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## Practice Characteristics of Emergency Department Extracorporeal Cardiopulmonary Resuscitation (eCPR) Programs in the United States: The Current State of the Art of Emergency Department Extracorporeal Membrane Oxygenation (ED ECMO)

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None of the authors declares any conflict of interest.

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**Abstract**

**Purpose**—To characterize the current scope and practices of centers performing extracorporeal cardiopulmonary resuscitation (eCPR) on the undifferentiated patient with cardiac arrest in the emergency department.

**Methods**—We contacted all US centers in January 2016 that had submitted adult eCPR cases to the Extracorporeal Life Support Organization (ELSO) registry and surveyed them, querying for programs that had performed eCPR in the Emergency Department (ED ECMO). Our objective was to characterize the following domains of ED ECMO practice: program characteristics, patient selection, devices and techniques, and personnel.

**Results**—Among 99 centers queried, 70 responded. Among these, 36 centers performed ED ECMO. Nearly 93% of programs are based at academic/teaching hospitals. 65% of programs are less than 5 years old, and 60% of programs perform 3 cases per year. Most programs (90%) had inpatient eCPR or salvage ECMO programs prior to starting ED ECMO programs. The majority of programs do not have formal inclusion and exclusion criteria. Most programs preferentially obtain vascular access via the percutaneous route (70%) and many (40%) use mechanical CPR during cannulation. The most commonly used console is the Maquet Rotaflow®. Cannulation is most often performed by cardiothoracic (CT) surgery, and nearly all programs (>85%) involve CT surgeons, perfusionists, and pharmacists.

**Conclusions**—Over a third of centers that submitted adult eCPR cases to ELSO have performed ED ECMO. These programs are largely based at academic hospitals, new, and have low volumes. They do not have many formal inclusion or exclusion criteria, and devices and techniques are variable.

### Keywords

Extracorporeal cardiopulmonary resuscitation—eCPR; Emergency department extracorporeal membrane oxygenation—ED ECMO; Out-of-hospital cardiac arrest—OHCA; In-Hospital Cardiac Arrest—IHCA; Program characteristics; Extracorporeal life support—ECLS

## Introduction

The use of extracorporeal life support for adult patients in acute cardiopulmonary arrest is increasing, and was recently added as a consideration for treatment of refractory cardiac arrest by the American Heart Association (AHA).<sup>1</sup> Compared to traditional closed chest cardiopulmonary resuscitation (CPR), which results in a low flow perfusion state<sup>2,3</sup> with time-limited outcomes,<sup>3</sup> extracorporeal CPR provides near-full to full cardiopulmonary support without the physical trauma of chest compressions.<sup>4</sup> This may facilitate treatments that are otherwise precluded by standard CPR, such as angiography or other diagnostic imaging; therefore extracorporeal cardiopulmonary resuscitation (eCPR) has been proposed as ideal for patients in refractory cardiac arrest failing traditional CPR.<sup>5</sup> For both in- and out-of-hospital cardiac arrest (IHCA and OHCA) treated with eCPR published survival ranges from 13–54%.<sup>6–11</sup> While this range is generally equal or superior to the aggregate survivals of 9% and 20% from conventional CPR of OHCA and IHCA,<sup>12,13</sup> respectively, the breadth may reflect heterogeneity in arrest etiology, patient selection and management.

The advantages of applying extracorporeal life support (ECLS) utilizing veno-arterial extracorporeal membrane oxygenation (VA-ECMO) during cardiopulmonary arrest include stable and augmented perfusion, allowing providers to cease external chest compressions, which in turn decreases trauma,<sup>4</sup> stress,<sup>14–16</sup> frequent interruptions, and resultant low flow state of manual external chest compressions;<sup>2</sup> disadvantages include increased cost, resources, and care complexity. Unfortunately, the cost/benefit of eCPR compared to conventional CPR is not known, as most studies are retrospective<sup>10,17,18</sup> or observational,<sup>8,11</sup> and few control for or describe cannulation techniques or post-cannulation management;<sup>6</sup> as such, there is a profound knowledge gap around the absolute benefit, use appropriateness

and ideal patient management of eCPR, which may lead to inappropriate use and outcome disparities.

