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CONTEMPORARY REVIEW

Designing a Cardiac Arrest System That Includes Extracorporeal Cardiopulmonary Resuscitation: A Contemporary Review

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ABSTRACT: Extracorporeal cardiopulmonary resuscitation for refractory out-of-hospital cardiac arrest is increasingly used, with survival rates up to ≈30% reported in select highly organized systems, although outcomes vary widely across programs. However, outcomes are driven largely by system performance rather than the procedure itself. To date, most literature has focused on efficacy, patient selection, and cannulation techniques, with limited emphasis on system-level design. This narrative review synthesizes the key components required to implement an effective extracorporeal cardiopulmonary resuscitation–enabled cardiac arrest system from optimizing the existing emergency medical services, understanding the expected number and distribution of potential patients undergoing extracorporeal cardiopulmonary resuscitation, using geographic information systems to optimize system design to the value of integrated structured identification pathways, streamlined intra-arrest transport strategies, coordinated postresuscitation care within specialized cardiac arrest centers, and cost-effectiveness considerations.

Key Words: extracorporeal cardiopulmonary resuscitation ■ extracorporeal membrane oxygenation cardiopulmonary resuscitation ■ OHCA ■ prehospital ECPR

The use of extracorporeal cardiopulmonary resuscitation (ECPR) in refractory out-of-hospital cardiac arrest (OHCA) is increasing, with survival rates of up to ≈30% reported in well-organized systems.[1,2] However, outcomes from many other settings have demonstrated relatively poor survival,[3] highlighting the need for improvements in system-level design. Reported outcomes therefore vary widely across programs, reflecting differences in patient selection, system maturity, and the underlying performance of regional cardiac arrest systems of care. ECPR is 1 step in a system of care for refractory cardiac arrest rather than a procedure in isolation. Its impact derives not from the technology alone, but from a coordinated, complex resuscitation program in which success is not guaranteed.[4–6] Outcomes depend on the effective functioning of the entire system, including early case identification, early effective bystander cardiopulmonary resuscitation (CPR), high-performance professional CPR, rapid ECPR team activation, timely cannulation, and coordinated systematic multidisciplinary postresuscitation care.

ECPR system design directly influences both clinical outcomes and cost effectiveness.[7] Here, we provide an overview of key system-level considerations for establishing ECPR within cardiac arrest systems. Procedural and cannulation-specific aspects are beyond the scope of this review and are addressed elsewhere.[8,9]

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Nonstandard Abbreviations and Acronyms

ARREST	Expedited Transfer to a Cardiac Arrest Center for Non–ST-Elevation Out-of-Hospital Cardiac Arrest
CARES	Cardiac Arrest Registry to Enhance Survival
ECPR	extracorporeal cardiopulmonary resuscitation
INCEPTION	Early Initiation of Extracorporeal Life Support in Refractory OHCA
OHCA	out-of-hospital cardiac arrest
PRECARE	Prehospital ECPR for Refractory Cardiac Arrest
ROSC	return of spontaneous circulation
SAVE-J	Multicenter Retrospective Observational Study on Extracorporeal Cardiopulmonary Resuscitation for Out-of-Hospital Cardiac Arrest Patients in Japan

ASSESSMENT AND OPTIMIZATION OF THE EXISTING CARDIAC ARREST SYSTEM

Any existing cardiac arrest systems should adhere to the highest international standards.[10] Existing OHCA pathways should be optimized given that initial basic life support and advanced life support performance determines which patients are in a physiological state that is recoverable with ECPR. Each element within the cardiac arrest survival chain should be reviewed, benchmarked against international standards and guidelines, and, where possible, optimized before commencement of an ECPR service. Key service-wide considerations are provided in Table 1. Importantly, the preparation required to deliver an ECPR program, encompassing dispatch optimization, bystander CPR programs, defibrillation strategies, and refinement of intra-arrest transport, can strengthen broader OHCA care, producing measurable gains in conventional survival even among the majority of patients who never receive ECPR.

ECPR ELIGIBILITY CRITERION CONSIDERATIONS

Core Eligibility Criteria

No consensus exists on patient selection criteria for ECPR in refractory OHCA, although cardiac arrest characteristics and patient factors remain key determinants of survival and neurological recovery.[11] Inclusion criteria and key features of major randomized trials are summarized in Table 2. A systematic review found no universally accepted criteria, but most programs converge on core common elements: age limits (typically 18–75 years), witnessed arrest, bystander CPR <5 minutes from cardiac arrest, initial shockable rhythm or pulseless electrical activity with signs of life during CPR, and limits on no-flow and low-flow duration.[12] Additional physiological and metabolic markers, such as arterial blood gases, nonresolving ventricular fibrillation, lactate, and "signs of life," are variably incorporated.[11]

More restrictive inclusion criteria are predictive of improved survival rate and decreased case volume (of an already low-frequency event)[12,13] but an increased risk of excluding potentially salvageable patients[12] and further reducing case numbers and critical team experience. Too broad selection criteria run the risk of a lower overall survival rate, which may not be commensurate with a viable long-term service. Advanced age is associated with poorer outcomes; early data suggested <2% favorable neurological recovery in patients aged >75 years, although subsequent analyses report survival of ≈23% in those aged 70 to 79 years, supporting cautious rather than absolute age thresholds.[14–16] There's also an argument on inclusion/exclusion based on biological versus chronological age, which is challenging to discern with real-time decision making and limited information. Artificial intelligence models may play a future role in predicting ECPR candidates with neurologically intact survival on the basis of precannulation data.[17]

