

REVIEW

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Prehospital extracorporeal cardiopulmonary resuscitation: global trends and the Turkish perspective

Fatih Denizli^{1*} , Zühal Kınış² and Etem Hizaler³

Abstract

Extracorporeal cardiopulmonary resuscitation (ECPR) is an advanced intervention used in refractory cardiac arrest to maintain circulation and prevent neurological injury. By diverting blood through an external oxygenator and returning it to the arterial system, ECPR provides higher cardiac output and organ perfusion than conventional CPR, thereby reducing the risks associated with prolonged low-flow states. Recent research has increasingly focused on the feasibility of initiating ECPR in prehospital environments—such as ambulances or mobile intensive care units—to minimize time to cannulation and improve survival with favorable neurological outcomes. International studies suggest that, when applied to appropriately selected patients, prehospital ECPR can reduce low-flow duration and enhance both survival and neurological recovery. However, high costs, specialized training requirements, and operational challenges currently limit its implementation to select systems with established protocols. While in-hospital ECMO use has been reported in Turkey, no published data exist regarding prehospital ECPR applications. This review examines the effectiveness, feasibility, and operational challenges of prehospital ECPR based on current literature and case experiences, and evaluates its potential within the Turkish healthcare system. Based on the reviewed literature and contextual analysis, a centralized Hub-and-Spoke model supported by a Targeted-Dispatch approach may represent a feasible strategy for resource-limited settings such as Turkey, prioritizing refractory VF/VT patients and aiming for cannulation within the critical 60-minute low-flow window. Although promising for the future of advanced prehospital resuscitation, ECPR requires meticulous planning, robust training programs, and strong interprofessional coordination. This review proposes an evidence-based Implementation Science framework tailored to national conditions to support structured and sustainable integration of ECPR into Turkish Emergency Medical Services.

Keywords Extracorporeal cardiopulmonary resuscitation, Prehospital ECPR, Extracorporeal membrane oxygenation, Out-of-hospital cardiac arrest, Prehospital emergency

*Correspondence:

Fatih Denizli
fatihdenizli0000@gmail.com

¹Ministry of Health, Kayseri, Türkiye

²Faculty of Medicine, Department of Anesthesia and Reanimation, Erciyes University, Kayseri, Türkiye

³Department of First Aid and Emergency Care, Kayseri University, Kayseri, Türkiye

Introduction

Extracorporeal cardiopulmonary resuscitation (ECPR) is an advanced life support technique that uses venoarterial extracorporeal membrane oxygenation (VA-ECMO) to provide temporary circulatory and respiratory support in patients with refractory cardiac arrest when spontaneous circulation cannot be restored through conventional resuscitation. In this procedure, the patient's blood is withdrawn from the venous system, oxygenated via a membrane oxygenator, and then pumped back into the arterial system. This process enhances cardiac output and oxygenation, thereby shortening the duration of critical organ hypoxia. While high-quality basic life support (chest compressions) provides only a limited portion of cardiac output (approximately 0.6 L/min), ECPR increases blood flow to vital organs (up to 2.0 L/min), aiming to prevent ischemic injury to essential organs such as the brain and heart [1, 2]. ECPR is typically performed in hospital emergency departments or intensive care units; however, in recent years, the feasibility of implementing this technique in prehospital settings, such as ambulances or mobile medical units, has also been investigated. The main objective of this approach is to improve survival rates and minimize potential neurological damage by reducing the time interval between cardiac arrest and the initiation of ECPR [1, 3, 4]. The literature indicates that a shorter duration between cardiac arrest and ECPR initiation has a direct effect on neurological outcomes and that initiating ECPR as early as possible after arrest—preferably within 60 min—significantly increases the likelihood of recovery [5, 6].

Randomized controlled trials have demonstrated that early in-hospital ECPR may offer a survival advantage over conventional CPR (e.g., the ARREST trial) [7]. In the ARREST trial, the survival rate in the early ECPR group was significantly greater than that in the conventional CPR group. In contrast, the INCEPTION trial conducted in the Netherlands and the PRAGUE OHCA trial conducted in the Czech Republic reported that this advantage was not observed in patients with prolonged low-flow durations (the period without effective circulation following cardiac arrest). On the basis of these findings, the current consensus suggests that ECPR provides meaningful benefit only in carefully selected cases [2]. On the other hand, owing to its high cost and the need for specialized expertise, its widespread implementation remains limited [8]. Purington et al. [9] emphasized that ECPR is a resource-intensive intervention that can be performed only in centers with established expertise in extracorporeal membrane oxygenation (ECMO) and that only 2–10% of out-of-hospital cardiac arrest (OHCA) patients are potential candidates. These findings indicate that, at present, prehospital ECPR is feasible only for

a limited group of patients who meet specific selection criteria.

