneity. Paired researchers reassessed the three articles with low-quality scores [21, 23, 56]. We believe that the reasons for the high heterogeneity may be related to the different aetiologies of CS and the different designs of the studies. For in-hospital mortality, the results of network comparison of VA-ECMO plus Impella versus VA ECMO, VA ECMO versus Impella, and IABP versus medical therapy also showed high heterogeneity. Subsequently, we also conducted a sensitivity
| Study | Year | No. of participants | Study design | Setting | Etiology of CS | Quality assessment |
|-------|------|---------------------|--------------|---------|----------------|-------------------|
| ECMO plus IABP vs. IABP | | | | | | |
| Perazzolo Marra et al. | 2013 | 35 | Obs | Europe | AMI | 5 |
| Tsao et al. | 2012 | 58 | Obs | Asia | AMI | 7 |
| Sheu et al. | 2010 | 219 | Obs | Asia | STEMI | 9 |
| PLVADs vs IABP | | | | | | |
| Seyfarth et al. (ISAR-SHOCK) | 2008 | 26 | RCT | Europe | AMI | 7 |
| Schrage et al | 2018 | 352 | Obs | Europe | AMI | 9 |
| Bochaton et al | 2019 | 13 | RCT | Europe | AMI | 4 |
| Dagmar et al. (IMPRESS trial) | 2016 | 48 | RCT | Europe | AMI | 7 |
| Shah et al | 2012 | 27 | Obs | United States | STEMI or UA/NSTEMI | 6 |
| Thiele et al | 2005 | 41 | RCT | Europe | AMI | 7 |
| Manzo-Silberman et al. | 2013 | 78 | Obs | Europe | ACS | 9 |
| Burkhoff et al. | 2006 | 33 | RCT | United States, Europe | AMI (70%) | 5 |
| Schwartz et al. | 2012 | 76 | Obs | United States | STEMI (68%) | 7 |
| ECMO plus IABP vs. ECMO | | | | | | |
| Park et al. | 2014 | 96 | Obs | Asia | AMI | 8 |
| Chung et al. | 2011 | 20 | Obs | Asia | AMI | 5 |
| Aoyama et al. | 2014 | 38 | Obs | Asia | AMI, INCA (2 pts, OHCA 7 pts) | 6 |
| PLVAD vs. medical therapy | | | | | | |
| Feistritzer et al. | 2020 | 1024 | RCT | Europe | AMI | 7 |
| IABP vs medical therapy | | | | | | |
| Sanborn et al. (SHOCK Registry) | 2000 | 383 | Obs | United States, Canada, Europe, New Zealand | AMI | 9 |
| Anderson et al. (GUSTO-I) | 1997 | 310 | Obs | United States, Europe | STEMI | 9 |
| Barron et al. (NRM-2) | 2001 | 2990 | Obs | United States | AMI | 8 |
| Gu et al | 2010 | 91 | Obs | Asia | STEMI | 5 |
| Prondzinsky et al. (IABP-SHOCK) | 2010 | 40 | RCT | Europe | AMI | 7 |
| Zeymer et al. (Euro Heart Survey PCI) | 2012 | 653 | Obs | Europe | STEMI or NSTEMI | 8 |
| Dziewierz et al. (EUROTRANSFER registry) | 2014 | 51 | Obs | Europe | STEMI | 5 |
| Brunner et al. | 2019 | 42 | Obs | Europe | AMI | 5 |
| Thiele et al. (IABP-SCHOCK II) | 2012 | 598 | RCT | Europe | AMI | 7 |
| Kim et al. (KAMIR) | 2015 | 1214 | Obs | Asia | AMI | 8 |
| ECMELLA vs. Impella | | | | | | |
| Castro et al. | 2020 | 27 | Obs | Europe | ICMP(53.3%), DCM (26.7%) | 6 |
| ECMELLA vs. ECMO | | | | | | |
| Pappalardo et al. | 2016 | 63 | Obs | Europe | STEMI (54%) | 9 |
| PATEL et al | 2019 | 66 | Obs | United States | STEMI (32%), NSTEMI (14%) | 6 |
| Tepper et al | 2016 | 45 | Obs | United States | AMI (26%), PCS (28%) | 7 |
| Schrage et al. (STOP-SHOCK) | 2020 | 510 | Obs | Europe | AMI (63%) | 9 |
| MOURAD et al | 2018 | 16 | Obs | Europe | AMI | 5 |
| AKANNU et al | 2019 | 225 | Obs | United States | AMI (25.78%), PCS (36.44%) | 6 |
| ECMO vs. Impella | | | | | | |
| Wernly et al | 2021 | 149 | Obs | Europe | AMI (51%) | 8 |
| Lamarche et al | 2010 | 61 | Obs | Europe | ACS (39.3%) | 8 |
| Lemor et al. | 2020 | 900 | Obs | United States | AMI | 7 |
| Karami et al. | 2020 | 128 | Obs | Europe | AMI | 8 |
| Karatolios et al. | 2020 | 166 | Obs | Europe | AMI (86%) | 8 |
analysis. Paired researchers reassessed the four articles with low-quality scores [23, 56, 58, 59]. The heterogeneity for all interventions was low following the exclusion of these four studies. Similarly, paired researchers discussed the reasons for the high heterogeneity. We agreed that the reason for the high heterogeneity may be the variations in the aetiology of CS and the study designs. After elimination of studies with low-quality scores, this NMA had a very favourable consistency, and the model had a comparatively favourable degree of conformity. In addition, most of the evidence levels of intervention comparison remained above medium. Regarding in-hospital mortality, the results of the SUCRA and cumulative ranking plots showed that Tandem Heart or Impella was superior to other interventions reducing in-hospital mortality. However, the studies of in-hospital mortality had a certain degree of publication bias. This notion reduced the level of evidence of Tandem Heart or Impella. In addition, compared with IABP plus Impella, IABP had a lower risk of in-hospital mortality (OR 5.89, 95% CI 1.33–6.4) and 30-day mortality (OR 1.78, 95% CI 2.6–4.56). After discussion among the researchers, the above results were considered to be less convincing. Only one study compared IABP plus Impella and IABP. Paired researchers reassessed the article with low-quality scores [60]. We cannot draw a conclusion from one study, which is unconvincing.