Physiological and Metabolic Modifiers

Low-flow time is a consistent prognostic marker. Extracorporeal membrane oxygenation (ECMO) flow in ECPR is generally recommended within 60 minutes of the start of the cardiac arrest,[8] and time to ECMO flow is commonly incorporated into selection criteria. However, ECPR-treated outcomes beyond 60 minutes are still likely to exceed matched cardiac arrest cases treated with conventional resuscitation.[18] Given these limitations, many systems apply additional "modifiers" to refine selection. Signs of life, such as gasping, pupillary reflexes, or spontaneous movement, are associated with improved outcomes, although their absence does not preclude recovery.[19–21] Furthermore, there are degrees of signs of life, ranging from CPR-induced consciousness and evidence of cortical function (eg, localizing during CPR/moving limbs) to evidence of brainstem function only (breathing, gasping/coughing, pupillary reactivity, or even just miosis). Metabolic metrics and indicators of adequate vital organ perfusion such as regional cerebral oxygen saturation, pH, PaO_2, and lactate may further inform candidacy.[22–27] End-tidal CO_2 is widely used as

Table 1. Key Existing OHCA System Elements for Optimization Before ECPR Introduction

EMS system factors and importance	Optimization opportunity
Reducing time to response, CPR, and defibrillation • Shorter response and defibrillation intervals are consistently associated with higher OHCA survival[6] • Frequency and quality of telephone CPR instructions and the rate of bystander CPR and defibrillation influence outcomes of patients with OHCA who may be considered for ECPR[7,8]	• Dispatch OHCA recognition in >75% of cases in <1 min; and dispatch assisted CPR to achieve >75% bystander CPR • Dedicated OHCA arrest desk in dispatch • Protocolized resource workflow • Expanded automated external defibrillator availability • Embedding automated external defibrillator–enabled first-responder systems into ECPR activation pathways
Basic life support and advanced life support • The effectiveness of an ECPR-enabled cardiac arrest system remains fundamentally bound by the quality of basic life support and advanced life support delivered before cannulation	• Consistent high-quality CPR: chest compression depth, rate 100–120/min, fraction >90%, and preshock pause captured and optimized[9] • Early automated external defibrillator use with rapid rhythm analysis and shock delivery[10] and nondisruptive airway management[11]; • Mechanical CPR to allow for transport[10] • Early identification of ECPR candidates with communication (prealerts) with ECPR-centers[12] • High-fidelity simulation emphasizing team-based resuscitation, role assignment, interruption minimization, and ECPR scenarios.[9,13] • Robust continuous quality improvement through OHCA registries and multidisciplinary reviews[10]
Airway management • The optimal airway management strategy is not clear • Patients with observational refractory OHCA found endotracheal intubation superior to supraglottic airways for oxygenation, ventilation, ECPR eligibility, and neurologically favorable survival when ECPR was performed[11] • Poor airway performance, for example, prolonged pauses, may offset any theoretical benefit of advanced airways in OHCA[9]	• Minimizes interruptions to compressions • Airway plan for first-responder paramedics and for transportation • Endotracheal intubation if experienced providers and if it does not prolong time to ECPR • Audit airway quality and success rates
Hospital management • Cardiac arrest outcomes (ECPR or not) are depending on postresuscitation care • Predefined hospital to manage cardiac arrests with appropriate resources, training, and experience	• Cardiac arrest centers identified and appropriately resourced • Compliance with international guidelines on postresuscitation care • Avoidance of premature withdrawal of life-sustaining therapy
Monitor care processes and outcomes	• Establish a cardiac arrest registry • Achieve outcomes for EMS-treated cases of >10% survival to hospital discharge with favorable neurological outcomes

CPR, cardiopulmonary resuscitation; ECPR, extracorporeal cardiopulmonary resuscitation; EMS, emergency medical services; and OHCA, out-of-hospital cardiac arrest.

a marker of CPR quality but has limited specificity for neurological prognosis.[28,29]

In the absence of universal criteria, ECPR programs should adopt prespecified data-informed, standardized criteria that integrate clinical, physiological, and metabolic/biochemical factors to support rapid, consistent decision making.

EXPECTED ECPR-ELIGIBLE PATIENT NUMBERS AND SYSTEM PLANNING

Designing an ECPR program begins with quantifying how many patients are potentially likely to benefit, when and where they present, and how system design can provide them with an achievable time window for ECPR. This requires a system-level, data-driven approach that integrates epidemiology, geographic information systems modeling, and realistic assessment of local logistics and capabilities. Although only a small proportion of patients with OHCA meet ECPR criteria, this proportion is highly sensitive to both patient characteristics and system configuration.

Across studies, ECPR-eligible patients comprise ≈3% to 11% of all OHCAs.[30–33] These estimates are typically derived from registry data (eg, CARES [Cardiac Arrest Registry to Enhance Survival]) applying standard criteria: nontraumatic cause, witnessed arrest, initial shockable rhythm, age within a defined range, absence of prohibitive comorbidity, and refractory arrest despite high-quality advanced life support.[11,33,34] Spatial mapping of arrest locations overlaid with emergency medical services (EMS) coverage, hospital locations, and realistic transport times allows estimation of both the number and distribution of eligible patients relative to existing ECPR services. In the United States, linking CARES data with spatial access modeling showed that only ≈3% to 4% of patients with OHCA met clinical criteria, and <2% could reach an ECPR center within a 60-minute collapse-to-ECMO window under hospital-based models.[34]

This "denominator work" is foundational, identifying gaps in existing ECPR systems and informing decisions on the number and location of centers, expected case volumes, and the optimal delivery