In Turkey, the TROHCA (Out-of-Hospital Cardiac Arrest in Turkey) study conducted by Şener et al. [10] ($n=1003$) reported that only 4.4% of OHCA patients who reached the hospital were discharged alive, whereas only 2.7% achieved a favorable neurological outcome. These rates are below the global average and highlight deficiencies in the conventional chain of survival, such as the low rate of bystander CPR. In Turkey, the Ministry of Health's 2021 ECMO device guidelines specifically define extracorporeal cardiopulmonary resuscitation (ECPR) and recommend that ECMO preparations be initiated within 10 min if spontaneous circulation cannot be achieved with standard CPR [11]. ECPR has not yet been widely implemented in Turkey, and the literature on the subject remains limited. Current studies have focused primarily on in-hospital ECPR applications. For example, in a case report by Yeşil et al. [12], an in-hospital pediatric ECPR procedure was described, where the patient successfully recovered without any neurological sequelae following three days of ECMO support. In a series conducted at Koşuyolu High Specialty Training and Research Hospital, the rate of neurologically intact survival after VA-ECMO was reported to be 36.4% for 22 in-hospital cardiac arrest patients [13]. Similarly, a study carried out by Başkent University between 2012 and 2015 revealed that only 30.4% of 46 patients who underwent VA-ECMO for cardiac causes were successfully weaned from ECMO. Moreover, an announcement by Karadeniz Technical University Farabi Hospital revealed that only a limited number of centers in Turkey are registered with the Extracorporeal Life Support Organization (ELSO), indicating that the national ECMO/ECPR capacity remains quite restricted [14]. In line with these findings, Bekgöz et al. [15] highlighted the lack of specialized teams capable of performing ECMO transport in Turkey and noted that prehospital emergency medical personnel have not yet been trained in this area. Overall, these findings suggest that ECPR practices in Turkey are still in an early developmental stage, with prehospital ECPR not yet implemented and currently discussed only at a theoretical or research level.

The aim of this study is to review the national and international literature on prehospital ECPR applications and to present the current state of knowledge. This study was designed as a narrative review rather than a formal systematic review or meta-analysis. A structured literature search was conducted through major databases including Web of Science (WoS), Google Scholar, Scopus, PubMed, and TR Dizin between 2015 and 2025, together with official reports from relevant public health institutions and professional organizations. However, the study did not follow a predefined PRISMA protocol or perform a

formal quantitative risk-of-bias assessment. The included literature was selected according to clinical relevance, recency, methodological contribution, and applicability to prehospital ECPR practice. Priority was given to randomized controlled trials, systematic reviews, observational cohort studies, ELSO guidelines, and official institutional reports related to extracorporeal cardiopulmonary resuscitation. In this context, patient selection criteria, implementation models, training processes, logistical challenges, and ethical considerations were comprehensively analyzed. By addressing these dimensions within an integrated framework, this study aims to contribute to the development of strategies, policies, and recommendations for the potential implementation of prehospital ECPR in Turkey. In addition, the manuscript distinguishes between evidence synthesized from the literature and the authors' context-specific implementation proposals regarding the Turkish healthcare system. Therefore, sections discussing the Consolidated Framework for Implementation Research (CFIR)-based, Targeted-Dispatch strategy, and pilot-model recommendations should be interpreted as expert-informed implementation perspectives derived from the current literature rather than as empirically validated clinical models.

Current evidence on extracorporeal cardiopulmonary resuscitation

The primary goal of ECPR is to ensure adequate organ perfusion and thereby prevent ischemic injury. Although conventional CPR can provide circulation, a prolonged low-flow duration increases the risk of irreversible damage to vital organs such as the brain and heart. Studies have demonstrated that for every 10-minute delay between cardiac arrest and the initiation of ECPR, the

likelihood of favorable neurological recovery decreases significantly. Therefore, establishing circulatory support rapidly through interventions such as ECPR is crucial [4, 16, 17]. Clinical studies have shown that in-hospital ECPR performed for cardiac arrest is associated with improved survival, whereas prehospital ECPR has not demonstrated similarly favorable outcomes [16]. In the ARREST trial, hospital discharge rates were 43% in the early ECPR group ($n=14$) compared with only 7% in the conventional CPR group ($n=15$) [7]. Conversely, the PRAGUE-OHCA and INCEPTION trials reported no significant differences between groups. These results may be attributable to the longer average times to ECPR initiation in these studies (approximately 61–74 min). A comparison of the key findings from major randomized controlled trials (ARREST, PRAGUE-OHCA, and INCEPTION) is presented in Table 1.

These studies emphasize that initiating ECPR within an average of less than 60 min is quite important [2]. While a sub-60-minute low-flow duration is widely accepted as a critical benchmark, this threshold should not be interpreted as an absolute cutoff. Evidence suggests that favorable neurological outcomes may still be achieved in selected patients with longer low-flow durations, particularly when high-quality CPR is maintained and appropriate patient selection criteria are met. Therefore, the success of ECPR should be considered as a function of both timing and resuscitation quality, rather than time alone. Although the benefits of ECPR in in-hospital settings have been well established, the number of registered centers worldwide remains limited. For example, in 2022, a total of 14,509 ECPR cases were reported across 557 registered ECMO centers globally [18]. The majority of these cases involved in-hospital applications, whereas prehospital cases were relatively rare. The reported survival rates for these patients are approximately 30%. However, given that these outcomes are based on relatively small case series, further prospective studies are needed to strengthen the evidence base [1, 2]. Purington et al. [9] demonstrated that ECPR is a highly resource-intensive intervention that is feasible only in hospitals with specialized ECMO expertise and that only approximately 2–10% of out-of-hospital cardiac arrest cases may be eligible for ECPR. Accordingly, the current evidence suggests that ECPR can be effective in carefully selected cases when performed under well-structured protocols, but its widespread application across broader patient populations remains challenging at this stage [2].

