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Extracorporeal Cardiopulmonary Resuscitation for Cardiac Arrest: A Narrative Review

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Abstract

Extracorporeal cardiopulmonary resuscitation (ECPR) is an advanced medical rescue treatment for cardiac arrest patients who are refractory to standard treatment in emergency medicine. It incorporates a membrane oxygenator extracorporeally (through veno-arterial access) to maintain and restore oxygenation and circulation during etiological management of cardiac arrest.

This review summarizes current evidence regarding patient selection, technical considerations, clinical outcomes, special circumstances, post-resuscitation management, factors affecting outcomes, and future directions in ECPR. Evidence from observational studies supports ECPR for selected in-hospital cardiac arrest patients, whereas randomized trials in out-of-hospital cardiac arrest have produced variable findings, with greater benefits observed in carefully selected patients, particularly those with shockable rhythms. ECPR may also provide important rescue support during severe intoxication, accidental hypothermia, and massive pulmonary embolism. Successful post-ECPR care requires coordinated temperature management, coronary angiography, anticoagulation, neurological monitoring, and prevention of mechanical complications.

Categories: Cardiology
Keywords: acls, cardiac arrest, critical care medicine, extracorporeal cardiopulmonary resuscitation, extracorporeal membrane oxygenation

Introduction And Background

Conventional cardiopulmonary resuscitation (CCPR), based on manual chest compressions, has remained the foundation of cardiac arrest management for more than five decades [1-4]. However, its ability to restore effective circulation is limited [5]. Moreover, CCPR may cause trauma and restrict simultaneous diagnostic and therapeutic interventions, delaying identification and treatment of reversible arrest causes [6].

Extracorporeal cardiopulmonary resuscitation (ECPR) is "a salvage procedure in which extracorporeal membrane oxygenation (ECMO) is initiated emergently on patients who have had cardiac arrest and on whom the CCPR has failed" [3,5,7]. It helps to maintain and restore oxygenation and circulation during etiological management of cardiac arrest [8].

Importantly, ECPR is not part of routine advanced life support and is not currently recommended as a universal component of standard cardiac arrest algorithms. Rather, it is an advanced rescue strategy reserved for carefully selected patients with refractory cardiac arrest when conventional resuscitation fails, and appropriate expertise, equipment, and infrastructure are available [9].

The present review encompasses the indications, complications, and overall efficacy in patient outcomes using ECPR, which may provide cardiologists with an overall view of the applications of ECPR and its efficacy and safety. This review provides a narrative description of the individual subtopics without giving a systematic PRISMA search and meta-analysis based on individual outcomes, as that does not fall within the scope of the present review.

Current status and objectives

Despite its potential as an advanced medical rescue treatment, the optimal role of ECPR in cardiac arrest management remains a subject of ongoing investigation. While CCPR based on manual chest compressions has remained the foundation of cardiac arrest care for over five decades, its ability to restore effective circulation is inherently limited. ECPR is not recommended as a universal component of standard advanced life support algorithms; rather, current research evaluates it as an advanced rescue strategy for carefully selected patients with refractory cardiac arrest when conventional resuscitation fails [8].

This narrative review aims to synthesize the physiological basis, patient selection criteria, technical

considerations, clinical outcomes, special circumstances, and post-resuscitation management surrounding ECPR to provide a comprehensive framework for its application in contemporary critical care practice.

Review

Literature search strategy

A literature search was conducted by two investigators independently to identify relevant publications addressing the clinical applications, patient selection, technical considerations, and outcomes of ECPR. PubMed/MEDLINE, Scopus, Web of Science, and Google Scholar were searched using combinations of the following keywords: "extracorporeal cardiopulmonary resuscitation," "ECPR," "extracorporeal membrane oxygenation," "cardiac arrest," "in-hospital cardiac arrest," "out-of-hospital cardiac arrest," "patient selection," and "clinical outcomes", separated by the Boolean operator "OR".