Table 2. Inclusion and Exclusion Criteria of Major ECPR Trials

Trial	ARREST trial	PRAGUE OHCA trial	INCEPTION trial
Trial characteristics			
Enrollment period	August 2019–June 2020	March 2013–October 2020	May 2017–February 2021
Intervention	ECPR	Intra-arrest transport with mechanical CPR and ECPR upon arrival at the hospital if no ROSC was obtained	ECPR
Primary outcome	Survival to hospital discharge	Neurologically intact (cerebral performance category 1 or 2) survival at 180 d	Neurologically intact (cerebral performance category 1 or 2) survival at 30 d
Time of randomization	Upon arrival at the ED	Prehospital setting	Prehospital setting
Eligibility criteria			
Age eligibility criteria, y	18–75	18–65	18–70
Initial rhythm criteria	Ventricular tachycardia/fibrillation	Ventricular tachycardia/fibrillation, pulseless electrical activity, asystole	Ventricular tachycardia/fibrillation
Definition of refractory OHCA	Failure to achieve ROSC after at least 3 defibrillation attempts	Failure to achieve ROSC within 5 min of advanced life support	Failure to achieve ROSC within 15 min of advanced life support
ECPR system of care			
ECPR cannulators	Interventional cardiologists	Interventional cardiologists	Cardiothoracic surgeons, interventional cardiologists, intensivists
Cannulation location	Cardiac catheterization laboratory	Cardiac catheterization laboratory	ED, cardiac catheterization laboratory
Number of centers	1	1	10
Protocolized care	Yes	Yes	No
Results			
Total patients enrolled	30	256	160 (26 excluded after randomization)
Patients enrolled in intervention group	15	124	70
Patients successfully receiving ECPR	15	92	46
ECPR patients/center/month during the study period	1.5	1	0.29
Low-flow time, min, mean	59	61	74
Door-to-ECMO time, min, median	12	12	36
Neurologically favorable survival of control group, n/N (%)	1/15 (7)	29/132 (22)	10/62 (16)
Neurologically favorable outcome of intervention group, n/N (%)	6/14 (43)	39/124 (31.5)	14/70 (20)
Prematurely terminated	Yes	Yes	No

CPR, cardiopulmonary resuscitation; ECMO, extracorporeal membrane oxygenation; ECPR, extracorporeal cardiopulmonary resuscitation; ED, emergency department; OHCA, out-of-hospital cardiac arrest; ROSC, return of spontaneous circulation.

strategy to achieve adequate access.[7,35] Simulation studies highlight the impact of system design: Spigner et al demonstrated using Monte Carlo modeling that varying deployment locations, base numbers, and travel speeds substantially alter the number of patients reachable within target time windows.[36] Similarly, Gottula et al[34] and Song et al[37] showed that strategies such as prehospital ECPR and rendezvous at strategically located hospitals can markedly increase population-level access.

Understanding temporal patterns is essential for staffing and activation planning. Data from the Minnesota Mobile Resuscitation Consortium show that ECPR cases occur throughout the week, with clustering during daytime and evening hours, but also a meaningful overnight volume. This pattern supported the need for 24/7/365 mobile team availability and informed scheduling of cannulating physicians and ECMO clinicians.[11] These denominators and geospatial analyses are not a one-off exercise. Programs should reevaluate registry-based eligibility, geographic information systems access modeling, and temporal demand patterns periodically as their service matures (at minimum every 2–3 years, and earlier when EMS configuration, hospital infrastructure, or eligibility criteria change) to confirm that the current delivery model continues to match actual case distribution and capacity.

ECPR DELIVERY STRATEGY

ECPR may be delivered via 3 principal delivery strategies: hospital-based ECPR for OHCA, rendezvous ECPR, and prehospital ECPR (Figure 1A through 1C). The delivery strategy used for an ECPR system will ultimately vary by system on the basis of available resources, geography, and health system infrastructure. An explanation of and considerations for these delivery models are provided below. While the choice of the individual strategy may vary according to the individual setting and resources, the key component of success is that the team treating patients with ECPR (at all phases) must be highly trained, experienced, and committed to this patient population. Higher institutional and provider ECPR case volumes are associated with improved patient outcomes and process efficiency.[38,39] Although many centers have substantial venoarterial ECMO experience, ECPR requires specific training, logistic structure, and systems familiarity, as structured ECPR training and program refinement have been associated with improved performance and outcomes.[39,40]

Hospital-Based ECPR for OHCA

Hospitals with established ECPR programs provide the technical expertise and multidisciplinary infrastructure required for ECPR, making them natural anchors for service delivery. In this model, EMS transports patients to an ECPR-capable center for hospital-based cannulation (Figure 1A). However, when targeting ECMO flow within 60 minutes, the effective catchment area is limited. Additionally, distributing low-frequency cases across multiple centers may dilute team experience.[33] Advantages of a hospital-based model include procedural expertise, resource concentration, and ease of standardization, leveraging existing ECMO programs.[32,33,35] While adding more centers yields only modest gains in population coverage,[37] regional emergency department (ED)-based programs have demonstrated promising outcomes when implemented within coordinated systems.[41]

Rendezvous Model

In a rendezvous model, the ECMO team is activated at the time of arrest and responds in parallel with EMS to predefined sites, while EMS transports the patient (Figure 1C). These sites are ideally located midway between the patient and the ECPR team.[35] The responding team is coordinated by a central resuscitation consortium requiring collaboration across institutions. This consortium-based rendezvous model effectively extends the reach of a single high-volume ECPR team