Prehospital extracorporeal cardiopulmonary resuscitation applications

The primary objective of prehospital ECPR is to minimize the low-flow interval. In the conventional approach, CPR is initiated at the scene, and the patient is then

Table 1 Comparison of prehospital ECPR randomized controlled trials

Feature	ARREST	PRAGUE OCHA	INCEPTION
Location	USA (Minneapolis)	Czech Republic (Prague)	Netherlands
Design	Single-center, randomized	Single-center, randomized	Multicenter, randomized
Number of Patients	30	264	34
Average Low Flow Duration	59 min	58 min	74 min
Significant Difference	Yes	No (However, long-term survival was important)	No
Basic Conclusion	ECPR improves survival in selected patients.	An ECPR-based approach may increase long-term survival.	A long low-current period reduces success.

Source: Created by the author

transported to the hospital, during which time circulation may be interrupted for several minutes. In contrast, prehospital ECPR aims for field teams to reach the scene as quickly as possible and establish ECMO support either directly on-site or within a mobile intensive care unit. Accordingly, ECPR initiation is undertaken in parallel with basic life support measures such as chest compressions and airway management [1]. Studies have reported favorable neurological outcomes in approximately 20–25% of patients who underwent prehospital ECPR [2]. For example, Leroux et al. [16] reported no significant differences in survival rates between prehospital and in-hospital ECPR; however, the low-flow duration was observed to be 30 min shorter in prehospital cases. Similarly, Bougouin et al. [19] reported a 20% hospital discharge rate in prehospital ECPR cases. In the study by Walter et al. [20], survival with good neurological outcomes was achieved in 24.6% of 69 prehospital ECPR patients. Hutin et al. [21] reported a survival rate of 15% with favorable neurological outcomes in prehospital ECPR cases, although the average low-flow duration exceeded 110 min despite the use of helicopter transport. These findings indicate that prehospital ECPR is feasible in specialized centers with the necessary resources and demonstrates meaningful survival potential. However, in Turkey, no prehospital ECPR cases have been reported in the literature to date, with existing evidence limited to only in-hospital case reports. Overall, the current data suggest that the success of prehospital ECPR is closely linked to rapid logistics, appropriate patient selection, and the provision of high-quality CPR. Figure 1 illustrates the stages of the prehospital ECPR process and the steps involved in transferring patients from the scene to an ECPR-capable center.

As illustrated in Fig. 1, the prehospital ECPR process consists of several sequential steps: early intervention initiated with the receipt of the emergency call (112), dispatch of the ambulance and ECPR team to the scene, precannulation assessment and stabilization onsite, followed by the initiation of prehospital ECPR cannulation and restoration of circulation through ECMO. After

these steps, ECPR optimization is performed, and the patient is subsequently transferred to an ECPR-capable center under the principles of intensive care transport medicine.

Extracorporeal cardiopulmonary resuscitation cannulation and access techniques

ECMO can be performed via central or peripheral access. Central access requires an invasive surgical procedure involving sternotomy to open the thoracic cavity and place catheters into the right atrium and the aorta. Owing to the high risk of complications and substantial resource demands, central access is currently not considered feasible in prehospital settings. On the other hand, peripheral cannulation can be performed via the percutaneous Seldinger technique, the open cut-down Seldinger (semi-Seldinger) approach, or the open cut-down method with an end-to-side arterial graft. In this technique, the femoral artery and femoral vein—or alternatively, the internal jugular vein—are typically chosen as access sites [22, 23]. Although evidence comparing different cannulation techniques in the prehospital setting remains limited, recent studies support the use of both the Seldinger and semi-Seldinger methods—either with or without ultrasound guidance—in prehospital ECPR protocols. Selecting the appropriate cannulation technique is critically important for the success of ECPR. In prehospital environments, establishing access via peripheral vessels via the Seldinger or semi-Seldinger technique offers advantages by shortening the intervention time and reducing complications [24–26].

International application examples

Prehospital ECPR is a recently emerging field and is currently being implemented in a limited number of centers worldwide. Some of these centers are as follows:

France (Paris)

ECPR was first successfully implemented in France in 2011 within mobile intensive care units (MICUs) in Paris and has since been adopted in several other cities [27,

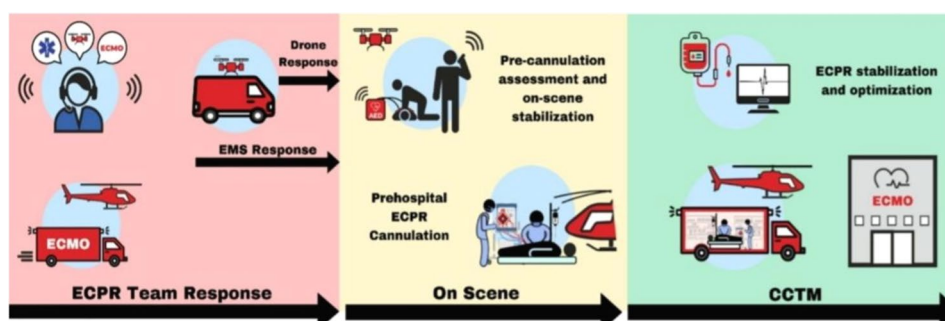


Fig. 1 Prehospital ECPR process: onsite stabilization and intensive care transport timeline to the ECPR center. Source: [9]