In this NMA, we included 39 clinical trials and evaluated the safety of various MCSs using the Bayesian method. For patients with CS, IABP is associated with the lower incidence of 30-day mortality than VA-ECMO and Impella.

VA-ECMO is a temporary mechanical circulatory support system that provides immediate and complete cardiopulmonary support in the event of CS and cardiac arrest [61]. The centrifugal pump of VA-ECMO can propel up to 8 L/min of blood and promote cannula arterial return and venous drainage. A hollow fibre membrane oxygenator is spliced into the circuit, which not only provides blood oxygenation but also carbon dioxide (CO2) clearance via sweep gas flow. The latter function differentiates other MCS strategies, such as PLVADs and IABP [16]. Previously, strategies for LV unloading mainly included pulmonary vein or septal left atrial intubation, atrial septostomy, percutaneous mechanical circulatory support, transapical cannulation, or concomitant MCS devices, including IABP or PLVADs, such as Tandem-Heart [62–65]. However, many strategies require more difficult and invasive procedures with a considerable degree of correlation with serious complications [63]. Impella PLVAD (Abiomed, Danvers, MA) has been approved for use in the United States; in addition, it is also approved for the treatment of CS. The safety and effectiveness of VA-ECMO concomitant with Impella has been increasingly evaluated by several studies.

An increasing number of MCS devices have been developed for treating CS to enhance efficacy or to replace medical therapy to avoid potentially detrimental effects [66]. MCS devices can be classified based on the site of blood return, the sites from which blood is withdrawn from the body, their mechanism of action, and whether the devices provide carbon dioxide and oxygen gas exchange [66]. Devices include PLVADs, ECMO devices, percutaneous left atrial decompression devices, and aortic counterpulsation pumps. It should be noted that despite comparable effects on cardiac output and blood pressure, the effects of different forms of MCS on the heart and lung may be significantly different, specifically as determined by myocardial oxygen demand and pulmonary capillary wedge pressure (which is related to LV end-diastolic pressure) [67]. In addition, a scientific statement from the American Heart Association in 2017 noted little evidence for the selection of patients with CS who are suitable for MCS devices [68]. Therefore, in view of the feasibility and controversy of MCS in the treatment of CS patients, it is necessary to evaluate which type of MCS equipment has the superiority to better reduce mortality. MCS devices improve the systemic hemodynamics of CS patients by pumping blood from one vascular compartment to another, demonstrating the feasibility of MCS in the treatment of CS patients [67].

VA-ECMO has become a frequently used therapy for circulatory support during CS [69]. The clinical application of VA-ECMO has been widely accepted by doctors. However, VA-ECMO is still not easier to perform in the clinical setup with the improvement of peripheral cannulation. In addition, VA-ECMO might cause haemodynamic changes due to femoral artery retrograde flow, which can increase cardiac afterload and may also cause an increase in pulmonary capillary wedge pressure and left ventricular end diastolic pressure (LVEDP), which will eventually lead to the

### Table 1 (continued)

| Study                        | Year | No. of participants | Study design | Setting | Etiology of CS                  | Quality assessment |
|------------------------------|------|---------------------|--------------|---------|--------------------------------|-------------------|
| ECMO plus IABP vs. PLVADs    |      |                     |              |         |                                |                   |
| Kagawa et al.                | 2012 | 73                  | Obs          | Asia    | ACS, INCA, OHCA                 | 9                 |

(continued)
**Fig. 2** The forest plots of MCS for in-hospital mortality and 30-day mortality
occurrence of pulmonary oedema and an increase in myocardial oxygen consumption [70, 71]. Furthermore, the associated phenomenon of LV distention cannot be ignored. LV distention is typically associated with ventricular arrhythmias and stasis of blood in the LV. Therefore, during the use of VA-ECMO, the use of a second MCS device offers great potential theoretical advantages, which play an important role in reducing myocardial oxygen consumption, pulmonary oedema, and LV distention [70, 72]. For traditional LV unloading strategies, in addition to surgical venting, IABP has always been considered a mainstream intervention. However, sufficient evidence is not available to demonstrate the capacity of IABP to reduce the occurrence of pulmonary oedema and an increase in myocardial oxygen consumption [70, 71].