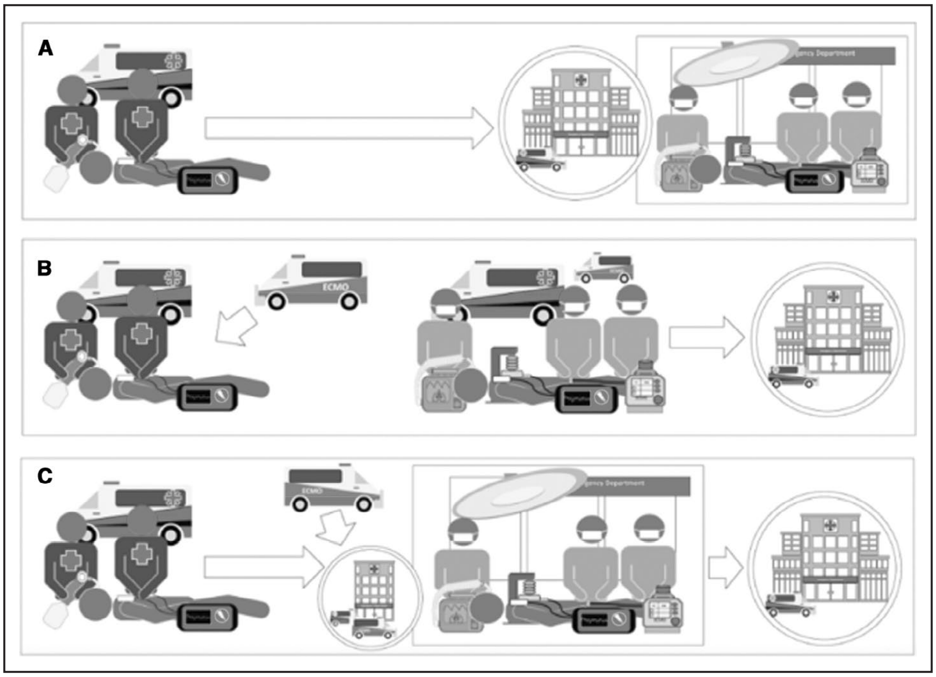

Figure 1. ECPR delivery strategies.
A, Hospital-based ECPR: The patient is transported from the scene of the OHCA event to the nearest ECPR hospital. **B**, Prehospital ECPR: A mobile ECPR team is dispatched and institutes ECPR support at the site of OHCA. **C**, Rendezvous ECPR: A mobile team meets the patient and paramedics at any nearest hospital, implements ECPR, and transfers the patient back to an ECMO center. ECPR indicates extracorporeal cardiopulmonary resuscitation; ECMO, extracorporeal membrane oxygenation; and OHCA, out-of-hospital cardiac arrest.

without requiring each hospital to independently maintain full ECPR capability.[35]

In optimized systems, patients are transferred directly to the cannulation suite, which can be based in the cardiac catheterization laboratory or the ED, depending on local infrastructure, bypassing all other tasks until ECPR cannulation is complete. As ECPR is usually followed by emergent coronary intervention, the ECMO team should activate the cardiac catheterization laboratory, like ST-segment–elevation myocardial infarction activations, following ECPR initiation, at the cannulation site or the receiving site. If cannulation occurs at a non-ECMO center, the patient is subsequently transferred with the ECMO team providing ongoing care.[35] This workflow mirrors high-performing programs such as the Minnesota Mobile Resuscitation Consortium, which reported 100% cannulation success and ≈43% favorable neurological survival at 3 months within a coordinated, community-wide system that included a centralized intensive care unit.[35,42] Rendezvous models require cross-institutional credentialing and coordination across multiple health systems.[35] In established programs, cannulating physicians are typically dedicated to ECPR while on call; where this is not feasible, systems must plan for backfill of clinical duties during activations.

Prehospital ECPR

Prehospital ECPR delivers ECMO at the scene of cardiac arrest, effectively bringing the intervention to the patient (Figure 1B). Cannulation may be performed by prehospital clinicians trained in ECPR or by hospital-based ECMO teams deployed to the scene from their primary hospital.[35,42,43] Either option must ensure that the cannulation team have extensive experience in cannulation during ongoing CPR. Following initiation, patients are transported to an ECMO center for ongoing care. Approaches vary by system: Some perform cannulation entirely on scene without patient movement,[7,42,44,45] while others transfer the patient into a protected environment (eg, ambulance or ambulance station; Melbourne, Australia, and Minneapolis, MN) before cannulation to mitigate environmental challenges, without leaving the scene.[46] Observational data from Paris and other programs demonstrate that on-scene cannulation is feasible even in public settings, including crowded venues, when logistics and training are optimized.[44,45,47] Teams may respond via helicopter EMS or ground units, depending on geography and system design. Some programs (OnScene trial) deploy helicopter EMS for all cases where physician-led crews provide ECPR capability,[42] while others use geographic information systems–informed dispatch to determine the optimal response modality.[34,35,42]

Prehospital ECPR substantially increases access by extending the effective catchment area and enabling ECPR initiation within 60 minutes across a greater geographical footprint than hospital-based models.[34,36,37,48] It also increases case volume per team, supporting skill maintenance. For patients already eligible within hospital-based systems, prehospital cannulation further reduces low-flow time, improving neurological outcomes.[7,49,50] Meta-analyses of observational data report ≈25% favorable neurological survival, with low-flow times ≈30 minutes shorter than in-hospital ECPR, reinforcing time to flow, not location, as the key determinant of outcome.[7,51]

Limitations of prehospital ECPR include training and maintenance of the prehospital team skill set (particularly in the initiation phase where volumes may be low), cannulation with limited imaging capabilities (typically ultrasound only), and prolonged extrication and transport times back to the hospital, after establishment of ECMO flow to access definitive intervention for the pathology causing the arrest (eg, percutaneous coronary intervention [PCI] for ST-segment–elevation myocardial infarction). The Minnesota Mobile Resuscitation Consortium's Mobile ECMO Truck has demonstrated feasibility with cannulation times and success rates equivalent to in-hospital cannulation, but this approach, with mobile fluoroscopic capabilities, requires a large physical footprint and substantial resources.[34,35] Other prehospital programs have demonstrated successful cannulations using a smaller footprint configuration, without fluoroscopic capabilities; there are currently limited data comparing the outcomes of the different prehospital configurations.

Criteria for prehospital ECPR activation differ between systems, which directly affects time to ECMO flow and geographic reach. The PRECARE (Prehospital ECPR for Refractory Cardiac Arrest) study (prehospital physician led) activates the prehospital team for any witnessed arrest under age 70 years, to avoid any delays.[47] The CHEER 3 (Refractory cardiac arrest treated with mechanical CPR, ECMO and early reperfusion 3) study (hospital-based clinician led), waits for a situation report by initial responding paramedics before leaving their hospital to attend the OHCA.[43] Waiting for a situation report reduces false positive callouts but extends the time to ECMO flow for true cases. A broader activation criterion (that inherently will have more false-positive callouts) is more manageable for existing prehospital clinicians compared with a hospital-based team leaving their existing roles. Furthermore, dedicated prehospital ECPR-capable teams can be also used to perform other non-ECPR high acuity shock and resuscitation cases. However, prehospital ECPR requires substantial resources and significant scalability and sustainability challenges. The optimal solution will be resource and health system dependent, but these considerations need to be addressed before system commencement. Following ECPR initiation, the prehospital team further stabilizes the patient with a post-cannulation bundle of care and patients are transported to an ECMO center for coronary angiography and further management.[35,52]