28]. In this system, the ECPR team operates on a 24/7 basis and typically consists of an anesthesiologist or critical care/emergency medicine physician, an anesthesia nurse, and a paramedic [1]. The team is dispatched to witnessed cardiac arrest cases in parallel with the mobile intensive care vehicle and aims to establish ECMO support within 60 min of the incident. In the first reported case in Paris, Lebreton et al. [27] described an ECPR performed on a marathon runner, where approximately 60 min after the emergency call, ECPR support providing a flow of 4.5 L/min to the arterial circulation was initiated. Within 48 h, mechanical ventilation was reduced or discontinued, and other organ functions began to recover. The Paris experience demonstrates that the integration of ECPR with high-quality basic life support—particularly chest compressions and airway management—by mobile teams is crucial for optimal outcome

Albuquerque (USA)

In 2019, a prehospital ECPR program capable of initiating ECMO in the field was developed through a collaboration between the University of New Mexico and the local fire department. The team operates in a specially equipped ambulance designed to facilitate onsite ECMO implementation and consists of an intensivist trained in ECPR procedures and two paramedics. This unit primarily responds to witnessed cardiac arrest cases in which the estimated transport time to the hospital exceeds 35 minutes, allowing ECMO initiation at the scene [26].

Netherlands

All air ambulance units in the Netherlands are equipped with ECPR capabilities. In witnessed cardiac arrest cases, police, fire, and ambulance teams arrive at the scene to initiate high-quality CPR. If the case meets the ECPR eligibility criteria, the helicopter team is dispatched to the scene to commence ECPR, after which the patient is transported to a medical facility by ground ambulance [2].

Regensburg (Germany)

The model implemented in Germany differs slightly from those used in other countries. In out-of-hospital cardiac arrest (OHCA) cases, both the ambulance crew and the ECPR team are dispatched simultaneously to the patient, ensuring the provision of high-quality CPR from the outset. The ECPR team then evaluated the patient's eligibility for the procedure on the basis of specific criteria. Exclusion factors include trauma, terminal illness, and unwitnessed cardiac arrest, whereas ECPR is initiated when parameters such as a total CPR duration of less than 60 minutes are met [20]. As illustrated by these international examples, prehospital ECPR programs are typically multidisciplinary in structure and involve collaboration

among physicians, nurses, and paramedics working in coordination with mobile intensive care units. In Turkey, however, no prehospital ECPR program has yet been initiated; current evidence suggests that international experiences could serve as valuable models for potential implementation.

Team structure and training

To enable the implementation of prehospital ECPR, teams must receive advanced, specialized training. International ECPR teams typically include at least one physician, one nurse, one paramedic, and an intensive care specialist. In addition to standard CPR competencies, these teams are required to undergo comprehensive training in onsite ECPR cannulation, ECMO system setup, and device management. For example, in Australia, a comprehensive training program was developed for a group comprising 11 physicians and 6 critical care paramedics. Although the participants initially had no prior ECMO experience, they were trained through a multiphase educational approach that included animal models, cadaver-based cannulation practices, simulation exercises, and theoretical instructions. As a result, all participants successfully achieved the established learning objectives and demonstrated competence in initiating ECMO in prehospital settings. This example highlights that both paramedics and physicians can be effectively trained to function as members of ECPR teams. The training methods commonly employed for this purpose include the following [29]:

- Animal models: These models provide hands-on practice in performing cannulation and managing hemodynamic complications under time-constrained conditions.
- Cadaver cannulation: This enables trainees to practice femoral cannulation techniques directly on human tissue.
- Simulation: Case-based scenarios are used to enhance team coordination and crisis management skills.
- Examinations and assessments: Written and practical evaluations are conducted to measure learning progress and competency.

Accordingly, internationally recognized certified training standards have been established. For example, the Extracorporeal Life Support Organization (ELSO) guidelines recommend that ECPR teams possess expertise in the ECMO system setup, maintenance, and complication management. In line with these recommendations, it is emphasized that physicians and paramedics involved in ECPR should complete both basic and advanced levels of ECMO training through certified programs [29].

