Clinical paper

Challenges in the development and implementation of a healthcare system based extracorporeal cardiopulmonary resuscitation (ECPR) program for the treatment of out of hospital cardiac arrest

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Abstract

Introduction: Extracorporeal cardiopulmonary resuscitation (ECPR) can treat cardiac arrest refractory to conventional therapies. Many institutions are interested in developing their own ECPR program. However, there may be challenges in logistics and implementation.

Aims: The aim of our protocol was to demonstrate that an ECPR team was feasible within our healthcare system and that the identification of UPMC Presbyterian as a receiving center allowed for successful treatment within 30 min from EMS dispatch.

Methods: We developed out of hospital cardiac arrest (OHCA) ECPR protocols for Emergency Medical Services (EMS), EMS communications, and our in-hospital ECPR team. Inclusion criteria indentified patients with a potentially reversible arrest etiology and high probability of recoverable brain injury using a simple checklist: witnessed collapse, layperson CPR, initial shockable rhythm, and age 18–60 years. We trained local EMS crews to screen patients and reviewed the criteria with a Medcom Command Physician prior to transport to our hospital.

Results: From October 2015 to March 31st 2018, EMS treated 1165 EMS OHCA cases, transported 684 (57%) to a local hospital, and transported 120 (10%) to our institution. Of these, five (4.1%) patients underwent ECPR. Among excluded cases, 64 (53%) had nonshockable rhythms, 48 (40%) were unwitnessed arrests, 50 (42%) were over age 60 and the remaining 20 (17%) had no documented reasons for exclusion. For ECPR cases, median prehospital CPR duration was 26 [IQR 25 – 40] min. Four patients (80%) received mechanical CPR. Interval from arrest to arrival on scene was 5 [IQR 4 – 6] min and interval from radio call to activation of ECPR was 13 [IQR 7 – 21] min. Interval from EMS dispatch to departure from scene was 20 [IQR 19 – 21] min. Time from EMS dispatch to initiation of ECPR was 63 [IQR 59 – 69] min.

Conclusions: ECPR is an infrequent occurrence in EMS practice. Most apparently eligible patients did not get ECPR, highlighting the need for ongoing programmatic development, provider education, and qualitative work exploring barriers to implementation.

Keywords: Cardiac arrest, Extracorporeal cardiopulmonary resuscitation (ECPR), Emergency medical services

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**Introduction**

Over 350,000 Americans suffer an out of hospital cardiac arrest (OHCA) annually, but survival from OHCA remains poor at 10–12%. Many OHCA result from reversible cardiac causes such as acute coronary syndrome and dysrhythmias. Enthusiasm for the use of veno-arterial extracorporeal membrane oxygenation (ECMO) as a more effective way to restore circulation during cardiac arrest, a strategy termed extracorporeal cardiopulmonary resuscitation (ECPR) has been increasing. Only a few centers in the US implement ECPR, and most are tertiary academic referral centers in major metropolitan areas. Currently, there are no standardized protocols for ECPR and current guidelines support ECPR primarily as a salvage treatment. Prior reports do not agree upon a single structure for the development or makeup of ECPR teams. Some institutions have developed teams as an extension of acute coronary interventional teams, including both cardiology and cardiology surgery. These teams have a broader mission to address the hemodynamic instability from cardiogenic shock due to acute myocardial infarction and to provide access to mechanical circulatory support when needed. A recently published position statement on ECMO for cardiac failure illustrates the structure of such teams.

With relatively little guidance on development or implementation of ECPR teams, institutions may face challenges in developing their own. We recently published our institutional experience with ECPR. Concurrent with this work, we developed an institutional protocol for the use of ECPR in refractory OHCA. The purpose of this paper is to describe the challenges and initial results we have encountered during implementation and development of our ECPR program in hopes that it will help others who are seeking to initiate a similar program.

**Methods**

**ECPR protocol design**

This protocol was a quality improvement initiative within UPMC. All patients receiving ECMO at our institution are prospectively entered into a registry with approval of the UPMC Quality Improvement Review Committee. The University of Pittsburgh Human Subjects Research Protection Office approved data collection from these quality improvement databases for this analysis.

**Setting**

We implemented the protocol at UPMC-Presbyterian Hospital in Pittsburgh PA, USA. Our institution is one of the regional clinical centers in the Resuscitation Consortium (ROC) and has previously participated in randomized clinical trials involving complex protocols for management of out of hospital cardiac arrest.

