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Emergency department extracorporeal membrane oxygenation: Current concepts, systems-based implementation, and future directions

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Abstract:

Extracorporeal membrane oxygenation (ECMO) has emerged as a time-critical resuscitative strategy for carefully selected patients with refractory cardiac arrest and other reversible causes of circulatory or respiratory failure. As the role of emergency department ECMO (ED ECMO) continues to expand, emergency physicians have become integral members of multidisciplinary extracorporeal resuscitation teams. This review aims to summarize the current evidence on ED ECMO while highlighting practical considerations for program implementation, workflow optimization, and future directions. This invited narrative review synthesizes contemporary evidence regarding the indications, patient selection, cannulation strategies, pericannulation management, and postcannulation physiological challenges of ED ECMO, with particular emphasis on extracorporeal cardiopulmonary resuscitation. In addition to published literature, practical aspects of ED ECMO implementation, including multidisciplinary team organization, operational governance, workflow optimization, quality metrics, and institutional experience, are discussed. Emerging concepts such as artificial intelligence-assisted decision support, digital twin-enabled system modeling, and regional implementation strategies are also reviewed. Current evidence indicates that successful ED ECMO depends not only on technical proficiency but also on timely patient selection, standardized protocols, efficient multidisciplinary coordination, and optimized operational systems. Contemporary implementation frameworks emphasize integrated governance, continuous quality improvement, and structured performance metrics to enhance clinical effectiveness. Emerging digital technologies, including artificial intelligence and systems modeling, may further improve patient selection, operational efficiency, and program scalability. ED ECMO should be regarded as a comprehensive, systems-based resuscitation strategy rather than a standalone rescue procedure. Future progress is likely to depend on the integration of evidence-based patient selection, standardized workflows, multidisciplinary collaboration, intelligent operational systems, and continuous quality improvement. The development of regional ED ECMO networks supported by robust emergency medical service infrastructure may improve timely access to extracorporeal resuscitation and optimize patient outcomes.

Keywords:

Cardiac arrest, critical care, emergency medicine, extracorporeal cardiopulmonary resuscitation, extracorporeal membrane oxygenation, resuscitation

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Box-ED Section

What is already known on the study topic?

- Extracorporeal membrane oxygenation (ECMO) and extracorporeal cardiopulmonary resuscitation improve outcomes in carefully selected patients with refractory cardiac arrest, but success is highly time-dependent and requires specialized multidisciplinary teams.

What is the conflict on the issue? Is it important for readers?

- Current literature on emergency department ECMO (ED ECMO) focuses predominantly on technical and clinical aspects, whereas practical implementation, workflow integration, team coordination, and operational governance remain insufficiently addressed. This gap is important for readers because successful ED ECMO depends not only on appropriate patient selection and technical expertise, but also on the ability to establish a timely, coordinated, and reproducible institutional workflow.

How is this study structured?

- This invited narrative review integrates current evidence with practical institutional experience, covering patient selection, cannulation, workflow design, operational systems, quality metrics, and future innovations in ED ECMO.

What does this study tell us?

- Successful ED ECMO depends on systems-based implementation, not cannulation alone, requiring standardized workflows, multidisciplinary coordination, continuous quality improvement, and intelligent operational support.

extracorporeal membrane oxygenation (VA ECMO) is established to restore systemic perfusion and to allow time to treat the underlying cause, most often by coronary reperfusion.^[5]

ECMO is increasingly initiated in the emergency department (ED), where refractory arrest is first identified, and a cannulation team can be assembled. In a meta-analysis of eight studies that included 51,173 patients, those who received ED-initiated ECPR had higher survival to hospital discharge than patients treated with CCPR (odds ratio: 3.34), although the effect on favorable neurologic outcome was uncertain and varied widely between studies.^[6] This review examines the current concepts, clinical applications, and future directions of ED ECMO, including its history, physiological rationale, indications, cannulation, outcomes, and the logistics of an ED ECMO program.

Literature Review Strategy

This invited narrative review was based on a comprehensive literature search of PubMed/MEDLINE. Articles published in English addressing ED ECMO, ECPR, prehospital ECMO, and extracorporeal life support in emergency medicine were prioritized. Landmark randomized controlled trials, international guidelines, consensus statements, registry reports, and high-quality observational studies were preferentially included. In addition, the review incorporates the authors' institutional experience in establishing and operating an ED ECMO program in Türkiye. As this article was not designed as a systematic review, formal study selection, risk-of-bias assessment, or meta-analysis were not performed.

Introduction

Out-of-hospital cardiac arrest (OHCA) is common, and most patients do not survive it despite conventional cardiopulmonary resuscitation (CCPR). In the United States, approximately 79 per 100,000 people have an OHCA each year, and about 10% of those treated by emergency medical services (EMS) survive to hospital discharge; in Europe, survival to discharge is approximately 8%.^[1,2] Closed-chest compression contributes to these poor outcomes because it generates only 25% to 40% of prearrest cardiac output and therefore supplies insufficient blood flow to the heart and brain.^[3] Outcomes are also strongly time-dependent: beyond 30 min of cardiopulmonary resuscitation (CPR), mortality increases by approximately 25% for every additional 10 min, and neurologically favorable recovery after prolonged conventional resuscitation is uncommon.^[4]

Extracorporeal CPR (ECPR) was developed to overcome this limitation. During ongoing CPR, venoarterial

Historical Background of Extracorporeal Membrane Oxygenation and Emergency Use

ECMO originated from the heart-lung machines used in cardiac surgery, which had already shown that blood could be oxygenated outside the body.^[7] In an early case, Hill *et al.* used a membrane lung to treat a patient with major trauma, and the patient survived.^[8] These early positive results were difficult to reproduce. Interest in the technique then declined. In separate randomized trials, extracorporeal support did not improve survival in adults with severe respiratory failure.^[9,10] For many years, the technique was used mainly in newborns, because it improved their survival.^[7]

Venovenous (VV) ECMO returned to adult respiratory care on the basis of two randomized trials. In CESAR, adults with severe respiratory failure who were referred to an ECMO center had better survival without severe disability.^[11] About a decade later, ECMO to Rescue

Lung Injury in Severe Acute Respiratory Distress Syndrome (ARDS) compared early VV ECMO with conventional care in very severe ARDS.^[12] Mortality was lower in the ECMO group, but the difference did not reach statistical significance, and a large proportion of control patients later crossed over to ECMO. The trial is nonetheless generally regarded as supporting VV ECMO as a rescue therapy when conventional management fails. By the late 2010s, VV ECMO was an accepted treatment option for severe respiratory failure.

ECMO was also used in cardiac arrest. In a propensity-matched study of in-hospital arrest, ECPR improved both short- and long-term survival compared with conventional CPR.^[13] This was an early indication that ECPR could rescue arrests that would otherwise be fatal.

Types of Extracorporeal Membrane Oxygenation and Indications in Emergency Medicine

Venoarterial extracorporeal membrane oxygenation

VA ECMO is a type of ECMO where blood is drained from the right atrium, pumped to a membrane lung, and returned into the arterial system [Figure 1]. Oxygenated blood can be returned into the aorta in a retrograde fashion via the femoral artery or in an antegrade fashion by placing a return cannula into the subclavian, axillary, or carotid artery.^[14] The rationale for reinfusing blood into the aorta retrogradely is to provide oxygen to the coronary arteries and to the brain in the ECPR setting. VA-ECMO augments systemic perfusion through retrograde aortic flow; however, it also increases left ventricular afterload and may contribute to LV distension. Oxygenated retrograde flow may support coronary and cerebral oxygen delivery. VA ECMO provides both cardiac and respiratory support and is typically indicated for cardiogenic shock, massive pulmonary embolism, and cardiac arrest scenarios.