Table 2 ELSO Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
• Being under 70 years of age • Cardiac arrest being witnessed	Presence of advanced or life-limiting illnesses (e.g., end-stage heart, kidney, or liver failure; advanced COPD; terminal malignancy)
• No-flow duration < 5 min (from arrest to initiation of CPR) • Low-flow duration < 60 min (from arrest to establishment of ECMO flow)	Incompatibility with the patient's goals of care
• Initial rhythm being VF/VT/PEA • ETCO₂ > 10 mmHg (≈ 1.3 kPa) • Presence of intermittent ROSC or recurrent VF • Presence of signs of life during resuscitation	Moderate to severe aortic valve insufficiency (cases beyond mild are excluded)

Source: [18, 32]

Table 3 Inclusion and exclusion criteria for Sub30

Inclusion Criteria	Exclusion Criteria
High likelihood of cardiac-origin cardiac arrest.	Being under 18 or over 65 years of age.
The event being witnessed (bystander-observed OHCA).	Known or obvious advanced pregnancy (conditions that may require resuscitative hysterectomy).
Initiation of chest compressions by bystanders within the first 3 min.	Absence of signs of life (no physical movement or respiration) and the presence of findings suggesting inadequate chest compressions: • No electrical activity after 20 min, • ETCO₂ level below 1.3 kPa (< 10 mmHg).
Persistence of cardiac arrest at 20 min after the emergency call, or inability to maintain spontaneous circulation (ROSC) achieved in the prehospital setting.	Cases in which ECMO is not expected to provide clinically meaningful benefit (e.g., advanced malignancy, severe frailty).

Source: [24]

In Turkey, however, no formal ECMO transport teams or prehospital ECPR training programs have yet been established. Therefore, to initiate prehospital ECPR practices in the country, not only clinical preparedness but also comprehensive national-level planning, legal regulations, the development of standardized protocols, and the implementation of structured training programs for qualified teams are essential.

Patient selection criteria

In prehospital ECPR, patient selection is conducted with great precision and caution. According to widely accepted criteria, eligible patients should have experienced witnessed cardiac arrest, receive immediate CPR at the scene, have a low-flow duration typically less than 60 min, and present with a shockable initial rhythm (preferably VF/VT). In addition, patients with terminal illnesses, traumatic cardiac arrest, advanced age, or

severe comorbidities are generally excluded. For example, in France and the Netherlands, protocols set the upper age limit between 65 and 70 years and emphasize initiating CPR within five minutes of collapse. Although Turkey does not yet have a national hospital or prehospital ECPR protocol, both the ELSO guidelines and initiatives such as the United Kingdom's "Sub30" project recommend similarly strict inclusion criteria [1, 30, 31]. The inclusion criteria for ECPR recommended in the 2021 ELSO guidelines are presented in Table 2.

The Sub30 study is a UK-based ongoing research project on the implementation of prehospital ECPR. The inclusion and exclusion criteria proposed in the study are presented in Table 3.

When the ELSO and Sub30 study criteria are compared, the upper age limit defined in the Sub30 study is lower, and the time interval until CPR initiation at the scene is shorter. Additionally, the Sub30 study does not include an initial cardiac rhythm criterion. Considering these criteria and the limitations of available resources, the focus is placed on patients who are most likely to benefit [2, 20]. Expanding these criteria could increase the number of individuals who survive; however, it may negatively affect the rates of favorable neurological outcomes. Therefore, ECMO application criteria should be continuously evaluated in light of evolving techniques.

Proposed implementation strategy for prehospital ECPR in Turkey

Based on the evidence synthesized in the preceding narrative review, the following section presents an evidence-informed pilot implementation strategy for prehospital ECPR in Turkey. Rather than representing a validated clinical protocol, this framework is intended to guide future pilot implementation, feasibility studies, and policy development within the Turkish emergency medical system.

The transition of prehospital ECPR from a research concept to a reliable operational practice in Turkey requires a systematic and evidence-based approach that can effectively manage organizational complexity and sustain clinical fidelity. To achieve this, we propose utilizing an Implementation Science framework—particularly the Consolidated Framework for Implementation Research (CFIR)—to guide the planning, execution, and evaluation of the pilot phase. ECPR is inherently a complex intervention, where maintaining fidelity—consistent adherence to key procedural steps such as timely cannulation and uninterrupted high-quality CPR—is fundamental to success. Therefore, simplification and contextual adaptation are crucial. The intervention should be integrated into the existing 112 EMS system rather than establishing a completely new infrastructure. For example, the exclusive adoption of peripheral

Seldinger or semi-Seldinger techniques can improve procedural speed and reduce complications.

Within the Turkish context, Outer Setting barriers include weaknesses in the conventional chain of survival—particularly low bystander CPR rates, which contribute to poor out-of-hospital cardiac arrest (OHCA) survival outcomes (2.7% favorable results). Although bystander CPR remains one of the most important determinants of survival after OHCA, its reported rate in Turkey is considerably lower than that in many developed EMS systems. Published national studies indicate

Table 4 Proposed implementation outcomes for the Turkish prehospital ECPR pilot program

Outcome Domain	Definition	Metric (Example)	Alignment with Turkish Contextual Challenges
Feasibility	Extent to which ECPR can be carried out successfully within existing EMS infrastructure and resource limitations.	Proportion of eligible patients receiving ECPR within the 60-minute low-flow threshold. Rate of successful cannulation on the first attempt.	Directly assesses logistics and mobilization capabilities, given the necessity for rapid response in dense urban areas.
Acceptability	Degree to which stakeholders (EMS staff, hospital staff, public) view ECPR intervention and protocols as appropriate and sustainable.	Survey scores (e.g., Likert scale) on team satisfaction, perceived utility, and burnout rates among ECPR personnel.	Measures the sustainability of the human capital investment in a restricted capacity environment.
Fidelity	Degree to which the complex ECPR protocol is implemented as designed in the field setting.	Audit checklist scores for adherence to pre-cannulation assessment, documentation accuracy, and continuous high-quality CPR metrics (e.g., time off-chest).	Ensures standardization of care and mitigates risks associated with limited initial expertise in Turkey.
Sustainability	Extent to which ECPR use is maintained long-term after initial pilot funding ceases and can be integrated into national healthcare reimbursement.	Cost per neurologically intact survivor (cost-effectiveness ratio); proportion of ECPR team costs covered by long-term operating budgets after Year 3.	Crucial metric for justifying the high resource allocation in a resource-constrained health economy.

