Received: 15 October 2020 | Revised: 7 January 2021 | Accepted: 14 January 2021
DOI: 10.1002/emp2.12380

JACEP OPEN WILEY

REVIEW ARTICLE

Cardiology

Extracorporeal cardiopulmonary resuscitation for refractory cardiac arrest: a scoping review

Dennis Miraglia MD[1] | Christian Almanzar MD[2] | Elane Rivera MD, MPH[3] | Wilfredo Alonso MD[3]

[1] Department of Emergency Medicine, San Francisco Hospital, San Juan, Puerto Rico, USA

[2] Department of Internal Medicine, Brandon Regional Hospital, Brandon, Florida, USA

[3] Department of Internal Medicine, Good Samaritan Hospital, Aguadilla, Puerto Rico, USA

Correspondence
Dennis Miraglia, MD, Department of Emergency Medicine, San Francisco Hospital, PO Box 29025, San Juan, PR 00929, USA.
Email: dennismiraglia@hotmail.com

Funding and support: By *JACEP Open* policy, all authors are required to disclose any and all commercial, financial, and other relationships in any way related to the subject of this article as per ICMJE conflict of interest guidelines (see www.icmje.org). The authors have stated that no such relationships exist.

Abstract

Background: Extracorporeal cardiopulmonary resuscitation (ECPR) is an emerging concept in cardiac arrest and cardiopulmonary resuscitation. Recent research has documented a significant improvement in favorable outcomes, notable survival to discharge, and neurologically intact survival.

Objectives: The present study undertakes a scoping review to summarize the available evidence by assessing the use of ECPR, compared with no ECPR or the standard of care, for adult patients who sustain cardiac arrest in any setting, in studies which record survival and neurologic outcomes.

Methods: This review followed the PRISMA extension for scoping reviews (PRISMA-ScR) guidelines. Four online databases were used to identify papers published from database inception to July 12, 2020. We selected 23 observational studies from Asia, Europe, and North America that used survival to discharge or neurologically intact survival as a primary or secondary endpoint variable in patients with cardiac arrest refractory to standard treatment.

Results: Twenty-three observational studies were included in the review. Eleven studies were of out-of-hospital cardiac arrest, 7 studies were of in-hospital cardiac arrest, and 5 studies included mixed populations. Ten studies reported long-term favorable neurological outcomes (ie, Cerebral Performance Category score of 1 – 2 at 3 months [n = 3], 6 months [n = 3], and 1 year [n = 4]), of which only 4 had statistical significance at 5% significance levels. Current knowledge is mostly drawn from single-center observations, with most of the evidence coming from case series and cohort studies, hence is prone to publication bias. No randomized control trials were included.

Conclusions: This scoping review highlights the need for high-quality studies to increase the level of evidence and reduce knowledge gaps to change the paradigm of care for patients with shock-refractory cardiac arrest.

KEYWORDS
cardiac arrest, ECPR, extracorporeal cardiopulmonary resuscitation, extracorporeal membrane oxygenation, extracorporeal life support, refractory ventricular fibrillation, resuscitation

Supervising Editor: Mike Wells, MBBCh, PhD

1 | INTRODUCTION

Cardiac arrest has been traditionally treated with advanced cardiovascular life support, including high-quality cardiopulmonary resuscitation (CPR), rapid defibrillation (class IIa, LOE C), standard-dose epinephrine (1 mg every 3–5 min) (class IIb, LOE B-R), and antiarrhythmic medication to facilitate successful defibrillation, increase the return of spontaneous circulation (ROSC), and maintain a stable hemodynamic state.[1,2] Despite efforts to improve outcomes in cardiac arrest patients the rates of survival to discharge and neurologically intact survival have improved only minimally over the past decade in the United States (US).[3]

There is a subset of cardiac arrest patients who develop refractory cardiac arrest, requiring prolonged resuscitation efforts.[4] Prolonged CPR is associated with severe metabolic disturbances with uncertain consequences on organ injury and neurological outcomes. A number of interventions, including mechanical CPR provided by properly trained personnel (class IIb, LOE B-R), use of an impedance threshold device (class IIb, LOE C-LD), and extracorporeal cardiopulmonary resuscitation (ECPR) (class IIb, LOE C-LD), have been increasingly used as rescue bridges to support further treatment in patients that do not respond to the standard of care.[1,2]

ECPR refers to the initiation of cardiopulmonary support, while bypassing the heart and lungs during resuscitation to support patients with refractory cardiac arrest.[5] This involves the cannulation of a large vein and artery and initiation of veno–arterial extracorporeal membrane oxygenation (VA-ECMO). By bypassing the entire cardiopulmonary system, the heart is allowed time to recover from an insult while systemic mechanical circulatory support and simultaneous extracorporeal gas exchange to the whole body are maintained.[5] Efforts to treat patients with refractory cardiac arrest have led to the implementation of VA-ECMO used as ECPR to facilitate return of perfusion and mitigate multiorgan dysfunction, as the probability of achieving ROSC decreases when the duration of CPR exceeds 30 minutes.[6]

Multiple cohort studies have shown that such an approach has been associated with an increased rate of survival to discharge and neurologically intact survival compared with no ECPR or the standard of care, that is, conventional CPR.[6–12] However, only low quality evidence support the notion that this expensive and resource intensive strategy increases long-term neurologically intact survival after refractory cardiac arrest.

2 | OBJECTIVES

The aim of this scoping review was to summarize the available evidence by assessing the use of ECPR, compared with no ECPR or the standard of care, for adult patients who sustain cardiac arrest in any setting (out-of-hospital or in-hospital), in those studies that record survival and neurologic outcomes, as well as to identify gaps in the literature that may require further research. A further objective was to summarize the effect estimate among those studies reporting long-term neurologically intact survival, defined as a Cerebral Performance Category (CPC) score of 1 – 2.

3 | MATERIALS AND METHODS

We followed the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta Analyses Extension for Scoping Reviews) guidelines,[13] the scoping review guidance document developed by the Joanna Briggs Institute[14] (updated in 2017),[15] and the methodological framework developed by Arksey and O'Malley.[16] Our scoping review protocol was drafted and registered with Open Science Framework.

3.1 | Stage 1: Identify the research question

We follow the patient/population, intervention, comparison and outcomes process (or framework) to frame and answer the review question. Question: Among adults (≥16 years) resuscitated from cardiac arrest in any setting (out-of-hospital or in-hospital) (population) and treated with ECPR (intervention), compared to no ECPR or the standard of care (comparator), what is the number of studies reporting long-term neurologically intact survival and what is their point estimate at the individual study level (outcomes)?

3.2 | Stage 2: Identify relevant studies

3.2.1 | Databases

The following bibliographic databases were searched: The Cochrane Central Register of Controlled Trials (CENTRAL), MEDLINE (Ovid interface), and Embase (Ovid interface). We used the Science Citation Index (Web of Science) to identify additional citations. The databases were searched from their inception to July 12, 2020. We repeated the search on August 14, 2020, to identify additional relevant studies. The search strategy was initially created in MEDLINE and then adapted for each database using a combination of keywords, subject headings, and Boolean operators. We also searched ongoing trial databases including controlledtrials.com and clinicaltrials.gov. The reference lists of relevant studies were screened to identify further studies of interest. All clinical studies published in English as full-text articles on indexed journals were considered. The search strategy for MEDLINE can be found in Appendix A.

3.2.2 | Searching other resources

We searched the reference lists of the International Liaison Committee on Resuscitation (ILCOR) evidence worksheets. We searched conference proceedings of important meetings and abstracts, including those of the American Heart Association (AHA) and the European Resuscitation Council (ERC). The search was completed on August 14, 2020.

3.3 | Stage 3: Study selection

3.3.1 | Study eligibility and selection criteria

We included randomized and quasi-randomized controlled trials, and observational analytic studies (cross sectional-studies, cohort studies, case-control studies). Studies were deemed relevant to our review if they met the following criteria: (1) documented cardiac arrest in any setting (out-of-hospital or in-hospital) in adults (≥16 years); (2) used ECPR as the intervention; (3) had CPR as comparator only, defined as either basic life support or advanced cardiovascular life support protocols; and (4) reported survival or neurologically intact survival outcomes within the following time frames: short-term (hospital discharge, 30 days, and 1 month) and long-term (3 months, 6 months, 1 year, and up to 2 years). Studies conducted on mixed populations were considered for inclusion if data from the out-of-hospital cardiac arrest subpopulation could be extracted and computed separately or if the out-of-hospital cardiac arrest subpopulation was >50% of the total population. Studies that assessed only the use of ECPR techniques (including ECMO or cardiopulmonary bypass) in the context of cardiogenic shock or respiratory failure were not included. We excluded patients with an etiology of cardiac arrest from trauma, known terminal-stage malignancies, or known pregnancy, as well as studies involving infants, children, and adolescents (ie, those younger than 16 years of age).

We used EndNote X9 software to identify and remove duplicate citations. Two authors independently assessed all the titles and abstracts for potentially eligible studies. We subsequently reviewed the full text of potentially eligible studies and independently assessed them for compliance with the inclusion criteria. We resolved any disagreement by discussion or by involving a third review author.

3.4 | Stage 4: Chart the data

A data-charting form was jointly developed by the 2 authors, and we utilized double data extraction. The 2 authors independently extracted all relevant data from eligible studies using a pre-defined standardized data-charting form. The 2 authors then independently charted the data and continuously updated the data-charting form. Microsoft Excel was used for this stage. Any study discarded during the charting process was approved by the 2 authors before the analysis was completed. We resolved any disagreement by discussion or by involving a third review author.

3.5 | Stage 5: Summarize and report the results

We grouped all studies reporting survival and neurological outcomes by type of study design (randomized and quasi-randomized controlled trials, or observational analytic studies [cross-sectional studies, cohort studies, case-control studies]), research setting, participant demographics, inclusion and exclusion criteria, resuscitative parameters, intervention, exposure, comparator, and key findings. A narrative synthesis was undertaken to describe the articles included in terms of the type of study design, and results were prioritized based on relevance to the research question. We planned to present the point estimate at the individual study level if data permitted, that is, the effect estimate (ie, odds ratios) and 95% confidence interval for each study reporting long-term neurologically intact survival. Studies reporting long-term neurologically intact survival were grouped by time frames (ie, 3 months, 6 months, and 1-year) and analyzed according to the type of setting, that is, in-hospital or out-of-hospital, along with the effect estimate at the individual study level. Missing statistical parameters were calculated using Review Manager version 5.3 (Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen 2014).[17] Aggregate data and narrative synthesis are presented in the results section.