Articles published in English during the preceding 15 years were considered. Randomized controlled trials, observational studies, meta-analyses, and relevant review articles were selected based on their relevance to the objectives of this review. Duplicate publications and articles not directly relevant to the scope of the review were excluded. Only freely available full-text articles were used for the narrative review. The selection of literature was based on its clinical relevance and contribution to the understanding of ECPR. As this was a narrative review, no formal PRISMA-based screening process or risk-of-bias assessment was undertaken.

Indications

An appropriate selection and triage of the patients who are indicated for ECPR is significant because of the high cost and invasive nature of ECPR intervention, to allow for clinical benefits over subtle complications [10].

To guide clinical decision-making, selection criteria are categorized into "PRO", "CON", and "STOP" criteria [11-17].

"PRO" criteria define situations associated with a reasonable chance of neurologically favorable survival, including witnessed collapse, age under 65 years, initial shockable rhythm, and an estimated time to ECPR of under 60 minutes after collapse. "CON" criteria indicate high-risk factors that require critical, case-by-case assessment, such as an unwitnessed collapse with a suspected short latency, age over 75 years, non-shockable initial rhythms, an end-tidal carbon dioxide ($etCO_2$) under 10 mmHg, near-infrared spectroscopy (NIRS) under 16%, an arterial blood-gas pH under 6.7, or lactate over 20 mmol/L. "STOP" criteria reflect situations with virtually no chance of meaningful survival, where ECPR should not be considered; these include a "no-flow" time exceeding 10 minutes, unwitnessed collapse without bystander CPR, frailty, severe terminal comorbidities, known patient wishes against resuscitation, or prolonged global hypoxemia prior to arrest (Table *1*).

Clinical Parameter	Favorable Triage (PRO/Inclusion)	Gray Zone/Critical Evaluation (CON)	Futility Threshold (STOP/Exclusion)
Patient Age	Under 65 years [1,3,13,14]	65 to 75 years [11]	Over 75 years (Japanese database CPC ≤2 rate 1.7% [15]; Korean IPTW analysis survival significantly lower) [16]
Initial/Admission Rhythm	VF or pVT (Shockable rhythm on arrival) [10,13]	PEA (Witnessed with bystander CPR and signs of life, or shockable conversion) [5,13,17]	Asystole (Unwitnessed non-shockable; no conversion or signs of life)
Witness Status & Bystander CPR	Witnessed collapse with immediate, high-quality bystander CPR (<5 mins no-flow time) [13]	Unwitnessed collapse with suspected short latency [9]	Unwitnessed collapse with zero bystander CPR; no-flow time >10 mins [1]
Low-Flow CPR Duration	Refractory state recognized early, with rapid transport to ECPR team [1,3]	CPR duration >60 mins [5]	Prolonged global hypoxemia before arrest [1]
Underlying Etiology	Acute myocardial infarction / coronary artery disease, accidental hypothermia, acute intoxication, or massive PE [1,3.5]	Decompensated chronic heart failure, myocarditis [5]	Aortic dissection, severe traumatic brain injury, uncontrolled major hemorrhage, terminal malignancies [1]
Physiologic & Metabolic Markers	$etCO_2$ >10 mmHg, active signs of life (gasping, reactive pupils, body movement) [1,3,13]	$etCO_2$ <10 mmHg, cerebral NIRS <16%, arterial pH <6.7, or serum lactate >20 mmol/L [1]	Severe persistent global hypoxemic brain injury preceding arrest [1]

TABLE 1: Criteria for selection of candidates for ECPR in refractory OHCA

The table was independently compiled and prepared by the authors using information obtained from multiple published sources, which are appropriately cited within the table. The table has not been reproduced or adapted from any single previously published source.

ECPR, Extracorporeal Cardiopulmonary Resuscitation; CPR, Cardiopulmonary Resuscitation; VF, Ventricular Fibrillation; pVT, Pulseless Ventricular Tachycardia; PE, Pulmonary Embolism; PEA, Pulseless Electrical Activity; CPC, Cerebral Performance Category; IPTW, Inverse Probability of Treatment Weighting; OHCA, Out-of-Hospital Cardiac Arrest.