In an effort to increase use appropriateness of eCPR, we sought to first characterize the existing practices of centers performing eCPR on the undifferentiated patient in cardiac arrest. We also sought to describe the characteristics of programs in the US that perform Emergency Department ECMO (ED ECMO), including case volume, patient selection criteria, involved personnel, cannulation processes, hardware selection and post-cannulation management.

## Methods

### Study Design

This was a prospective survey sent to the publically listed program representatives about a hospital program. This project did not meet the definition of human subject research. No previous published surveys of eCPR team composition or management were found to validate; questions were developed by consensus from a convened group of recognized resuscitation experts and from described characteristics of eCPR programs.<sup>7–9,11,19–21</sup> Questions were refined and reviewed by the senior researchers of the ERECT Collaborative.

### Setting

We contacted all US centers that have submitted adult eCPR cases to the Extracorporeal Life Support Organization (ELSO) international patient registry and surveyed them, identifying programs that had performed eCPR in the Emergency Department (ED) as most exemplary of the fully undifferentiated cardiac arrest patient. While a survey of IHCA eCPR patient selection, application characteristics, and management in the US would increase the pool for analysis, we sought to isolate the use of eCPR in the ED because of the recognition that patients who suffer IHCA often have previous diagnoses, and a higher chance of being peri-operative, which necessarily guides the post arrest management and treatment.

### Data Collection

We administered an online survey (SurveyMonkey Inc., Palo Alto, California, USA) through an email sent to the publically listed Program Director and Program Coordinator in January, 2016 for all centers (97) that had submitted adult eCPR cases to ELSO. Additional emails were sent to select centers (2) who had published on or discussed ED ECMO use at national conferences or on social media, as determined by the authors.<sup>7,22</sup> Follow up “2<sup>nd</sup> Notice” emails were sent to all centers who had not responded to the survey after two weeks, based on data suggesting that one followup provides the highest yield for physician surveys.<sup>23</sup> This tailored approach resulted in 4 personalized emails going to each program—the suggested near maximum yield for physician surveys<sup>24</sup>—and avoided overburdening any one person. No other means was used to contact the programs. The survey was closed after 2 months, when there were no on-going responses and a 70% response rate—above the accepted standard for online survey response rates.<sup>24,25</sup> The 2 month duration was based upon our estimate of our population, and by referencing published standards for duration and cost effectiveness of online surveys.<sup>24,25</sup> The survey described the purpose of the inquiry, that

aggregated results would be analyzed, and results released back to the participants. The survey was sent on behalf of the authors and members of the Extracorporeal RESuscitation Consortium (ERECT), a multi-institutional collaborative research group focused on advancing the science and practice of eCPR. The survey consisted of demographics and contact information, followed by 30 multiple-choice questions; most included a space for “Other” with an associated free text response box. Data were not collected on patient survival/success rate, as survey respondents were individually identifiable through the tool, and we felt this fact may dissuade participation and honest responses. A final general free text response box was also included. The questions are entirely reflected in Tables 1–3. No question was required. After demographics were collected, the survey asked programs to continue through the full survey only if they had done eCPR in the ED. Determination of academic / teaching-hospital vs non-teaching hospital was made by review of the public website of each institution or phone call to the program coordinator when this was not clear.

### Statistical Analysis

Data were summarized as absolute values and percentages. Geography, services involved throughout the ECMO process, and numerical values of PTT, ACT and anti-factor Xa were displayed graphically. All responses are included, edited for clarity, with “Other” responses summarized in Results. The analysis group was geographically placed (Figure 1) but then de-identified for further analysis. Data are presented in Figures 2–3 and Tables 1–3.

## Results

### Program Characteristics

Among 99 centers contacted, there were 70 unique centers that responded. Among all respondents, 36 centers (analysis group) had performed eCPR in the ED. For the manuscript, this group is referred to as having an ED ECMO program, regardless of program formality.

A total of 93% of all programs (n=36) are academic or teaching hospitals, yet only 38% describe themselves as having a “formal” ED ECMO program to place eCPR in the ED. Programs are generally new, with >65% of programs 5 years old, and 45% 3 years old. Furthermore, 60% of programs perform 3 cases per year. It should be noted that the vast majority of programs (~90%) had both intensive care unit (ICU) based, and salvage ECMO (ECMO placed when cardiopulmonary collapse is imminent)/eCPR for in-patients and the operating room before starting their ED ECMO program (Table 1).

