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The Heart Team approach to cardiac arrest

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Cardiac arrest is a critical emergency in cardiovascular medicine, requiring rapid, multidisciplinary interventions to enhance patient survival and neurological outcomes. This review explores the unique challenges of managing out-of-hospital (OHCA) and in-hospital cardiac arrest (IHCA), with a focus on mechanical circulatory support (MCS) and extracorporeal cardiopulmonary resuscitation for selected patients. While OHCA management should prioritize rapid transport to specialized centres, IHCA may allow for immediate, patient-tailored interventions. Post-cardiac arrest syndrome adds complexity, often requiring nuanced MCS escalation and weaning. Standardized protocols, ethical considerations, and further research are essential to refine patient selection and improve outcomes, ultimately advancing cardiac arrest care.

Introduction

Cardiac arrest represents one of the most critical and complex emergencies in modern medicine, characterized by the abrupt cessation of effective cardiac function, immediate haemodynamic collapse, and organ ischaemia. Distinguishing between out-of-hospital cardiac arrest (OHCA) and in-hospital cardiac arrest (IHCA) is essential, as each setting presents unique logistical, clinical, and resource-based challenges. Survival rates at hospital discharge remain alarmingly low, at ~8% for OHCA and 18% for IHCA across European countries.[1,2,3] Despite regional variations in survival rates, a disparity yet remains between initial return of spontaneous circulation (ROSC) and survival to hospital discharge, highlighting the need to improve

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survival rates and neurological outcomes. Achieving such improvements relies on timely and co-ordinated interventions by a multidisciplinary Heart Team, comprising cardiologists, cardiac surgeons, intensivists, and emergency medicine specialists, who can bridge the gap between immediate resuscitation and long-term recovery.

Personalized therapeutic interventions, such as mechanical circulatory support (MCS), should be tailored to the specific clinical context and patient characteristics. Advanced diagnostic tools are equally indispensable and help identify underlying causes of arrest and guide targeted therapeutic decisions. A holistic approach that includes early identification of treatable conditions, customized MCS application, and continuous patient assessment is vital for enhancing outcomes in this high-risk population.

The transition from ROSC to recovery is often fraught with challenges, including post-cardiac arrest syndrome (PCAS) and MCS-related complications, necessitating early recognition and meticulous management. Timely escalation and weaning of MCS, including strategies for unloading the left ventricle (LV), may play a pivotal role in facilitating myocardial recovery. Ethical considerations surrounding end-of-life care and organ donation are also essential in the management of cardiac arrest, particularly in cases of refractory arrest or irreversible brain injury. In some countries, integrating organ donation programmes with extracorporeal cardiopulmonary resuscitation (ECPR) strategies has shown potential to enhance organ viability and transplantation outcomes.

Multidisciplinary Heart Team-based collaborations are crucial in delivering compassionate care and optimizing clinical outcomes. This comprehensive approach to cardiac arrest management, which includes advanced MCS strategies, post-arrest care, and ethical decision-making, might set the foundation for an effective and individualized response to one of the most complex challenges in cardiovascular medicine.

Differences between out-of-hospital and in-hospital cardiac arrest

OHCA and IHCA differ significantly in patient characteristics, available resources, and response protocols, each of which affects the approach to advanced resuscitation and post-resuscitation care.[3] In OHCA, rapid identification of cardiac arrest, transport to specialized cardiac arrest centres, and evaluation for potential ECPR are essential. Conversely, the hospital setting of IHCA might generally enable more immediate intervention due to availability of patient history, continuous monitoring, and a more controlled environment.