Venovenous extracorporeal membrane oxygenation

In VV ECMO, blood is drained from the atriocaval junction via a drainage cannula, which is placed in the inferior vena cava, pumped to the membrane lung, and returned into the right atrium [Figure 1]. Because of the ECMO blood flow is circulated on the venous side of the body, VV ECMO provides only respiratory support and is typically reserved for severe respiratory failure unresponsive to optimal ventilatory management, such as ARDS secondary to pneumonia or trauma.^[11,12,15]

Extracorporeal cardiopulmonary resuscitation

ECPR refers to VA ECMO initiation during ongoing CCPR. With a 10% global hospital discharge rate with

OHCA and 30% in in-hospital cardiac arrest (IHCA), cardiac arrest itself is associated with a very high mortality and morbidity rate.^[16] In OHCA, after 15 min of ongoing CCPR, the chance of neurologically intact survival drops below 1%.^[17] Therefore, aside from conventional VA ECMO, ECPR is a prominently timely mannered intervention. One can say that “time is life” for ECPR. Even though randomized controlled trials investigating the utility of ECPR in selected patients with refractory cardiac arrest are controversial, ECPR has a 24% risk reduction of all-cause mortality in one year.^[18-22] Thus, ECPR must come to mind for the emergency physician in selected patients. Although ECPR is typically indicated in refractory cardiac arrest, the underlying causes for the cardiac arrest may include myocardial infarction, intoxications, and overdoses.^[23-25] This narrative review will mostly focus on ECPR.

Extracorporeal Membrane Oxygenation Circuit and Physiology

ECMO is an advanced extracorporeal life-support modality that provides temporary cardiopulmonary support in critically ill patients when conventional therapeutic strategies are insufficient [Figure 2]. Rather than constituting a definitive treatment, ECMO functions as a bridge to recovery that preserves systemic perfusion and gas exchange while allowing time for the identification and targeted management of the underlying primary pathology.^[26] In this time-critical setting, ECPR mitigates systemic and cerebral hypoxia, facilitates rapid correction of refractory metabolic acidosis, and restores hemodynamic stability, thereby enabling definitive treatment of reversible causes of arrest through percutaneous intervention, surgical embolectomy, or other targeted therapeutic approaches.

The ECMO circuit operates by draining deoxygenated venous blood from the patient through a drainage cannula, propelling it via a centrifugal pump toward a membrane oxygenator, and returning oxygenated, carbon dioxide-depleted blood to the vascular system through a return cannula. Gas exchange within the oxygenator is governed by physicochemical principles, primarily the surface area of the hollow fiber membrane and the diffusion gradients established across the blood-gas interface.^[27-29] Oxygen transfer is predominantly determined by membrane surface area, extracorporeal blood flow, and hemoglobin concentration, whereas carbon dioxide removal is substantially more efficient because of its greater diffusibility.^[30,31]

In contrast to conventional mechanical ventilation, in which gas exchange is modulated through minute ventilation and alveolar recruitment, ECMO transfers a major component of the respiratory

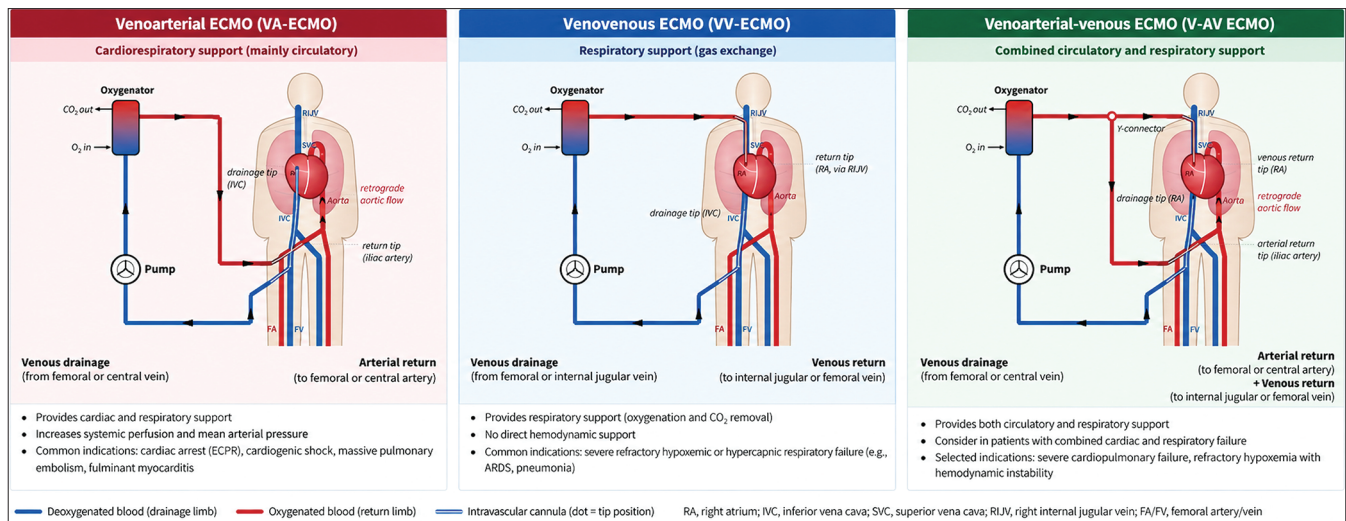


Figure 1: Schematic overview of extracorporeal membrane oxygenation types. ECMO: Extracorporeal membrane oxygenation

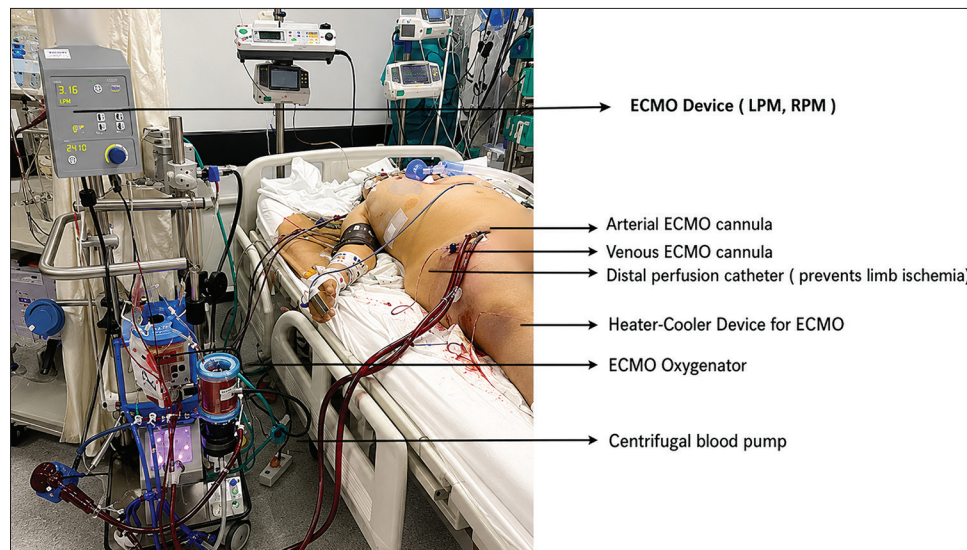


Figure 2: Extracorporeal membrane oxygenation circuit and cannulas. ECMO: Extracorporeal membrane oxygenation, LPM: Liters per minute, RPM: Revolutions per minute

workload to an artificial membrane lung, thereby substantially altering cardiopulmonary physiology. To maintain long-term circuit performance and improve hemocompatibility, oxygenator surfaces are commonly modified with biocompatible coatings, including heparin- or phosphorylcholine-based surfaces. Similarly, extracorporeal circuit tubing is coated with biocompatible materials to attenuate contact-mediated coagulation activation and systemic inflammatory responses.^[32,33]

In ECMO management, assessment of oxygenation based solely on arterial oxygen saturation (SaO₂) or arterial partial pressure of oxygen (PaO₂) is physiologically incomplete. The principal therapeutic target is not the achievement of supraphysiological oxygenation indices, but the preservation of an adequate balance between systemic oxygen delivery (DO₂) and oxygen

consumption (VO₂). DO₂ is determined by the integrated effects of arterial oxygen content, cardiac output, hemoglobin concentration, and extracorporeal blood flow, whereas VO₂ reflects the metabolic requirements of the patient. Under physiological conditions, the DO₂/VO₂ ratio is generally maintained at approximately 5:1, while ECMO guidelines recommend preserving a minimum ratio of 3:1.^[34-36] When this ratio falls below critical thresholds, oxygen consumption becomes supply-dependent, resulting in lactate accumulation, impaired aerobic metabolism, and tissue hypoxia.

In patients with critical supply dependency precipitated by severe anemia or hypermetabolic states, optimization of systemic oxygen delivery may be achieved more physiologically by targeted red blood cell transfusion to increase hemoglobin concentration rather than by indiscriminately increasing extracorporeal blood flow.