**Subjects**

We defined ECPR as veno-arterial ECMO placement in patients with OHCA refractory to conventional medical treatment. Patients that achieved sustained return of spontaneous circulation (ROSC), defined as pulse for at least 20 min without ongoing chest compressions or defibrillations, but with continued hemodynamic instability were not included in our protocol.

**ECPR team and patient logistics**

Our ECPR team consists of multiple disciplines including Emergency Medicine (EM), EMS, Cardiology, Cardiothoracic Surgery, Critical Care Medicine and the Post-Cardiac Arrest Service (PCAS). A logistical plan of patient flow from the field to the intensive care unit (ICU) is shown in Fig. 1. We highlighted important transition points along patient flow that would allow us to recognize candidates for ECPR and also recognize cases for which efforts might be futile, allowing us to allocate our resources appropriately and minimize unnecessary team activations.

For the purposes of initial screening, we developed a checklist based on 4 Utstein characteristics with the goal of identifying patients likely to have a reversible cause of their collapse and likely recoverable brain injury: witnessed collapse, lay person CPR, initial shockable rhythm, and age 18–60 years old. If the EMS providers recognized these inclusion criteria, they contacted a medical command physician by radio, who would confirm inclusions and also review exclusion criteria (see Table 1). If eligible, EMS would apply a mechanical CPR device, such as the LUCAS™, (JOLIFE AB, Sweden) and transport immediately to our hospital for ECPR. Additionally, the command physician activated the ECPR team by group page that would respond to the emergency department (ED). EMS delivered patients to a major procedure room within the ED where ECMO cannulation equipment and ECMO pumps are located.

The cannulation team is composed of: two physicians from cardiothoracic surgery or critical care medicine who staff the cardiothoracic ICU (CTICU) and who are credentialed to perform femoral venous and arterial cannulation, the CTICU charge nurse, CTICU nurse and perfusionist who assist with transition on to ECMO. The PCAS or EM physician directed the continued resuscitation until

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**Fig. 1 – ECPR logistics and patient flow. Dark arrows denote continuation along activation, clear arrows denote termination of activation and transition to usual care.**
ECMO was started. Once on ECMO, the patient was transferred to the cardiac catheterization lab for coronary angiography and then to the cardiothoracic ICU for ongoing management. To be eligible for the protocol, patients had to arrive to the ED within 30 min and cannulation had to occur within 60 min from arrest.

Post resuscitation care was provided by cardiothoracic intensivists in the ICU. We employed targeted temperature management for all patients. In the absence of a neurological catastrophe hypothermia was continued for 24 h followed by slow re-warming. Evidence of brain death or poor neurologic prognosis was an indication for termination of cardiopulmonary support. A transthoracic echocardiogram was obtained to assess for biventricular function. ECMO weaning trials were performed at discretion of the ICU attending physician to evaluate for arterial pulsatility and cardiac recovery. The absence of spontaneous heart beat, cardiac wall motion or pulsatility on the arterial line after 24 h was an indication for termination of cardiopulmonary support. If the patient recovered neurologically, but still required cardiac support after 96 h, we began evaluation for left ventricular assist device.

We performed functional and neurological testing using modified Rankin score in patients who survived to hospital discharge. We also conducted routine telephone follow up to assess functional recovery.

**Statistical analysis**

Continuous variables are summarized as median and interquartile range [IQR]; categorical variables are presented as frequency and percentage of total. Data analyses were performed using Microsoft Excel ver 2007.

**Results**

Over 30 months, from October 1st 2015 until March 31st 2018, EMS responded to and attempted resuscitation for a total of 1165 OHCA. EMS transported 664 (57%) cases with 120 coming to our institution. Of these 120 patients, only 5 met our criteria for ECPR. Of the remaining 115 patients, 64 (53%) had nonshockable rhythms, 48 (40%) were unwitnessed, 50 (42%) were above age 60 and 20 (17%) had no documented reasons for exclusion.

The 5 patients transported to our institution who met criteria for our protocol were treated with ECPR. Demographic data are shown in Table 2. Median pre-hospital CPR duration was 26 [IQR 25–40] min. Interval from arrest until EMS arrival on scene was 5 [IQR 4–6] min, and from arrival on scene to contacting command physicians was 13 [IQR 7–21] min. Interval from arrival on scene to beginning transport to the hospital was 20 [IQR 19–21] min and from EMS dispatch to initiation of ECMO was 63 [IQR 59–69] min (see Table 3).