Out-of-hospital cardiac arrest referral: definitions in practice

The location where patients experiencing sudden cardiac arrest are initially resuscitated and stabilized is of critical importance. The advent of ECPR poses new questions about the optimal pathway of care, from the scene of the collapse to the hospital.[4,5,6,7] Direct transport to a cardiac arrest centre following OHCA may be associated with higher survival rates,[8,9] especially when time to ECPR implementation is short. To achieve optimal outcomes, systems should identify suitable patients, expedite hospital transfer, and facilitate rapid cannulation and extracorporeal membrane oxygenation (ECMO) flow. As such, it is important to note that a Cardiac Arrest Centre differs from an ECPR Centre. While Cardiac Arrest Centres provide specialized resuscitation care, ECPR centres are additionally equipped for ECPR and pre-primed extracorporeal circuits, which maintain sterility, do not impair oxygenator performance, and should be considered essential prerequisites.[10] The precise number of centres performing ECPR in Europe remains unclear. Nevertheless, the European chapter of the Extracorporeal Life Support Organization (ELSO), referred to as EuroELSO, includes ECMO centres in over 130 cities across Europe, many of which are equipped to provide ECPR.[11] On a global scale, a total of 593 ELSO-registered centres were documented as of 2023.[12]

Reducing time on the scene might enable earlier initiation of veno-arterial ECMO (VA-ECMO), a goal currently being evaluated by some centres through pre-hospital ECPR. While pre-hospital ECPR has been shown feasible with experienced VA-ECMO teams, logistical complexities may pose challenges to making this approach a sustainable standard. Additionally, only about half of ECPR protocol activations may result in actual VA-ECMO use and cannulation issues might not be resolved without transoesophageal echocardiography (TEE) or fluoroscopy, representing a key limitation.[13]

Out-of-hospital cardiac arrest network challenges

Given the critical importance of timing, performing VA-ECMO implantation during active mechanical chest compressions is highly demanding, and every institution should identify the ideal setting for this procedure. However, the professional profile of the implementing physician is often diverse, ranging from interventional cardiologists, cardiac surgeons, intensivists, or emergency department physicians. Consequently, each professional brings varied technical approaches and monitoring techniques. Ultimately, VA-ECMO implantation and initiation should ideally be both safe and swift, with cannula size carefully selected and able to accommodate potential hyperflow needs if required. In clinical practice, vascular adverse events and cannulation errors may occur. Therefore, as VA-ECMO flow is started, mechanical chest compressions should continue until a stable blood pressure is established.

An early step in assessing a patient with OHCA involves evaluating the potential futility of resuscitation efforts. Although estimating futility is challenging, a subset of patients may meet termination of resuscitation criteria.[14] Beyond this, there exists a continuum of risk for unfavourable outcomes. Therefore, it is important to consider individual risk factors and the clinical context for each case within the Heart Team. For example, a young patient without comorbidities may still be considered for ECPR despite multiple negative prognosticators, whereas an older patient with significant comorbidities, such as a previous sternotomy, chronic kidney disease, peripheral artery disease, and ventricular fibrillation as the initial rhythm, might not be suitable for invasive treatments.

The availability of catheterization laboratory services near the scene of the event, even if not classified specifically as a Cardiac Arrest Centre or ECPR Centre, adds a layer of clinical complexity. It is crucial to distinguish between haemodynamically stable patients who achieve ROSC and exhibit ST-segment elevations on post-ROSC electrocardiogram (ECG) as they are likely to benefit from early percutaneous coronary intervention (PCI). This is in contrast to those patients requiring ongoing cardiopulmonary resuscitation (CPR), for which rapid systemic reperfusion becomes the primary goal. For this latter group, VA-ECMO therapy may be warranted if the patients meet ECPR eligibility criteria. Ultimately, patient allocation to PCI centres, dedicated cardiac arrest centres, or ECPR centres may depend on logistical capabilities and resource availability within each regional healthcare network.