Excessive escalation of flow rates may impose additional mechanical stress on the circuit and blood elements, increasing the risk of cavitation and shear stress-induced hemolysis.^[37,38]

Cannulation for Extracorporeal Cardiopulmonary Resuscitation in the Emergency Department

ECMO cannulation for ECPR is a high-risk, time-critical procedure that provides a bridge to the treatment of reversible pathologies while requiring a coordinated multidisciplinary approach. Among all determinants of neurological outcome following ECPR, low-flow time, defined as the interval between the initiation of CPR and the establishment of extracorporeal blood flow, remains the most important prognostic factor. Current evidence suggests that low-flow time should ideally be maintained below 60 min whenever possible.^[39,40]

Recent large-scale cohort studies have demonstrated that door-to-needle time, defined as the interval between ED arrival and successful ECMO cannulation, is a critical predictor of favorable neurological outcomes. National registry data have shown that maintaining a door-to-needle time of <30 min is strongly associated with favorable neurological recovery (Cerebral Performance Category: ≤ 2). Conversely, neurological recovery declines markedly once cannulation exceeds approximately 27–30 min. Moreover, shorter cannulation times have been associated with significantly lower rates of cannulation-related adverse events and major bleeding complications.^[40–42]

ECMO cannulation may be performed either in the prehospital setting or within the ED. Although prehospital cannulation has the potential to further reduce low-flow time, it is associated with considerable logistical complexity and unpredictable environmental challenges. In contrast, ED cannulation offers several important advantages, including immediate access to advanced imaging, a sterile and controlled procedural environment, rapid coronary angiography when indicated, and prompt recognition and management of procedure-related complications.

For adult ECPR, femoral arterial and femoral venous cannulation represent the preferred vascular access strategy. This approach enables cannulation within a relatively immobile operative field, distant from the chest compression team, while allowing a wide sterile working area despite ongoing mechanical CPR. Depending on institutional expertise, vascular access may be obtained using a fully percutaneous (Seldinger), surgical cutdown, or hybrid technique combining direct vessel visualization with guidewire-assisted

cannulation. Whenever vascular anatomy permits, ipsilateral placement of both arterial and venous cannulas should be preferred to simplify the procedure and reduce cannulation time.^[42]

Ultrasound guidance should be considered mandatory for vascular access. Ultrasound allows accurate identification of the optimal puncture site, typically just proximal to the bifurcation of the superficial and deep femoral arteries, thereby facilitating rapid cannulation while minimizing vascular injury. In addition, ultrasound-guided guidewire insertion reduces the risk of inadvertent vascular cannulation, such as placement of both cannulas into the venous system, and enables confirmation that the venous guidewire has advanced into the inferior vena cava and the arterial guidewire into the abdominal aorta.

Following ultrasound-guided arterial and venous puncture, guidewires are inserted, and systemic anticoagulation is initiated with an intravenous bolus of 50–100 IU/kg unfractionated heparin. Sequential dilators are then advanced over the guidewires to dilate the skin, subcutaneous tissues, and vascular entry sites before final insertion and clamping of the arterial and venous ECMO cannulas. During this stage, repeated defibrillation attempts should be avoided, and mechanical chest compressions may be interrupted briefly, preferably for < 60 s, if necessary to facilitate safe cannulation.

For adult patients, arterial cannulas measuring 15–17 Fr in diameter and 23–25 cm in length, together with 19–21-Fr, 55–60-cm multistage venous cannulas, generally provide sufficient blood flow to achieve the target ECMO flow of 3–4 L/min. Wire-reinforced cannulas should be preferred to reduce the risk of kinking, whereas heparin-coated cannulas may decrease thrombotic complications. Percutaneous cannulation is typically performed using 0.035-inch, 145-cm super-stiff J-tip guidewires. Guidewire selection should follow the manufacturer's recommendations to ensure optimal compatibility between guidewire stiffness and cannula flexibility, thereby minimizing the risk of vascular injury. In patients with severe peripheral arterial disease or marked vascular tortuosity, hydrophilic or soft-tip guidewires may facilitate vessel passage but should subsequently be exchanged for appropriately stiff guidewires before cannula insertion.

After successful cannulation, the preprimed ECMO circuit is introduced into the sterile field. Both the circuit and cannulas are flushed with normal saline to eliminate residual air before being connected using a wet-to-wet technique. Pump speed is initially set at approximately 1500 rpm and gradually increased until the target blood

flow of 3–4 L/min is achieved. Adequate circuit function can be confirmed visually by the presence of dark venous blood entering the oxygenator and bright red oxygenated blood returning through the arterial limb. To avoid sudden hypertension after initiation of extracorporeal support, discontinuation of adrenaline infusion may be considered when clinically appropriate.^[42,43] Continuous unfractionated heparin infusion should then be commenced, with anticoagulation monitored using activated clotting time (ACT), activated partial thromboplastin time, or anti-factor Xa assays. Once adequate ECMO flow has been established and systemic perfusion restored, both mechanical and manual chest compressions should be discontinued.

Rationale for Emergency Department Extracorporeal Membrane Oxygenation

The management of cardiac arrest is a time-sensitive matter as the potential to reverse shock diminishes with time. Unfortunately, achieving return of spontaneous circulation (ROSC) does not necessarily translate into a favorable neurological outcome. The primary reason is that the brain parenchyma is considerably more vulnerable than myocardial tissue to the cellular oxygen deprivation that develops following cardiac arrest. Therefore, to maximize the likelihood of achieving ROSC accompanied by good neurological recovery, the ultimate goal of successful resuscitation, both the no-flow and low-flow intervals following cardiac arrest must be minimized as much as possible.

In patients with IHCA, cumulative rates of ROSC associated with favorable neurological outcomes are known to plateau after approximately 15–20 min of ongoing CPR, indicating a marked decline in the probability of meaningful neurological recovery beyond this time frame.^[44,45] Consequently, patients experiencing IHCA who are considered potential candidates for ECPR require ECMO teams that are available 24/7 and capable of delivering a rapid, seamless, and highly coordinated response.

For patients who arrest in the ED, transferring them to the operating room or catheterization laboratory for ECMO cannulation introduces significant and often unpredictable life-threatening risks associated with transport. Therefore, ECMO cannulation should be performed directly in the ED not only for this specific patient population but also for any critically ill patient whose condition is deteriorating and for whom transport poses substantial risk, particularly when ECPR or emergent ECMO support is indicated.

The question of who should perform ECMO cannulation is already answered, and continuing this debate serves

little practical purpose.^[46] Although the expertise of vascular surgeons in vascular access and cannulation is indisputable, patient survival should not depend on their immediate availability. In many institutions, vascular surgeons are not available around the clock, and even in tertiary centers, they may be occupied in the operating room when an emergency arises. Delays under such circumstances should not compromise the survival of patients requiring time-critical extracorporeal support. Emergency physicians are uniquely positioned to fill this role. As clinicians who are available 24 h a day, 7 days a week, accustomed to making rapid and accurate decisions under extreme pressure, and proficient in a broad range of life-saving invasive procedures, they can become highly competent ECMO cannulators following structured training. Indeed, the first case series describing ED ECMO was reported in the late 1990s, providing early evidence for the feasibility of this approach.^[47] However, the first structured ED ECMO system was defined by Shinar *et al.* in the United States of America (USA) in 2012.^[48] Through these experiences, emergency physicians have not only demonstrated the feasibility of ED ECMO but have also helped define emergency medicine-specific indications that extend beyond the traditional indications for ECMO.