All patients underwent cannulation in the ED. The first patient was unable to be successfully cannulated and due to concern for vascular injury resuscitative efforts were terminated. Another patient had injury to the femoral artery during cannulation which was successfully
Successful team development necessitates buy in from the institution, as well as key faculty who regularly care for ECMO patients and a physician champion to lead the team.\(^6,\text{8,13,14}\)

We developed our team from providers in cardiothoracic surgery with the support of critical care medicine, who function as the primary provider and in our institution are credentialed to cannulate for ECMO. We involved individuals from cardiology including interventional cardiology, cardiac intensive care and cardiac transplant services as these patients may also need evaluation for left ventricular assist devices. Neurologic prognostication can be challenging following arrest and to address this we included providers from our PCAS. Pre-hospital care was coordinated by Pittsburgh EMS leadership as well as providers from Medic Command.

### Challenges in field resuscitation

Resuscitation in the field is performed by local EMS teams. There are a number of items that need to be assessed while performing CPR, but first, appropriate patient identification is necessary. Not all arrests are appropriate for ECMO, and as we identified, only 57% of patients were transported to the hospital. Of the patients that do not achieve ROSC and are pronounced dead at the scene, a small but significant percentage is likely to have benefited from ECMO.\(^15,16\) It is difficult to identify these patients; however characteristics that increase the likelihood of a cardiopulmonary etiology and improved survival include initial shockable rhythm, complaint of dyspnea or angina and witnessed arrest with bystander CPR.\(^17\)

However, a recent study by Pabst et al, demonstrated improved survival of ECPR patients who presented with pulseless electrical activity (PEA) compared to asystole.\(^18\) They noted a higher prevalence of electrolyte abnormalities and the need for continuous renal replacement therapy in the PEA group, suggesting ECPR could be used to stabilize a patient while buying time to identify the diagnosis and correct the underlying metabolic derangement. Due to the complexity of patient selection and the challenge of limiting our patient cohort to those with initial shockable rhythms we may have been over selective and excluded these patients who may have benefited from ECPR.

Pre-hospital provider education was also a challenge. Our catchment area is composed of 88 neighborhoods which are covered by 14 EMS units.\(^19\) Education was provided to EMS leadership, disseminated to local teams, presented at quarterly EMS meetings, and finally to emergency medicine residents who also respond to OHCA. Incomplete dissemination of our protocol may have contributed to lower enrollment; however, by offering additional presentations, continued presence at community arrests by the emergency medicine residents and more time since initial roll out, knowledge of our protocol has since grown.

### Table 3 - Resuscitation characteristics and clinical outcomes.

| Complication | Patients
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Interval from 911 call to EMS arrival (min)</td>
<td>5 (4 – 6)</td>
</tr>
<tr>
<td>Interval arrival to command MD notified (min)</td>
<td>13 (7 – 21)</td>
</tr>
<tr>
<td>Interval arrival to leave scene (min)</td>
<td>20 (19 – 21)</td>
</tr>
<tr>
<td>Interval arrival to arrival at hospital (min)</td>
<td>34 (30 – 45)</td>
</tr>
<tr>
<td>Re-arrest</td>
<td>2 (40%)</td>
</tr>
<tr>
<td>Number of defibrillations</td>
<td>5 (3 – 6)</td>
</tr>
<tr>
<td>Number of epinephrine doses</td>
<td>6 (6 – 7)</td>
</tr>
<tr>
<td>Interval arrival at ED to cannulation complete (min)</td>
<td>21 (16 – 33)</td>
</tr>
<tr>
<td>Interval EMS arrival to ECPR initiated (min)</td>
<td>63 (59 – 69)</td>
</tr>
<tr>
<td>Initial laboratory values</td>
<td></td>
</tr>
<tr>
<td>Lactate</td>
<td>11 (10 – 13)</td>
</tr>
<tr>
<td>pH</td>
<td>7.27 (7.19 – 7.33)</td>
</tr>
<tr>
<td>HCO\textsubscript{3}</td>
<td>15 (14 – 16)</td>
</tr>
<tr>
<td>Cr</td>
<td>1.5 (0.9 – 2.2)</td>
</tr>
<tr>
<td>AST</td>
<td>330 (281 – 365)</td>
</tr>
</tbody>
</table>

Data expressed as number followed by interquartile range or percentage.
EMS, emergency medical services; ECPR, extracorporeal cardiopulmonary resuscitation; ECMO, extracorporeal membrane oxygenation; AKI, acute kidney injury; PCI, Percutaneous coronary intervention.