In-hospital cardiac arrest peculiarities

Patients with IHCA usually present a distinct set of characteristics. More specifically, the treating physician will often know the patients' medical history and clinical status, the time of collapse is typically clear, and the no-flow period is generally shorter. For practical purposes, occurrence of IHCA could be divided into three scenarios, each with unique clinical implications:

(1) **Cardiac catheterization laboratory:** During urgent or elective coronary angiography and PCI, vascular access can be easily obtained peri-procedurally. Based on the underlying pathology, the patient's haemodynamic status, and the level of mechanical support required, either a micro-axial flow pump (mAFP) or VA-ECMO may be considered. If the coronary procedure can be performed successfully and timely, an mAFP might be the preferred option, while VA-ECMO implantation would serve as a backup in case of mAFP failure or need for more haemodynamic support and/or oxygenation. The mAFP is typically quick to deploy and can be implanted while preparing for VA-ECMO if escalation is needed.

(2) **Intensive care unit (ICU):** IHCA in the ICU is often a consequence of multi-organ failure. However, some ICU patients may experience sudden cardiac arrest due to reversible causes. Conventional CPR may usually be effective for achieving rapid ROSC, but ECPR may be considered in cases of refractory cardiac arrest, taking into account the clinical situation, comorbidities, and patient preferences.

(3) **Inpatient wards:** IHCA in typical inpatient wards generally involves patients with severe underlying conditions, some of whom may have contraindications for ECPR. Candidacy for EPCR in these patients should be rigorously evaluated, with special consideration given to patients in orthopaedic wards. These patients, often admitted for trauma-related disorders, may be at an elevated risk of pulmonary embolism (PE), which should be assessed as a potential cause of arrest. Cannulation in these cases presents specific challenges such as venous clots that may obstruct the iliac and caval veins and pose a risk of either ingestion or distal embolism by the cannula. In addition, recent lower limb or pelvic surgeries may create anatomical variations that complicate positioning of the cannulae.

In addition to the challenges of managing OHCA and IHCA, it is essential to consider the systemic implications that extend beyond achieving ROSC, as highlighted by the complexities of PCAS.

From return of spontaneous circulation to recovery: the post-cardiac arrest syndrome

Cardiac arrest exerts a profound systemic impact that extends far beyond the restoration of circulation. Post-cardiac arrest syndrome is characterized by significant injury to the heart and brain, as well as systemic ischaemia-reperfusion injury. Additionally, PCAS can adversely affect other organ systems, adding a complexity to patient recovery.[15] A hallmark feature of PCAS is severe vasodilation driven by systemic inflammation, which can further compromise haemodynamics.[16] The severity and extent of PCAS are influenced by various factors, including patient age, pre-existing comorbidities, and the cause and duration of the cardiac arrest event. These factors are crucial for tailoring MCS strategies that address both the direct and systemic effects of cardiac arrest, aligned with each patient's physiological profile.[17] Thus, given the complexity of PCAS and its implications for patient recovery, strategic use of MCS in cardiac arrest is essential. Timely intervention and well-defined escalation and weaning protocols may be critical for optimizing patient outcomes.

Mechanical circulatory support in cardiac arrest

ECPR is the application of VA-ECMO in patients experiencing refractory cardiac arrest without stable ROSC.[18] Recent randomized controlled trials (RCTs) have demonstrated that, within well-structured systems, ECPR may have the potential to improve survival rates and neurological outcomes in select patients compared with conventional CPR.[5,6,7] However, considerable variation in trial settings, inclusion and exclusion criteria, cardiac arrest procedures, and outcomes highlight the ongoing challenges in ECPR application.[19] Key challenges include establishing standardized definitions for refractory cardiac arrest, optimizing timing for ECPR evaluation post-collapse, identifying appropriate candidates for ECPR, and developing pre-hospital treatment strategies ('stay and play' vs. 'load and go').[20] Additionally, logistical issues such as regional management of cardiac arrest (including cannulation site and pre-hospital ECPR team integration),[21] in-hospital treatment with ECPR-trained personnel, the management and prevention of complications, and ethical considerations (neuroprognostication, organ donation, and end-of-life care[22]) add complexity.