Indications for Emergency Department Extracorporeal Membrane Oxygenation

In the ED, the primary indication for ECPR is refractory cardiac arrest [Figure 3]. It can be used in both IHCA and OHCA. Because the time from the onset of arrest to ECMO flow significantly affects neurologic outcome, ECPR should be considered when CCPR has been unsuccessful for 10–15 min.^[49] The patients most likely to benefit are those with a witnessed arrest, prompt bystander CPR, a shockable initial rhythm, and a reversible cause such as acute coronary occlusion.^[49] In the Extracorporeal Life Support Organization (ELSO) data, survival to hospital discharge after ECPR is approximately 29%.^[49]

Beyond acute coronary occlusion, ECMO can also provide circulatory support in other reversible conditions [Figure 4]. In these patients, ECMO buys time for treatment of the underlying cause. In high-risk pulmonary embolism, ECMO provides hemodynamic support. Although the reported survival appears high, the findings are highly variable. For this reason, no definite conclusion can be drawn.^[50] In cardiotoxic drug poisoning, ECMO can improve survival in selected patients with refractory circulatory failure or cardiac arrest.^[25] In cardiac arrest due to accidental hypothermia, rewarming with ECMO allows a favorable chance of survival with a good neurologic outcome.^[51]

Category	Specific Indications
Cardiac arrest (ECPR)	- Refractory cardiac arrest with potentially reversible cause - Cardiac arrest due to acute coronary syndrome, massive pulmonary embolism, or hypothermia (selected patients) - Failure to achieve ROSC despite high-quality CPR
Cardiogenic shock	- Refractory cardiogenic shock despite optimal medical therapy - Acute myocardial infarction with hemodynamic collapse - Fulminant myocarditis - Post-cardiotomy or post-cardiac procedure shock - Severe valvular dysfunction (e.g., acute mitral regurgitation)
Respiratory failure	- Severe refractory hypoxemic respiratory failure (e.g., ARDS, severe pneumonia, aspiration) - Severe refractory hypercapnic respiratory failure - Bridge to lung transplantation
Massive pulmonary embolism	- Hemodynamic instability or cardiac arrest - Refractory shock despite thrombolysis, thrombectomy or surgical embolectomy - Bridge to definitive reperfusion therapy
Severe hypothermia	- Cardiac arrest or profound hemodynamic instability due to accidental hypothermia - Rewarming with ECMO in selected patients
Other selected indications	- Drug intoxication (selected, potentially reversible cases) - Bridge to definitive therapy (e.g., transplantation, ventricular assist device) - Severe sepsis with refractory shock (selected cases)

Figure 3: Indications for extracorporeal membrane oxygenation in the emergency department. ECMO: Extracorporeal membrane oxygenation, ARDS: Acute respiratory distress syndrome, ECPR: Extracorporeal Cardiopulmonary Resuscitation, CPR: Cardiopulmonary Resuscitation, ROSC: Return of Spontaneous Circulation

ECMO type	Clinical scenario	Urgency level*	Primary objective
VA-ECMO (ECPR)	Refractory cardiac arrest (in appropriate ECPR candidate)	Immediate	Restore systemic perfusion while treating the reversible cause
VA-ECMO	Refractory cardiogenic shock	Emergent	Circulatory support and bridge to recovery/intervention
VA-ECMO	Massive pulmonary embolism with shock or cardiac arrest	Immediate – Emergent	Stabilization and bridge to reperfusion therapy
VA-ECMO	Fulminant myocarditis with profound shock	Emergent	Bridge to myocardial recovery
VA-ECMO	Severe accidental hypothermia with cardiac arrest	Immediate	Extracorporeal rewarming and circulatory support
VV-ECMO	Refractory hypoxemic respiratory failure (e.g., ARDS)	Urgent	Gas exchange and lung-protective ventilation
VV-ECMO	Severe refractory hypercapnic respiratory failure	Urgent	CO ₂ clearance and correction of respiratory acidosis
V-AV ECMO	Combined respiratory and circulatory failure	Emergent	Simultaneous oxygenation and hemodynamic support

* Urgency level definitions:

- Immediate:** initiate ECMO as soon as possible (minutes)
- Emergent:** initiate ECMO after rapid assessment (ideally within hours)
- Urgent:** consider ECMO early (hours rather than minutes)

Figure 4: ECMO type by clinical scenario and urgency level: A quick reference. ECMO: Extracorporeal membrane oxygenation

Beyond cardiac arrest, the application of ED ECMO in patients with acute pulmonary embolism, sepsis, drug overdose, status asthmaticus, trauma, and other conditions resulting in severe hypoxemia or profound circulatory failure has expanded the scope of extracorporeal support.

ECMO is used to support the circulation in refractory cardiogenic shock. It is most useful when the underlying cause is treatable. In fulminant myocarditis, VA ECMO supports the circulation until the heart recovers. In a meta-analysis, short-term mortality in patients with fulminant myocarditis supported with VA ECMO

was approximately 35%, and the authors stated that cardiopulmonary support with VA ECMO should be considered when conventional treatment fails, particularly in younger patients.^[52] In Takotsubo syndrome, mechanical circulatory support such as ECMO has been described as a bridge to recovery.^[53] Current evidence indicates that ECMO is a feasible treatment option in drowning-related cardiac arrest and supports the use of ECPR as a rescue therapy in selected drowning cases in which conventional resuscitation has failed.^[54] In addition, when resuscitation fails, ECMO maintains organ perfusion and thereby allows organ donation.^[55]

Patient Selection for Extracorporeal Cardiopulmonary Resuscitation

Because ED ECMO is a resource-intensive, logistically demanding, and highly time-sensitive life-saving intervention, appropriate patient selection is essential to maximize its clinical benefit. For cardiac arrest, numerous ECMO eligibility algorithms have been proposed in the literature, most of which have been derived from predictors associated with survival and favorable neurological outcomes following ECPR.

Common selection criteria include younger age, a short no-flow interval (ideally <5 min), a short low-flow interval (ideally <15 min), an initial shockable rhythm, and the presence of signs of life during CPR, such as gasping, preserved pupillary light reflexes, or involuntary movements.^[49,56-59] Several algorithms developed for OHCA also incorporate the anticipated transport time to an ECMO-capable center to optimize patient selection.^[60] Our institutional ECPR algorithm consists of a two-step triage system that encompasses both the prehospital and in-hospital phases of care [Figure 5].