**Study**  | **P-value** | **Odds Ratio (95% CrI)**
--- | --- | ---
Impella vs VA-ECMO plus Impella | direct | 0.76 (0.44, 1.3)
| indirect | 0.91 (0.39, 2.3)
| network | 0.79 (0.51, 1.3)
Medical therapy vs VA-ECMO | direct | 0.79 (0.41, 1.7)
| indirect | 0.67 (0.31, 1.5)
| network | 0.71 (0.44, 1.2)
IABP vs Impella | direct | 0.92 (0.62, 1.4)
| indirect | 1.1 (0.42, 3.0)
| network | 0.94 (0.66, 1.3)
Medical therapy vs IABP | direct | 0.94 (0.66, 1.4)
| indirect | 1.1 (0.42, 3.5)
| network | 0.96 (0.71, 1.4)

**Fig. 3** The network diagrams

**Fig. 4** The consistency in direct and indirect comparisons of 30-day mortality

**Fig. 5** The funnel plot of all studies: (A) Venoarterial extracorporeal membrane oxygenation concomitant with Impella; (B) Venoarterial extracorporeal membrane oxygenation; (C) Impella; (D) Intra-aortic balloon pump; (E) Venoarterial extracorporeal membrane oxygenation plus Intra-aortic balloon pump; (F) Medical therapy; (G) Tandem Heart; (H) Impella plus Intra-aortic balloon pump; (I) Venoarterial extracorporeal membrane oxygenation or Intra-aortic balloon pump; (J) Tandem Heart or Impella; (K) Surgical Venting
vascular adverse events. More researchers believe that the effectiveness of IABP in CS is reduced because the haemodynamic support produced by IABP is closely related to the cardiac output produced by the ventricle itself [73–75]. With the advancement of Impella technology, an Impella rotary pump can generate 2.5–3.5 L of blood flow, which plays a considerable role in improving coronary perfusion, and can greatly improve haemodynamic endpoints, thereby compensating for the shortcomings of IABP [51, 76]. Although Impella can significantly improve coronary perfusion, there is still a risk of haemolysis, which is a common problem noted among pump devices [77]. Therefore, the VA-ECMO plus Impella intervention strategy can be more beneficial in the treatment of CS patients as it can significantly reduce the central venous pressure compared with VA-ECMO alone [31, 38]. Related studies have shown that among AMI patients complicated by CS, the use of PLVAD is associated with a significantly higher risk of in-hospital mortality and haemorrhage compared with IABP [68]. However, it cannot be ignored that despite the early use of IABP, the prognosis of patients with CS remains poor [78].

Regarding the use of Impella, haemolysis is a known common complication associated with acute renal failure and increased demand for blood transfusions [77]. In addition, bleeding is also a common complication of the use of MCS equipment during CS, which is related to vascular damage caused by arterial and venous cannulation [79]. When using VA-ECMO and Impella, it is necessary to administer a sufficient dose of anticoagulants to prevent thrombosis. This process enhances the risk of bleeding [80]. Acute renal failure is also a treatment challenge faced by clinicians. However, prolonging survival is considered to be the ultimate goal of CS management. Therefore, it is of great significance to evaluate the safety of various MCSs for CS patients. The various aetiologies of CS included in the NMA may have a certain degree of influence on the results of this study. Therefore, it is necessary to discuss the baseline data of this study. The aetiologies of CS in this NMA include unstable angina (UA), acute myocardial infarction (AMI), in-of-hospital cardiac arrest (INCA), out-of-hospital cardiac arrest (OHCA), ischaemic cardiomyopathy (ICMP), and dilative cardiomyopathy (DCM). However, after the exclusion of studies with low-quality scores, the heterogeneity, consistency, and convergence of the model had good results, which may be related to the analysis of the sole event of death in this NMA. However, MCS equipment is adopted for the treatment of CS patients, and mortality data provide a very important reference for clinicians to specify the diagnosis and treatment plans. This study compared the pros and cons of various MCS interventions. In addition, in this NMA, some interventions have been included in a small number of clinical trials, resulting in a small sample size for those interventions. However, as the applications of MCS are gradually recognized by clinicians, further clinical studies on MCS devices will emerge, to assess their clinical safety.