Strict adherence to institutional protocols and seamless collaboration with emergency medical services might be essential for optimizing patient care pathways and outcomes. The ELSO has proposed ECPR eligibility guidelines, recommending criteria such as <70 years of age, witnessed cardiac arrest, no-flow times <5 min, low-flow times <60 min, and the absence of both asystole in the initial rhythm and life-limiting diseases.[23] Despite these efforts, further scientific investigations are essential to address unresolved issues in cardiac arrest management. Adequately powered RCTs are required to fill existing knowledge gaps and emerging technologies. For example, the CARL system might potentially be able to enhance therapeutic control during cardiac arrest, as demonstrated by preliminary European feasibility studies.[24,25]

An additional challenge with ECPR is that short-term survival remains low, ranging from 20 to 43% across RCTs. Retrograde aortic perfusion during VA-ECMO therapy increases LV afterload, potentially impeding cardiac and pulmonary recovery,[26] especially in patients that already have impaired cardiopulmonary function. Similar to strategies used in managing cardiogenic shock,[27] VA-ECMO can be potentially combined with a percutaneous mAFP (a strategy known as ECMELLA, i.e., combination of ECMO and mAFP) which may improve patient outcomes by mitigating LV overload and enhancing myocardial and systemic perfusion. A recent meta-analysis of pooled data from 1,014 patients with ECPR across 32 centres suggests a potential survival advantage with ECMELLA over VA-ECMO alone, particularly in cases of refractory cardiac arrest induced by acute myocardial infarction.[28] However, additional RCTs are urgently needed to ascertain whether active LV unloading can effectively mitigate the adverse outcomes associated with VA-ECMO in ECPR.

For further management of this complex scenario, a surgically implanted axillary mAFP, capable of full-flow support (up to 5.5 L/min), may facilitate earlier and more effective weaning from ECMO, targeting LV failure directly. Optimal timing for escalating MCS could potentially prevent irreversible multi-organ dysfunction, although there are limited RCT data to guide these critical decisions, underscoring the need for further research.[29]

MCS escalation and de-escalation strategies that enable a groin-free configuration and promote antegrade flow without extracorporeal circulation might offer clinical advantages, such as earlier extubation, improved patient mobilization, initiation of physical exercise, and maintenance of haemodynamic support.[30] In ECMELLA, the weaning sequence should ideally prioritize VA-ECMO discontinuation. However, compromised right ventricular (RV) function may require a stepwise reduction in VA-ECMO or a transition to tailored RV support. This Heart Team-based individualized approach may be crucial in optimizing patient outcome and minimizing haemodynamic deterioration during MCS de-escalation.

Noteworthy, within the ECPR context, immediate surgical placement of a mAFP is highly impractical due to the need for surgical cut-down and visualization of the axillary artery, which often requires fluoroscopic guidance. Rather, percutaneous VA-ECMO remains the most feasible and immediate intervention for rapidly restoring circulation. Although clinical expertise with surgically implanted mAFP grows, robust evidence for its efficacy in addressing cardiac arrest is limited. From a pathophysiological perspective, the application of mAFP following VA-ECMO initiation, or in patients with persistent LV failure post-ROSC, may aid myocardial recovery or serve as a bridge-to-decision strategy. Furthermore, implantation of a high-flow mAFP, such as the Impella 5.5 system, under local anaesthesia may offer LV support and unloading for patients who have experienced cardiac arrest and achieved ROSC.[31] This strategy offers a minimally invasive approach to improve haemodynamic stability and patient outcome during the critical post-arrest phase. However, more randomized evidence evaluating efficacy and safety is urgently needed. Building on these MCS escalation and weaning strategies, comprehensive diagnostics in cardiac arrest are crucial in guiding therapeutic decisions and optimizing patient outcomes.