Technical considerations of ECPR

Initiating ECPR is an extremely challenging technical task that must be performed rapidly under active chest compressions [18]. The primary configuration used is peripheral venoarterial extracorporeal membrane oxygenation (VA-ECMO). Large-bore cannulas for drainage and return are placed in the femoral vessels, usually via percutaneous Seldinger technique, with open surgical cut-down reserved as a backup option when needed [19]. A venous drainage cannula (usually 21-25 Fr) goes into the common femoral vein and is advanced so its tip sits in the superior vena cava or right atrium, maximizing venous drainage. An arterial return cannula (usually 13-19 Fr) is placed in the common femoral artery, with its tip positioned at the aortic bifurcation or common iliac artery, to deliver oxygenated blood back into systemic circulation [1]. It has been presented in a pictorial manner in Figure *1*.

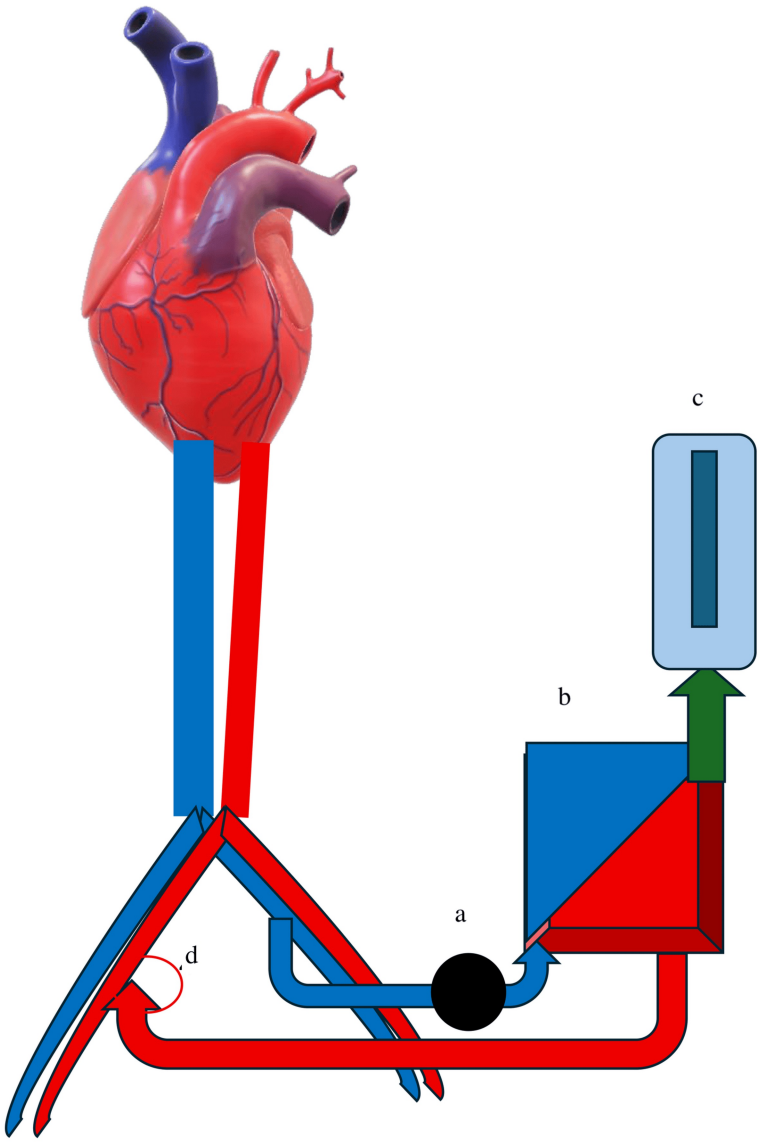

FIGURE 1: Peripheral femoro-femoro venoarterial ECMO apparatus

a: centrifugal pump; b: membrane; c: air/oxygen exchanger; d: re-injection cannula. The red arrow indicates the arterial cannula entering the femoral artery, the blue arrow indicates the venous cannula entering the femoral vein, and the green arrow indicates the pipe connecting the membrane to the air/oxygen exchanger. The figure was self-created by authors using Microsoft Word (Microsoft Corporation, Redmond, USA) by combining basic shapes and inserted illustrative elements, including a 3D heart model.