The present study is the first network meta-analysis of various MCS interventions, and it explores the best intervention strategy for the treatment of CS. In addition, the study makes an indirect comparison between interventions that were not included in clinical research. In addition, 39 articles and 10,985 patients were included in this NMA, which makes our results more credible. However, the aetiologies of CS that are not fully controlled may represent the shortcomings of our research.

Conclusions
IABP is recommended to reduce 30-day mortality in CS patients.

Review registration
PROSPERO, CRD42021282526

Supplementary Information
The online version contains supplementary material available at https://doi.org/10.1186/s12872-022-02495-0.

Acknowledgements
None.

Authors’ contributions
QZ, BW, and SW made substantial contributions to the conception of the study; QZ, CZ, BW and SW made substantial contributions to the acquisition and analysis of the data and to the interpretation of data; QZ, BW, HL, and SW drafted the work; and all authors have substantively revised the draft. All authors have approved the submitted version. All authors have agreed both to be personally accountable for the author’s own contributions and to ensure that questions related to the accuracy or integrity of any part of the work, even ones in which the author was not personally involved, are appropriately investigated, resolved, and the resolution documented in the literature. All authors read and approved the final manuscript.

Funding
This study was supported by the National Natural Science Foundation of China (82072141), Key R&D Program of Shandong Province (2019GSF108261), Natural Science Foundation of Shandong Province (ZR2020MH030), and Clinical Research Foundation of Shandong University (2020SUCRCC014).

Availability of data and materials
All data generated or analyzed during this study are included in this manuscript and its additional files.
Declarations

Ethics approval and consent to participate
This work was approved by the Ethics Committee of Qilu Hospital of Shandong University and conducted in accordance with the Helsinki declaration. Patient consent was waived by the review board as all the data were collected from published data.

Consent for publication
Not applicable.

Competing interests
The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author details
1. Department of Emergency and Chest Pain Center, Qilu Hospital, Cheeulo College of Medicine, Shandong University, NO. 107, Jinan 250012, Shandong, China. 2. Clinical Research Center for Emergency and Critical Care Medicine of Shandong Province, Institute of Emergency and Critical Care Medicine of Shandong University, Qilu Hospital, Cheeleoo College of Medicine, Shandong University, Jinan 250012, Shandong, China. 3. Key Laboratory of Cardiopulmonary-Cerebral Resuscitation Research of Shandong Province, Qilu Hospital, Cheeelo College of Medicine, Shandong University, Jinan 250012, Shandong, China. 4. The Key Laboratory of Cardiovascular Remodeling and Function Research, Chinese Ministry of Education, Chinese Ministry of Health and Chinese Academy of Medical Sciences; The State and Shandong Province Joint Key Laboratory of Translational Cardiovascular Medicine, Qilu Hospital, Cheeelo College of Medicine, Shandong University, Jinan 250012, Shandong, China. 5. Clinical Trial Center, Qilu Hospital, Cheeelo College of Medicine, Shandong University, Jinan 250012, Shandong, China.

Received: 30 September 2021 Accepted: 4 February 2022
Published online: 13 February 2022