4 | RESULTS

4.1 | Study selection

Searches of bibliographic databases and other sources yielded 4807 citations. Once duplicates were removed, 3485 citations remained. One hundred and thirty-eight records were eligible for full-text review, of which 23 were eligible for inclusion. We included 23 studies for analysis and a total of 55,125 adult patients, 2116 of whom received ECPR.[18–40] These included 23 observational studies, some of which used logistic regression analysis and some of which performed propensity score matching. One of them performed a post hoc analysis of data from a prospective, observational cohort, including propensity score matching.[21] A PRISMA flow chart of the search and the study selection process is presented in Figure 1. We excluded many studies without a control group with a thorough study design that showed considerable results following ECPR but which were not relevant to this analysis.[41] No randomized clinical trials were identified, although several are registered on the International Clinical Trials Registry Platform (ClinicalTrails.gov identifiers: NCT03101787, NCT03880565, NCT03065647, NCT01511666, NCT02527031, and NCT03700125).

4.2 | Study characteristics

Studies included adult patients resuscitated from in-hospital or out-of-hospital cardiac arrest; some included mixed populations. Eleven studies were of out-of-hospital cardiac arrest,[18–28] 7 studies were of in-hospital cardiac arrest,[29–35] and 5 studies included mixed

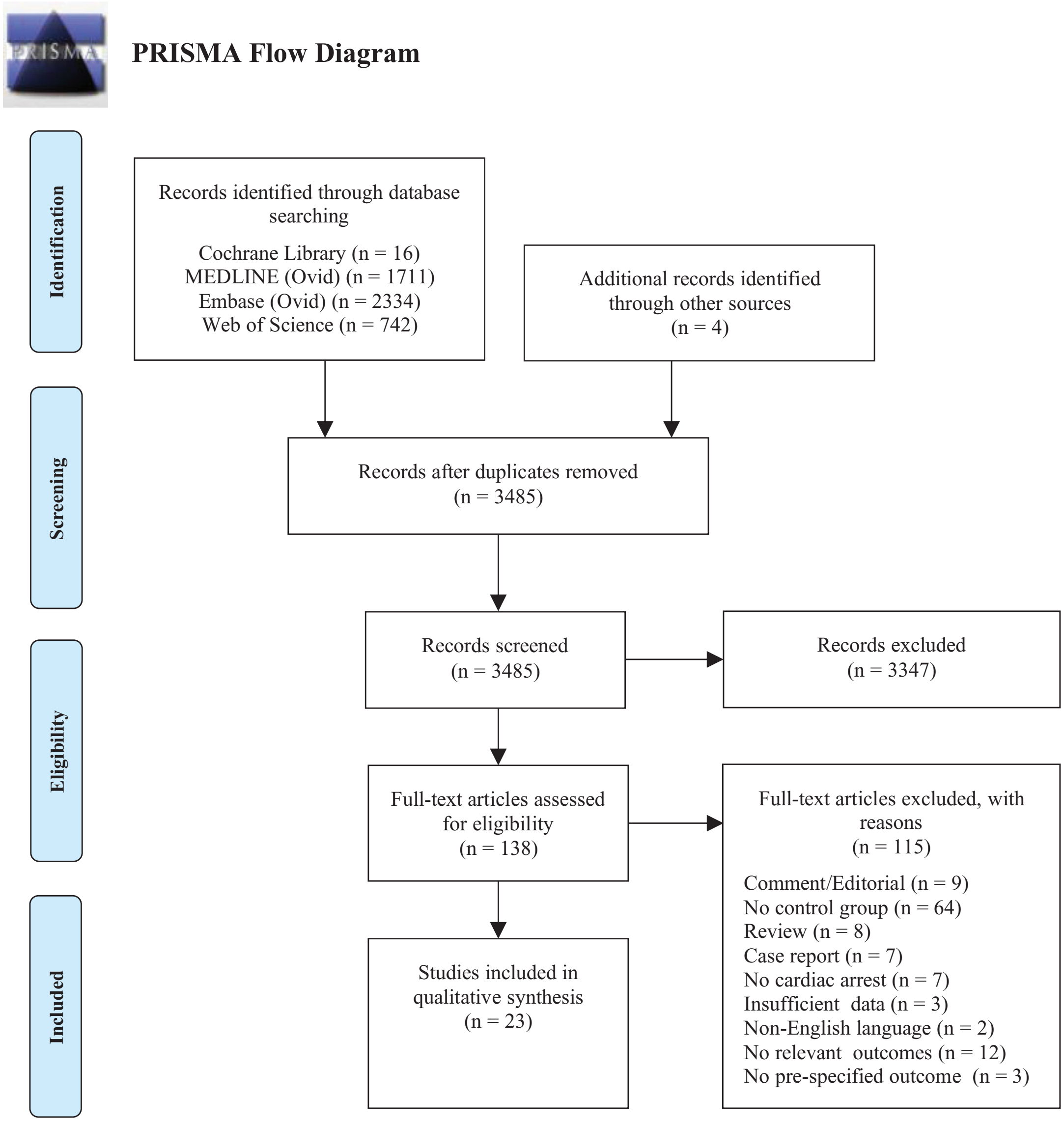

FIGURE 1 Preferred reporting items for systematic reviews and meta-analyses flow diagram for the scoping review process—clinical search strategy. From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA Statement. *PLoS Med* 2009;6:e1000097

populations.[36–40] All of the studies were published between 2008 and 2020. Most studies were conducted at single centers located in East Asia (n = 14), for example, Japan, the Republic of Korea, and Taiwan, followed by Europe (n = 6), for example, France, Italy, Germany, and Scandinavian countries, and North America (n = 3). The inclusion criteria for ECPR differed among the included studies. We identified that the majority of patients receiving ECPR in these studies tended to be younger than 75 years, with more witnessed arrests, with more bystander CPR, and with potentially reversible conditions. The most consistent criterion for inclusion was refractory cardiac arrest. In most studies, age, usually <75 years (low end: 10 years; high end: no upper age), rhythm at the time of CPR (shockable rhythms [ventricular fibrillation/pulseless ventricular tachycardia]), no-flow time of ≤5 minutes (up to <15 minutes), witnessed cardiac arrest, and cardiac arrest of presumed cardiac etiology were generally the most cited inclusion criteria.

An overview of possible decision criteria for use of ECPR for shock-refractory cardiac arrest is provided in Table 1. Data for bystander CPR, the exact no-flow time and low-flow times, and number of electrical defibrillations delivered were infrequently reported. Therapeutic decisionmaking and ethological base therapy such as, coronary angiography, coronary artery bypass graft, and percutaneous coronary intervention (PCI) were reported in 18 of 23 studies. However, several studies did not report any form of ethological base therapy. Therapeutic hypothermia (TH) was used in 13 of 23 studies. The TH protocols used targets ranging between 32°C and 36°C. Several studies did not report their specific hypothermia targets and others did not report the use of TH. Most of the studies reported short-term outcomes (ie, hospital discharge, 30 days, and 1 month), including survival to discharge (n = 19) and neurologically intact survival (n = 14). Eleven studies reported long-term outcomes, including long-term survival and long-term

TABLE 1 Possible decision criteria for use of extracorporeal pulmonary circulation with regard to shock-refractory cardiac arrest

Inclusion criteria	Exclusion criteria
• 18–75 years of age	• Unable to provide high-quality CPR[a]
• Cardiac arrest of presumed cardiac etiology	• ROSC with sustained hemodynamic recovery ≤3 standard defibrillation shocks
• Early bystander CPR	• Known terminal illness
• Initial presenting rhythm of VF/VT	• Comorbidities with reduced life expectancy
• Reversible causes of cardiac arrest	• Past/present clinical signs of neurological damage or expected poor prognosis
• Persistent shockable rhythm after received 3 standard defibrillation/AED-shocks	• Terminal heart failure (NYHA III or IV)
• Persistent shockable rhythm after received 300 mg IV/IO bolus of amiodarone	• Severe pulmonary disease (COPD GIII of GIV)
• Transfer time from the field to the receiving facility <30 min	• Nursing home/long-term care facility residents
• Medical facility able to perform CAG, PCI, and TTM	• Pregnant
	• Trauma: Revised Trauma Score <11 or Injury Severity Score >15
	• Threatening hemorrhage
	• Presence of legal documents[b]
	• Any reason to contact medical control to do not attempt resuscitation

Notes: Performing extracorporeal pulmonary circulation is the wrong focus in systems that are not optimized either with telecommunicator CPR/dispatcher-assisted CPR and are unable to dispatch multiple advanced emergency medical service units or that do not have the infrastructure and resource requirements to implement programs with strict patient selection criteria, or to perform effective high-performance CPR or mechanical CPR in the field and during transport with a dedicated operating protocol for refractory cardiac arrest that includes reducing the scene time to a minimum (ie, 10–12 minutes), and provide early transport (ie, estimated transfer time from the scene of <30 minutes) to receiving facilities able to perform CAG, PCI, and TTM.

Abbreviations: AED, automated external defibrillator; CAG, coronary angiography; COPD, chronic obstructive pulmonary disease; CPR, cardiopulmonary resuscitation; ECPR, extracorporeal cardiopulmonary resuscitation; IO, intraosseous; IV, intravenous; NYHA, New York Heart Association; PCI, percutaneous coronary intervention; ROSC, return of spontaneous circulation; TTM, targeted temperature management; VF, ventricular fibrillation; VT, ventricular tachycardia.

[a]End-tidal carbon dioxide, arterial partial pressure of oxygen or oxygen saturation, and lactic acid before initiation of ECPR may represent important criteria for resuscitation continuation decisions that should be further investigated.

[b]Refer to physician order for life sustaining treatment, advanced directives, living wills, do not resuscitate/do not intubate.

neurologically intact survival. Shin et al (2013) reported 2-year survival and neurological outcome, though this study included the same patient population as his previous study (2011), but reported different outcomes. This study defined favorable neurological outcome as a Modified Glasgow Outcome Score ≥4. As the authors compiled the data for Table 2, this article was removed from the analysis. This discarded article was approved by the authors before the analysis was completed. The rest of the studies defined favorable neurological outcome as a CPC score of 1 – 2. An overview of each included study is provided in Table 3 and 4.