To minimize delays in starting the procedure, many experienced centers utilize preprimed ECMO circuits - which are pre-sterile for achieving immediate connection following vascular access [20], or point-of-care ultrasound - which allows for lesser cannulation times and lesser vascular injuries with real-time ultrasound [21]. Fluoroscopy and transesophageal echocardiography are also valuable tools to confirm guidewire and cannula positioning [22].

Once VA-ECMO flow is established, conventional chest compressions can be stopped. However, retrograde blood flow from the arterial cannula into the aorta increases left ventricular (LV) afterload. If the stunned myocardium is unable to eject blood against this increased pressure, LV distension, pulmonary edema, and myocardial ischemia can occur. ECPR protocols must therefore incorporate diagnostic monitoring (e.g., echocardiographic assessment of aortic valve opening) and therapeutic options for LV unloading, such as an intra-aortic balloon pump or a percutaneous ventricular assist device [23-26].

Outcomes following ECPR

Patients experiencing in-hospital cardiac arrest (IHCA) have demonstrated better hospital survival with ECPR compared with CCPR in certain studies [27,28]. Similar findings have been reported in pediatric populations. Brown et al. reported survival to ICU discharge in 51% of children receiving ECPR, with 47% surviving to hospital discharge. Favorable neurological outcomes were observed in 59% of ICU survivors [29]. These findings highlight the potential role of ECPR in both adult and pediatric cardiac arrest, although outcomes remain dependent on patient selection and timely initiation of extracorporeal support.

Long-term outcomes in adults, however, demonstrate that survival does not necessarily translate into complete functional or neurological recovery. In the EXCEL registry, Pound et al. reported 32.7% survival at six months, with favorable functional outcomes in 79.4% of survivors [30]. Nevertheless, survivors experienced greater disability and reduced health status compared with their pre-arrest condition. Similarly, Thevathasan et al. demonstrated substantial recovery of cardiac function among long-term adult ECPR survivors, with LV ejection fraction reaching approximately 51% at 22 months [31]. These findings emphasize that the assessment of ECPR outcomes should extend beyond survival to include neurological recovery, functional independence, psychological health, and long-term quality of life.

Additional studies have reported considerable variation in survival and neurological outcomes across adult and pediatric populations. Takemoto et al. reported adult survival rates of approximately 33-35%, with favorable neurological outcomes in 23-29%, whereas pediatric survival ranged from 10% to 70%, with favorable neurological recovery in 10-40% [32]. Among 147 adults receiving ECPR for refractory IHCA, Sokolov et al. reported 22.4% survival to hospital discharge and favorable neurological outcomes in 20.4% [33]. Martínez-Martínez et al. reported 29.6% survival at 180 days among 54 adults, with 15 patients achieving good neurological outcomes [34]. In pediatric patients, Bilodeau et al. reported 31% overall survival among 140 children, with higher survival following emergency department cardiac arrest than out-of-hospital cardiac arrest (OHCA) (41% vs. 20%) [35]. Differences in patient characteristics, arrest etiology, timing of ECPR initiation, and institutional expertise likely contribute to this variability, limiting direct comparisons across studies.

OHCA outcomes

Evidence regarding the effectiveness of ECPR in refractory OHCA remains heterogeneous, with outcomes varying across randomized trials and observational studies. The ARREST trial by Yannopoulos et al. demonstrated significantly higher hospital survival with ECPR compared with CCPR (42.9% vs. 6.7%), with favorable neurological outcomes among ECPR survivors at three months [10]. However, these findings should be interpreted in the context of a highly selected patient population and an experienced, single-center ECPR program.