### Patient Selection

The majority of programs do not have many formal inclusion and exclusion criteria (Table 2). Almost all programs included patients with cardiac arrest and an initial shockable rhythm, but around half included non-shockable initial rhythms, respiratory arrests, hypothermia and drug overdoses. Not surprisingly, a thin majority of programs also performed salvage ECMO on ED patients with cardiogenic shock and pulses as part of their ED ECMO program. The majority of programs (>60%) did not have an upper age exclusion limit of >70 years, many did not exclude patients with unwitnessed arrest (44%) or without bystander CPR (>60%). More surprising is how many did not formally exclude patients with

>10min of no CPR (~70%), concomitant major trauma (>50%), or known significant medical comorbidities, such as cachexia, obesity or pre-existing renal failure (85–95%). Aggregate examples of exclusion criteria volunteered by respondents included: low exhaled end-tidal carbon dioxide (EtCO<sub>2</sub>) or poor quality CPR, recent thrombolytics, physician discretion, documented intracranial hemorrhage, or out of hospital arrest.

### Devices and Techniques

Nearly 40% of programs use automated compression devices during cannulation, and >70% obtain vascular access percutaneously. Over 30% of programs utilize more protocols for their ED ECMO resuscitations compared to standard resuscitations. Of note, while 36% of programs perform a surgical cut-down to the femoral vessels, nearly 25% perform a modified cut-down, a hybrid of percutaneous and cut down, in which the percutaneous approach enters the vessels within the cut-down site.

A plurality of programs utilizes the Maquet Rotaflow® console (41%, Table 3), a small centrifugal pump console, which may be due to the comparative cost of the Rotaflow®.<sup>26</sup> Almost all programs utilize distal limb perfusion catheters, which are equally likewise placed by cardiothoracic (CT) surgery. The majority of programs systematically assess for left ventricular over-distension, and use of a left ventricular impellar-type decompression pump or an atrial septostomy are common ways to decompress. Among the “Other” category, 8 programs volunteered that they place a left ventricular or left atrial vent in a “Y” configuration with the venous cannula. While multiple approaches and methods have been described,<sup>27</sup> for percutaneous VA ECMO this is generally a femoral venous approach percutaneous cannula (8–15 Fr) passed across the atrial septum into the left atrium and connected to the pre-pump side of the ECMO circuit in order to continuously aspirate blood.

All programs used anticoagulation (not shown) and most programs begin anticoagulation around the time of vascular access or dilation (Table 3). The choice of anticoagulant varied highly, as did the target ranges for laboratory monitoring (Figure 3). First line anticoagulant medications included unfractionated heparin (60%) and bivalirudin (10%), whereas bivalirudin and argatroban were often second line (>50% and 29%, respectively), whereas low molecular weight heparin (LMWH) and coumadin were almost never used. Programs used a variety of laboratory tests for monitoring anticoagulation levels for each anticoagulant that was used.

### Personnel

Nearly all ED ECMO programs (>85%) involve CT surgery, perfusion, and pharmacy and most (70%) involve emergency medicine (Table 2). Unsurprisingly, as ECMO in adults has historically been managed by cardiothoracic surgery, in the vast majority of programs surveyed, the cannula is placed by CT surgery, with only 4 programs having emergency medicine physicians cannulate (Table 1). In up to 45% of ED ECMO programs, cardiology/interventional cardiology is not defined as “always” involved. Over half of programs (60%) neither involve neurology nor palliative care. Very few programs (2, 6%) operate without regular perfusion involvement.



## Discussion

In an effort to further the study of eCPR and therefore use appropriateness, we sought to characterize eCPR practice patterns and current use for the undifferentiated cardiac arrest in the US. Attempts have been made to characterize practices surrounding eCPR by systematically reviewing the literature,<sup>28</sup> but unfortunately, to date, the eCPR literature is mostly single center with limited descriptions of team composition or management and we found no eCPR practice surveys. To our knowledge, our study is the first to describe in detail the practice and program characteristics of centers actively performing eCPR on undifferentiated patients in cardiac arrest in the emergency department. We identified 36 centers that are actively engaged in providing ED eCPR in the United States. Nearly all centers are academic or teaching, and involve the core services of CT surgery, perfusion and pharmacy, with most cannulations performed by CT surgery and only rarely by emergency physicians. Few programs are formally multidisciplinary, but a majority have similar pericannulation and core management similarities, including exclusion criteria, cannula size, separation of the cannulation procedure from the resuscitation, and the use of anticoagulation, though differences exist in post cannulation management, including drug selection, routine cardiac catheterization and left ventricular decompression.