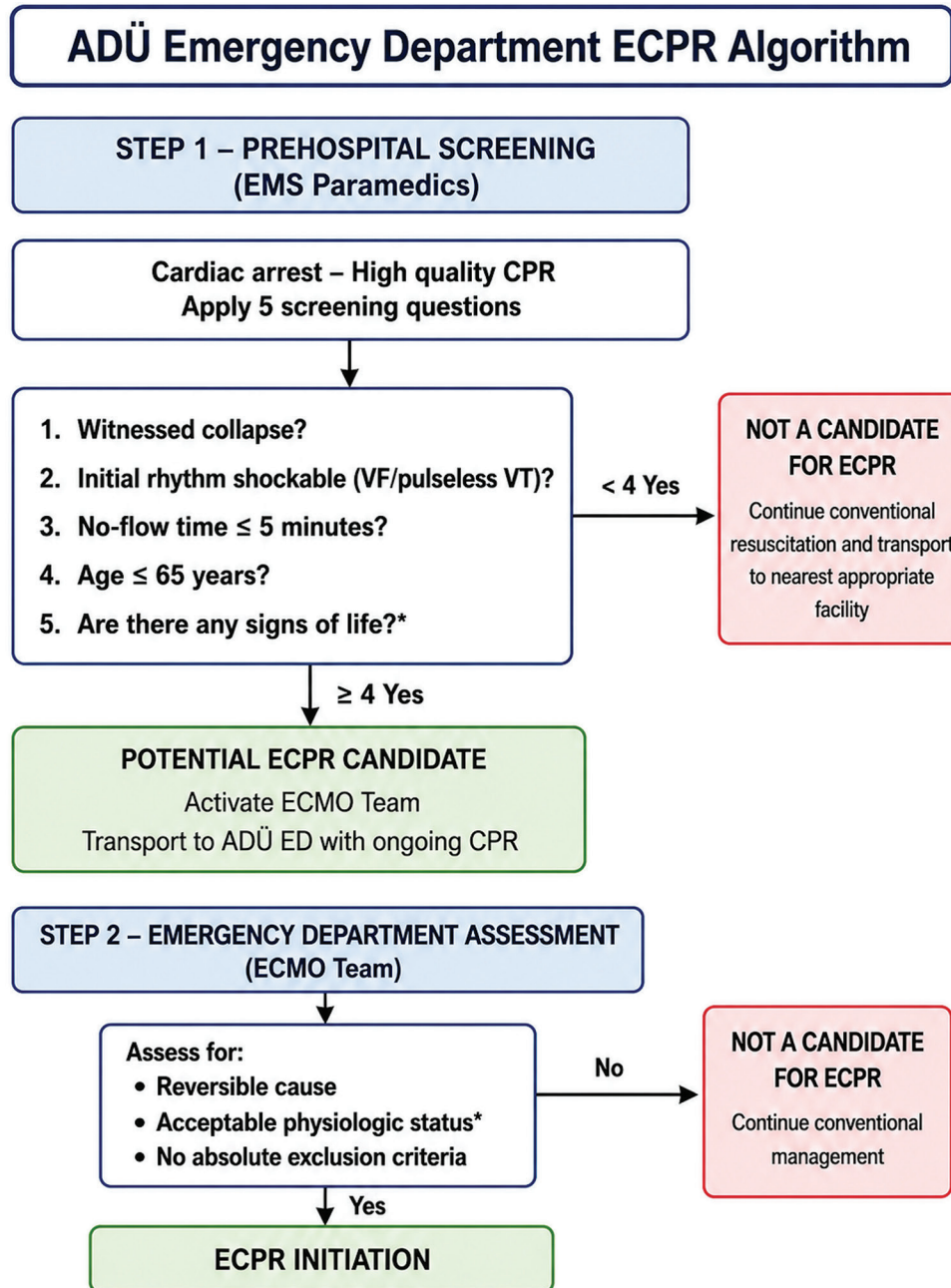


Figure 5: Adnan Menderes University Department of Emergency Medicine extracorporeal cardiopulmonary resuscitation algorithm. *Gasping, positive pupil reflexes, involuntary movements, ECPR: Extracorporeal cardiopulmonary resuscitation, EMS: Emergency Medical Services, CPR: Cardiopulmonary resuscitation, VF: Ventricular fibrillation, VT: Ventricular tachycardia, ECMO: Extracorporeal membrane oxygenation, ED: Emergency department

The first step is performed by paramedics at the scene to identify potential ECPR candidates. Patients meeting the initial eligibility criteria are transported to our institution under predefined transport protocols. Upon arrival at the ED, the second step of the algorithm is systematically reassessed by the treating physicians, who then determine the patient's final eligibility for ECPR. As data collection for this prospective evaluation is still ongoing, outcome data validating the performance of this algorithm are not yet available. The clinical results and predictive performance of the algorithm will therefore be reported in a subsequent publication.

Although conditions such as terminal metastatic malignancy, contraindications to systemic anticoagulation, advanced chronic obstructive pulmonary disease, and irreversible end-organ damage are widely accepted as exclusion criteria for ECPR, there is no universal consensus regarding their absolute applicability.^[46] In clinical practice, these exclusion criteria should therefore be interpreted within the context of the individual patient's overall condition rather than as rigid thresholds. One of the major reasons for this is that patients selected for ECPR are frequently unable to provide a medical history because of their clinical condition, and reliable collateral information may not be immediately available. Consequently, obtaining a complete and accurate history before ECMO initiation is not always feasible. Although this is far from ideal, it represents a common and unavoidable challenge in the ED of patients requiring ECPR. More recently, stop criteria have been proposed as a pragmatic framework for identifying patients who are unlikely to benefit from ECPR.^[26] These criteria include a no-flow interval >10 min, unwitnessed collapse without bystander CPR, frailty in older adults, severe terminal comorbidities, previously expressed patient wishes against CPR or ECPR, and prolonged global hypoxemia. The presence of any one of these criteria is generally considered a strong recommendation against the initiation of ECPR, as the likelihood of achieving meaningful survival with favorable neurological recovery is exceedingly low.

Several key factors should be considered when identifying appropriate candidates for ED ECMO among critically ill patients without cardiac arrest. As with all potential ED ECMO candidates, the presence of a reversible underlying pathology and early recognition of the need for extracorporeal support are fundamental determinants of patient selection. Timely evaluation is particularly important, as delays may allow irreversible organ injury to develop, thereby diminishing the potential benefit of ECMO. According to recent publications, patients presenting with nonshockable rhythms have a poorer prognosis and are generally considered less favorable candidates for ECPR.^[61] However, another

meta-analysis from France yielded interesting results, as there may be a 12% survival with good neurological outcome at 30 days after ECPR if the patients had signs of life such as involuntary movements, positive pupil reflexes, and gasping during conventional CPR.^[62]

The fundamental principle that should always guide clinical decision-making is that ECMO is a bridge, not a destination. Therefore, candidates should have a realistic prospect of being bridged to recovery, definitive therapy, durable mechanical circulatory support, or organ transplantation. In the absence of a meaningful bridge strategy, the initiation of ECMO is unlikely to provide sustained clinical benefit.

Current Evidence and Landmark Trials

ECPR has increasingly emerged as an accepted resuscitative strategy for OHCA, offering a potential alternative to CCPR.^[63] The Refractory Cardiac Arrest Treated with Mechanical CPR, Hypothermia, ECMO and Early Reperfusion (CHEER) trial, regarded as one of the earliest and most compelling pieces of evidence for ECPR in the literature, marked a paradigmatic shift in the management of refractory OHCA [Table 1]. This multicomponent protocol, which integrated high-quality mechanical CPR, early neuroprotective hypothermia, rapid cannulation, and cause-directed emergency coronary intervention, demonstrated a 45% rate of survival to hospital discharge with favorable neurological outcome, thereby establishing the clinical feasibility and efficacy of this approach. The central insight provided by the study was that, in the treatment of refractory cardiac arrest, ECMO should not be regarded as a stand-alone rescue therapy; rather, its maximal survival benefit is achieved only when it is implemented within a standardized and comprehensive resuscitation ecosystem. In this respect, the CHEER study served as a catalyst for the global expansion of ED-based ECPR programs and contributed to the updating of international resuscitation guidelines to incorporate such invasive strategies.^[64]

Advanced Reperfusion Strategies for Patients with OHCA and Refractory Ventricular Fibrillation (ARREST), one of the most important randomized controlled trials in the ECPR literature, demonstrated the marked superiority of early ECMO support over standard advanced cardiac life support (ACLS) in patients with refractory ventricular fibrillation (VF) or pulseless ventricular tachycardia and was terminated early because of this striking benefit. The methodology of the study underscored, in a compelling manner, the critical importance of strict "time thresholds" and a "structured logistical network" in the management of refractory cardiac arrest. Rather than prolonging resuscitation efforts in the field, the strategy

Table 1: Landmark extracorporeal cardiopulmonary resuscitation trials and registry data

Landmark ECPR trials and registry data: A comparative summary				
Study/registry	Study design and population	Key intervention/logistical strategy	Primary/secondary key outcomes	Clinical impact and take-home message
CHEER (2015)	Single-center prospective study; refractory OHCA	Comprehensive ecosystem: mechanical CPR, early neuroprotective hypothermia, rapid cannulation, and early coronary intervention	45% survival to hospital discharge with favorable neurological outcome	Proved that ECPR is not a stand-alone rescue tool but must be embedded within a standardized resuscitation protocol
ARREST (2020)	RCT; refractory VF/pVT OHCA	“Load-and-go” strategy: Rapid automated mechanical CPR transport to an ECMO center versus standard ACLS	Terminated early due to marked superiority and striking survival benefit of early ECMO support over standard ACLS	Highlighted the critical importance of strict time thresholds and a structured prehospital logistical network
Prague OHCA (2022/2024)	RCT; in-hospital ECPR evaluating a “load-and-go” strategy	Intra-arrest transport and ECPR versus standard ACLS	ITT analysis: No statistical difference in 180-day favorable neurological survival. Secondary analysis: In patients without prehospital ROSC, ECPR showed substantially higher survival (23.9% vs. 1.2%)	Provides a critical therapeutic window for neurologically intact survival in the terminal phase of refractory arrest (>45–50 min)
INCEPTION (2023)	Multicenter, pragmatic RCT; refractory OHCA	Real-world, multicenter pragmatic ECPR delivery versus standard CPR	Comparable 30-day survival with favorable neurological outcome: 20% (ECPR) versus 16% (standard)	Intensified debates on the cost-effectiveness balance, highlighting the need for center experience and strict practice standardization
SAVE-J II (2024)	Large-scale, real-world registry study; adult OHCA	Evaluation of institutional annual ECPR case volume impact	Survival to discharge: High-volume centers: 33.4%; low-volume centers: 26.8%	Statistically demonstrated that ECPR success and complication profiles are highly volume-dependent and tied to institutional experience
ELSO registry	Global multi-center database (>450 centers)	Benchmark of global real-world outcomes and rescue ECPR applications	Survival rates: Neonates: 42%; Pediatrics: 41%; Adults: 30%	Adult survival (30%) underlines critical logistical challenges, the necessity of rapid cannulation, and strict patient selection (e.g., witnessed arrest and shockable rhythms)