In contrast, the Prague OHCA trial evaluated a comprehensive invasive strategy incorporating rapid transportation, mechanical CPR, ECPR, and immediate invasive treatment. Although neurologically favorable survival at 180 days was numerically higher with the invasive strategy, the difference did not reach statistical significance [14]. Similarly, the multicenter INCEPTION trial did not demonstrate a statistically significant improvement in 30-day outcomes with ECPR compared with CCPR [17].

The differences in outcomes across these trials may partly reflect variations in patient selection, study design, resuscitation protocols, cannulation times, and institutional expertise. Importantly, the Prague trial evaluated a bundled invasive resuscitation strategy rather than the isolated effect of ECPR, while the multicenter design of INCEPTION incorporated variability in institutional experience and procedural implementation. These findings suggest that the potential benefits of ECPR may depend substantially on timely implementation and the availability of experienced multidisciplinary teams.

Observational evidence further highlights the variability in outcomes. Bougouin et al. analyzed a registry of 13,191 OHCA cases and reported 8.4% hospital survival among the 525 patients treated with ECPR [36]. A meta-analysis by Debaty et al., including 15 studies and 841 patients with refractory OHCA, reported a median favorable neurological outcome rate of 15% [37]. Similarly, Pozzi et al. reported 8.8% hospital survival among 68 patients with refractory OHCA treated with extracorporeal life support [38]. Overall, current evidence suggests that ECPR may improve outcomes in carefully selected patients with refractory OHCA; however, its effectiveness remains influenced by patient selection, low-flow duration, procedural expertise, and institutional organization. The conflicting findings of randomized trials also emphasize the need for standardized ECPR protocols and further research to identify patient populations most likely to benefit [1,39].

Special circumstances

Severe Intoxication

ECPR can serve as a bridge to recovery in patients experiencing refractory cardiac arrest due to cardiotoxic drug intoxication. A cohort analysis reported survival only among patients with persistent arrest who received ECPR [40]. Furthermore, a systematic review involving 236 adults receiving ECPR for intoxication reported a 48.3% survival rate to hospital discharge [41]. These findings suggest a potential role for ECPR in

selected patients with severe intoxication, particularly when the underlying toxic effects may be reversible.

Accidental Hypothermia

In hypothermic cardiac arrest, ECPR provides circulatory support and facilitates rapid core rewarming. Retrospective studies have reported variable survival rates ranging from 42% to 100% [39,42]. A Japanese registry analysis found that prolonged low-flow duration was not negatively associated with survival in patients with hypothermia below 32°C [42]. This suggests that conventional low-flow time thresholds may not be directly applicable to hypothermic cardiac arrest, where the reduced metabolic demand may offer some degree of neurological protection.

Massive Pulmonary Embolism (PE)

A task force assessed cardiac arrest associated with massive PE and reported survival rates exceeding 60% when venoarterial ECMO and ECPR were combined with surgical embolectomy or catheter-directed thrombolysis [43]. These findings highlight the potential role of ECPR as a bridge to definitive reperfusion therapy in selected patients with massive PE.

Factors affecting outcomes

The success of an ECPR program depends on several interrelated factors, including patient characteristics, procedural efficiency, duration of resuscitation, and the quality of post-resuscitation care. In addition to appropriate patient selection, institutional experience and coordinated multidisciplinary management play important roles in determining clinical outcomes.

Cannulation and Procedural Volume

Cannulation under ongoing CPR is technically demanding, and procedural complications can adversely affect outcomes. Traumatic vascular access increases the risk of vascular injury, bleeding, and distal limb ischemia. Placement of a distal perfusion catheter is recommended to reduce limb ischemia, although registry data indicate that its utilization remains inconsistent, with placement rates as low as 5% [44].