### Patient Selection

Patient selection practices are highly varied. The significance of the general lack of strict selection criteria to identify arrest etiologies or patient types may signify that most ED ECMO programs in the US are not systematically targeting a particular patient type or post-ECMO therapy. It is not clear from our study whether a lack of inclusion and exclusion criteria imply a lack of post eCPR etiology targeted therapies, such as coronary revascularization, pulmonary thrombectomy or toxin hemodialysis, though we did observe that coronary angiography is only used “always” in 4 (12%) of programs. Though in light of the broad inclusion criteria of our study group and resultant heterogeneity of arrest etiologies, the necessity of requiring angiography after every eCPR can be debated. Publications of eCPR include heterogeneous etiologies ranging from hypothermia to refractory arrhythmias,<sup>6,9</sup> with some of the best outcomes in those series with narrow inclusion criteria and multidisciplinary coordinated therapies post eCPR.<sup>6,9</sup> Without strict inclusion and exclusion criteria, it is unlikely that a homogenous population will be captured in any eCPR program. Juxtaposed to this is the observation that higher volume ECMO centers have been associated with improved outcomes.<sup>29</sup>

### Devices and Techniques

The majority of cannulations in our study occurred via the percutaneous peripheral route. Traditionally, ECMO cannulations were performed centrally during cardiopulmonary bypass surgery, or peripherally via surgical cutdown. Since the 1990s, use of the peripheral percutaneous approach for patients not undergoing cardiopulmonary bypass has increased in usage.<sup>30</sup> For peripheral VA-ECMO in adults, access is mostly commonly femoral,<sup>31,32</sup> with other peripheral locations (axillary<sup>33</sup>) and methods (triple wire<sup>34</sup>) described. For emergent VA cannulations, the peripheral femoral approach predominates in adults.<sup>7–10,21,31,35,36</sup> Given the known risk of vascular injury, ischemia and edema associated with femoral

cannulations,<sup>32,35,37</sup> it is not surprising that vascular surgery is involved in >25% of US programs.

## Personnel

In our study, cardiothoracic surgeons perform cannulation at most centers, though several report cannulation by emergency physicians. We also found that most programs limit mandated personnel to the specialties of CT surgery, perfusion and pharmacy, with emergency physicians and cardiologists “always” involved in <50% and <20% of the programs, respectively.

We could not find clear published documentation of ECMO team composition for eCPR. First described in 1966 by a surgeon,<sup>38</sup> the first eCPR/salvage ECMO case series was published by a thoracic surgeon in the 1970s.<sup>39</sup> Subsequent series from thoracic surgeons and cardiologists were published in the 1990s,<sup>40,41</sup> followed by the first publication by an emergency physician in 1997.<sup>42</sup> While there were notable subsequent larger series of eCPR<sup>43</sup> and a prospective observational study in 2008,<sup>8</sup> the next publication of emergency physician-initiated eCPR for OHCA was not published until 2012.<sup>7,19</sup> Since that time, team composition for emergency department eCPR has not well characterized. This is the first study to describe in detail emergency department eCPR team composition and roles. Given the potential complexity of care coordination for post-eCPR interventions (*ex*: angiography, LV decompression) and management, we agree that a rehearsed and multidisciplinary team approach to the entire ED ECMO process may be best for patient care.<sup>5</sup>

In summary, we present the first national survey of ED ECMO practices in the US. We have demonstrated that this practice is in its infancy in the United States, and optimal patient selection, techniques, and personnel are still being defined. Most importantly, because ED ECMO provides cardiopulmonary support, but may not reverse the cause of the arrest, we submit that that the range of survival observed through published eCPR cases could be improved through defined matching of eCPR to therapies directed at identification and reversal of the arrest. We agree with previous suggestions that this is most easily achieved through studies focusing on narrow selection criteria to isolate arrest etiologies.<sup>5</sup> This may be best demonstrated in the CHEER trial, where eCPR was followed by angiography, revascularization and hypothermia, and in 51% of patients who underwent coronary angiography, a culprit lesion was identified and opened.<sup>21</sup>