CHEER: Refractory Cardiac Arrest Treated with Mechanical CPR, Hypothermia, ECMO and Early Reperfusion, ARREST: Advanced Reperfusion Strategies for Patients with OHCA and Refractory Ventricular Fibrillation, RCT: Randomized controlled trial, INCEPTION: Extracorporeal Life Support in Refractory OHCA, SAVE-J II: Advanced Cardiac Life Support for Ventricular Fibrillation with Extracorporeal Circulation in Japan, ELSO: Extracorporeal Life Support Organization, ECMO: Extracorporeal membrane oxygenation, OHCA: Out-of-Hospital Cardiac Arrest, ECPR: Extracorporeal CPR, ROSC: Return of spontaneous circulation, ACLS: Advanced cardiac life support, VF: Ventricular fibrillation, pVT: Pulseless ventricular tachycardia, CPR: Cardiopulmonary resuscitation, ITT: Intention-to-treat

of rapidly transporting patients to an ECMO-capable center under automated mechanical chest compressions has, on the basis of the robust evidence provided by the ARREST trial, become a life-saving standard in contemporary practice.^[18]

Another landmark randomized trial, Prague OHCA, evaluated in-hospital ECPR using a “load-and-go” strategy. Although the initial intention-to-treat analysis did not demonstrate a statistically significant difference in 180-day survival with favorable neurological outcome, secondary analyses showed that, among patients who did not achieve prehospital ROSC, ECPR was associated with a substantially higher survival rate compared with standard ACLS (23.9% vs. 1.2%).^[21] These findings suggest that an invasive resuscitation strategy incorporating intra-arrest transport and ECPR may provide a critical therapeutic window for achieving neurologically intact survival in the terminal phase of refractory cardiac arrest (>45–50 min), when conventional resuscitative efforts are no longer effective. Although this approach

may be associated with lower rates of sustained ROSC, it appears to offer a meaningful survival advantage in carefully selected patients who fail to respond to standard ACLS. The success of this strategy depends largely on effective prehospital time management and the rapid integration of eligible patients into predefined invasive resuscitation algorithms within critical time thresholds.^[65]

Conversely, the Early Initiation of Extracorporeal Life Support in Refractory Out-of-Hospital Cardiac Arrest (INCEPTION) trial, which was conducted with a multicenter and pragmatic design, reported comparable rates of 30-day survival with favorable neurological outcome between the ECPR group (20%) and the standard resuscitation group (16%).^[19] Although these findings failed to demonstrate a clear superiority in clinical outcomes, they brought several critical issues to the forefront, including the standardization of ECPR practices, institutional experience, and the rational allocation of resources. In doing so, the study

further intensified the ongoing debate regarding the cost-effectiveness balance of this treatment strategy.^[66]

The large-scale Study of Advanced Cardiac Life Support for Ventricular Fibrillation with Extracorporeal Circulation in Japan (SAVE-J II) registry study, which provides real-world data, helps to explain these discrepant findings. The study demonstrated that survival to hospital discharge among OHCA patients treated with ECPR was directly associated with the annual ECPR case volume of the treating center, with higher survival rates observed in high-volume centers than in low-volume centers (33.4% vs. 26.8%). It also showed that complication rates varied according to institutional case volume, thereby emphasizing that the success of ECPR is closely dependent on institutional experience and operational capacity.^[67]

According to ECPR data from ELSO, the leading global authority, registry body, and scientific guidance organization for artificial heart-lung support systems, neonatal, and pediatric populations demonstrate comparable and relatively higher survival rates, with 3,196 cases and 42% survival in neonates and 8,717 cases and 41% survival in pediatric patients. In contrast, although the adult population represents a substantially larger case volume, with 26,186 cases, the survival rate decreases to 30%. This 30% survival rate in adult ECPR highlights the critical importance of logistical challenges in ED management, appropriate patient selection, including the distinction between asystole and shockable rhythms, as well as the presence of witnessed cardiac arrest, and the need for rapid cannulation.^[68]

ELSO database offers critical information for benchmarking survival outcomes and complication profiles associated with ECPR, particularly when it is used as a rescue therapy in cases of OHCA in which conventional resuscitation methods are insufficient.^[69]

The utilization of ECPR increased more than tenfold between 2003 and 2014 and has now reached more than 15,000 registered cases in 450 centers worldwide, with survival rates approaching 30% in selected patients, thereby supporting the clinical feasibility of this therapeutic approach.^[70] Nevertheless, the growing adoption of ECPR continues to pose substantial challenges for the optimization of clinical protocols, largely due to the heterogeneity of patient populations and the lack of standardized practices across centers.^[71] In this context, the use of prognostic indicators such as shorter resuscitation duration, witnessed arrest, and the absence of nonshockable rhythms such as asystole as a standardized framework for patient selection may substantially improve treatment success rates.^[72] Furthermore, the success of these systems is directly

dependent on the quality of coordination between prehospital teams and specialized centers, as well as the early initiation of bystander CPR.^[23]

In conclusion, large-scale literature and registry data demonstrate that the success of ECPR is not a static clinical outcome but is instead directly contingent upon an institutional and technical learning curve. However, the significant heterogeneity across study populations and trial designs introduces substantial complexity, rendering data analysis challenging and inherently nonhomogeneous. Despite these analytical limitations, evidence consistently shows that as center case volumes and procedural experience increase, the maturation of logistical coordination and technical proficiency optimizes survival rates while minimizing complications. Consequently, ECPR represents a time-sensitive, dynamic organizational ecosystem whose clinical efficacy and success rates scale linearly as institutional expertise accumulates and the learning curve is progressively mastered.

Workflow and Logistics in the Emergency Department

Once a patient has been identified as an appropriate candidate for ED ECMO, several practical considerations are essential to ensure that the procedure is performed rapidly, efficiently, and with minimal complications. These key principles can be summarized as follows.

Before the patient arrives at the emergency department

The successful implementation of high-risk, time-critical interventions such as ECPR depends not only on technical expertise but also on meticulous logistical preparation. All equipment required for ECMO cannulation should be organized in a standardized and readily accessible manner to eliminate unnecessary delays and minimize the procedural chaos associated with searching for equipment during resuscitation. For this purpose, a dedicated ECMO cart should be prepared. This mobile cart should contain all essential cannulation equipment, including puncture needles, guidewires, dilators, ECMO cannulas, vascular clamps, sterile scissors, and other procedural accessories, arranged according to a standardized layout designed to minimize human error. Each compartment should be clearly labeled, allowing every team member to locate the required equipment immediately. An alternative strategy is to prepare a dedicated ECPR box with a single guiding principle: "Open everything inside!" [Figure 6]. Such a standardized package ensures that all equipment required for ECPR is immediately available in one location, minimizing delays related to equipment



Figure 6: Extracorporeal membrane oxygenation cart and extracorporeal cardiopulmonary resuscitation box at Aydın Adnan Menderes University Department of Emergency Medicine. ECMO: Extracorporeal membrane oxygenation, E-CPR: Extracorporeal cardiopulmonary resuscitation

retrieval and simplifying procedural workflow during this highly time-sensitive intervention.

Although there is no universally accepted composition of an ECMO team, it commonly includes emergency physicians, perfusionists, vascular surgeons, intensivists, and cardiologists who work in close collaboration. Regardless of its exact composition, the most critical characteristic of an effective ECMO team is that its members are dedicated personnel who regularly participate in ECMO care. This continuity is perhaps the single most important factor in maximizing team performance and procedural efficiency.

Team competency should be reinforced through regular didactic education, hands-on training, and high-fidelity simulation exercises until coordinated team performance becomes instinctive.^[73] Clearly defined roles and responsibilities ensure that every team member understands their specific tasks before, during, and after cannulation, thereby improving procedural safety and overall patient outcomes.