Institutional experience also influences procedural efficiency and safety. Centers performing more than 12 adult ECPR cases annually have demonstrated significantly lower mortality and fewer mechanical complications [44]. Differences in procedural expertise were also evident across major trials. Experienced interventional cardiologists in the single-center ARREST and Prague trials achieved mean cannulation times of approximately 12 minutes, whereas the multicenter INCEPTION trial reported a median cannulation time of 20 minutes, with limb ischemia and unsuccessful cannulation occurring in 6% and 9% of patients, respectively [10,14,17]. These observations highlight the importance of experienced cannulation teams, standardized protocols, and regular procedural training.

Duration of Delay (Low-Flow Time)

The duration of low-flow time, defined as the interval between initiation of CPR and establishment of ECMO flow, is an important determinant of survival following ECPR. Prolonged low-flow duration is associated with progressive ischemic injury and a reduced likelihood of favorable neurological recovery. The ARREST trial reported a mean low-flow time of 59 minutes, with 43% survival [10], whereas the Prague trial reported a median low-flow time of 61 minutes, with 22% survival [14]. In comparison, the INCEPTION trial reported a median low-flow time of 74 minutes, with 15% survival [17]. Although differences in patient selection and trial protocols also influence these outcomes, the findings emphasize the importance of minimizing delays in establishing extracorporeal circulation. Current ELSO guidelines recommend achieving ECMO flow within 60 minutes after collapse to optimize the likelihood of favorable neurological survival [13].

Patient Age and Initial Rhythm

Patient age and initial cardiac rhythm are important prognostic factors influencing outcomes following ECPR. Advanced age is associated with a lower likelihood of favorable neurological survival. Japanese registry data demonstrated that only 1.7% of patients older than 75 years survived to one month with favorable neurological status (CPC ⩽2) [15]. Similarly, a Korean cohort reported significantly lower favorable neurological survival among patients older than 66 years compared with those aged 66 years or younger (28.6% vs. 43.7%; $p = 0.007$) [16]. Initial shockable rhythms, particularly ventricular fibrillation and pulseless ventricular tachycardia, are also associated with better survival than non-shockable rhythms such as pulseless electrical activity and asystole [1]. Therefore, age and initial rhythm should be considered alongside arrest circumstances, no-flow duration, comorbidities, and other clinical indicators rather than as isolated determinants of ECPR eligibility.

Post-ECPR Care and Clinical Controversies

Optimal outcomes following ECPR require coordinated multidisciplinary post-resuscitation care, including temperature management, coronary reperfusion, anticoagulation, and appropriate management of cannulation-related complications. Although ECPR-specific randomized evidence for targeted temperature management remains limited, clinical practice generally follows recommendations established for patients receiving CCPR. The ARREST and Prague OHCA trials used mild hypothermia at 33-34°C for 24 hours, whereas the INCEPTION trial permitted institution-specific temperature management protocols [10,14,17].

Coronary angiography is generally recommended following ECPR in patients without an evident noncardiac cause of arrest, particularly when an acute coronary etiology is suspected. Restoration of circulation through ECMO does not address the underlying ischemic pathology, making timely coronary assessment and reperfusion important components of post-resuscitation management [3].

Anticoagulation presents an additional challenge because it is required to prevent extracorporeal circuit thrombosis but may increase bleeding risk following prolonged chest compressions. Major hemorrhage and intracranial bleeding are important complications [45]. Strategies such as withholding the initial heparin bolus or using lower activated clotting time targets may help reduce bleeding complications, although anticoagulation protocols must be individualized according to thrombotic and hemorrhagic risks.

The optimal cannulation location also remains controversial. Emergency department-based cannulation may facilitate earlier ECPR initiation, whereas catheterization laboratory cannulation offers fluoroscopic guidance and access to experienced vascular intervention teams. Therefore, institutional protocols should prioritize rapid deployment while ensuring procedural safety and timely access to definitive coronary intervention [1].