Lastly, our study demonstrated that even among the low numbers of ED ECMO at many centers, nearly all centers had experience with ICU based and inpatient eCPR/salvage ECMO before expanding to the ED. We advocate that given the complexity of eCPR and the association of higher volume ECMO with improved outcomes,<sup>29</sup> that use appropriateness of eCPR and ED ECMO be studied in experienced, high volume centers. We do not yet know if eCPR is superior to traditional CPR for cardiac arrest, or only superior in those with refractory cardiac arrest. We call for structured randomized clinical trials among experienced centers with strict inclusion and exclusion criteria, structured cannulation processes and post arrest management derived from those programs with the best published eCPR outcomes.

## Limitations

The survey was generated based on published characteristics of eCPR series and studies in the literature, but not previously validated. We would encourage further studies to use our survey and validate it, which we will provide. As may be noted from the Discussion, we did not define ED ECMO as only applying to OHCA patients. Of note, only two centers listed OHCA as exclusion for eCPR. One short coming was that the definitions of some terminology were not specified; for example, the term “involvement” varied, such that while 70% of respondents reported that patients would “always” or “as needed” go to the cardiac catheterization laboratory after ED ECMO, 45% of programs also reported that cardiology/interventional cardiology was not involved throughout the entire ED ECMO process. It seems that either other services are performing the cardiac catheterization, or many programs operate with auxiliary support services that are not considered to be involved throughout the entire eCPR/ED ECMO program.

## Conclusions

Among all centers submitting eCPR cases to the ELSO registry, approximately one-third have performed eCPR in the ED. Among these, the majority expanded from in-patient salvage ECMO, also perform in-patient eCPR, and do not have many formal inclusion or exclusion criteria. We hope that describing the national landscape brings awareness to this growing rescue technique, and enables emerging programs to refine their approaches.

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## References

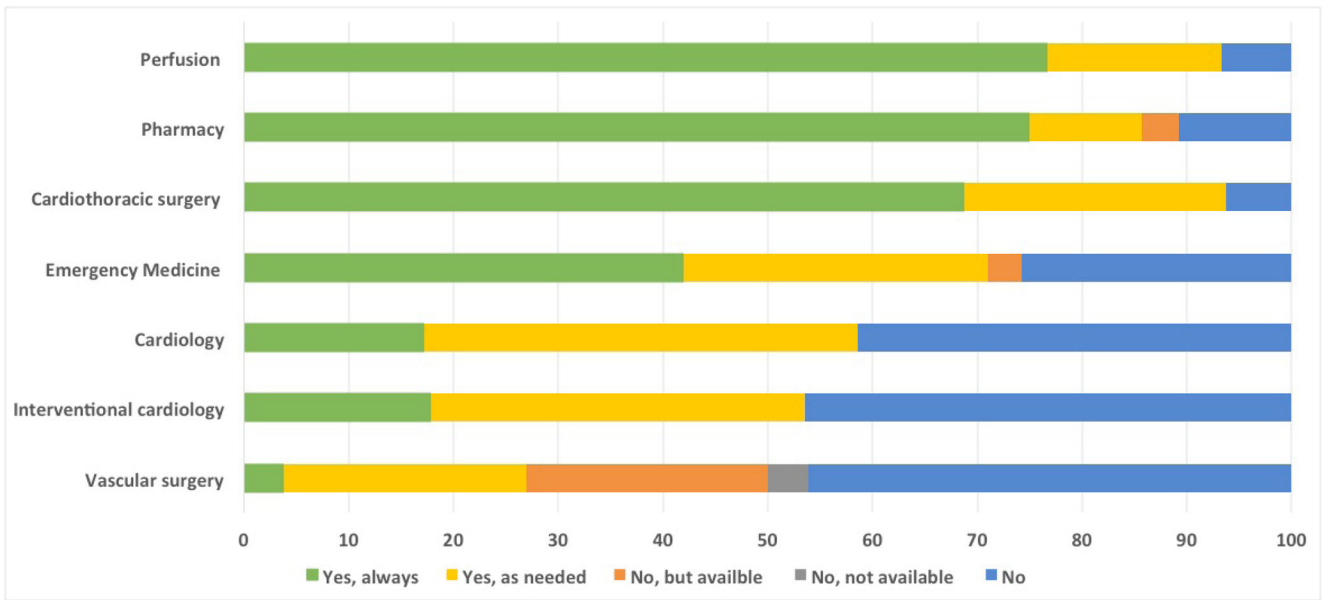
1. Brooks SC, Anderson ML, Bruder E, et al. Part 6: Alternative Techniques and Ancillary Devices for Cardiopulmonary Resuscitation. *Circulation*. 2015; 132(18 suppl 2):S436–S443. [PubMed: 26472994]
2. Berg RA, Sanders AB, Kern KB, et al. Adverse hemodynamic effects of interrupting chest compressions for rescue breathing during cardiopulmonary resuscitation for ventricular fibrillation cardiac arrest. *Circulation*. 2001; 104(20):2465–2470. [PubMed: 11705826]
3. Goto Y, Funada A, Goto Y. Relationship Between the Duration of Cardiopulmonary Resuscitation and Favorable Neurological Outcomes After Out-of-Hospital Cardiac Arrest: A Prospective, Nationwide, Population-Based Cohort Study. *Journal of the American Heart Association*. 2016; 5(3):e002819. [PubMed: 26994129]
4. Ihnát Rudinská L, Hejna P, Ihnát P, Tomášková H, Smatanová M, Dvořák I. Intra-thoracic injuries associated with cardiopulmonary resuscitation - Frequent and serious. *Resuscitation*. 2016; 103:66–70. [PubMed: 27095124]
5. Müller T, Lubnow M. The future of E-CPR: A joint venture. *Resuscitation*. 2013; 84(11):1463–1464. [PubMed: 23954661]