4.3 | Long-term neurologically intact survival

Forest plot of long-term neurologically intact survival is presented in Figure 2. Of the studies reporting long-term neurologically intact survival comparing ECPR with no ECPR or standard CPR, 7 performed propensity score matching and 3 performed multivariate logistic regression analysis. All studies that reported long-term neurologically intact survival reported a greater likelihood of short-term neurologically intact survival in the ECPR group (compared with neurologically intact survival in the conventional CPR group) and improved long-term neurologically intact survival at 3 months, 6 months, and 1-year follow-up with the use of ECPR, but not all reported statistical significance at the study level. Of the 3 studies that reported a 3-month neurologically intact survival,[20,21,39] 1 had statistical significance at 5% significance levels.[20] Of the 3 studies that reported 6-month neurologically intact survival,[18,19,32] 2 had statistical significance at 5% significance levels.[18,32] Of the 4 studies that reported 1-year neurologically intact survival,[30,31,33,36] only 1 had statistical significance at 5% significance levels.[36] All studies reporting long-term neurologically intact survival defined favorable neurological outcome as a CPC score of 1–2. An overview of studies reporting long-term neurologically intact survival along with the effect estimates at the individual study level is provided in Table 2.

5 | LIMITATIONS

This scoping review should be interpreted in the context of certain limitations. The primary limitation of the scoping review is that risk of bias and methodological quality are generally not appraised. Second,

TABLE 2 Effect estimates—long-term neurologically intact survival

Authors, year, country	Enrollment, y	OHCA vs IHCA	No. of participants	Outcome/ follow-up[a]	ECPR No. (%)	CCPR No. (%)	Point estimate[b]
Blumenstein et al[33] Germany	4	IHCA	104	1 y	10/52 (19)	6/52 (12)	1.82 (0.61–5.46)[c]
Chen et al[30] Taiwan	2	IHCA	92	1 y	9/46 (20)	5/46 (11)	1.99 (0.61–6.49)[c]
Kim et al[20] Korea	7.5	OHCA	104	3 mo	8/52 (15)	1/52 (2)	9.27 (1.12–77.07)[c]
Lin et al[31] Taiwan	2	IHCA	54	1 y	5/27 (19)	3/27 (11)	1.82 (0.39–8.51)[c]
Maekawa et al[21] Japan	4.5	OHCA	48	3 mo	7/24 (29)	2/24 (8)	4.53 (0.83–24.65)[c]
Patricio et al[39] Belgium	5	OHCA	99	3 mo	12/49 (24)	8/50 (16)	1.70 (0.63–4.12)[c]
Sakamoto et al[18] Japan	3	OHCA	451	6 mo	29/258 (11)	5/193 (3)	4.76 (1.81–12.54)
Schober et al[19] Austria	10	OHCA	239	6 mo	1/7 (14)	13/232 (6)	2.82 (0.31–25.08)
Shin et al[32] Korea	6.5	IHCA	120	6 mo	14/60 (23)	3/60 (5)	5.78 (1.57–21.35)[c]
Siao et al[36] Taiwan	2	OHCA	60	1 y	8/20 (40)	3/40 (8)	8.22 (1.88–36.05)

Abbreviations: CCPR, conventional cardiopulmonary resuscitation; CPC, cerebral performance category; ECPR, extracorporeal cardiopulmonary resuscitation; IHCA, in-hospital cardiac arrest; OHCA, out-of-hospital cardiac arrest.

Notes: Kim et al,[20] Maekawa et al,[21] Patricio et al,[39] Shin et al,[32] Blumenstein et al,[33] Chen et al,[30] and Lin et al[31] performed propensity score matched analysis. Sakamoto et al,[18] Schober et al,[19] and Siao et al[36] performed logistic regression analysis. Of these studies, Sakamoto et al,[18] was a non-randomized, multicenter, prospective cohort design. The studies by Shin et al[32,35] included the same patient population, but reported different outcomes; only data from Shin et al[32] is presented in the above table.

[a]Refers to long-term neurologically intact survival, defined as a CPC score of 1 – 2.

[b]Effect estimates represent odds ratios (OR) with a 95% confidence interval (CI) at the individual study level.

[c]Refers to adjusted results (OR [95% CI]) at the individual study level.

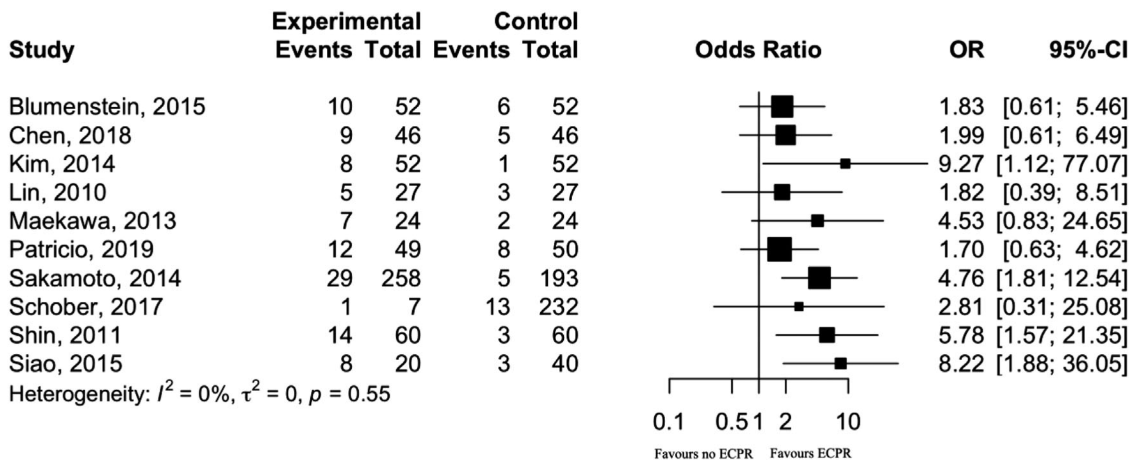

FIGURE 2 Forest plot of long-term neurologically intact survival in adult in-hospital and out-of-hospital cardiac arrest. Squares indicate study-specific odds ratios. Horizontal lines indicate 95% confidence intervals of the estimate. Squares to the right of the solid vertical line favor the intervention group, but this is conventionally significant ($P < 0.05$) only if the horizontal line does not overlap the solid line. The studies are ordered by alphabetical order within each outcome. Kim et al,[20] Maekawa et al,[21] and Patricio et al[39] reported 3 months neurologically intact survival. Sakamoto et al,[18] Schober et al,[19] and Shin et al[32] reported 6 months neurologically intact survival. Blumenstein et al,[33] Chen et al,[30] Lin et al[31] and Siao et al[36] reported 1 year neurologically intact survival

TABLE 3 Characteristics of extracorporeal cardiopulmonary resuscitation group and the conventional cardiopulmonary resuscitation group of included studies

Authors, year, country	Study design	Years of inclusion	Location	Total sample size, (n)	Received ECPR, (n)	Age, (mean [SD]/median [IQR])	Male, (%)	Inclusion criteria/criteria for ECPR	Exclusion criteria/ contraindication for ECPR
Blumenstein et al[33] Germany	Retrospective propensity score matched cohort	2009–2011	IHCA	352	32	ECPR: 72 (55–78) CCPR: 73 (68–78)	ECPR: 54CCPR: 60	No age limit, witnessed cardiac arrest, admission due to presumed cardiac etiology, CPR for >10 min. Criteria for ECPR: Witnessed IHCA, refractory CA, defined as the absence of ROSC after conventional CPR, absence of severe co-morbidities that would have precluded ICU treatment, condition leading to CA presumed to be reversible or eligible for revascularization or heart transplantation.	Known terminal malignancies, severe trauma, aortic dissection, severe aortic failure, coagulation disorders, uncontrollable hemorrhage, irreversible brain damage, signed consent for DNR order.
Bougouin et al[22] France	Retrospective Cohort[a]	2011–2018	OHCA	13191	525	ECPR: 50 ±13 CCPR: 66 ± 16	ECPR: 84 CCPR: 67	All cases of sudden OHCA (defined as unexpected death without any obvious extra cardiac cause) in patients older than 18 y were included in the registry. ECPR was used either in the absence of ROSC or after transient ROSC followed by recurrent cardiac arrest.	Obvious extra cardiac cause of cardiac arrest (trauma, drowning, drug overdose, electrocution, or asphyxia from external cause). Contraindications for ECMO implantation were presence of major comorbidities, non-witnessed OHCA, persistent asystole, and expected delay from CPR to ECMO over 100 min.
Cesana et al[37] Italy	Retrospective Cohort	2011–2015	OHCA/IHCA	148	63	ECPR: 59 ± 10 CCPR: 63 ± 9	ECPR: 87 CCPR: 75	Age 18–75 y, witnessed cardiac arrest, ischemic etiology, absence of comorbidities precluding ICU admission. Criteria for ECPR: No ROSC after 15 min of CPR, age between 18 and 75 years, witnessed IHCA or OHCA, absence of terminal malignancies, aortic dissection, severe peripheral arterial disease, severe cardiac failure or severe aortic failure; no-flow time ≤6 min; low-flow time ≤45 min before cannulation beginning, end tidal CO_2 >10 mm Hg.	Exclusion criteria and contraindication for ECPR not reported.