that bystander CPR is performed in only approximately 2–5% of OHCA cases, highlighting a major weakness in the current chain of survival. Therefore, strengthening public CPR education and increasing bystander intervention should be considered a parallel priority alongside any future implementation of prehospital ECPR [10, 33]. Accordingly, ECPR implementation must proceed in parallel with strengthening basic life support (BLS) systems. Policymakers should view ECPR not as a substitute but as an apex intervention that complements investment in BLS and the broader EMS capacity. Realistically, resources should target the limited proportion (approximately 2–10%) of patients who are expected to meet conservative ECPR eligibility criteria and have the potential for meaningful neurological recovery. This estimate is derived from previous observational studies and ELSO-based patient selection frameworks, which consistently demonstrate that only a small proportion of OHCA patients fulfill strict ECPR eligibility criteria after applying established inclusion and exclusion criteria [18, 33, 34]. At the Inner Setting level, the limited national ECMO and ECPR capacity, along with the absence of specialized ECMO transport teams, represents a major challenge. Initial implementation should therefore adopt a centralized hub-and-spoke model, emphasizing strong policy endorsement, secured funding, and the creation of dedicated mobile units staffed with ECPR-trained physicians, critical care nurses, and specialized perfusionists or paramedics. Successful implementation of this model would also require formal collaboration between regional EMS authorities, tertiary referral hospitals, university medical centers, and the Ministry of Health. Nationally standardized referral pathways, shared clinical protocols, joint simulation training, and continuous performance audits could facilitate interinstitutional cooperation and improve operational consistency during the pilot phase. From an Implementation Science standpoint, success must be evaluated not solely through clinical outcomes but also by monitoring implementation outcomes such as fidelity, acceptability, feasibility, and sustainability (Table 4). Rather than requiring immediate nationwide implementation, the proposed strategy adopts a phased pilot approach. Initial funding should be sought through collaboration between the Ministry of Health, university hospitals, and national research funding agencies. Demonstrating feasibility, safety, and cost-effectiveness during the pilot phase would provide the evidence necessary to support subsequent governmental reimbursement and long-term policy adoption.

To achieve the critical sub-60-minute low-flow duration benchmark, the proposed Turkish model should employ a Targeted-Dispatch strategy—leveraging the rapid response of local EMS teams combined with the

Table 5 Refined inclusion criteria for ECPR candidates in the Turkish pilot phase

Criterion Category	Turkish Pilot Inclusion Standard (Phase I)	Rationale (Focus on Maximizing Favorable Outcome)
Age Limit (Upper)	65 years	Adopting the stricter Sub30 limit to maximize potential for favorable neurological recovery, ensuring responsible resource allocation in the initial phase.
Witness Status & CPR Quality	Witnessed OHCA and Bystander CPR initiated within 5 min, OR Continuous mechanical CPR applied upon EMS arrival.	Minimizes no-flow time in accordance with conservative international ECPR selection principles while providing a pragmatic eligibility criterion for the Turkish pilot phase.
Initial Rhythm	Refractory Ventricular Fibrillation (VF) or Pulseless Ventricular Tachycardia (VT) only.	Stricter than standard ELSO guidelines (excluding PEA initially), focusing exclusively on cardiac etiologies with the highest documented survival benefit from ECPR.
Low-Flow Duration Limit	ECPR cannulation must commence within 60 min of estimated collapse.	Mandatory benchmark derived from successful RCTs, ensuring circulatory support is established before irreversible ischemic neurological injury occurs.
Comorbidities	Absolute exclusion of advanced or life-limiting illnesses, including terminal malignancy or severe end-stage organ failure.	Ensuring the judicious and ethical use of extremely limited, high-cost resources.

expertise of a specialized ECPR unit. The operational sequence is as follows:

- **Initial Response:** The local 112 EMS unit is dispatched immediately for suspected OHCA cases. High-quality Basic and Advanced Life Support (BLS/ALS) should commence without delay, ideally supported by mechanical compression devices to maintain continuous circulation.
- **ECPR Team Activation:** If the arrest is witnessed, inclusion criteria (Table 5) are met, and ROSC is not achieved within 10 min of ALS, the central ECPR team—comprising an ECPR-trained physician, a critical care nurse, and a perfusionist—is deployed from the ECPR-capable hub hospital. This ensures seamless transition between local resuscitation and advanced circulatory support, similar to the Regensburg model in Germany.
- **Field Cannulation:** The ECPR team performs percutaneous cannulation using portable ECMO equipment and ultrasound guidance, either on-site

or within a mobile intensive care unit (MICU). Ultrasound use is mandatory to optimize first-pass success and minimize complications, thereby preserving the temporal efficiency critical for favorable outcomes. If percutaneous cannulation cannot be successfully achieved within an acceptable time despite ultrasound guidance, prolonged attempts should be avoided. Under these circumstances, rapid transport to the nearest ECPR-capable center for alternative cannulation strategies, including surgical cannulation when appropriate, may represent a safer and more practical option. The decision should be guided by procedural safety, anticipated delays, and the remaining low-flow time available.