Diagnostics in cardiac arrest

Key determinants for guiding diagnostics and therapy in cardiac arrest include the initial arrest rhythm, whether or not the collapse was witnessed, the achievement of ROSC, and the duration of no-flow and/or low-flow times. Immediate application of focused cardiac ultrasound is crucial to identify treatable causes of cardiac arrest, such as PE or cardiac tamponade. Standard haemodynamic monitoring, such as ECG, blood pressure measurement, and end-tidal CO_2 ($EtCO_2$), should also be employed to monitor the patient's haemodynamic profile.[32]

Upon ROSC, imaging can aid in selecting the appropriate MCS device according to patient's clinical phenotype. For example, in patients with IHCA secondary to acute coronary syndrome and LV failure, percutaneous mAFP support may be considered.[33,34] In cases of refractory cardiac arrest with biventricular involvement, where the patient is a suitable candidate for ECPR according to local protocols, a focused TEE examination might be performed to identify contraindications (e.g. aortic dissection) and treatable causes (e.g. cardiac tamponade). TEE is also invaluable for guiding cannulation and monitoring patient-device interactions, potentially indicating a need for additional unloading strategies.[35]

Basic monitoring (e.g. telemetry, invasive blood pressure measurement, and $EtCO_2$) should be initiated promptly, complemented by devices assessing peripheral perfusion, such as near-infrared spectroscopy for cerebral and limb perfusion. For patients with successfully resuscitated cardiac arrest who display persistent ST-segment elevation or its equivalents on ECG, immediate percutaneous reperfusion is recommended (Class I, Level B).[36] However, the choice between staged vs. immediate complete coronary revascularization remains contentious. Notably, two RCTs showed no survival benefit from early coronary angiography in haemodynamically stable OHCA patients without ST-segment elevations post-ROSC.[37,38]

In stabilized cardiac arrest patients receiving MCS, daily echocardiographic assessment is essential in monitoring cardiac function, evaluating myocardial recovery, and guiding ongoing management. Use of a pulmonary artery catheter (PAC) might also be helpful to determine the timing and effectiveness of additional unloading measures and to detect early indicators of cardiac recovery, such as the pulmonary artery pulsatility index (PAPi).[29] Pulmonary artery catheter can further guide treatment adjustments based on a more comprehensive haemodynamic profile, especially in patients who have experienced cardiac arrest.[39]

Weaning trials to evaluate cardiac recovery should commence once metabolic, respiratory, and circulatory stability are achieved. For patients who have undergone therapeutic hypothermia, these trials should begin only after a normothermic temperature is restored. A multiparametric approach is advised during weaning trials, incorporating echocardiographic measures, blood pressure, heart rate, pulmonary capillary wedge pressure (PCWP), PAPi, and lactate. If, during stepwise MCS reduction, there are a significant increase in heart rate (>15% from baseline), a drop in blood pressure or pulse pressure (>15–20% from baseline), a decrease in peripheral oxygen saturation or P_aO_2, or an increase in PCWP, the trial should be terminated and the cause of failure investigated.[40] Conversely, if PAPi increases, echocardiographic indices of ventricular function show improvement and haemodynamic and respiratory stability are maintained, the weaning process may proceed.[41]

As diagnostics guide therapeutic decisions in cardiac arrest, potential outcomes, including organ donation, might be considered, particularly in the context of donation after circulatory death (DCD, *Figure 1*).

Exit strategy: from circulatory death to organ donation

Although heart recovery remains the primary objective once MCS is initiated during or after cardiac arrest, the potential for organ donation might be promptly evaluated in cases of refractory arrest or irreversible brain injury. In these scenarios, organ donation, especially DCD, becomes a viable consideration. Controlled DCD (cDCD) is where organ retrieval is planned following the withdrawal of life-sustaining therapy and uncontrolled DCD (uDCD) occurs when resuscitation efforts fail following an unexpected cardiac arrest. Due to logistical challenges, such as the need for round-the-clock availability of specialized teams and family discussions during acute and traumatic situations, uDCD remains less common than cDCD. A recent survey revealed that only six European countries currently have established uDCD programs.[42] Moreover, ethical and legal frameworks for declaring cardiac or brain death and the organ donation consent process vary widely based on local and national regulations. One key difference across protocols is the required no-touch period for declaring circulatory death, which ranges from 5 to 20 min. To bridge the gap between circulatory death and organ retrieval and to preserve organ viability, abdominal normothermic regional