(Continues)

TABLE 3 (Continued)

Authors, year, country	Study design	Years of inclusion	Location	Total sample size, (n)	Received ECPR, (n)	Age, (mean [SD]/median [IQR])	Male, (%)	Inclusion criteria/criteria for ECPR	Exclusion criteria/ contraindication for ECPR
Chen et al[30] Taiwan	Prospective propensity score matched cohort	2004–2006	IHCA	172	59	ECPR: 57 ± 14 CCPR: 60 ± 15	ECPR: 85 CCPR: 87	Age 18–75 y, witnessed cardiac arrest, CPR for >10 min, cardiac etiology. Only patients who underwent witnessed arrest of cardiac origin and CPR duration (defined as the interval from beginning CPR to return of spontaneous circulation or death) for >10 min were recruited in the study cohort.	CPR <10 min, known severe irreversible brain damage, terminal malignancy, a traumatic origin with uncontrolled bleeding; non-cardiac arrest, signed DNR order.
Cho et al[29] Korea	Retrospective Cohort	2001–2013	IHCA	20	12	ECPR: 60 ± 20 CCPR: 55 ± 16	ECPR: 50 CCPR: 25	Cardiac arrest cause by pulmonary thromboembolism. Criteria for ECPR: CPR performed for >10 min, unstable vital signs after ROSC.	Non-survivors of CPR, OHCA, and no evidence of pulmonary thromboembolism in imaging studies such as computed tomography, fluoroscopic angiography, and echocardiography.
Choi et al[23] Korea	Retrospective cohort	2011–2015	OHCA	60	10	ECPR: 58 ± 6 CCPR: 59 ± 12	ECPR: 70 CCPR: 76	Age ≤75 years, witnessed cardiac arrest, bystander CPR or no-flow time ≤5 min, prehospital low-flow time ≤30 min and refractory arrest >10 min of conventional CPR at the ED, known absence of severe comorbidities that preclude admission to the ICU.	DNR, a poor performance status or terminal illness that preceded the arrest due to malignancy or neurologic disease, trauma, intracranial hemorrhage, acute aortic dissection with pericardial effusion, and achievement of sustained ROSC within 10 min after ED arrival.
Choi et al[24] Korea	Retrospective propensity score matched cohort[c]	2009–2013	OHCA	36547	320	ECPR: 56 (45–68) CCPR: 58 (47–68)	ECPR: 81 CCPR: 81	Age >18 y with presumed cardiac etiology and resuscitation by EMS. The etiology of cardiac arrest was identified by a medical record review. We presumed cardiac etiology if there was no description of definite non-cardiac etiology such as trauma, drowning, poisoning, burns, asphyxia, or hanging in the medical records.	CPR not attempted in the emergency department or if information about clinical outcomes at discharge could not be extracted.

(Continues)

TABLE 3 (Continued)

Authors, year, country	Study design	Years of inclusion	Location	Total sample size, (n)	Received ECPR, (n)	Age, (mean [SD]/median [IQR])	Male, (%)	Inclusion criteria/criteria for ECPR	Exclusion criteria/ contraindication for ECPR
Chou et al[34] Taiwan	Retrospective cohort	2006–2010	IHCA	23	43	ECPR: 61 ± 12 CCPR: 70 ± 15	ECPR: 93 CCPR: 74	Age > 18 y, acute myocardial infarction in the emergency department, CPR for > 10 min.	Age ≤18 y, terminal malignancy, previously known severe irreversible brain damage, presence of DNR, ROSC within 10 min.
Kim et al[20] Korea	Retrospective cohort propensity score-matched cohort	2006–2013	OHCA	499	55	ECPR: 54 (41–69) CCPR: 54 (42–68)	ECPR: 77 CCPR: 73	Age ≥18 y, sudden cardiac arrest with presumed correctable causes, witnessed cardiac arrest with or without bystander CPR, no-flow time (expected to be short, even for unwitnessed cardiac arrest). ECPR team was activated if above criteria were met and patient required prolonged CPR > 10 min as in-hospital CPR duration or when recurrently arrested in the emergency department after achieving sustained ROSC for at least 20 min.	Cardiac arrest due to a clearly uncorrectable cause, presence of a terminal illness or malignancy, suspected traumatic origin of arrest; no informed consent from family.
Lee et al[38] Korea	Retrospective cohort	2009–2014	OHCA/IHCA	955	81	ECPR: 59 ±19 CCPR: 64 ±18	ECPR: 69 CCPR: 65	CPR duration > 10 min or when the repetitive arrest events occurred without ROSC for > 20 min.	Terminal malignancy, irreversible brain damage, multiorgan failure, family refusing ECMO. ECPR was not performed in OHCA cases of unwitnessed cardiac arrest, OHCA without bystander CPR, age >80 y, asystole.
Lin et al[31] Taiwan	Retrospective propensity score matched cohort	2004–2006	IHCA	118	55	ECPR: 59 ±12 CCPR: 61 ± 13	ECPR: 81 CCPR: 61	Age 18–75 y with circulatory arrest of cardiac origin, as judged by 2 independent members in the IHCA Task Force committee. Indication for ECPR: CPR duration > 10 min without sustained ROSC.	Severe trauma, uncontrollable hemorrhage, terminal malignancy, age >75 y, irreversible brain damage, signed consent for DNR.

(Continues)

TABLE 3 (Continued)

Authors, year, country	Study design	Years of inclusion	Location	Total sample size, (n)	Received ECPR, (n)	Age, (mean [SD]/median [IQR])	Male, (%)	Inclusion criteria/criteria for ECPR	Exclusion criteria/ contraindication for ECPR
Maekawa et al[21] Japan	A post hoc analysis of data from a single-center prospective cohort, including propensity score matching	2000–2004	OHCA	162	53	ECPR: 57 (48–63) CCPR: 57 (50–68)	ECPR: 80 CCPR: 80	Age ≥16 years, CPR duration >20 min after witnessed arrest of presumed cardiac origin. Criteria for ECPR: Initiated if the ROSC did not occur or could not be maintained during transportation, if the patient was assessed to have good activities of daily life before cardiac arrest by interview with the patient's relatives, and if the cardiac arrest was clinically presumed as cardiac in origin by the patient's information reported by paramedics and rapid echocardiographic examination.	Previously signed DNR order, pronounced dead before hospital arrival. Contraindication for ECPR: Non-cardiac cause of arrest. Cardiac arrest was presumed to be of cardiac origin unless it was known or likely to have been caused by trauma, submersion, hypothermia, drug overdose, asphyxia, exsanguination, or any other noncardiac cause including intracranial hemorrhage, acute aortic dissection, and terminal malignancy.
Matsuoka et al[25] Japan	Population-based retrospective cohort	2010–2017	OHCA	518	188	ECPR: 66 (57–75) CCPR: 68 (58–77)	ECPR: 78 CCPR: 79	Age >18 y with refractory VF or pulseless VT, defined as cardiac arrest without ROSC after receiving conventional resuscitation by EMS in the field.	Cardiac arrest from trauma, other external causes, known pregnancy, or known terminal-stage malignancies.
Patricio et al[39] Belgium	Retrospective propensity score-matched cohort	2012–2017	OHCA/IHCA	351	49	ECPR: 57 ± 17 CCPR: 57 ± 14	ECPR: 74 CCPR: 61	All cardiac arrest patients admitted to the ICU. Criteria for ECPR: Age <65 y, witnessed arrest, <2 min of estimated no-flow time, <75 min of estimated time to ECMO placement, no severe comorbidity, and signs of life during CPR.	Patients with orders established prior to the CA and patients pronounced dead before hospital arrival were excluded.
Poppe et al[26] Austria	Retrospective cohort[b]	2013–2014	OHCA	96	12	ECPR: No specified CCPR: No specified	ECPR: No speci-fied CCPR: No speci-fied	Age >18 y, ongoing resuscitation performed by the Municipal Ambulance Service of Vienna. Load & go criteria: An initially shockable rhythm, age <75 y, a bystander witnessed collapse, bystander CPR, and no sustained ROSC within 15 min of ALS by EMS.	Exclusion criteria and contraindication for ECPR not reported.

(Continues)

TABLE 3 (Continued)

Authors, year, country	Study design	Years of inclusion	Location	Total sample size, (n)	Received ECPR, (n)	Age, (mean [SD]/median [IQR])	Male, (%)	Inclusion criteria/criteria for ECPR	Exclusion criteria/ contraindication for ECPR
Sakamoto et al[18] Japan	Multi-center prospective cohort	2008–2011	OHCA	451	258	ECPR: 56 (NR) CCPR: 58 (NR)	ECPR: 90 CCPR: 89	VF/VT on the initial electrocardiogram, cardiac arrest on arrival to hospital with or without prehospital ROSC, arrival at hospital within 45 min of the emergency call or the cardiac arrest, no ROSC for 15 min after hospital arrival in spite of ongoing CPR.	Age <20 or >75 years, poor level of activities of daily living prior to arrest, arrest of non-cardiac origin (ie, trauma, drug intoxication, primary cerebral disorder, aortic dissection, terminal phase of cancer), core temperature <30°C, no informed consent from patient representatives.
Schober et al[19] Austria	Retrospective cohort	2002–2012	OHCA	239	7	ECPR: 46 (31–59) CCPR: 60 (50–70)	ECPR: 72 CCPR: 75	Refractory cardiac arrest >30 min without occurrence of ROSC (ROSC according to Utstein criteria), arrest of cardiac origin.	Clear clinical indication for the use of ECPR (ie, severe hypothermia).
Shin et al[32] Korea	Retrospective cohort propensity score-matched cohort	2003–2009	IHCA	406	85	ECPR: 61 ± 15 CCPR: 61 ± 14	ECPR: 62 CCPR: 63	Patients between the ages of 18 and 80 years, CPR duration >10 min, witnessed in-hospital cardiac, and arrest was presumed to be of cardiac etiology. ECMO was usually considered when there was no ROSC after 10–20 min of CPR, recurrent arrest, or when the patient could not be expected to recover as a result of underlying severe left ventricular dysfunction or coronary artery disease despite.	Previous severe neurological damage, current intracranial hemorrhage, malignancy in the terminal stage, arrest of traumatic origin with uncontrolled bleeding, arrest of septic origin, irreversible organ failure, and patients who previously signed DNR orders.