Discussion

ECPR programs are challenging to develop and implement. The most important and arguably most challenging aspect is identifying all of the team members and having them agree to participate. Care of this patient occurs in multiple settings including the community, ED, and ICU. Additionally, the patient will undergo multiple procedures including ECMO cannulation and coronary angiography. As such, the patient will benefit from a team with the capabilities to care for the patient in these settings and readily perform these procedures.\(^7,9\)

### Table 4 - Patient outcomes.

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age (yrs)</th>
<th>Sex</th>
<th>Etiology</th>
<th>Complications</th>
<th>ECMO duration (h)</th>
<th>Survival</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>32</td>
<td>M</td>
<td>Dysrhythmia</td>
<td>Aortic injury</td>
<td>0</td>
<td>N</td>
</tr>
<tr>
<td>2</td>
<td>47</td>
<td>F</td>
<td>Dysrhythmia</td>
<td>AKI, shock liver, CNS hemorrhage</td>
<td>38</td>
<td>N</td>
</tr>
<tr>
<td>3</td>
<td>26</td>
<td>M</td>
<td>Dysrhythmia, hypothermia</td>
<td>None</td>
<td>74</td>
<td>Y</td>
</tr>
<tr>
<td>4</td>
<td>53</td>
<td>M</td>
<td>Acute coronary syndrome</td>
<td>Femoral artery injury, shock liver, AKI, sepsis</td>
<td>68</td>
<td>Y</td>
</tr>
<tr>
<td>5</td>
<td>57</td>
<td>M</td>
<td>Acute coronary syndrome</td>
<td>AKI, shock liver, withdrawal support</td>
<td>48</td>
<td>N</td>
</tr>
</tbody>
</table>

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Performing CPR in the back of moving ambulance is potentially harmful to the patient and provider. Prior evidence shows mixed results as to whether quality remains the same during transport,\(^{20,21}\) thus, transportation while performing CPR is not routinely performed. Mechanical CPR has been shown as a safe alternative to conventional CPR\(^{22}\) and is supported by guidelines for use while transporting the patient.\(^{23}\) However, mechanical CPR devices, are not widespread and if the responding EMS team did not have one of these devices, there may have been a delay in transport until another team arrived with one. In our system, the emergency medical resident team has a mechanical CPR device available which should have minimized this delay if it occurred.

Delays due to time management can also occur. Recent guidelines have encouraged time from arrest to establishment of circulation with ECMO to be 60 min\(^{24}\) and Kim et al., demonstrated improved survival in those treated with ECPR within 21 min of beginning CPR by a healthcare provider.\(^{25}\) emphasizing the need for early transport. Unfortunately, there are several fixed time periods that occur once EMS dispatch is notified, such as time to arrive on scene and the time to transport to the hospital, both of which may take 5–10 min. Delays may also develop as a result of communication with Medic Command physicians. Having a clear set of easily identifiable criteria will help minimize this delay and avoid confusion as to whether to stay or go. As this is a modifiable criterion, we encourage our EMS providers to notify medic command and transport as soon as possible. That said, current Pennsylvania state regulations recommend EMS teams perform 10 min of CPR prior to moving the patient.\(^{26}\) This represents a classical teaching that has been drilled into providers causing not only a delay in transportation, but also a potential cultural hurdle as one must question the “stay and play” vs. “load and go” mentality.

Finally, as we noted in our study, there is significant variability in destination hospitals. Prior published data from our center\(^{27}\) demonstrates a survival benefit in patients who are treated at a cardiac arrest center, which is a center with a dedicated post cardiac arrest service that is able to provide evidenced based post-arrest care. Prior studies have demonstrated that academic, high volume, tertiary care centers may provide post-arrest care but are inferior to a dedicated post arrest service.\(^{28,29}\) This becomes increasingly more important when discussing the use of ECPR, not only a more specialized procedure but also more resource intensive. Unfortunately, a major challenge we encountered was the initial transportation to the nearest hospital, more of a cultural normal within our EMS system. Our facility is located within a 10 mile radius of eight other hospitals, raising the question why transport to our hospital when “outside hospital” is just down the street. Future guidelines will likely address the benefit of post arrest care at a cardiac arrest center; however transportation to the nearest hospital for stabilization has been the standard practice for years and represents a strong cultural bias that will be difficult to change.