6. Stub D, Bernard S, Pellegrino V, et al. Refractory cardiac arrest treated with mechanical CPR, hypothermia, ECMO and early reperfusion (the CHEER trial). *Resuscitation*. 2015; 86:88–94. [PubMed: 25281189]
7. Bellezzo JM, Shinar Z, Davis DP, et al. Emergency physician-initiated extracorporeal cardiopulmonary resuscitation. *Resuscitation*. 2012; 83(8):966–970. [PubMed: 22306260]
8. Chen Y-S, Lin J-W, Yu H-Y, et al. Cardiopulmonary resuscitation with assisted extracorporeal life-support versus conventional cardiopulmonary resuscitation in adults with in-hospital cardiac arrest: an observational study and propensity analysis. *The Lancet*. 2008; 372(9638):554–561.
9. Fagnoul D, Taccone FS, Belhaj A, et al. Extracorporeal life support associated with hypothermia and normoxemia in refractory cardiac arrest. *Resuscitation*. 2013; 84(11):1519–1524. [PubMed: 23816899]
10. Johnson NJ, Acker M, Hsu CH, et al. Extracorporeal life support as rescue strategy for out-of-hospital and emergency department cardiac arrest. *Resuscitation*. 2014; 85(11):1527–1532. [PubMed: 25201611]
11. Sakamoto T, Morimura N, Nagao K, et al. Extracorporeal cardiopulmonary resuscitation versus conventional cardiopulmonary resuscitation in adults with out-of-hospital cardiac arrest: a prospective observational study. *Resuscitation*. 2014; 85(6):762–768. [PubMed: 24530251]
12. Mozaffarian D, Benjamin EJ, Go AS, et al. Heart disease and stroke statistics-2015 update: a report from the American Heart Association. *Circulation*. 2015; 131(4):e29–e322. [PubMed: 25520374]
13. Girotra S, Nallamothu BK, Spertus JA, Li Y, Krumholz HM, Chan PS. Trends in Survival after In-Hospital Cardiac Arrest. *The New England Journal of Medicine*. 2012; 367(20):1912–1920. [PubMed: 23150959]
14. Hunziker S, Semmer NK, Tschan F, Schuetz P, Mueller B, Marsch S. Dynamics and association of different acute stress markers with performance during a simulated resuscitation. *Resuscitation*. 2012; 83(5):572–578. [PubMed: 22115935]
15. Hunziker S, Pagani S, Fasler K, Tschan F, Semmer NK, Marsch S. Impact of a stress coping strategy on perceived stress levels and performance during a simulated cardiopulmonary resuscitation: a randomized controlled trial. *BMC Emergency Medicine*. 2013; 13(1):8. [PubMed: 23607331]
16. Hunziker S, Laschinger L, Portmann-Schwarz S, Semmer NK, Tschan F, Marsch S. Perceived stress and team performance during a simulated resuscitation. *Intensive Care Medicine*. 2011; 37(9):1473–1479. [PubMed: 21695475]
17. Choi DS, Kim T, Ro YS, et al. Extracorporeal life support and survival after out-of-hospital cardiac arrest in a nationwide registry: A propensity score-matched analysis. *Resuscitation*. 2016; 99:26–32. [PubMed: 26683472]
18. Shin TG, Jo IJ, Sim MS, et al. Two-year survival and neurological outcome of inhospital cardiac arrest patients rescued by extracorporeal cardiopulmonary resuscitation. *International Journal of Cardiology*. 2013; 168(4):3424–3430. [PubMed: 23664696]
19. Shinar Z, Bellezzo J, Paradis N, et al. Emergency department initiation of cardiopulmonary bypass: a case report and review of the literature. *JEM*. 2012; 43(1):83–86.
20. Paden ML, Conrad SA, Rycus PT, Thiagarajan RR. Extracorporeal Life Support Organization Registry Report 2012. *ASAIO Journal*. 2013; 59(3):202–210. [PubMed: 23644605]
21. Stub D, Bernard S, Pellegrino V, et al. Refractory cardiac arrest treated with mechanical CPR, hypothermia, ECMO and early reperfusion (the CHEER trial). *Resuscitation*. 2014:1–7.
22. Shinar, Z., Bellezzo, JM., Weingart, SD. [Accessed January 31, 2016] ED ECMO. ED ECMO. Audio-Podcast <http://edecmo.org/category/podcasts/>
23. Willis GB, Smith T, Lee HJ. Do Additional Recontacts to Increase Response Rate Improve Physician Survey Data Quality? *Medical Care*. 2013; 51(10):945–948. [PubMed: 23969583]
24. Dillman, DA., Smyth, Jolene D., Christian, Leah M. *Internet, Mail, and Mixed Mode Surveys: The Tailored Design Method*. 3. New York: John Wiley & Sons; 2009.
25. Klabunde CN, Willis GB, McLeod CC, et al. Improving the Quality of Surveys of Physicians and Medical Groups: A Research Agenda. *Evaluation & the Health Professions*. 2012; 35(4):477–506. [PubMed: 22947596]