- **Stabilization and Transport:** Following successful cannulation and flow optimization, the patient should be rapidly transferred to the designated ECPR center under strict critical care transport protocols, addressing one of the major current deficiencies in ECMO logistics.

Although the proposed 60-minute low-flow threshold is consistent with current ELSO recommendations, its achievement cannot currently be assumed across all regions of Turkey. The proposed pilot model is therefore intentionally limited to metropolitan areas with high EMS capacity, short transport distances, and ECPR-capable referral hospitals. The Targeted-Dispatch strategy aims to maximize the likelihood of meeting this benchmark through early activation of a dedicated ECPR team rather than assuming nationwide applicability. Future pilot studies should prospectively evaluate whether this target can be consistently achieved under real-world Turkish EMS conditions before wider implementation is considered [18, 35]. Given the high resource demand, initial Turkish ECPR protocols must strictly follow the most conservative international recommendations, focusing efforts on patients with the highest likelihood of neurologically favorable outcomes (Table 5).

The proposed criterion of bystander CPR initiation within 5 min is based on international ECPR patient-selection frameworks emphasizing minimization of no-flow time rather than representing a Turkey-specific evidence threshold. Although shorter intervals, such as within 3 min, may theoretically provide greater neurological benefit, current evidence does not support a universally accepted cutoff. Considering the current characteristics of the Turkish EMS system and bystander CPR rates, the 5-minute threshold was selected as a pragmatic criterion for an initial pilot phase while maintaining consistency with conservative international recommendations. Future Turkish pilot studies should prospectively

evaluate whether stricter time thresholds improve patient selection and clinical outcomes [1, 24].

Moreover, establishing a comprehensive ethical and legal governance framework under a national multidisciplinary task force (including legal experts, intensivists, emergency physicians, and ethicists) is essential. This framework should clarify three key domains frequently overlooked in emerging ECPR programs:

- **Clinical Responsibility and Legal Liability:** The professional scope and liability of each team member—particularly paramedics and nurses involved in ECMO circuit management—must be clearly defined. Explicit accountability hierarchies for on-site decision-making and flow optimization should be established. Because prehospital ECPR is proposed only as a pilot implementation strategy, detailed legal responsibilities and reimbursement mechanisms have not yet been established in Turkey. We believe that these issues should be addressed through national legislation before clinical implementation. A dedicated legal framework should define professional responsibilities, while reimbursement policies should be developed jointly by the Ministry of Health and the national health insurance authority to ensure sustainable financing and institutional accountability.
- **Consent and Patient Autonomy:** As most ECPR candidates are unresponsive, implied consent applies initially; however, hospitals must implement rapid mechanisms to identify advance directives or contact legal representatives to determine long-term care decisions.
- **Futility and Withdrawal of Life Support:** Objective clinical and neurological criteria must guide both the decision to initiate and discontinue ECPR (e.g., unwitnessed arrest, traumatic etiology, persistently low EtCO₂ <10 mmHg after 20 min of high-quality CPR). This ensures ethical stewardship of limited resources.

A rigorous Cost–Utility Analysis (CUA) is also indispensable to evaluate long-term program sustainability. Drawing from international experience, cost-effectiveness improves substantially when secondary benefits—such as increased organ donation rates—are factored into QALY-based models. The Turkish pilot should therefore calculate the marginal cost per neurologically intact survivor, while planning mechanisms for the continuous financing of consumables, training, and personnel. Integrating these recurring costs into the national health budget will be crucial for long-term viability. The proposed implementation strategy should therefore be considered as a pilot framework that requires prospective validation

through feasibility studies before broader implementation can be recommended.

Discussion and future perspectives

The proposed implementation strategy presented in the previous section is derived from the evidence synthesized in this narrative review and should be interpreted as a conceptual framework rather than a validated clinical protocol. Its feasibility and long-term sustainability depend on multiple organizational, logistical, financial, and clinical factors. Therefore, the following discussion focuses on the practical challenges, implementation barriers, and future directions that should be considered before broader adoption of prehospital ECPR in Turkey. Although prehospital ECPR represents an innovative approach, it also involves numerous challenges. The first of these is the issue of resources and cost. Mobile ECMO devices, especially those equipped with ambulances or helicopters, and many trained personnel are needed. In a study conducted in Australia, Zmudzki et al. [36] estimated the average cost per patient for prehospital ECPR at 12,741 AUD. The study also demonstrated that the cost-effectiveness ratio was approximately 44,000 AUD per QALY in the base scenario; however, when secondary benefits such as organ donation were included in the model, this ratio significantly decreased to approximately 22,000 AUD per QALY. These findings suggest that prehospital ECPR programs may be cost effective under certain conditions. Owing to the high resource requirements, conducting economic analyses to assess feasibility is crucial. However, cost-effectiveness evaluations should consider not only economic indicators but also ethically sensitive dimensions such as patient autonomy, long-term care needs, and organ donation. In countries with constrained healthcare budgets, such as Turkey, the implementation of such a program should first be evaluated at a pilot regional level. Within the Turkish context, public awareness and stakeholder acceptance may also influence implementation success. Given current limitations in bystander CPR rates, strengthening public BLS education and community engagement should remain the primary national priority. Prehospital ECPR should therefore be considered a complementary advanced intervention rather than an alternative to improving the existing chain of survival. On the other hand, current studies are largely observational in nature, and robust randomized trials remain limited. Geographic and organizational factors (such as urbanization, EMS infrastructure, and the structure of the healthcare system) further challenge the generalizability of the findings [18, 37, 38].