### Challenges during cannulation

The procedure of cannulation itself is also a challenge. Percutaneous cannulation is more appropriate for OHCA then central cannulation as it allows for continued CPR during the procedure. Cannulation is performed with ultrasound or direct visualization of the vasculature via cut-down.\(^{8,30}\) Access sites are the common femoral artery and vein. Alternative sites such as internal jugular vein and subclavian artery are available, but are more challenging due to ongoing CPR. Vascular injury is an uncommon complication, but can occur during this time and delay cannulation times. In our patients, cannulation was performed within 15 min, similar to previously reported studies.\(^{30–32}\)

During the chaos of an ongoing resuscitation it can be difficult for the ECPR team to function efficiently, thus it is important to have predefined roles. Our team is composed of one physician from the ED or PCAS who leads the resuscitation and establishes an advanced airway, two physicians who perform cannulation, two cardiothoracic ICU nurses, and a perfusionist to assist with starting the ECMO pump. Additionally, the team is supported by staff in the ED such as nurses who assist with medication administration and record keeping, as well as respiratory therapy to assist with ventilator and airway management.

### Challenges in post-resuscitation care

Care of any patient following resuscitation, let alone treated with ECPO, poses a special set of challenges. Patients are prone to developing respiratory failure, infection, and kidney injury.\(^{33}\) Furthermore, these patients are also at risk for complications directly related to ECMO such as cannulation site bleeding, gastrointestinal bleeding, limb ischemia, and central nervous system infection or hemorrhage.\(^{3,34}\)

Additionally, ethical considerations surrounding neurologic and cardiac prognostication must be taken into account. Upon instituting ECPR, surrogate decision makers are informed of a ≥6 h window of support to allow for neurologic recovery. The presence of a catastrophic neurologic event on imaging study, EEG findings consistent with myoclonic status epilepticus, bilaterally absent N20 SSEP waves or absent papillary reflex by 72 h are indications of poor neurologic prognosis.\(^{35}\) If any of these occurred, next of kin was informed and cardiopulmonary support was withdrawn.

Cardiac prognostication may be more challenging. One scenario is the patient who has recovered neurologically, but failed to wean from ECMO. At this point the decision is either to withdraw from cardiopulmonary support, continue on for several more days with hope of recovery or proceed with LVAD implantation. There is no clear timeline of when to transition from ECMO to ventricular assist device or transplant. Implantation of LVAD has not been well described in the OHCA population, however follow up studies of survivors from in-hospital ECPR report transition to LVAD and transplant as 5% and 9–10%, respectively.\(^{36,37}\)

Finally, the question of using ECPR as a bridge to organ donation has also arisen. Brain dead patients following ECPR may be candidates for organ donation. However, organ donation following refractory cardiac arrest, termed uncontrolled donation after circulatory determination of death (uCDDD), is more complex. Recently, ECMO has been used as a bridge to transplantation in this setting, known as normothermic regional perfusion (nRP), where femoral-femoral cannulation is applied with mechanical occlusion of the aorta to selectively perfuse the abdominal organs.\(^{38}\) Its use can lead to expanded donor pools and improved long-term organ function.\(^{39}\) Many of the ethical concerns surrounding ECMO as a resuscitative strategy vs. means of perfusing organs prior to donation. Both, ECPR and uCDDD programs can exist at the same institution,\(^{40}\) however if there is no contraindication to ECPR, the goal should always be resuscitation first.
Conclusion

The goal of our ECPR program was to test its feasibility in our healthcare system. It proved to be both feasible and safe; however we encountered a significant number of challenges. Logistical challenges such as rapid deployment of a mechanical CPR device or procedural challenges such as who performs ECMO cannulation, can be anticipated and appropriately addressed. Other challenges such as whether to transport a patient to a local hospital two minutes away or a cardiac arrest center 15 min away are more difficult to address. Before the practice of ECPR can become routine, further study is needed as well as additional support from both guidelines and healthcare system leadership. In the meantime, we hope these lessons may provide some guidance to help others navigate the challenges in their own healthcare system.

Conflicts of interest

The authors disclose that there are no potential conflicts of interest.

REFERENCES