Upon patient arrival in the emergency department

Whenever possible, patients at risk of cardiac arrest should be identified upon arrival in the emergency department, as initiating ED ECMO during the prearrest

or periarrest phase may substantially increase the likelihood of survival. Accordingly, we recommend that patients presenting in a periarrest state or with impending circulatory collapse undergo both femoral arterial and venous vascular access as part of the XAaBCDE (a = vascular access) primary survey advocated by the Endovascular Resuscitation and Trauma Management concept. Establishing vascular access before circulatory arrest may significantly reduce the time to ECMO initiation if cardiac arrest subsequently occurs. Although vascular access is routinely performed under ultrasound guidance, successful cannulation may become considerably more challenging after cardiac arrest because of profound vasoplegia and circulatory collapse. This often results in repeated unsuccessful puncture attempts, increased risks of vascular injury and bleeding, prolonged cannulation times, and heightened procedural stress for the entire resuscitation team. Early vascular access before complete hemodynamic collapse may therefore improve both procedural success and overall ECPR performance.

Postextracorporeal Membrane Oxygenation Management

The 1st h after ECPR is used to stabilize the patient and the circuit, identify the cause of the arrest, and prevent early complications. An arterial line in the right upper limb best reflects native cerebral oxygenation and helps detect differential hypoxemia, while mean arterial pressure is held between 60 and 80 mmHg to balance organ perfusion against left ventricular distension.^[49] A pump flow of roughly 3.0–3.6 L/min is typical, and lactate clearance with central venous oxygen saturation confirms that support is adequate.^[74,75]

When the left ventricle distends and pulmonary edema appears, inotropic support, higher positive end-expiratory pressure, and, if necessary, a venting device such as an Impella are used to unload it.^[75] Neuroprotection rests on avoiding hyperoxia by keeping arterial oxygen saturation at 92%–97%, titrating sweep gas to avoid hypocarbia, and controlling temperature at 33°C–36°C for 24 h through the ECMO heat exchanger.^[49] The ideal target is unsettled, since the Targeted Temperature Management 2 (TTM2) trial showed no mortality difference between hypothermia and normothermia after cardiac arrest.^[76]

Identifying the cause is equally urgent: a 12-lead electrocardiogram is obtained at once, emergent coronary angiography is pursued when no clear noncardiac cause is evident, and whole-body computed tomography with bedside ultrasound screens for both the cause and complications such as pneumothorax or occult hemorrhage, the latter sometimes signaled by falling

circuit flow.^[49] Because femoral cannulation threatens the distal limb, an antegrade perfusion cannula is sited early, and leg perfusion is followed with near-infrared spectroscopy (NIRS).^[75] The main early management targets are summarized in Table 2.^[49,74,75]

Outcomes are better at higher-volume centers, so patients should be moved early to an experienced ECMO unit.^[77] After infarction-related arrest, Sugiura *et al.* found that incomplete reperfusion, a mean arterial pressure below about 63.5 mmHg at 4 h, a lactate above about 3.55 mmol/L at 24 h, and no recovery of ejection fraction by 24 h predict failure to wean and warrant early consideration of a ventricular assist device.^[78]

Prehospital and In-hospital Implementation Challenges

ECPR is one of the most resource-intensive and logistically demanding interventions in modern emergency medicine and, consequently, cannot be implemented universally. Unlike elective ECMO, there is rarely sufficient time for meticulous preparation before cannulation. Therefore, ECPR programs require compact, lightweight, and easily transportable ECMO systems, together with circuits that can be assembled and primed rapidly. These characteristics are particularly important because ECPR is frequently performed under challenging conditions, both within the ED and, especially, in the prehospital environment, where workspace is often limited.

Recent technological advances have substantially improved the feasibility of ECPR. Modern ECMO systems have become increasingly compact, lightweight, and portable, facilitating both in-hospital and prehospital deployment. Concurrently, ECMO circuits have become more standardized, easier to prime, and equipped with integrated sensors that enable continuous monitoring of circuit performance. In addition, the introduction of automated priming systems has further simplified circuit preparation and

reduced one of the major logistical barriers to timely ECPR initiation.^[79]

Another major challenge is resource allocation and equipment logistics, both of which require strong institutional and administrative support. Given that ECMO consoles, disposable circuits, and associated consumables remain limited resources in most healthcare systems, careful planning is required to determine the optimal number and strategic placement of devices to ensure timely availability when needed.^[80]

Ensuring the continuous availability of an experienced ECMO team represents perhaps the greatest challenge to the long-term sustainability of an ED ECMO program. One of the principal operational dilemmas is whether team members should remain in-house around the clock or be available through an on-call system. Because ECPR cases occur unpredictably and are relatively infrequent during the early stages of program development, most institutions rely on on-call activation. However, mobilizing the team may require 20-30 min before arrival at the hospital, a delay that may be incompatible with the time-sensitive nature of ECPR. Conversely, maintaining a fully staffed in-house ECMO team is rarely feasible because of substantial personnel and financial constraints. Furthermore, the combination of frequent activations, high emotional stress, and the inherently poor prognosis of many ECPR patients may contribute significantly to staff fatigue and burnout.^[80,81]

Successful ECPR also requires seamless coordination both within and between institutions. Effective collaboration among EMSs, resuscitation teams, emergency physicians, cardiologists, cardiovascular surgeons, perfusionists, and intensive care specialists is essential, with clearly defined responsibilities and shared operational priorities. Establishing a standardized “ECMO activation” or “Code ECMO” system capable of simultaneously notifying all relevant personnel may substantially improve team synchronization and reduce activation delays.

Table 2: Early postextracorporeal cardiopulmonary resuscitation management targets (first hours after cannulation)

Parameter	Target/strategy	Rationale
Arterial line site	Right upper limb (radial/brachial)	Reflects native cerebral oxygenation; detects differential hypoxemia (harlequin)
Mean arterial pressure	≥60 and <80 mmHg	Organ perfusion while limiting LV distension
ECMO blood flow	~3.0–3.6 L/min (CI>2.0 L/min/m ²)	Adequate perfusion while allowing native ejection
Arterial O ₂ saturation	92%–97%	Avoid hyperoxic reperfusion injury
PaCO ₂	Gradual normalization to ~40 mmHg	Avoid neurologic injury from rapid CO ₂ shifts
Temperature (TTM)	33°C–36°C×24 h, then rewarm (36°C if bleeding)	Neuroprotection (optimal physiological targets during ECPR have not yet been established; see text)
LV distension	Echo for aortic regurgitation/ pulmonary edema → PEEP±venting	Prevent pulmonary edema and irreversible cardiac injury

LV: Left ventricle, ECMO: Extracorporeal membrane oxygenation, CI: Cardiac index, TTM: Targeted temperature management, ECPR: Extracorporeal cardiopulmonary resuscitation, PEEP: Positive end-expiratory pressure, PaCO₂: Partial pressure of carbon dioxide in arterial blood, CO₂: Carbondioxide

Ultimately, time remains the most critical resource in ECPR. From activation of the ECPR team and initiation of mechanical chest compressions to successful cannulation and establishment of extracorporeal blood flow, only a narrow therapeutic window, approximately 30 min, exists to maximize the likelihood of neurologically intact survival. Achieving this goal requires immediate equipment availability, preprimed ECMO circuits, well-defined workflows, and highly trained team members who are familiar with their individual roles and responsibilities.^[81]

Finally, successful implementation of ED ECMO extends beyond rapid cannulation. Programs must also be prepared to prevent and manage complications such as limb ischemia, vascular injury, and major bleeding. Equally important are the establishment of dedicated ECMO teams and backup personnel, clearly defined clinical protocols, continuous education, high-fidelity simulation training, and structured multidisciplinary debriefing following every ECPR case, regardless of clinical outcome. Together, these elements form the foundation of a sustainable, high-quality ED ECMO program.

Complications

Although peripheral VA ECMO rapidly restores systemic perfusion, it may also produce several important physiological complications that require early recognition and prompt management. The three principal complications include distal limb ischemia, left ventricular distension, and differential hypoxemia.