In summary, the 3 delivery models lie along a continuum that trades geographic reach and time-to-flow against infrastructure, environmental control, and operational complexity. Hospital-based ECPR concentrates expertise, infrastructure, and procedural standardization at 1 site but limits eligibility to patients within a narrow transport radius and risks diluting team experience if cases are dispersed across multiple centers. The rendezvous model extends the reach of a single high-volume team into intermediate hospitals, preserving controlled cannulation environments and shared post-resuscitation pathways, at the cost of cross-institutional credentialing and coordination. Prehospital ECPR brings the intervention to the patient, offering the greatest geographic coverage and the shortest low-flow times, but requires substantial investment in field-capable teams, advanced training, transport assets, simulation, and quality assurance, and competes with other prehospital roles for finite resources. We note that much of the supporting evidence for prehospital ECPR remains observational and derives from highly specialized programs in mature EMS systems; reproducibility in different settings remains an open question.

Regardless of the location of the ECPR delivery system and site of cannulation, before ECPR system commencement a clear identification of which hospitals can provide/receive ECPR, their current resourcing, ability to accept patients, and the times when they can accept patients is required and must be communicated to the EMS to ensure seamless integration.

COMPARATIVE CONSIDERATIONS: IN-HOSPITAL, RENDEZVOUS, AND PREHOSPITAL MODELS

Selecting an ECPR delivery model requires balancing competing priorities: timely access for eligible patients, maintenance of operator expertise, procedural safety, and cost effectiveness. Hospital-based, rendezvous, and prehospital strategies exist along a continuum, trading geographic reach and time to flow against environmental control, infrastructure requirements, and operational complexity.[7,33–35]

Assessment of OHCA registries combined with geographic information systems modeling informs the optimal design of ECPR systems, including hospital locations, rendezvous sites, and prehospital team bases. Hospital-based strategies inherently limit eligibility to patients within a narrow transport radius capable of achieving collapse-to-flow times under 60 minutes, excluding a substantial proportion of potentially salvageable patients, particularly in rural and low-density regions.[33,34]

Rendezvous models expand access compared with single-center strategies while preserving controlled environments for cannulation and early stabilization.[35,37] A recent Monte Carlo simulation reported an increase in the proportion of patients achieving ECMO flow within 60 minutes, reduced low-flow times, and increased rates of favorable neurologic outcome compared with hospital-based approaches.[53]

Prehospital strategies, whether implemented by ground-based or helicopter EMS-based teams, consistently yield the highest probability of achieving ECMO flow within 60 minutes and the greatest predicted gains in cerebral performance category 1 to 2 survival.[34,37,48] However, these benefits come at the cost of increased operational complexity and the need for highly specialized teams, requiring robust systems for training, governance, and quality assurance.[42,44,45,47,54] Furthermore, there is an opportunity cost of redirecting these resources to potential ECPR cases and away from other time-critical emergencies that has yet to be elucidated.

To date, no comparative data identify a single universally superior model. Rather, ECPR system performance appears to depend less on the chosen delivery model than on how that model is executed locally: minimization of low-flow time, maintenance of high team proficiency through case volume and deliberate training, alignment of activation pathways with regional geography and EMS capability, and integration of postcannulation care within specialized cardiac arrest centers. Each system should be designed around its specific OHCA epidemiology, resources, and existing cardiac arrest infrastructure rather than imported wholesale from a different setting.

IDENTIFYING ECPR-ELIGIBLE PATIENTS

Once inclusion criteria are defined, a structured pathway for identifying and managing ECPR candidates should be integrated across the entire cardiac arrest system, from EMS dispatch to postresuscitation management. Identification begins in the prehospital setting, with dispatch recognition of potential candidates (eg, witnessed collapse, shockable rhythm on a public automated external defibrillator), triggering parallel alerts to EMS and ECPR centers. The balance between dispatch-level screening and on-scene paramedic confirmation differs across programs and reflects local EMS structure: dispatch-level identification favors sensitivity and earlier parallel activation, while on-scene paramedic assessment improves specificity but accepts a longer interval before the ECPR team is mobilized. Most mature programs combine both: an early prealert at dispatch based on simple criteria (witnessed arrest, presumed cardiac cause, shockable rhythm) followed by paramedic confirmation on scene, with explicit stand-down pathways when criteria are no longer met. Some systems use dedicated paramedics to screen for eligibility in real time.[47]

Notification of ECPR teams varies and may include direct clinician-to-team phone calls, centralized ECPR hotlines, smartphone applications, or ED notification pathways that activate the ECPR team. On-scene eligibility is then confirmed, followed by delivery of a standardized pre-ECPR care bundle before rapid transport (hospital-based or rendezvous models) or arrival of the ECPR team (prehospital models).

On hospital arrival, a focused handover should confirm key eligibility criteria before immediate transfer for cannulation, targeting a door-to-flow time of <10 minutes and arrest to flow time of <60 minutes.[24,35]

MINIMIZING LOW-FLOW TIME

Success in ECPR for OHCA depends on minimizing time to reperfusion (ECMO flow; Table 2), encompassing both the no-flow period (collapse to CPR initiation) and the low-flow period (CPR to cannulation).[49,50] Prolongation of either phase significantly reduces the likelihood of favorable neurological recovery. No-flow time has the greatest impact, with each additional minute without bystander CPR associated with an ≈13% relative reduction in good outcomes, while each minute of low-flow beyond 30 minutes reduces favorable neurological survival by ≈2.5%.[55–58]

Accordingly, ECPR systems must be designed to minimize both intervals. Reducing no-flow time requires early recognition and widespread bystander CPR, which independently improves 30-day survival.[56,59] Optimizing low-flow time depends on coordinated, parallel workflows: rapid triage of ECPR candidates, short scene times, use of mechanical CPR for transport, and streamlined pathways to cannulation, including rendezvous or prehospital ECPR where appropriate.[2,35,60]