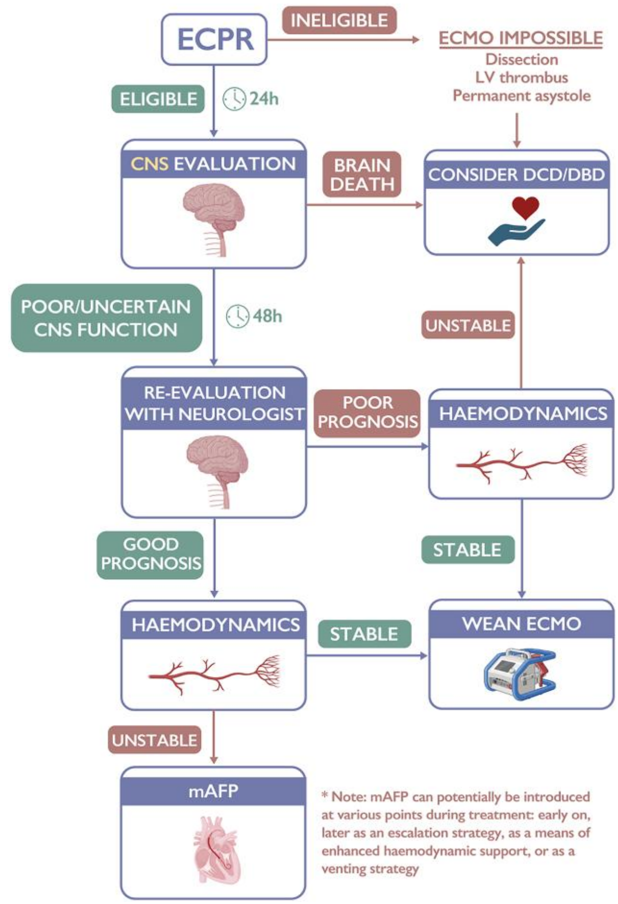

Figure 1 Patients with refractory cardiac arrest and extracorporeal cardiopulmonary resuscitation management. Patients with refractory cardiac arrest, who meet eligibility criteria for extracorporeal cardiopulmonary resuscitation (ECPR), may be considered for ECPR to achieve immediate cardiopulmonary stabilization. In contrast, patients who do not fulfil ECPR criteria may be considered for donation after circulatory death with the patient's advanced directives and the preferences of their relatives. Neurological prognostication should be initiated following ECPR as part of the post-cardiac arrest therapeutic protocol. At 24 h, central nervous system function should be assessed, and in cases where brain death is diagnosed, donation after brain death may be considered in alignment with the patient's advanced directives and the preferences of their relatives. If central nervous system function is poor or uncertain, a follow-up assessment is conducted after 48 hours (h). However, if cooling is in place at 24 h, completing brain death diagnostics is not feasible at this time point and might be delayed. During the post-cardiac arrest treatment phase, veno-arterial extracorporeal membrane oxygenation (VA-ECMO) should be gradually weaned in stable patients. If adverse effects associated with VA-ECMO, such left ventricular overload or pulmonary congestion, or insufficient level of haemodynamic support with VA-ECMO alone become apparent, the additional insertion of a percutaneous or surgically implanted micro-axial flow pump (mAFP) may be considered, a strategy commonly referred to as "ECMELLA". The optimal timing for initiating left ventricular unloading or escalating support with mAFP remains uncertain. The use of a surgically implanted mAFP may theoretically offer further benefits by facilitating the weaning process from VA-ECMO and supporting patient recovery (extubation and mobilization).

perfusion has emerged as a critical technique to maintain perfusion and enhance potential for transplantation.