(Continues)

JACEP OPEN
JOURNAL OF THE AMERICAN COLLEGE OF EMERGENCY PHYSICIANS OPEN
A GLOBAL JOURNAL OF EMERGENCY MEDICINE
Open Access
WILEY

TABLE 3 (Continued)

Authors, year, country	Study design	Years of inclusion	Location	Total sample size, (n)	Received ECPR, (n)	Age, (mean [SD]/median [IQR])	Male, (%)	Inclusion criteria/criteria for ECPR	Exclusion criteria/contraindication for ECPR
Shin et al[35] Korea	Retrospective cohort propensity score-matched cohort	2003–2009	IHCA	406	85	ECPR: 61 ± 15 CCPR: 61 ± 16	ECPR: 60 CCPR: 68	Prolonged arrest and no ROSC within 10–15 min after initiation of CPR, when ROSC could not be maintained due to recurrent arrest, or when recovery without ECMO support was unlikely due to known severe left ventricular dysfunction or coronary artery disease despite relatively short CPR duration.	Age >80 y, previous severe neurological damage, current intracranial hemorrhage, malignancy in the terminal stage, arrest of traumatic origin with uncontrolled bleeding, arrest of septic origin, irreversible multi-organ failure leading to cardiac arrest, and patients who signed DNR orders. Patients with CPR duration of <10 min, unwitnessed arrest.
Siao et al[36] Taiwan	Retrospective cohort	2011–2013	OHCA/IHCA	60	20	ECPR: 55 ± 12 CCPR: 60 ± 11	ECPR: 90 CCPR: 70	Age 18–75 y, cardiac arrest with initial VF and CPR initiated within 5 min (no-flow duration <5 min), refractory VF defined as VF resistant to at least 3 defibrillations, 3 mg of epinephrine, 300 mg of amiodarone, and no ROSC achieved after CPR for >10 min.	Severe head trauma or severe acute active bleeding, severe sepsis, VF that developed during resuscitation for initial asystole or pulseless electrical activity, terminal stage of malignancy, any history of severe neurological deficits (including dementia, intracranial hemorrhage, or ischemic stroke and bedridden state).
Venturini et al[40] United States	Retrospective cohort	2011–2016	OHCA/IHCA	31	14	ECPR: 49 (NR) CCPR: 61 (NR)	ECPR: : No specified CCPR: : No specified	Patients who arrived at the CCL with chest compressions ongoing (either manual or mechanical), cardiac arrest patients who received advanced cardiovascular life support resuscitation and/or use of a mechanical chest compression device.	Exclusion criteria and contraindication for ECPR not reported.

(Continues)

TABLE 3 (Continued)

Authors, year, country	Study design	Years of inclusion	Location	Total sample size, (n)	Received ECPR, (n)	Age, (mean [SD]/median [IQR])	Male, (%)	Inclusion criteria/criteria for ECPR	Exclusion criteria/contraindication for ECPR
Yannopolous et al[27] United States	Cohort -before/after-design.	2015–2016	OHCA	188	18	ECPR: 56 ± 10 CCPR: 56 ± 7	ECPR: 78 CCPR: 75	Age 18–75 y, cardiac etiology, shockable rhythm, at least 3 standard defibrillation shocks, amiodarone 300 mg, eligible for mechanical CPR, transfer from scene time to CCL <30 min. Criteria for ECPR: ECMO cannulation, time to catheterization laboratory <60 min, ETCO2 at arrival >10 mmHg, PaO_2 >50 mmHg, O_2 saturation >85%, lactate <18.	Nursing home resident, DNR, known terminal illness, significant bleeding, contraindication to mechanical CPR.
Yannopolous et al[28] United States	Cohort -before/after -design.	2015–2016	OHCA	232	50	ECPR: 58 ± 10 CCPR: 56 ± 7	ECPR: 71 CCPR: 73	Age 18–75 y, cardiac etiology, shockable rhythm, at least 3 standard defibrillation shocks, amiodarone 300 mg, eligible for mechanical CPR, transfer from scene time to CCL <30 min. Criteria for ECPR: ECMO cannulation, time to catheterization laboratory <60 min, $ETCO_2$ at arrival >10 mmHg, PaO_2 > 50 mmHg, O_2 saturation >85%, lactate <18.	Nursing home resident, DNR, known terminal illness, significant bleeding, contraindication to mechanical CPR. Contraindication for ECPR not reported.

Notes: There was some overlap between the out-of-hospital studies by Yannopolous et al.[16,17] There was also some overlap between the in-hospital studies by Chen et al[30] and Lin et al,[31] and between Cho et al[29] and Shin et al.[32,35] The studies by Shin et al[32] and Shin et al[35] included the same patient population, but reported different outcomes.

Abbreviations: CA, cardiac arrest; CCL, cardiac catheterization laboratory; CCPR, conventional cardiopulmonary resuscitation; CPC, cerebral performance category; CPR, cardiopulmonary resuscitation; DNR, do not resuscitate; ECLS, extracorporeal life support; ECMO, extracorporeal membrane oxygenation; ECPR, extracorporeal cardiopulmonary resuscitation; EMS, emergency medical services; $ETCO_2$, end-tidal carbon dioxide; ICU, intensive care unit; IHCA, in-hospital cardiac arrest; OHCA, out-of-hospital cardiac arrest; ROSC, return of spontaneous circulation; TIMI, thrombolysis in myocardial infarction; VA-ECMO, venoarterial extracorporeal membrane oxygenation; VF, ventricular fibrillation; VT, ventricular tachycardia.

[a]Data analyzed from the Sudden Death Expertise Center registry (Greater Paris area). The cases occurred in Paris and 3 of its suburbs (Hauts-de-Seine, Seine-Saint-Denis, and Val-de-Marne), an area covering 762 km^2 with a population of 6.8 million.

[b]Data analyzed from Vienna Cardiac Arrest Registry (Vienna). Of 864 patients, only 96 (11%) were transported with ongoing CPR. The required Load & go criteria were fulfilled in 16 (16.6%) cases. Of these, 5 patients (31.3%) were treated with ECLS.

[c]Data analyzed from the cardiovascular disease surveillance database (Korea). The database consists of 3 disease entities and a nationwide EMS-assessed OHCA. The cohort was followed by a hospital medical record review for hospital resuscitation and post-resuscitation care and clinical outcomes.

TABLE 4 Clinical characteristics and outcomes of the extracorporeal cardiopulmonary resuscitation group and the conventional cardiopulmonary resuscitation group of included studies

Authors, year, country	Low-flow time (mean [SD]/median [IQR], min)	Initial shockable rhythm VF/VT (%)	Cardiac etiology (%)	Bystander CPR (%)	Witnessed (%)	TTM (%)	Reperfusion therapy (PCI/CABG) (%)	Survival to discharge/ 1-month (%)	CPC 1–2 at discharge/ 1-month (%)	Survival at 3-month[1], 6-month[2], and 1-year[3] (%)	CPC 1–2 at 3-month[1], 6-month[2], and 1-year[3] (%)
Blumenstein et al[33] Germany	ECPR: 33 (19–47) CCPR: 37 (30–45)	ECPR: 4 CCPR: 2	ECPR: 100 CCPR: 100	ECPR: N/A CCPR: N/A	ECPR: 100 CCPR: 100	ECPR: 14 CCPR: 4	ECPR: 17 CCPR: 33	ECPR: 14/52 (27) CCPR: 9/52 (17)	ECPR: 11/52 (21) CCPR: 7/52 (13)	ECPR: 12/ 52 (23)[3] CCPR: 7/52 (14)[3]	ECPR: 10/52 (19)[3] CCPR: 6/52 (12)[3]
Bougouin et al[22] France	ECPR: NR CCPR: NR	ECPR: 68 CCPR: 24	ECPR: NR CCPR: NR	ECPR: 79 CCPR: 47	ECPR: 97 CCPR: 75	ECPR: 100 CCPR: NR	ECPR: 31 CCPR: 5	ECPR: 44/523 (8) CCPR: 1061/ 12396 (9)	ECPR: 32/523 (6)[a] CCPR: 878/12396 (7)	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR
Cesana et al[37] Italy	ECPR: 56 ± 24 CCPR: 19 ± 19	ECPR: 64 CCPR: 72	ECPR: 100 CCPR: 100	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR	ECPR: 91 CCPR: 61	ECPR: 100 CCPR: 100	ECPR: 13/63 (21) CCPR: 49/85 (58)	ECPR: NR CCPR: NR	ECPR: 12/63 (19)[3] CCPR: 48/85 (56)[3]	ECPR: NR CCPR: NR
Chen et al[30] Taiwan	ECPR: NR CCPR: NR	ECPR: 46 CCPR: 41	ECPR: 100 CCPR: 100	ECPR: N/A CCPR: N/A	ECPR: 100 CCPR: 100	ECPR: 0 CCPR: 0	ECPR: 44 CCPR: 6	ECPR: 15/46 (33) CCPR: 8/46 (17)	ECPR: 14/46 (30) CCPR: 7/46 (15)	ECPR: 9/46 (20)[3] CCPR: 6/46 (13)[3]	ECPR: 9/46 (20)[3] CCPR: 5/46 (11)[3]
Cho et al[29] Korea	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR	ECPR: N/A CCPR: N/A	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR	ECPR: No specified[b] CCPR: No specified	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR
Choi et al[23] Korea	ECPR: 14 ± 10[c] CCPR: 19 ± 8[c]	ECPR: 30 CCPR: 26	ECPR: 80 CCPR: 58	ECPR: 80 CCPR: 82	ECPR: 100 CCPR: 100	ECPR: 67 CCPR: 67	ECPR: 56 CCPR: 13	ECPR: 3/10 (30) CCPR: 4/50 (8)	ECPR: 3/10 (30) CCPR: 2/50 (4)	ECPR: NRCCPR: NR	ECPR: NR CCPR: NR
Choi et al[24] Korea	ECPR: NR CCPR: NR	ECPR: 29 CCPR: 28	ECPR: 90 CCPR: 58	ECPR: 30 CCPR: 32	ECPR: 71 CCPR: 73	ECPR: 30 CCPR: 11	ECPR: 9 CCPR: 30	ECPR: 57/320 (18) CCPR: 52/320 (16)	ECPR: 29/320 (9) CCPR: 19/320 (6)	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR
Chou et al[34] Taiwan	ECPR: 54 ± 27 CCPR: 37 ± 20	ECPR: 60 CCPR: 39	ECPR: 100 CCPR: 100	ECPR: N/A CCPR: N/A	ECPR: NR CCPR: NR	ECPR: 0 CCPR: 0	ECPR: 86 CCPR: 35	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR	ECPR: 15/43 (35)[3] CCPR; 5/23 (22)[3]	ECPR: NR CCPR: NR
Kim et al[20] Korea	ECPR: 1.5 (0.6–6.4) CCPR: NR	ECPR: 60 CCPR: 56	ECPR: 94 CCPR: 94	ECPR: 42 CCPR: 31	ECPR: 81 CCPR: 81	ECPR: 27 CCPR: 23	ECPR: 75 CCPR: 21	ECPR: 9/52 (17) CCPR: 11/52 (21)	ECPR: 8/52 (15) CCPR: 1/52 (2)	ECPR: 5/52 (15)[1] CCPR: 4/52 (8)[1]	ECPR: 5/52 (15)[1] CCPR: 1/52 (2)[1]
Lee et al[38] Korea	ECPR: NR CCPR: NR	ECPR: 42 CCPR: 15	ECPR: NR CCPR: NR	ECPR: 100 CCPR: NR	ECPR: 100 CCPR: NR	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR	ECPR: 18/81 (22) CCPR: 120/874 (14)	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR

(Continues)

TABLE 4 (Continued)

Authors, year, country	Low-flow time (mean [SD]/median [IQR], min)	Initial shockable rhythm VF/VT (%)	Cardiac etiology (%)	Bystander CPR (%)	Witnessed (%)	TTM (%)	Reperfusion therapy (PCI/CABG) (%)	Survival to discharge/ 1-month (%)	CPC 1–2 at discharge/ 1-month (%)	Survival at 3-month[1], 6-month[2], and 1-year[3] (%)	CPC 1–2 at 3-month[1], 6-month[2], and 1-year[3] (%)
Lin et al[31] Taiwan	ECPR: 49 ± 27 CCPR: 31 ± 17	ECPR: 51 CCPR: 41	ECPR: 93 CCPR: 89	ECPR: N/A CCPR: N/A	ECPR: 100 CCPR: 100	ECPR: NR CCPR: NR	ECPR: 41 CCPR: 11	ECPR: 19/55 (35) CCPR: 17/66 (27)	ECPR: 13/55 (24) CCPR: 12/66 (19)	ECPR: 11/55 (20)[3] CCPR: 11/66 (18)[3]	ECPR: 8/55 (16)[3] CCPR: 10/66 (17)[3]
Maekawa et al[21] Japan	ECPR: NR CCPR: NR	ECPR: 54 CCPR: 58	ECPR: NR CCPR: NR	ECPR: 54 CCPR: 58	ECPR: NR CCPR: NR	ECPR: 38 CCPR: 29	ECPR: 21 CCPR: 25	ECPR: 9/24 (38) CCPR: 3/24 (13)	ECPR: NR CCPR: NR	ECPR: 9/24 (38)[1] CCPR: 2/24 (8)[1]	ECPR: 7/24 (29)[1] CCPR: 2/24 (8)[1]
Matsuoka et al[25] Japan	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR	ECPR: 48 CCPR: 46	ECPR: 77 CCPR: 76	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR	ECPR: 87/188 (46) CCPR: 67/330 (20)	ECPR: 43/188 (23) CCPR: 28/330 (9)	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR
Patricio et al[39] Belgium	ECPR: 54 ± 20 CCPR: 54 ± 22	ECPR: 30 CCPR: 28	ECPR: 72 CCPR: 42	ECPR: 74 CCPR: 71	ECPR: 88 CCPR: 85	ECPR: 88 CCPR: 31	ECPR: 24 CCPR: 15	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR	ECPR: 12/49 (24)[1] CCPR: 8/50 (16)[1]
Poppe et al[26] Austria	ECPR: 100 CCPR: 100	ECPR: 100 CCPR: 100	ECPR: NR CCPR: NR	ECPR: 100 CCPR: 100	ECPR: 100 CCPR: 100	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR	ECPR: 2/12 (17) CCPR: 8/84 (10)	ECPR: 1/12 (8) CCPR: 4/84 (5)	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR
Sakamoto et al[18] Japan	ECPR: NR CCPR: NR	ECPR: 100 CCPR: 100	ECPR: 87 CCPR: 77	ECPR: 49 CCPR: 46	ECPR: 72 CCPR: 78	ECPR: 92 CCPR: 54	ECPR: 89 CCPR: 68	ECPR: 69/260 (27) CCPR: 12/193 (6)	ECPR: 32/260 (12) CCPR: 3/193 (2)	ECPR: 56/260 (22)[2] CCPR: 8/192 (4)[2]	ECPR: 29/258 (11)[2] CCPR: 5/192 (3)[2]
Schober et al[17] Austria	ECPR: NR[d] CCPR: NR	ECPR: 57 CCPR: 58	ECPR: 100 CCPR: 100	ECPR: 28 CCPR: 31	ECPR: 86 CCPR: 88	ECPR: 43 CCPR: 21	ECPR: 28 CCPR: 5	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR	ECPR: 1/7 (14)[2] CCPR: 13/232 (6)[2]
Shin et al[32] Korea	ECPR: NR CCPR: NR	ECPR: 29 CCPR: 23	ECPR: 92 CCPR: 81	ECPR: N/A CCPR: N/A	ECPR: 100 CCPR: 100	ECPR: NR CCPR: NR	ECPR: 21 CCPR: 3	ECPR: 29/85 (34) CCPR: 39/321 (12)	ECPR: 24/85 (28) CCPR: 25/321 (8)	ECPR: 26/85 (31)[2] CCPR: 35/321 (11)[2]	ECPR: 24/85 (28)[2] CCPR: 24/321 (8)[2]
Shin et al[35] Korea	ECPR: NR CCPR: NR	ECPR: 29 CCPR: 3	ECPR: 74 CCPR: 57	ECPR: N/A CCPR: N/A	ECPR: 100 CCPR: 100	ECPR: NR CCPR: NR	ECPR: 22 CCPR: 22	ECPR: 19/60 (32) CCPR: 6/60 (10)	ECPR: 14/60 (23) CCPR: 3/60 (5)	ECPR: 12/60 (20)[f] CCPR: 3/60 (5)[f]	ECPR: 12/60 (20)[f] CCPR: 3/60 (5)[f]

(Continues)

TABLE 4 (Continued)

Authors, year, country	Low-flow time (mean [SD]/median [IQR], min)	Initial shockable rhythm VF/VT (%)	Cardiac etiology (%)	Bystander CPR (%)	Witnessed (%)	TTM (%)	Reperfusion therapy (PCI/CABG) (%)	Survival to discharge/ 1-month (%)	CPC 1–2 at discharge/ 1-month (%)	Survival at 3-month[1], 6-month[2], and 1-year[3] (%)	CPC 1–2 at 3-month[1], 6-month[2], and 1-year[3] (%)
Siao et al[36] Taiwan	ECPR: 49 ± 44 CCPR: NR	ECPR: 100 CCPR: 100	ECPR: 80 CCPR: 53	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR	ECPR: 45 CCPR: 23	ECPR: 60 CCPR: 40	ECPR: 12/20 (50) CCPR: 11/60 (28)	ECPR: 8/20 (40) CCPR: 3/40 (8)	ECPR: 12/20 (50)[3] CCPR: 10/40 (25)[3]	ECPR: 8/20 (40)[3] CCPR: 3/40 (8)[3]
Venturini et al[40] United States	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR	ECPR: 3/14 (21) CCPR: 3/17 (18)	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR
Yannopolous et al[27] United States	ECPR: NR[e] CCPR: NR	ECPR: 100 CCPR: NR	ECPR: 100 CCPR: 100	ECPR: 66 CCPR: 61	ECPR: 61 CCPR: NR	ECPR: 100 CCPR: NR	ECPR: 67 CCPR: NR	ECPR: 10/18 (53) CCPR: NR	ECPR: 9/18 (50) CCPR: 14/170 (8)	ECPR: NR CCPR: NR	ECPR: NR CCPR: NR
Yannopolous et al[28] United States	ECPR: 64 ± 13 CCPR: NR	ECPR: 100 CCPR: NR	ECPR: 100 CCPR: 100	ECPR: 84 CCPR: 75	ECPR: 80 CCPR: 77	ECPR: 100 CCPR: NR	ECPR: 84 CCPR: NR	ECPR: 28/62 (45) CCPR: NR	ECPR: 26/62 (42) CCPR: 26/170 (15)	ECPR: 26/62 (42)[2] CCPR: NR	ECPR: 26/62 (42)[2] CCPR: NR

Abbreviations: CABG, coronary artery bypass grafting; CCL, cardiac catheterization laboratory; CCPR, conventional cardiopulmonary resuscitation; CPC, cerebral performance category; CPR, cardiopulmonary resuscitation; ECPR, extracorporeal cardiopulmonary resuscitation; PCI, percutaneous coronary intervention; TTM, targeted temperature management; VF, ventricular fibrillation; VT, ventricular tachycardia.

Notes: Proportions – No. (%) of studies performing propensity score matching refers to the matched pre-arrest and post-arrest clinical characteristics and outcomes. For studies including a mixed population, results refer to OHCA subpopulation. The superscript numbers refer to post-hospital discharge/follow-up survival and CPC score of 1–2 at 3-month, 6-month, and 1-year.

[a] Of the 525 patients in the extracorporeal-CPR group, 44 (8%) were discharged alive. Of the survivors, 32/38 (84%, and 6 patients with missing data) had a favorable neurological outcome at hospital discharge compared with 878/916 (96%, 145 patients with missing data) of the CCPR survivors ($P = 0.001$).

[b] This study was included because it reviewed cardiac arrest in the unique setting of acute massive pulmonary thromboembolism (PTE). A total of 20 patients (11%) who experienced cardiac arrest at initial presentation or after diagnosis of PTE were included in this study. Percutaneous cardiopulmonary support (PCPS) was performed in 12 patients (60%, PCPS group), which involved the use of ECMO, to assist with CPR, or stabilize patients after recovery of spontaneous circulation.Thirteen patients survived to discharge, and the overall in-hospital mortality was 35%. All patients with CPR duration of 15 minutes or less were discharged without significant disability.

[c] Refers to prehospital low-flow time (min).

[d] Time from cardiac arrest to admission (min) in the ECPR group was 38 (27–66) and 56 (40–72) in the CCPR group. The time from admission to ECPR/ROSC (min) in the ECPR group was 55 (45–68) and 17 (8–27) in the CCPR group.

[e] Time from 911 call to delivery to the CCL was 60.1 ± 11. Time to CCL arrival on extracorporeal membrane oxygenation was 6.3 ± 2.

[f] Refers to outcomes after 2 years of follow-up. Minimal neurological impairment was defined as a Modified Glasgow Outcome Score ≥4.

in terms of methodology, this review was limited to 4 databases and articles published in English, which may have led to selection bias. It is possible that some studies were missed due to the selection of databases and search terms. Third, current scientific evidence rests principally on observational analytic studies, for example, cohort studies and observational descriptive studies, and case-series studies, with their potential for confounding selection bias, rather than randomized clinical trials. As a result, the ability to draw any conclusions from current studies is severely limited by the quality of the primary evidence. Furthermore, the majority of the evidence comes from Asia, meaning it is unlikely to reflect systems of care in other regions of the world; outcomes reported among comparator groups are also relatively low compared to those in other developed countries. All of these plus the variability of inclusion and exclusion criteria, indication, and potential risk of confounding bias, make their validity, comparability, and generalizability questionable, and could explain some of the inconsistencies in outcomes between studies. It is also important to note that there might be considerable differences in emergency medical services' transport strategies (ie, scoop and run, stay and treat), bypassing the nearest ECPR-incapable facilities and transporting patients to a PCI- and ECPR-capable facility, and variations in medical protocol and therapy bundles among studies.