References
1. van Diepen S, Katz JN, Albert NM, Henry TD, Jacobs AK, Kapur NK, Kilic A, Menon V, Ohman EM, Sweitzer NK, et al. Contemporary management of cardiogenic shock: a scientific statement from the American Heart Association. Circulation. 2017;136(16):e232–68.
2. Rihal CS, Naidu SS, Givertz MM, Sieto WY, Burke JA, Kapur NK, Kern M, Garratt KN, Goldstein JA, Dimas V, et al. 2015 SCAI/ACC/HFSA/STS Clinical Expert Consensus Statement on the Use of Percutaneous Mechanical Circulatory Support Devices in Cardiovascular Care: Endorsed by the American Heart Association, the Cardiological Society of India, and Sociedad Latino Americana de Cardiologia Intervention. Affirmation of Value by the Canadian Association of Interventional Cardiology-Association Canadienne de Cardiologie d'intervention. J Am Coll Cardiol. 2015;65(19):e7–26.
3. Vallabhajosyula S, Dunlay SM, Prondzinsky R, Lemm H, Swyter M, Unverzagt S, Carter M. Intra-aortic balloon pump during extracorporeal membrane oxygenation during transcatheter aortic valve replacement: a systematic review. J Am Heart Assoc. 2016;7(14).
4. Le Gall A, Follain A, Cholley B, Manzt J, Assaoui N, Peraccio R. Venoarterial-ECMO in the intensive care unit: From technical aspects to clinical practice. Anaesthesia Crit Care Pain Med. 2018;37(3):259–68.
5. Kolte D, Khera S, Aronove WS, Mujib M, Palaniwarvy C, Sule S, Jain D, Gt-sis W, Ahmed A, Frishman WH, et al. Trends in incidence, management, and outcomes of cardiogenic shock complicating ST-elevation myocardial infarction in the United States. J Am Heart Assoc. 2014;3(1):e00590.9.
6. Berg DD, Bohula EA, van Diepen S, Katz JN, Alviar CL, Baird-Zars VM, Barrett CF, Barness GW, Burke JA, Cremer PC, et al. Epidemiology of shock in contemporary cardiac intensive care units. Circul Cardiovasc Quality Outcomes. 2019;12(3):e005618.
7. Hetzer R, Radovanovic D, Jeger R, Pedrazzini G, Cuculí F, Urban PA, Ernst P, Rickli H. Twenty-year trends in the incidence and outcome of cardiogenic shock in AMIS plus registry. Circ Cardiovasc Interv. 2019;12(4):e007293.
8. Hetzel H, Zeymer U, Neumann FJ, Ferenc M, Olbrich HG, Hausleiter J, Richard G, Hennersdorf M, Empe K, Fuermau G, et al. Intraaortic balloon support for myocardial infarction with cardiogenic shock. N Engl J Med. 2012;367(14):1287–96.
9. Hetzel H, Akin I, Sandri M, Fuermau G, de Waha S, Meyer-Saraei R, Nordbeck P, Geisler T, Landmesser U, Skurk C, et al. PCI strategies in patients with acute myocardial infarction and cardiogenic shock. N Engl J Med. 2017;377(23):2419–32.
10. Hochman JS, Sleeper LA, Webb JG, Sanborn TA, White HD, Talley JD, Buller CE, Jacobs AK, Slater JN, Col J, et al. Early revascularization in acute myocardial infarction complicated by cardiogenic shock. SHOCK Investigators. Should We Emergently Revascularize Occluded Coronaries for Cardiogenic Shock. N Engl J Med. 1999;341(9):625–34.
11. Hetzel H, Ohman EM, Desch S, Eitel I, de Waha S. Management of cardiogenic shock. Eur Heart J. 2015;36(20):1223–30.
12. Hutton B, Salanti G, Caldwell DM, Chaimani A, Schmid CH, Cameron C, Ioannidis JP, Straus S, Thorlund K, Jansen JT, et al. The PRISMA extension statement for reporting of systematic reviews incorporating network meta-analyses of health care interventions: checklist and explanations. Ann Intern Med. 2013;162(11):777–84.
13. Thielke H, Alexy T, Kalra R, Kosmopoulos M, Elliott A, Bartos JA, Yannopoulos D. Overview of Veno-Arterial Extracorporeal Membrane Oxygenation (VA-ECMO) support for the management of cardiogenic shock. Front Cardiovasc Med. 2021;8:686558.
14. Thiele H, Zeymer U, Neumann FJ, Ferenc M, Olbrich HG, Hausleiter J, Richard G, Hennersdorf M, Empe K, Fuermau G, et al. Intraaortic balloon support for myocardial infarction with cardiogenic shock. N Engl J Med. 2012;367(14):1287–96.
15. Thiele H, Zeymer U, Neumann FJ, Ferenc M, Olbrich HG, Hausleiter J, Richard G, Hennersdorf M, Empe K, Fuermau G, et al. Intraaortic balloon support for myocardial infarction with cardiogenic shock. N Engl J Med. 2012;367(14):1287–96.
16. Thiele H, Zeymer U, Neumann FJ, Ferenc M, Olbrich HG, Hausleiter J, Richard G, Hennersdorf M, Empe K, Fuermau G, et al. Intraaortic balloon support for myocardial infarction with cardiogenic shock. N Engl J Med. 2012;367(14):1287–96.
17. Thiele H, Zeymer U, Neumann FJ, Ferenc M, Olbrich HG, Hausleiter J, Richard G, Hennersdorf M, Empe K, Fuermau G, et al. Intraaortic balloon support for myocardial infarction with cardiogenic shock. N Engl J Med. 2012;367(14):1287–96.
18. Thiele H, Zeymer U, Neumann FJ, Ferenc M, Olbrich HG, Hausleiter J, Richard G, Hennersdorf M, Empe K, Fuermau G, et al. Intraaortic balloon support for myocardial infarction with cardiogenic shock. N Engl J Med. 2012;367(14):1287–96.
19. Thiele H, Zeymer U, Neumann FJ, Ferenc M, Olbrich HG, Hausleiter J, Richard G, Hennersdorf M, Empe K, Fuermau G, et al. Intraaortic balloon support for myocardial infarction with cardiogenic shock. N Engl J Med. 2012;367(14):1287–96.
20. Thiele H, Zeymer U, Neumann FJ, Ferenc M, Olbrich HG, Hausleiter J, Richard G, Hennersdorf M, Empe K, Fuermau G, et al. Intraaortic balloon support for myocardial infarction with cardiogenic shock. N Engl J Med. 2012;367(14):1287–96.
21. Thiele H, Zeymer U, Neumann FJ, Ferenc M, Olbrich HG, Hausleiter J, Richard G, Hennersdorf M, Empe K, Fuermau G, et al. Intraaortic balloon support for myocardial infarction with cardiogenic shock. N Engl J Med. 2012;367(14):1287–96.
22. Thiele H, Zeymer U, Neumann FJ, Ferenc M, Olbrich HG, Hausleiter J, Richard G, Hennersdorf M, Empe K, Fuermau G, et al. Intraaortic balloon support for myocardial infarction with cardiogenic shock. N Engl J Med. 2012;367(14):1287–96.
23. Thiele H, Zeymer U, Neumann FJ, Ferenc M, Olbrich HG, Hausleiter J, Richard G, Hennersdorf M, Empe K, Fuermau G, et al. Intraaortic balloon support for myocardial infarction with cardiogenic shock. N Engl J Med. 2012;367(14):1287–96.
24. Thiele H, Zeymer U, Neumann FJ, Ferenc M, Olbrich HG, Hausleiter J, Richard G, Hennersdorf M, Empe K, Fuermau G, et al. Intraaortic balloon support for myocardial infarction with cardiogenic shock. N Engl J Med. 2012;367(14):1287–96.
25. Thiele H, Zeymer U, Neumann FJ, Ferenc M, Olbrich HG, Hausleiter J, Richard G, Hennersdorf M, Empe K, Fuermau G, et al. Intraaortic balloon support for myocardial infarction with cardiogenic shock. N Engl J Med. 2012;367(14):1287–96.
oxygenator-assisted primary percutaneous coronary intervention improved 30-day clinical outcomes in patients with ST-segment elevation myocardial infarction complicated with profound cardiogenic shock. Crit Care Med. 2010;38(9):1810–7.