Even small reductions in time to flow can yield meaningful gains in neurologically intact survival, reinforcing time to reperfusion as the central determinant of ECPR outcomes.[49,55,57,58,61,62] Accordingly, the success of any ECPR system depends not only on reducing delays but on deliberately building streamlined, parallelized processes that eliminate avoidable waiting at every step; the strongest programs are those that operationalize speed and coordination (ARREST [Expedited Transfer to a Cardiac Arrest Center for Non–ST-Elevation Out-of-Hospital Cardiac Arrest], PRAGUE [Effect of Intra-arrest Transport, Extracorporeal Cardiopulmonary Resuscitation, and Immediate Invasive Assessment and Treatment on Functional Neurological Outcome in Refractory Out-of-Hospital Cardiac Arrest]), whereas systems burdened by workflow inefficiency are far less likely to succeed (INCEPTION [Early Initiation of Extracorporeal Life Support in Refractory OHCA]).

INITIAL MANAGEMENT AND INTRA-ARREST TRANSPORTATION OF POTENTIAL ECPR PATIENTS

Most patients with OHCA who achieve return of spontaneous circulation (ROSC) do so within the first 15 minutes of professional resuscitation, with diminishing likelihood thereafter.[63] Observational data suggest the optimal window to transition to ECPR is after ≈8 to 20 minutes of on-scene resuscitation.[63–65] Contemporary ECPR pathways emphasize short scene times, rapid identification of eligible patients, and expedited transfer to an ECPR-capable center or rendezvous site.[35]

The EVIDENCE (Expedited transport versus more extended on-scene resuscitation for Out of Hospital Cardiac Arrest) trial evaluated expedited transport after professional resuscitation with a predefined care bundle, compared with standard care for which cases were transported after ≈25 minutes of professional resuscitation (15% versus 16%), and found no difference in neurologically intact survival.[66] Earlier transport strategies (eg, after 1–2 shocks) are feasible but require careful training and evaluation to ensure that CPR quality is not degraded and the chance of ROSC is not obviated. There is an ongoing tension between "stay and resuscitate" and "early transport" paradigms in OHCA care, and shifting toward an expedited intra-arrest transport model for ECPR-eligible patients has implications for the much larger group of patients who are not ECPR candidates. Many will achieve ROSC with optimized on-scene advanced life support, and transporting them prematurely risks degrading CPR quality, increasing on-the-move complications, and exposing crews to safety hazards without clear benefit. Programs adopting an ECPR-oriented transport paradigm should therefore preserve a parallel pathway for patients not undergoing ECPR in which on-scene advanced life support continues until ROSC or termination of resuscitation, and should monitor system-wide CPR quality, ROSC rates, and overall OHCA survival to confirm that benefits to ECPR-eligible patients do not come at a cost to the broader OHCA cohort.

During the extrication and transport phase, preservation of resuscitation quality is critical. EMS teams should be specifically trained to facilitate transport while minimizing interruptions to chest compressions and airway management and ventilation. Many systems prioritize continuous high-quality compressions (often mechanical), early airway control (preferring endotracheal intubation when performed by experienced providers without prolonging time to ECPR, and otherwise using a supraglottic device to maintain compression continuity; Table 1), and streamlined pharmacotherapy. Some protocols limit cumulative drug dosing to facilitate transport. To minimize pauses, certain systems omit routine pulse checks and pauses during extrication and transport to perform an algorithm-based COACHED (Continue compressions, Oxygen away, All else clear, Charging, Hands off, Evaluate rhythm, and Defibrillate) cycle, using brief CPR pauses for rhythm assessment and accepting the risk of missed transient ROSC to preserve perfusion.[8,67] While EMS high-performance CPR training programs typically reside in the on-scene setting, the practice of intra-arrest transport requires a similar dedicated training (and simulation) program, building on the principles of on-scene resuscitation, to achieve the same goals but in a more challenging setting.

Overall, intra-arrest management for ECPR candidates should prioritize continuous high-quality compressions with limited interruptions, an airway strategy that secures oxygenation and ventilation without prolonging time-to-ECPR (endotracheal intubation by experienced providers or supraglottic airway in transport, per Table 1), and rapid system activation, recognizing that optimal strategies remain incompletely defined and must be adapted to local capabilities.[68] Moreover, it must be recognized that this process represents a fundamental shift in management for many paramedics and EMS responders and systems; making such a change requires continuous training and assessment of quality and assurance metrics. High-quality resuscitation must be maintained while attempting to perform ECPR.

En route, EMS should notify/update the receiving ECPR center via a preactivated central dispatch or direct hotline to ensure that the hospital is ready to receive the patient.

POST-ECPR RESUSCITATION CARE AND ECPR CENTERS

Outcomes of ECPR programs are critically dependent on hospital processes and postresuscitation care. Before implementing an ECPR service, existing regional cardiac reperfusion networks should be reviewed to ensure that designated cardiac arrest centers meet contemporary 24/7/365 standards.

Many high-performing ECPR systems have evolved from established ST-segment–elevation myocardial infarction networks, characterized by continuous access to coronary angiography and PCI, rapid catheterization laboratory activation, and coordinated interfacility transfer pathways.[24,35]

Accordingly, guidelines recommend that centers receiving patients undergoing ECPR function as comprehensive cardiac arrest centers, with immediate access to coronary angiography, PCI, advanced critical care, and postresuscitation services available at all times.[69] Furthermore, centers managing patients undergoing ECPR should have the capabilities to manage the traumatic sequelae of prolonged resuscitation and chest compressions after resuscitation, with appropriate specialty support available 24/7/365 to manage complications as they arise; the specific specialties required will depend on the complication and on local institutional configuration.