Since completing this review, in August 2020, we searched for recent studies on the topic (results are not included in Tables 3 and 4). These either provide additional evidence for ECPR outcomes in a cardiac arrest population, or evidence supporting our review. The Advanced Reperfusion Strategies for Refractory Cardiac Arrest (ARREST) trial (ClinicalTrials.gov identifier: NCT03880565), funded by the National Heart, Lung, and Blood Institute (NHLBI), part of the National Institutes of Health was recently published.[42] Patients with refractory ventricular fibrillation/ventricular tachycardia out-of-hospital cardiac arrest were randomized to ECMO (n = 15) versus standard advanced cardiac life support (ACLS) (n = 15). This randomized trial showed early initiation ECMO-facilitated resuscitation resulted in an impressive 43% survival to hospital discharge. Because of this notable improvement in survival of patients receiving this program of care, the trial was terminated early on June 2020 by NHLBI after recommendation from the Data and Safety Monitoring Board.[42] Given the patient population of interest is so small and rarely encountered and the health economics required to justify the large resource requirement surrounding ECPR, these trials will never randomized very large numbers of patients. Further randomized studies are being carried out and the results of these ongoing studies should provide a bigger evidence base to inform best practice.

6 | DISCUSSION

The primary objective of our scoping review was simply to follow a systematic approach and to map evidence for the use of ECPR compared to no ECPR or the standard of care in adult patients who have sustained cardiac arrest in any setting, as well as to identify knowledge gaps in the literature that may require further research. A further objective was to summarize the effect estimate at the individual study level among those studies reporting long-term neurologically intact survival, rather than inferring recommendations on meaningful clinical significance from our gathered data, which was beyond the scope of this paper. In this review of 23 observational studies, we identified 10 studies that have reported long-term neurologically intact survival, of which 5 were of adult out-of-hospital cardiac arrest, 4 were of adult in-hospital cardiac arrest, and 1 was conducted on mixed populations. Despite the unmatched, unadjusted subgroup revealing an improvement in favorable long-term neurological outcomes in patients treated with ECPR, outcomes for the propensity-matched cohorts were not significantly different. These studies suggest that the intervention is likely better than the comparator group, though at the study level only 4 of 10 studies that reported long-term favorable outcome show long-term neurologically intact survival that is statistically significant at 5% significance levels.[18,20,32,36] Although there are design limitations and the data remains preliminary, it is noteworthy that in every single study, there were a higher percentage of neurologically intact survivors in the ECPR group as compared to the standard CPR group.

The 2018 ILCOR systematic review evaluated the use of ECPR techniques (including ECMO or cardiopulmonary bypass) compared with manual CPR or mechanical CPR.[43] Individual studies were all at very serious risk of bias, primarily due to confounding. ILCOR recommended the use of ECPR for selected patients with cardiac arrest refractory to the standard of care in settings where ECPR can be implemented (weak recommendation, very low certainty of evidence).[43] Currently, there is no clear evidence for either ECPR or no ECPR or the standard of care, but current evidence is more in favor of the intervention group (ECPR), with a number of lower-quality studies suggesting improved survival with good neurological outcome for select patients. In the absence of randomized controlled trials, neither the guidelines of the AHA nor the guidelines of the ERC on CPR recommend the routine use of ECPR for patients with cardiac arrest (Class 2b; LOE C-LD).[1,2] Patient-centered outcomes such as short- and long-term survival and neurologically intact survival have vary widely in published studies, principally drawn from non-US cohorts. However, ECPR has been associated with favorable outcomes in patients who would otherwise have died, with impressive resuscitation results almost never before reported in the literature;[27,28,44,45] but we need to recognize that best results require considerable resources and a program designed to provide superb out-of-hospital transport for rapid implementation of ECPR, PCI, and multidisciplinary postcardiac arrest critical care, which the majority of local or statewide health care system do not have, making the implementation of VA-ECMO used as ECPR suitable only in countries with the most well-developed health care systems.

The findings from these studies highlight a therapy and an area of emerging research on cardiac arrest and CPR that may contribute to the quality of life of selected individuals with refractory ventricular fibrillation/ventricular tachycardia, which is increasingly adding up to a paradigm change in resuscitative medicine that may mitigate the morbidity and mortality associated with shock-refractory cardiac arrest.[1] One of the major gaps in the literature that requires further research is the lack of randomized control trials, which would increase the level (quality) of evidence and reduce knowledge gaps, as the current knowledge is mostly drawn from single-center observations, with most of the evidence coming from case series and cohort studies, hence it is prone to publication bias.[1] This is followed by the variability of inclusion and exclusion criteria, the groups of patients that would benefit the most from the intervention, the optimal timing to implement the intervention, the optimal ECPR strategy, the prognostic factors associated with favorable outcomes, resource utilization (including cost per patient and cost per life saved), the consideration of organ donation among non-eligible/non-survivors, the best bundle of therapies and treatment options rather than an isolated view of this therapy, and the optimal post-cardiac arrest care strategy for ECPR survivors. Currently, selection criteria and procedure techniques differ across ECMO initiation hospitals and standardized protocols are lacking.[46] Furthermore, studies should evaluate this intervention in comparison to the current standard of care with stringent patient selection criteria and a uniform and clearly established protocol.[27] We advocate for the use of ECPR in patients <75 years of age with refractory cardiac arrest of presumed cardiac origin with an initial shockable rhythm, and an anticipated time from the 9-1-1 call is received inferior or equal to 60 minutes before to the initiation of ECPR. Emerging from the data are some important predictors of survival; end-tidal carbon dioxide ($EtCO_2$) >10 mm Hg, arterial partial pressure of oxygen (PaO_2) ≤50 mm Hg or oxygen saturation (SaO_2) ≤85%, lactic acid ≥18 mmol/L, and any episodes of ROSC during the resuscitation are all positive signs predictive of survival.[47,48] $EtCO_2$, PaO_2 or SaO_2, and lactic acid before initiation of ECPR may represent important criteria for resuscitation continuation decisions that should be further investigated.[46,47] More importantly, neurological prognostication and neurological outcome measures of at least 30 days post-cardiac arrest should be adopted as the minimal timing for measuring neurological outcome in these patients, and where possible there should be long-term assessment of health-related quality of life as well, according to the best scientific evidence and ethical principles, to provide the highest level of evidence to support the undertaking of such treatment.[49–52]

7 | CONCLUSIONS

The findings of this scoping review suggest that current knowledge is mostly drawn from single-center observational studies, highlighting the need for high-quality studies to increase the level of evidence and reduce knowledge gaps to change the paradigm of care for patients with refractory cardiac arrest. We further conclude that ongoing research will change current clinical practice and help in designing the next steps of clinical research, reinforcing the need for high-quality studies.

ACKNOWLEDGMENTS

The authors would like to thank the library staff at the Veterans Affairs Caribbean Healthcare System Library Service for assistance with producing the search strategy.

AUTHOR CONTRIBUTIONS

DM, CA, ER, and WA provided substantial contributions to the conception or design of the study. DM and ER were responsible for the acquisition, analysis, and interpretation of data. DM drafted the original manuscript. All authors reviewed the paper for important intellectual content and approved the final version to be published. All authors meet ICMJE authorship criteria. DM takes responsibility for the integrity of the paper as a whole.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