26. Kagawa E, Dote K, Kato M, Sasaki S, Nakano Y, Kajikawa M, Higashi A, Itakura K, Sera A, Inoue J, et al. Should we emergently revascularize occluded coronaries for cardiac arrest? Circulation. 2012;126(13):1605–13.

27. Schrage B, Schneider S, Zeymer U, Thiele H, Westermann D. Response by Schrage et al. to Letter Regarding Article, “Impella Support for Acute Myocardial Infarction Complicated by Cardiogenic Shock: A Matched-Pair IABP-SHOCK II Trial 30-Day Mortality Analysis.” Circulation. 2019;140(11):e559–60.

28. Schrage B, Becher PM, Bernhardt A, Bezerra H, Blankenberg S, Brunner S, Colson P, Cudemus, Deseda G, Dabboura S, Ecker D, et al. Left ventricular unloading is associated with lower mortality in patients with cardiogenic shock treated with vena-occlusive extracorporeal membrane oxygenation. Circulation. 2020;142(22):2099–106.

29. Mourad M, Gaudard P, De La Arenta P, Eliet J, Zenoal N, Rouvière P, Roubille F, Albalt B, Colson PH. Circulatory support with extracorporeal membrane oxygenation and/or impella for cardiogenic shock during myocardial infarction. ASAJO J. 2018;64(6):708–14.

30. Schwartz. Treating refractory cardiogenic shock with the tandemheart and Impella devices: a single center experience. Cardiol Res. 2012.

31. Akanem OI, Tikhonov D, Bauer I, Fischbichler G, Rottkoppa VK, Yuzefpolskaya M, Colombo PC, Karmalipols D, et al. EC-VAD: combined use of extracorporeal membrane oxygenation and percutaneous micro-axial pump left ventricular assist device. ASAJO J. 2019;65(3):219–26.

32. Wernly B, Karami M, Engstrom AE, Windecker S, Hunziker L, Lüscher TF, Henriques JP, Ferrari MW, Bonnefoy E. Mechanical circulatory support with the Impella pump and an intra-aortic balloon pump for cardiogenic shock in acute myocardial infarction. Eur Heart J. 2021;8(2):953–61.

33. Karami M, den Uil CA, Ouweneel DM, Engström AE, Akin S, Wernly B, Karami M, Engström AE, Windecker S, Hunziker L, Lüscher TF, Kim HK, Jeong MH, Ahn Y, Sim DS, Chae SC, Kim YJ, Hur SH, Seong IW, Hong TJ, Choi DH, et al. Clinical outcomes of the intra-aortic balloon pump for resuscitated patients with acute myocardial infarction complicated by cardiac arrest. J Cardiol. 2016;67(1):57–63.

34. Lamarche Y, Cheung A, Ignaszewski A, Higgins J, Kaan A, Griesdale DEG, Moss R. Comparative outcomes in cardiogenic shock patients managed with Impella microaxial pump or extracorporeal life support. J Thorac Cardiovasc Surg. 2011;142(1):60–5.

35. Malliaris Keleidos G, Mathisen S, Fichtinger M, Matthieben A, Varenne O, Ricome S, Zabaib A, Zuber B, Spaulding C, Cariano A. Percutaneous left ventricular assistance in post cardiac arrest: shock: comparison of intra aortic blood pump and IMPELLA Recover LP2.5. Resuscitation. 2013;84(5):609–15.