Given the complexity and limited volume of ECPR, resources should be concentrated in experienced centers rather than dispersed across multiple low-volume hospitals, particularly as additional centers yield only modest gains in catchment.[36] Data from the SAVE-J (Multicenter Retrospective Observational Study on Extracorporeal Cardiopulmonary Resuscitation for Out-of-Hospital Cardiac Arrest Patients in Japan) study demonstrate a strong association between center volume and outcomes, with higher survival in high-volume centers compared with medium- and low-volume centers (33.4% versus 24.1% and 26.8%; P=0.001).[2,3] These findings underscore that ECPR is not effective as a stand-alone intervention in low-volume settings but performs best within coordinated, high-volume systems with experienced teams.

Survival after ECPR varies substantially between centers and is strongly associated with modifiable factors, including postresuscitation care, case volume, and protocol standardization.[38,39,70] Centralizing postresuscitation care within dedicated ECPR centers of excellence enables concentration of expertise, higher procedural volumes, and refined care pathways, mirroring established volume–outcome relationships in trauma, transplant, and complex cardiac surgery.[71–74] Such centers can sustain dedicated multidisciplinary teams available 24/7/365, capable of rapid cannulation, minimizing low-flow time, and delivering protocolized critical care. Registry data suggest centers managing ≥12 ECPR cases annually achieve higher rates of neurologically intact survival and fewer complications, with each additional 10 cases per year associated with an ≈11% increase in survival.[38,70]

Routine coronary angiography and PCI after ECPR cannulation are central components of many programs. Although not definitively established in non–ST-segment–elevation myocardial infarction OHCA with stable ROSC, immediate angiography following ECPR is recommended, given the high prevalence of significant coronary disease in refractory arrest and observational data linking PCI after cannulation with improved survival and neurological outcomes.[75,76]

Cannulation may occur in the ED or in the cardiac catheterization laboratory. These settings enable immediate cannulation with minimal preparation and rely only on the on-call cannulating physician and ECMO clinician (a nurse or paramedic with additional ECMO-specific training), supporting rapid response times. After cannulation, patients are transferred for coronary angiography and PCI, with additional mechanical support (eg, an intra-aortic balloon pump or Impella) as indicated. ED-based models are scalable and avoid delays associated with assembling catheterization laboratory teams, particularly after hours.[35,42] In contrast, catheterization laboratory–based cannulation provides immediate access to fluoroscopy and advanced procedural support, allowing seamless transition to coronary angiography and PCI but often requires additional transportation time, lift access, and the catheterization laboratory team already present.

Postresuscitation intensive care unit care remains a critical determinant of outcomes and many medical and surgical specialties are often involved in the care of a single patient undergoing ECPR.[77–79] Recent expert consensus provides a framework for post-ECPR management, while acknowledging the limited evidence base.[80] ECPR centers should implement standardized postresuscitation protocols and ensure that all involved specialties are familiar with system pathways, particularly in networks with multiple receiving centers, to deliver consistent, high-quality care. All medical specialties involved in the care of a patient undergoing ECPR should be aware of the ECPR program and protocol.

ECPR systems should recognize the risk of early withdrawal of life support in patients undergoing ECPR, which occurs in up to 50% of patients undergoing ECPR.[81] Patients undergoing ECPR are complex and heterogeneous; often require multiple interventions to treat complications from prolonged chest compression, nosocomial infections, or ECMO-related complications (eg, CPR-induced trauma, cannulation complications); and may take longer to awaken than OHCA survivors managed with conventional resuscitation. Following prolonged low-flow time, sedation requirements during ECMO, and accumulating organ injury, neurological recovery in ECPR survivors frequently occurs days to weeks after cannulation rather than within the first 72 hours, and standard ROSC-based neuroprognostication windows may therefore be misleading in this population.[80] Support and time are critical aspects to achieving the optimal ECPR outcomes.

COST EFFECTIVENESS CONSIDERATIONS

The cost effectiveness of ECPR depends on intervention cost, survival rates, organ donation, and the quality and duration of survival (Figure 2). These factors highlight the importance of system design, appropriate patient selection, and high-quality care delivery. In underperforming systems with low survival, cost effectiveness is unlikely and may threaten service sustainability. In contrast, systems achieving survival rates of 25% to 30% are more likely to be cost effective and sustainable, particularly given evidence of good long-term quality of life among survivors in high-performing programs.[82,83]

Cost effectiveness also varies by health care setting and delivery model. Establishing ECPR within an existing ECMO program is likely more efficient than developing a new service de novo. Although resource-intensive, hospital-based ECPR has demonstrated cost effectiveness in several observational studies within established systems.[4,5,84] In contrast, trial-based

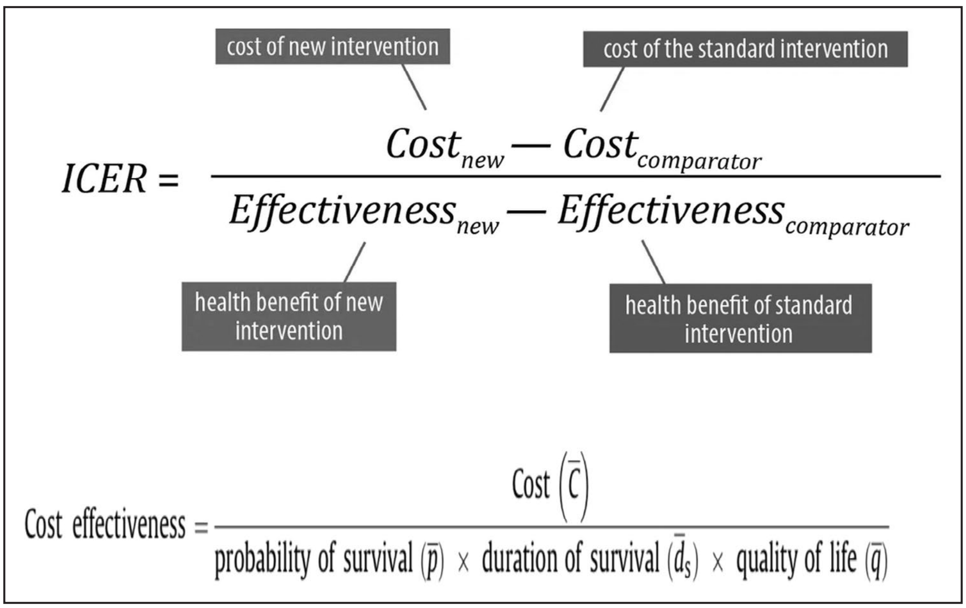

Figure 2. Cost effectiveness equation.
ICER indicates incremental cost effectiveness ratio.