Distal limb ischemia may occur because of femoral artery occlusion by the arterial cannula, particularly in patients with small-caliber or severely atherosclerotic vessels. To maintain distal limb perfusion, an 8–9-Fr distal perfusion catheter (DPC) should be inserted antegradely into the superficial femoral artery and connected to the side port of the arterial ECMO cannula, providing a minimum flow of approximately 100 mL/min.^[42] Although distal limb ischemia may ultimately result in limb loss, the initial priority during ECPR should remain restoration and stabilization of systemic circulation. Placement of the DPC may therefore be deferred until extracorporeal support has been successfully established. Continuous monitoring of lower-extremity perfusion using NIRS on both calves is recommended.

As it poses a retrograde blood flow to the aortic root, peripheral VA ECMO increases left ventricular afterload through retrograde aortic blood flow, potentially resulting in left ventricular distension. This complication is particularly common in patients with severely impaired left ventricular contractility or significant

aortic regurgitation, where the left ventricle is unable to overcome the elevated afterload, leading to pulmonary edema and ventricular distension. A pulmonary artery diastolic pressure exceeding 30 mmHg should prompt consideration of immediate left ventricular unloading. Available decompression strategies include atrial septostomy, surgical venting, or percutaneous mechanical unloading using devices such as the Impella.

Finally, differential hypoxemia (also known as Harlequin syndrome or North–South syndrome) represents a unique complication of peripheral VA ECMO. Initially, retrograde ECMO flow supplies oxygenated blood to the ascending aorta and coronary circulation. As myocardial function recovers, however, inadequately oxygenated blood returning from poorly functioning lungs is ejected from the left ventricle into the proximal aorta, where it mixes with retrograde ECMO flow. Consequently, the coronary arteries, brain, and right upper extremity may receive relatively deoxygenated blood, whereas the lower body remains well oxygenated. To facilitate early recognition, arterial pressure monitoring and blood gas sampling should always be performed from the right radial artery. Initial management includes optimization of mechanical ventilation to improve pulmonary oxygenation and increase the oxygen content of blood ejected from the left ventricle. In refractory cases, insertion of an additional cannula into the right internal jugular vein to convert the circuit to a veno-arterial-venous (VAV) ECMO configuration should be considered.

Future Perspectives/Directions

The future of ED ECMO lies not in being regarded as a heroic rescue intervention, but rather as a systems-based resuscitation strategy. Such a system should be designed to minimize every avoidable delay from the moment of cardiac arrest until the patient is successfully established on extracorporeal support, while delivering progressively higher-quality care throughout the entire continuum, from the initial collapse to definitive intensive care management.

Current ELSO quality metrics primarily focus on patient-centered outcomes, including survival, bleeding complications, and limb ischemia. While these indicators remain essential, we believe they do not fully capture the performance of an ED ECMO program. Future quality assessment should increasingly incorporate operational performance metrics that reflect the efficiency, responsiveness, and reliability of the entire resuscitation system. These metrics may include dispatch-to-arrival time, recognition-to-activation time, door-to-ECMO time, decision-to-cannulation time, cannulation time, ECMO team response time, equipment readiness, and

false activation rate. Expanding quality assessment beyond traditional ECMO-related outcomes would enable comprehensive evaluation of the entire operational pathway rather than the procedure alone. Such a systems-oriented approach would facilitate continuous quality improvement, identify process bottlenecks, enhance team performance, and ultimately improve both the accessibility and effectiveness of ED ECMO programs.

Although no universally accepted ECPR activation algorithm currently exists, most published algorithms are based on a “one-size-fits-all” approach. In our opinion, however, the fundamental principle of successful resuscitation lies in recognizing that no single algorithm can adequately account for the substantial physiological heterogeneity among patients. Consequently, patient selection and ECPR activation should progressively evolve toward a more individualized and precision-based approach, tailored to each patient’s unique clinical and physiological characteristics. With the integration of artificial intelligence, future ED ECMO programs may evolve into digital twin-enabled systems that continuously mirror the entire ED ECMO ecosystem. By integrating real-time patient, EMS, hospital, logistical, and operational data, these systems could support clinical decision-making, optimize workflow, predict system performance, and drive continuous quality improvement across the entire extracorporeal resuscitation pathway.

Finally, deeper integration of artificial intelligence into ECMO platforms has the potential to substantially improve patient management during extracorporeal support. By incorporating advanced machine learning and deep learning algorithms, future ECMO systems may evolve from passive life-support devices into intelligent clinical support platforms capable of continuously analyzing physiological data, predicting adverse events, and assisting clinicians in real-time decision-making. Rather than merely detecting abnormalities, these systems could provide evidence-informed recommendations for troubleshooting technical or physiological complications, thereby enhancing patient safety, reducing cognitive workload, and supporting more timely and effective clinical interventions.

Our Institutional Perspective and Experience

The following section reflects the authors’ institutional experience and should be interpreted as expert opinion rather than evidence-based recommendations. Prospective validation of several workflow components is currently ongoing. To the best of our knowledge, our institution is currently the first and only ED ECMO-capable tertiary care center in Türkiye. Over the past several years, we have focused not only on

establishing an ED ECMO service but also on developing an integrated systems-based model that encompasses prehospital triage, operational governance, dedicated team training, simulation-based education, and continuous quality improvement.

In addition to the workflow modifications described above, which were designed to reduce human error and prevent avoidable delays during the ED ECMO pathway, another important consideration is the use of third-generation ECMO devices that can be primed rapidly and easily. When available, such systems allow priming to be completed almost simultaneously with cannulation, thereby reducing time to extracorporeal flow.

Perfusionists are vital parts of the ECMO team; however, in a perfusionist-free ED ECMO model such as ours, if third-generation devices are not available and earlier-generation systems requiring longer priming times are used, keeping one ECMO circuit preprimed and immediately ready for use may be a practical strategy. This approach allows the entire team to focus primarily on cannulation, minimizing cognitive load and procedural delays during this time-critical intervention. Importantly, the ELSO states that preprimed ECMO circuits can be safely stored for up to 30 days, supporting the feasibility of maintaining a readily available circuit for time-critical ED ECMO programs.^[36]

Implementation Models for Türkiye

Türkiye possesses several unique advantages for the successful implementation of regional ED ECMO networks, including a well-developed EMS infrastructure, centralized dispatch coordination, and geographically distributed tertiary care hospitals. Rather than increasing the number of isolated ECMO centers, future efforts should focus on establishing integrated regional networks supported by standardized protocols, dedicated training programs, continuous quality assessment, and digital decision support systems. Such a systems-based implementation strategy has the potential to improve both the accessibility and quality of extracorporeal resuscitation across the country.

When the randomized controlled trials on ECPR are examined, reported arrest-to-ECMO times are generally approximately 1 h or longer.^[82] Although these data have not yet been published, our local experience in the city center of Aydın suggests that the median time interval for OHCA patients is approximately 38 min. Based on this observation, ECPR systems may theoretically function more effectively in smaller cities or in large metropolitan areas that are operationally divided into smaller, geographically defined catchment zones. Such

an approach could shorten transport intervals, improve team readiness, and reduce the total low-flow duration before ECMO initiation. Although ED ECMO systems developed in smaller cities may not fully address the logistical challenges encountered in large metropolitan areas, they can serve as valuable implementation models for larger-scale programs. The experience, operational knowledge, and outcome data generated from these systems may provide important insights for the design, optimization, and successful implementation of more complex regional ED ECMO networks.

Nevertheless, further scientific evidence is required to validate this hypothesis and determine the optimal geographic and operational scale for ECPR system design.

Conclusions

ECMO in emergency medicine bridges the gap between conventional resuscitation and definitive critical care. With growing institutional capacity and technological innovation, its role in Türkiye continues to expand. A national framework for ECMO utilization, training, and data collection could further enhance patient outcomes and promote equitable access.

ED ECMO is an emerging, high-impact resuscitative modality that can significantly improve outcomes in carefully selected patients. With optimized workflows and technological advances, ED ECMO is expected to become a cornerstone of advanced emergency medicine practice. Successful implementation of ED ECMO requires seamless integration with intensive care units, vascular surgery services, and cardiac catheterization laboratories to ensure coordinated multidisciplinary management throughout the entire continuum of care.

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Author contributions statement

Concept: YEÖ. Design: YEÖ and AMS. Literature Search: All authors. Writing – Original Draft: AMS, MS, and AK. Writing – Review and Editing: All authors. Supervision: YEÖ and MS.

Conflicts of interest

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