ORCID

Dennis Miraglia MD https://orcid.org/0000-0002-3887-3320

REFERENCES

1. Link MS, Berkow LC, Kudenchuk PJ, et al. Part 7: adult advanced cardiovascular life support: 2015 American Heart Association Guidelines update for cardiopulmonary resuscitation and emergency cardiovascular care. *Circulation*. 2015;132:S444-S464.
2. Soar J, Nolan JP, Böttiger BW, et al. European Resuscitation Council Guidelines for Resuscitation 2015: section 3. Adult advanced life support. *Resuscitation*. 2015;95:100-147.
3. Benjamin EJ, Muntner P, Alonso A, et al. Heart Disease and Stroke Statistics–-2019 Update: a report from the American Heart Association. *Circulation*. 2019;139:e56-528.
4. Koster RW, Walker RG, Chapman FW. Recurrent ventricular fibrillation during advanced life support care of patients with prehospital cardiac arrest. *Resuscitation*. 2008;78:252-257.
5. Keebler ME, Haddad EV, Choi CW, et al. Venoarterial extracorporeal membrane oxygenation in cardiogenic shock. *JACC: Heart Failure*. 2018;6:503-516.
6. Mattox KL, Beall AC. Resuscitation of the moribund patient using a portable cardiopulmonary bypass. *Ann Thorac Surg*. 1976;22:436-442.
7. Miraglia D, Miguel LA, Alonso W. Long-term neurologically intact survival after extracorporeal cardiopulmonary resuscitation for in-hospital or out-of-hospital cardiac arrest: a systematic review and meta-analysis. *Resuscitation Plus*. 2020;4:100045.
8. Ortega-Deballon I, Hornby L, Shemie SD, Bhanji F, Guadagno E. Extracorporeal resuscitation for refractory out-of-hospital cardiac arrest in adults: a systematic review of international practices and outcomes. *Resuscitation*. 2016;101:12-20.
9. Ouweneel DM, Schotborgh JV, Limpens J, et al. Extracorporeal life support during cardiac arrest and cardiogenic shock: a systematic review and meta-analysis. *Intensive Care Medicine*. 2016;42:1922-1934.
10. Kim SJ, Kim HJ, Lee HY, Ahn HS, Lee SW. Comparing extracorporeal cardiopulmonary resuscitation with conventional cardiopulmonary resuscitation: a meta-analysis. *Resuscitation*. 2016;103:106-116.
11. Beyea MM, Tillmann BW, Iansavichene AE, Randhawa VK, Aarsen KV, Nagpal AD. Neurologic outcomes after extracorporeal membrane oxygenation assisted CPR for resuscitation of out-of-hospital cardiac arrest patients: a systematic review. *Resuscitation*. 2018;130:146-158.
12. Miraglia D, Miguel LA, Alonso W. Extracorporeal cardiopulmonary resuscitation for in- and out-of-hospital cardiac arrest: systematic review and meta-analysis of propensity score-matched cohort studies. *JACEP Open*. 2020;1:342-361.
13. Tricco AC, Lillie E, Zarin W, et al. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. *Ann Intern Med*. 2018;169:46773.
14. Peters MD, Godfrey CM, Khalil H, McInerney P, Parker D, Soares CB. Guidance for conducting systematic scoping reviews. *Int J Evid Based Healthc*. 2015;13:141-146.
15. Peters MDJ, Godfrey C, McInerney P, Baldini Soares C, Khalil H, Parker D. Scoping reviews. In: Aromataris E, Munn Z, eds. *Joanna Briggs Institute Reviewer's Manual*. Adelaide, Australia: Joanna Briggs Inst; 2017.
16. Arksey H, O'Malley L. Scoping studies: towards a methodological framework. *Int J Soc Res Methodol*. 2005;8:19-32.
17. Nordic Cochrane Centre, The Cochrane Collaboration. Review Manager 5 (RevMan 5). Version 5.3. Copenhagen: Nordic Cochrane Centre, The Cochrane Collaboration, 2014.
18. Sakamoto T, Morimura N, Nagao K, et al. Extracorporeal cardiopulmonary resuscitation versus conventional cardiopulmonary resuscitation in adults with out-of-hospital cardiac arrest: a prospective observational study. *Resuscitation*. 2014;85:762-768.
19. Schober A, Sterz F, Herkner H, et al. Emergency extracorporeal life support and ongoing resuscitation: a retrospective comparison for refractory out-of-hospital cardiac arrest. *Emerg Med J*. 2017;34:277-281.
20. Kim SJ, Jung JS, Park JH, Park JS, Hong YS, Lee SW. An optimal transition time to extracorporeal cardiopulmonary resuscitation for predicting good neurological outcome in patients with out-of-hospital cardiac arrest: a propensity-matched study. *Crit care*. 2014;18:535.
21. Maekawa K, Tanno K, Hase M, Mori K, Asai Y. Extracorporeal cardiopulmonary resuscitation for patients with out-of-hospital cardiac arrest of cardiac origin: a propensity-matched study and predictor analysis. *Crit Care Med*. 2013;41:1186-1196.
22. Bougouin W, Dumas F, Lamhaut L, et al. Extracorporeal cardiopulmonary resuscitation in out-of-hospital cardiac arrest: a registry study. *Eur Heart J*. 2020;41:1961-1971.

23. Choi DH, Kim YJ, Ryoo SM, et al. Extracorporeal cardiopulmonary resuscitation among patients with out-of-hospital cardiac arrest. *Clin Exp Emerg Med*. 2016;3:132-138.
24. Choi DS, Kim T, Ro YS, et al. Extracorporeal life support and survival after out-of-hospital cardiac arrest in a nationwide registry: a propensity score-matched analysis. *Resuscitation*. 2016;99:26-32.
25. Matsuoka Y, Ikenoue T, Hata N, et al. Hospitals' extracorporeal cardiopulmonary resuscitation capabilities and outcomes in out-of-hospital cardiac arrest: a population-based study. *Resuscitation*. 2019;136:85-92.
26. Poppe M, Weiser C, Holzer M, et al. The incidence of "load&go" out-of-hospital cardiac arrest candidates for emergency department utilization of emergency extracorporeal life support: a one-year review. *Resuscitation*. 2015;91:131-136.
27. Yannopoulos D, Bartos JA, Martin C, et al. Minnesota resuscitation consortium's advanced perfusion and reperfusion cardiac life support strategy for out-of-Hospital refractory ventricular fibrillation. *J Am Heart Assoc*. 2016;5:e003732.
28. Yannopoulos D, Bartos JA, Raveendran G, et al. Coronary artery disease in patients with out-of-hospital refractory ventricular fibrillation cardiac arrest. *J Am Coll Cardiol*. 2017;70:1109-1117.
29. Cho YH, Kim WS, Sung K, et al. Management of cardiac arrest caused by acute massive pulmonary thromboembolism: importance of percutaneous cardiopulmonary support. *ASAIO J*. 2014;60:280-283.
30. Chen YS, Lin JW, Yu HY, et al. Cardiopulmonary resuscitation with assisted extracorporeal life-support versus conventional cardiopulmonary resuscitation in adults with in-hospital cardiac arrest: an observational study and propensity analysis. *Lancet*. 2008;372:554-561.
31. Lin JW, Wang MJ, Yu HY, et al. Comparing the survival between extracorporeal rescue and conventional resuscitation in adult in-hospital cardiac arrests: propensity analysis of three-year data. *Resuscitation*. 2010;81:796-803.
32. Shin TG, Choi JH, Jo IJ, et al. Extracorporeal cardiopulmonary resuscitation in patients with inhospital cardiac arrest: a comparison with conventional cardiopulmonary resuscitation. *Crit Care Med*. 2011;39:1-7.
33. Blumenstein J, Leick J, Liebetrau C, et al. Extracorporeal life support in cardiovascular patients with observed refractory in-hospital cardiac arrest is associated with favourable short and long-term outcomes: a propensity-matched analysis. *Eur Heart J Acute Cardiovasc Care*. 2016;5:13-22.
34. Chou TH, Fang CC, Yen ZS, et al. An observational study of extracorporeal CPR for in-hospital cardiac arrest secondary to myocardial infarction. *Emerg Med J*. 2014;31:441-447.
35. Shin TG, Jo IJ, Sim MS, et al. Two-year survival and neurological outcome of in-hospital cardiac arrest patients rescued by extracorporeal cardiopulmonary resuscitation. *Int J Cardiol*. 2013;168:3424-3430.
36. Siao FY, Chiu CC, Chiu CW, et al. Managing cardiac arrest with refractory ventricular fibrillation in the emergency department: conventional cardiopulmonary resuscitation versus extracorporeal cardiopulmonary resuscitation. *Resuscitation*. 2015;92:70-76.
37. Cesana F, Avalli L, Garatti L, et al. Effects of extracorporeal cardiopulmonary resuscitation on neurological and cardiac outcome after ischaemic refractory cardiac arrest. *Eur Heart J Acute Cardiovasc Care*. 2017;7(5):432-441.
38. Lee SH, Jung JS, Lee KH, Kim HJ, Son HS, Sun K. Comparison of extracorporeal cardiopulmonary resuscitation with conventional cardiopulmonary resuscitation: is extracorporeal cardiopulmonary resuscitation beneficial? *Korean J Thorac Cardiovasc Surg*. 2015;48:318-327.
39. Patricio D, Peluso L, Brasseur A, et al. Comparison of extracorporeal and conventional cardiopulmonary resuscitation: a retrospective propensity score matched study. *Crit Care*. 2019;23:27.
40. Venturini JM, Retzer E, Estrada JR, et al. Mechanical chest compressions improve rate of return of spontaneous circulation and allow for initiation of percutaneous circulatory support during cardiac arrest in the cardiac catheterization laboratory. *Resuscitation*. 2017;115:56-60.
41. Miraglia D, Ayala JE. Extracorporeal cardiopulmonary resuscitation for adults with shock-refractory cardiac arrest. *JACEP Open*. 2020.
42. Yannopoulos D, Bartos J, Raveendran G, et al. Advanced reperfusion strategies for patients with out-of-hospital cardiac arrest and refractory ventricular fibrillation (ARREST): a phase 2, single centre, open-label, randomised controlled trial. *The lancet*. 2020.
43. Holmberg MJ, Geri G, Wiberg S, et al. Extracorporeal cardiopulmonary resuscitation for cardiac arrest: a systematic review. *Resuscitation*. 2018;131:91-100.
44. Stub D, Bernard S, Pellegrino V, et al. Refractory cardiac arrest treated with mechanical CPR, hypothermia, ECMO and early reperfusion (the CHEER trial). *Resuscitation*. 2015;86:88-94.
45. Dennis M, Buscher H, Gattas D, et al. Prospective observational study of mechanical cardiopulmonary resuscitation, extracorporeal membrane oxygenation and early reperfusion for refractory cardiac arrest in Sydney: the 2CHEER study. *Crit Care Resusc*. 2020;22:26-34.
46. Michels G, Wengenmayer T, Hagl C, et al. Recommendations for extracorporeal cardiopulmonary resuscitation (eCPR): consensus statement of DGIIN, DGK, DGTHG, DGfK, DGNI, DGAI, DIVI and GRC. *Clinical Research in Cardiology*. 2018;108:455-464.
47. D'Arrigo S, Cacciola S, Dennis M, et al. Predictors of favourable outcome after in-hospital cardiac arrest treated with extracorporeal cardiopulmonary resuscitation: a systematic review and meta-analysis. *Resuscitation*. 2017;121:62-70.
48. Debaty G, Babaz V, Durand M, et al. Prognostic factors for extracorporeal cardiopulmonary resuscitation recipients following out-of-hospital refractory cardiac arrest. A systematic review and meta-analysis. *Resuscitation*. 2017;112:1-10.
49. Rankin J. Cerebral vascular accidents in patients over the age of 60, II: prognosis. *Scott Med J*. 1957;2:200-215.
50. Brain Resuscitation Clinical Trial I Study Group. A randomized clinical study of cardiopulmonary-cerebral resuscitation: design, methods, and patient characteristics. *Am J Emerg Med* 1986; 4:72-86.
51. Perkins GD, Jacobs IG, Nadkarni VM, et al. Cardiac Arrest and Cardiopulmonary Resuscitation Outcome Reports: update of the utstein resuscitation registry templates for out-of-hospital cardiac arrest. *Circulation*. 2015;132:1286-1300.
52. Geocadin RG, Callaway CW, Fink EL, et al. Standards for studies of neurological prognostication in comatose survivors of cardiac arrest: a scientific statement from the American Heart Association. *Circulation*. 2019;140:e517-e542.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

How to cite this article: Miraglia D, Almanzar C, Rivera E, Alonso W. Extracorporeal cardiopulmonary resuscitation for refractory cardiac arrest: a scoping review. *JACEP Open*. 2021;2:e12380. https://doi.org/10.1002/emp2.12380