economic evaluation from the INCEPTION study showed a low probability of cost effectiveness, consistent with the absence of survival benefit in that study.[4] Systematic reviews suggest that ECPR may be cost effective in selected settings but report substantial variability driven by differences in methodology, survival assumptions, and willingness-to-pay thresholds.[85,86] Evidence for prehospital ECPR is emerging, with early analyses suggesting favorable cost effectiveness compared with other advanced interventions.[87,88]

Cost effectiveness must also be considered at the system level, not solely at the individual-patient level. ECPR programs require substantial up-front investment in equipment, training, dedicated staffing, transport assets, and 24/7/365 hospital infrastructure. Where the broader OHCA chain of survival is not yet optimized (dispatch-assisted CPR, widespread bystander CPR education, public-access defibrillation, EMS response intervals, or postresuscitation care), the opportunity cost of redirecting resources into an ECPR program rather than these foundational interventions deserves explicit consideration. Population-level survival in OHCA may be more sensitive to bystander CPR rates and early defibrillation than to the availability of ECPR for the small fraction of refractory cases. Although robust data on this trade-off are limited, programs should explicitly weigh ECPR investment against incremental gains achievable through automated external defibrillator deployment, bystander CPR training, and dispatch optimization, and consider a minimum baseline OHCA survival or system performance threshold below which ECPR may not be the most cost-effective next investment.

A growing but often underappreciated consideration in ECPR is its potential to facilitate organ donation among patients who do not survive neurologically intact. In recent analysis, accounting for donor organ use meaningfully improves the estimated value of ECPR because even nonsurvivors may contribute kidneys, liver, lungs, and other transplantable organs, thereby partially offsetting the high up-front cost of the program.[89] This is especially relevant in systems with structured postarrest pathways, where ECPR can preserve organ perfusion long enough to enable donation after circulatory death or, in some cases, donation following withdrawal of life-sustaining therapy. Observational literature suggests that organs recovered from ECPR-supported donors can have acceptable graft and recipient outcomes, supporting the idea that organ donation should be incorporated into future health economic models of ECPR.[90] The inclusion of organ donation in the value calculation, however, remains ethically and operationally complex. Programs incorporating organ donation into their ECPR-system framework must navigate regional variability in legal definitions of death, dead-donor rules, family-consent processes, and the timing and acceptability of donation after circulatory death versus donation after withdrawal of life-sustaining therapy. Care must be taken that the prospect of organ donation does not influence the threshold for initiating, escalating, or withdrawing ECPR, and that decisions on continued support are made on the patient's own clinical trajectory. These considerations argue for transparent program-level policies, separation of treating and donation-coordination teams, and explicit alignment with the regional legal and ethical framework before organ donation is incorporated into a program's value proposition.

MEASURING SYSTEM-LEVEL IMPACT

Approximately 3% to 11% of patients with OHCA are eligible for ECPR even within optimized systems.[30–33] While prehospital ECPR, rendezvous configurations, and refined eligibility criteria may modestly expand this proportion, the large majority of patients with OHCA will remain ineligible. The conventional ECPR success metric (survival or neurologically intact survival among patients who receive ECPR) is informative for program performance but does not capture the impact of the program on the broader OHCA population. A more meaningful, system-level metric is whether the introduction of ECPR is associated with measurable improvements in overall OHCA outcomes at the population level. This question has been challenging to answer and remains a central critique from those skeptical of widespread ECPR adoption. Importantly, the preparation required to deliver an ECPR program (dispatch optimization, bystander-CPR initiatives, high-performance advanced life support, intra-arrest transport training, postresuscitation care, and structured quality improvement) can also improve outcomes for patients who never receive ECPR. Programs should

Table 3. Key Performance Indicators for an ECPR System

ECPR Key performance indicator
Prehospital miss rate of eligible OHCA
No-flow time
Low-flow time
Complication rates (ECPR and non-ECPR related)
Intensive care unit length of stay
Hospital length of stay
ECMO run time
Hospital or prehospital team arrival to ECMO flow time
Cannulation time
Postresuscitation care standard operating procedure compliance, for example, distal perfusion cannulae, whole-body computed tomography scanning
Adherence to international guidelines on neuroprognostication

ECMO indicates extracorporeal membrane oxygenation; ECPR, extracorporeal cardiopulmonary resuscitation; and OHCA, out-of-hospital cardiac arrest.

therefore monitor population-level OHCA metrics (overall survival, neurologically intact survival, bystander CPR rates, defibrillation intervals, and ROSC rates) alongside ECPR-specific outcomes and frame ECPR investment as 1 component of system uplift rather than an isolated procedure.

NEED FOR CONTINUAL IMPROVEMENT AND ASSESSMENT: KEY PERFORMANCE INDICATORS

ECPR systems will fail if there is not a culture of continual improvement and marginal gains. Regular quality and assurance should be undertaken to improve the system developed. Key performance metrics to monitor are outlined in Table 3.

CONCLUSIONS

Effective ECPR implementation for refractory OHCA requires a comprehensive, data-driven approach that optimizes every element of the cardiac arrest chain. Currently, there is no definitive evidence from randomized or comparative studies to suggest that 1 delivery model—hospital-based, rendezvous, or prehospital—is superior; rather, successful international programs remain limited in number, with evolving data indicating that outcomes depend heavily on local adaptation, concentrated experience in high-volume teams, rigorous training, continuous quality improvement, and integration of economic factors.

ARTICLE INFORMATION

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