Despite the promising conceptual advantages of on-site ECPR, its real-world feasibility in prehospital environments may be more limited than suggested by early reports. Several critical operational constraints must be

acknowledged. First, maintaining adequate aseptic conditions in uncontrolled field settings remains a significant challenge, particularly during percutaneous cannulation procedures, which inherently carry risks of infection and contamination. Second, the technical complexity of establishing a complete ECMO circuit in the field—including vascular access, circuit priming, and flow optimization—requires highly coordinated expertise and may be difficult to achieve consistently under time pressure and variable environmental conditions. In addition, specific procedural complications deserve further consideration. Femoral cannulation, the most commonly used approach in prehospital ECPR, carries a substantial risk of distal limb ischemia, particularly in the absence of routine distal perfusion catheter placement, which may not always be feasible in prehospital settings. Similarly, achieving effective hemostasis can be challenging, especially in patients receiving anticoagulation during ECMO initiation, increasing the risk of bleeding complications at the cannulation site. Furthermore, the high economic burden associated with mobile ECMO systems, specialized personnel, and logistics infrastructure further limits the scalability of fully on-site ECPR models [39]. Taken together, these factors suggest that while on-site ECPR may be feasible in highly specialized systems, hybrid approaches—such as rapid transport to ECPR-capable centers or initiation within mobile intensive care units—may represent more pragmatic and sustainable strategies in many healthcare contexts [9, 18, 23]. In real-world practice, these limitations may result in prolonged procedural times or unsuccessful cannulation attempts, potentially offsetting the theoretical time advantage of on-site ECPR initiation.

Another critical aspect is team coordination. Prehospital ECPR requires integrated collaboration between the initial response team in ground or air ambulances and the mobile ECPR team. Therefore, comprehensive protocols, effective communication, regular training, and simulation exercises are indispensable [1, 29]. Furthermore, the stabilization and transfer of patients supported by ECPR to a primary center are highly important. Purington et al. [9] reported that the standardization of transport and critical care management following ECPR remains insufficient and emphasized the need for clear protocols in patient management. At this point, decisions regarding the continuation or withdrawal of life support must be made by multidisciplinary teams in accordance with ethical principles. Moreover, clarifying legal regulations and clinical responsibilities is essential to ensure the reliability of ECPR implementation.

In the context of Turkey, future pilot studies should evaluate the feasibility, implementation outcomes, cost-effectiveness, and organizational performance of the proposed implementation strategy under real-world

conditions. Before wider implementation can be considered, standardized training programs, national referral centers, and coordinated governance mechanisms should be established and prospectively evaluated. Such an approach would facilitate evidence-based decision-making while strengthening Turkey's advanced life support capacity in line with international standards. In summary, the evidence reviewed suggests that prehospital ECPR may reduce low-flow duration and potentially improve survival with favorable neurological outcomes in carefully selected patients when rapid cannulation, high-quality CPR, appropriate patient selection, and coordinated multidisciplinary care can be achieved. For Turkey, the reviewed evidence supports a phased and regionally targeted pilot approach integrated into the existing 112 EMS system rather than immediate nationwide implementation. The potential benefits of this strategy include more timely extracorporeal support and improved outcomes for appropriately selected refractory OHCA patients; however, these effects cannot yet be assumed in the Turkish context and require prospective evaluation.

Conclusion

This narrative review examined the feasibility of prehospital ECPR in Turkey by integrating current international evidence with the characteristics of the Turkish emergency medical system. The evidence synthesized in this review indicates that a carefully selected and regionally targeted ECPR strategy may have a potential role as an advanced component of the existing prehospital chain of survival, particularly for appropriately selected patients with refractory OHCA. However, successful implementation in Turkey will require specialized training, ECPR-capable referral centers, standardized clinical and operational protocols, appropriate legal and ethical frameworks, sustainable financing, and prospective evaluation of feasibility, implementation outcomes, and cost-effectiveness before wider adoption can be considered.

Authors' contributions

Conceptualization: FD, ZK, EH; Methodology: FD, ZK; Formal analysis and investigation: FD, ZK; Data collection: FD; Writing—original draft preparation: FD; Writing—review and editing: ZK, EH; Supervision: ZK, EH. All authors read and approved the final manuscript.

Funding

The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Received: 21 May 2026 / Revised: 12 August 2026 / Accepted: 16 August 2026

Published online: 01 October 2026

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