36. Feistritzer H-J, Desch S, Freund A, Poess J, Zeymer U, Ouarar T, Schneider S, de Waha-Thiele S, Fuenan G, Eitel I, et al. Prognostic impact of active mechanical circulatory support in cardiogenic shock complicating acute myocardial infarction, results from the culprit-shock trial. J Clin Med. 2020;9(6):1976.

37. Karatolian K, Chatzis G, Markus B, Luesebrink U, Ahrens H, Divochev D, Syntilla S, Jerentrup A, Schieffer B. Comparison of mechanical circulatory support with extracorporeal membrane oxygenation or impella for patients with cardiogenic shock: a propensity-matched analysis. Clin Res Cardiol. 2020;10:10149.

38. Chung ES, Lim C, Lee H-Y, Choi J-H, Lee J-S, Park K-H. Results of Extracorporeal Membrane Oxygenation (ECMO) support before coronary reperfu- sion in cardiogenic shock with acute myocardial infarction. Korean J Thorac Cardiovasc Surg. 2011;14(4):273–8.

39. Patel SM, Lipinski JS, Al-Kindi SG, Patel T, Saric P, Liu J, Nadeem F, Ladas T, Alati A, Phillips A, et al. Simultaneous venoarterial extracorporeal mem- brane oxygenation and percutaneous left ventricular unloading therapy with impella is associated with improved outcomes in refractory cardiogenic shock. ASAJO J. 2019;65(1):21–8.

40. Barron HV, Every NR, Parsons LS, Angeja B, Goldberg RJ, Gore JM, Chou TM. The use of intra-aortic balloon counterpulsation in patients with cardiogenic shock complicating acute myocardial infarction: data from the National Registry of Myocardial Infarction 2. Am Heart J. 2001;141(6):933–9.

41. Dzwierz A, Siudak Z, Rakowski T, Kleczyński P, Zasada W, Dudek D. Impact of intra-aortic balloon pump on long-term mortality of unelected patients with ST-segment elevation myocardial infarction complicated by cardiogenic shock. Adv Interv Cardiol. 2014;5:175–80.

42. Zeymer U, Hochadel M, Hauptmann K-E, Wiegand K, Schuhmacher B, Brachmann J, Gitt A, Zahn R. Intra-aortic balloon pump in patients with acute myocardial infarction complicated by cardiogenic shock: results of the ALIKK-PICI registry. Clin Res Cardiol. 2012;102(3):223–7.

43. Sanborn TA, Sleeper LA, Bates ER, Jacobs AK, Boland J, French JK, Dens J, Dzawik V, Palmieri ST, Webb JG, et al. Impact of thrombolysis, intra-aortic balloon pump counterpulsation, and their combination in cardiogenic shock complicating acute myocardial infarction: a report from the SHOCK Trial Registry. Should we emergently revascularize Occluded Coronaries for cardiogenic shock? J Am Coll Cardiol. 2000;36(3):1123–9.

44. Anderson RD, Ohman ME, Holmes DR Jr, Col I, Stebbins AL, Bates ER, Stermel RJ, Granger CB, Topol EJ, Califf RM. Use of intraaortic balloon counterpulsation in patients presenting with cardiogenic shock: observations from the GUSTO-I Study. Global Utilization of Streptokinase and TPA for Occluded Coronary Arteries. J Am Coll Cardiol. 1997;30(3):708–15.
57. Aoyama N, Imai H, Kurosawa T, Fukuda N, Moriguchi M, Nishinari M, Nishii M, Kono K, Soma K, Izumi T. Therapeutic strategy using extracorporeal life support, including appropriate indication, management, limitation and timing of switch to ventricular assist device in patients with acute myocardial infarction. J Am Coll Cardiol. 2015;71(1):33–41.

58. Pappalardo F, Schulte C, Pieri M, Schrage B, Contiri R, Szelecki G, Greco T, Lembo R, Müllerleile K, Kolombo A, et al. Concomitant implantation of Impella® on top of veno-arterial extracorporeal membrane oxygenation may improve survival of patients with cardiogenic shock. Eur J Heart Fail. 2017;19(3):404–12.

59. Lemos A, Hosseini Dehkordi SH, Basir MB, Villallana PA, Jain T, Koenig GC, Alaswad K, Moses JW, Kapur NK, O’Neill W. Impella versus extracorporeal membrane oxygenation for acute myocardial infarction cardiogenic shock. Cardiovasc Revasc Med. 2020;21(12):1465–71.

60. Bochaton T, Huot L, Elbaz M, Delmas C, Aissaoui N, Farhat F, Mewton N, Bonnelye E. Mechanical circulatory support with the Impella® LPS 0 pump and an intra-aortic balloon pump for cardiogenic shock in acute myocardial infarction. The IMPELLA-STIC randomized study. Arch Cardiovasc Dis. 2020;113(4):237–43.