Practical challenges in India and solutions

ECPR in India faces significant infrastructural, clinical, and administrative challenges. Public awareness of CPR remains alarmingly low, with bystander CPR rates reported at just 1.3% [46]. Emergency medical services (EMS) suffer from a lack of trained paramedics, specialized mobile programs, and pre-hospital notification systems to alert receiving facilities. Patient transport is further hampered by severe traffic congestion, vast geographical distances, and a scarcity of ECMO-capable centers, which are predominantly confined to private-sector hospitals [47]. Furthermore, healthcare institutions struggle with acute shortages of trained personnel, high equipment costs, and cognitive skill decay due to low annual case volumes. Administrative and medicolegal obstacles also cause critical delays, including interdepartmental "activation paralysis," legal ambiguities surrounding emergency consent, and severe financial hurdles, with ECMO initiation costs ranging from INR 3 to 5 lakhs alongside steep daily ICU expenses [48].

To overcome these barriers, the review proposes a pragmatic, system-wide implementation roadmap. Community awareness can be expanded by integrating CPR training into school curricula and conducting public educational campaigns. EMS capabilities should be upgraded through structured dispatcher screening, "green corridor" traffic management for rapid ambulance transport, and mobile ECMO rendezvous models [49]. Within hospitals, establishing 24/7 multidisciplinary ECPR teams, positioning pre-primed ECMO circuits in emergency settings, and conducting routine simulation drills will ensure clinical readiness and minimize treatment delays [50]. Administrative streamlining requires standardized authorization protocols, deferred consent frameworks, and government-backed medicolegal safeguards [7]. Financial viability can be improved via insurance integration, government welfare schemes, central inventory sharing, and domestic consumable manufacturing under the "Make in India" initiative. Ultimately, a phased scaling strategy, starting with metropolitan pilot hubs and expanding into a national hub-and-spoke network monitored by a national registry, will ensure sustainable, data-driven implementation [47].

Strengths

This comprehensive review offers a systematic and well-organized synthesis of ECPR evidence across both pediatric and adult populations. It incorporates practical patient-selection frameworks, including PRO, CON, and STOP criteria, alongside technical aspects and considerations for specialized clinical settings. By integrating evidence from major trials such as ARREST and Prague, the review effectively translates complex clinical evidence into practical decision-making pathways for multidisciplinary critical care teams.

Limitations

The main limitation is the predominance of observational studies and meta-analyses underpinning the available evidence, particularly for IHCA, where prospective randomized controlled trials remain limited. Consequently, the reported outcomes may be influenced by selection bias, differences in institutional expertise and resources, and substantial heterogeneity in patient selection and management protocols. These limitations may limit the generalizability of the findings in different healthcare settings and patient populations.

Future considerations

Future efforts to optimize and broaden the use of ECPR should focus on improving training, rapid deployment, physiologic monitoring, and ethical frameworks. Because ECPR requires complex technical and multidisciplinary coordination, regular high-fidelity simulation and standardized training programs are essential. Such approaches can improve team performance and reduce the interval between cardiac arrest and ECMO initiation [51]. Prehospital ECPR and rendezvous models may further minimize low-flow duration by enabling early cannulation or rapid deployment of specialized ECMO teams to designated hospitals. Future decision-making may increasingly rely on continuous physiologic indicators, including end-tidal carbon dioxide, cerebral oxygenation measured by NIRS, and arterial pressure, rather than fixed time thresholds alone [52]. ECPR may also support organ donation by maintaining organ perfusion after devastating neurological injury. However, this possibility raises important ethical concerns, emphasizing the need for transparent institutional policies that clearly separate life-saving treatment from organ donation considerations [1].

Conclusions

ECPR is an important rescue strategy for selected patients with refractory cardiac arrest. By providing temporary circulatory and respiratory support through VA-ECMO, it restores systemic perfusion and oxygen delivery while allowing treatment of the underlying cause. Available evidence suggests that ECPR may improve neurologically favorable survival in carefully selected patients; however, inconsistent trial findings highlight the importance of patient selection, institutional expertise, and timely initiation.

Successful implementation requires an integrated chain of care, including rapid transport and cannulation, standardized protocols, and structured post-resuscitation management. Future efforts should focus on improving training, optimizing anticoagulation, and developing regional ECPR networks. Further studies are needed to refine patient selection and establish long-term neurological and functional outcomes.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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