The eligibility criteria for uDCD are not yet well defined. However, the International Liaison Committee on Resuscitation recently proposed an update to the Maastricht criteria to include patients with unwitnessed cardiac arrest, a cohort that represents nearly 45% of all OHCA cases.[43] This update recommends attempting resuscitation, including peripheral VA-ECMO use, to preserve organ perfusion and increase the likelihood of organ donation. While data remain limited, initial reports from combined ECPR/DCD programmes have shown high rates of successful organ and tissue transplantation. For example, a sub-study of the Prague OHCA RCT, which compared ECPR with standard treatment for refractory OHCA, showed significantly higher numbers of organ donors and favourable transplant outcomes in the ECPR group.[44]

To successfully implement an uDCD programme within local legislative frameworks, several components are essential:

- Strict protocols that coordinate efforts between the emergency department and the ICU.
- A 24 h-available ECPR team, either on-site or on-call, prepared to initiate cannulation during CPR.
- A transplantation team that collaborates with treating physicians to identify uDCD candidates and ensure seamless coordination throughout the donation process. This includes retrieving the patient's advance directives, engaging with the potential donor's family or relatives to discuss death and organ donation, performing medical evaluations to rule out contraindications (e.g. malignancies, chronic dysfunction, coronary, or peripheral arterial occlusions), and co-ordinating with transplant registries to ensure timely organ allocation.

Implementation of ECPR for uDCD presents critical challenges. First, expanding these programmes to more ECPR and cardiac arrest centres could enhance access, allowing for more frequent on-site cannulation during OHCA, which may reduce low-flow times, enhance organ perfusion, and ultimately increase survival rates and uDCD eligibility. Second, integrating organ donation considerations into cardiac arrest management algorithms and guidelines is crucial. Third, expanding registries to track clinical, organizational, and economic aspects of uDCD programs might support continuous quality improvement and help optimize both transplant outcomes and patient survival following cardiac arrest. Given the limited resources currently available for cardiac arrest care, efficient allocation will be critical for the sustainable and successful implementation of DCD programs.

Conclusions and outlook

The use of MCS has transformed cardiac arrest management for both OHCA and IHCA, representing a major advancement in patient care. Success with these interventions hinges on a multidisciplinary Heart Team approach, careful patient selection, and the timely application of MCS within well-defined clinical contexts. Key factors, such as the specific nature of cardiac arrest, comorbidities, and patient preferences, are paramount in determining the suitability of ECPR, while advanced diagnostics enable individualized therapeutic decisions.

OHCA and IHCA are two separate entities that present distinct logistical and clinical challenges. In OHCA, rapid transport to specialized cardiac arrest or ECPR centres, minimizing time to ECMO initiation when indicated, and addressing logistical hurdles are essential for optimizing outcomes. In contrast, IHCA allows for quicker access to advanced MCS devices due to the availability of patient history and an in-hospital setting. Irrespective of onset, PCAS might further complicate patient recovery and underscores the need for a tailored approach to MCS escalation and weaning. Combining VA-ECMO with active LV unloading might offer a promising approach to mitigate LV overload and reduce pulmonary congestion, potentially improving patient outcomes. However, these strategies come with risks, and timely intervention might be critical to prevent irreversible multi-organ dysfunction.

Consideration of organ donation has also become increasingly relevant, especially in cases of refractory arrest or irreversible brain injury, particularly through the expansion of DCD programs. When integrated with ECPR, DCD initiatives have the potential to increase organ viability and enhance transplantation outcomes, offering new avenues for life-saving interventions. However, despite these advancements, significant challenges remain. Standardizing protocols, refining patient ECPR selection criteria, and addressing ethical concerns regarding neuroprognostication and end-of-life care are all areas requiring further attention. Future RCTs will be pivotal in addressing these knowledge gaps and establishing more definitive guidelines for MCS in cardiac arrest. As research progresses, the integration of MCS into cardiac arrest protocols has the potential to further improve survival, neurological outcomes, and overall quality of life, all while upholding ethical considerations and compassionate care by a multidisciplinary Heart Team.

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