61. Telukuntla KS, Estep ME, Haddad EV, Choi CW, McGrane S, Zalawadiya S, Schlendorf KH, Condliffe DM, Dantzer MR, Wiger M, Menachem JN, et al. Venoarterial extracorporeal membrane oxygenation with concomitant impella versus venoarterial extracorporeal membrane oxygenation for cardiogenic shock. ASAIO J. 2020;66(5):497–503.

62. Russo JJ, Aleksova N, Pitcher I, Couture E, Parlowski S, Faraz M, Visintini S, Simard T, Di Santo P, Mathew R, et al. Left ventricular unloading during extracorporeal membrane oxygenation in patients with cardiogenic shock. J Am Coll Cardiol. 2019;73(6):654–62.

63. Conrad SA, Grier LR, Scott LK, Green R, Jordan M. Percutaneous cannulation for extracorporeal membrane oxygenation by intensivists: a retrospective single-institution case series. Crit Care Med. 2015;43(5):1010–5.

64. Kreebler ME, Hadid AV, Choi CW, Mcgrane S, Zalawadiya S, Schlendorf KH, Brinkley DM, Dantzer MR, Wiger M, Menachem JN, et al. Venoarterial extracorporeal membrane oxygenation in cardiogenic shock. JACC Heart Fail. 2018;6(9):503–16.

65. Burkhoff D, Sayer G, Doshi D, Uriel N. Hemodynamics of mechanical circulatory support. J Am Coll Cardiol. 2015;66(23):2664–62.

66. Saxena A, Garan AR, Kapur NK, O’Neill WW, Lindenfeld J, Penney SR, Uriel N, Burkhoff D, Kern M. Value of hemodynamic monitoring in patients with cardiogenic shock undergoing mechanical circulatory support. Circulation. 2020;141(14):1184–97.

67. Dhruba SS, Ross JS, Mortazavi BJ, Hurley NC, Krumholz HM, Curtis JP, Berkowitz A, Masoudi FA, Messenger JC, Parzynski CS, et al. Association of use of an intravascular microaxial left ventricular assist device vs intra-aortic balloon pump with in-hospital mortality and major bleeding among patients with acute cardiac infarction complicated by cardiogenic shock. JAMA. 2020;323(8):745–55.

68. Szymanski L, Sawyer L, Wood J, O’Neill W, Ferrans VJ, Shane A, Brooks M. Intra-aortic balloon pump protects against hydrostatic pulmonary oedema during peripheral venoarterial extracorporeal membrane oxygenation. Cardiovasc Revasc Med. 2020;21(12):1465–71.

69. Cheng R, Hachamovitch R, Makkar R, Ramzy D, Moriguchi J, Arabia F, Emtiazi F, Aazarbi B. Lack of survival benefit of concomitant intra-aortic balloon pump in extracorporeal membrane oxygenation: a pooled experience of 1517 patients. J Invasive Cardiol. 2015;27(10):453–8.

70. Vallabha4sujula S, O’Horo JC, Antharam P, Ananthaneni S, Vallabha4sujula S, Stulak JM, Beil MF, Dunlay SM, Gersh BJ, Rihal CS, et al. Concomitant intra-aortic balloon pump use in cardiogenic shock requiring venoarterial extracorporeal membrane oxygenation. Circ Cardiovasc Interv. 2018;11(9):e006930.

71. Esposito ML, Kapur NK. Acute mechanical circulatory support for cardiogenic shock: the “door to support” time. F1000Research. 2017;6:737.

72. Thiele H, Jobs A, Ouweevel DM, Henriques JPS, Seyfarth M, Desch S, Eitel I, Pöss J, Fuereman G, de Waha S. Percutaneous short-term active mechanical support devices in cardiogenic shock: a systematic review and collaborative meta-analysis of randomized trials. Eur Heart J. 2017;38(7):3523–31.

73. Badiey AP, Hernandez GA, Novoa I, Chaparro SV. Incidence of hemolysis in patients with cardiogenic shock treated with Impella Left ventricular assist device. ASAIO J (Am Soc Artif Internal Organs : 1992). 2016;62(1):11–14.

74. Mandava V, Rao SV. Percutaneous mechanical circulatory support devices in cardiogenic shock. Circ Cardiovasc Interv. 2017;10(5).

75. Chen Z, Zbang J, Kareem K, Tran D, Conway RV, Arias K, Griffin BP, Wu ZJ. Device-induced platelet dysfunction in mechanically assisted circulation increases the risks of thrombosis and bleeding. Artif Organs. 2019;43(8):745–55.

76. Sy E, Sklar M, Lequvier L, Fan E, Kanji HD. Anticoagulation practices and the prevalence of major bleeding, thromboembolic events, and mortality in venoarterial extracorporeal membrane oxygenation: a systematic review and meta-analysis. J Crit Care. 2017;39:87–96.

Publisher’s Note
Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.