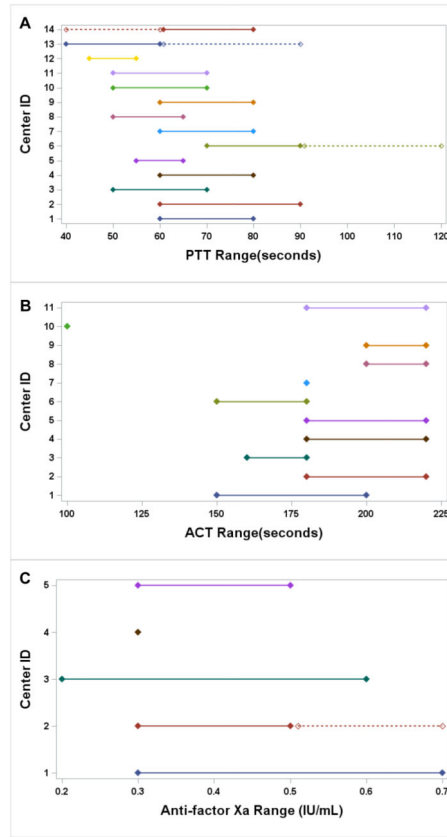
26. Palanzo DA, Baer LD, El-Banayosy A, Wang S, Undar A, Pae WE. Choosing a pump for extracorporeal membrane oxygenation in the USA. *Artif Organs*. 2014; 38(1):1–4. [PubMed: 24392864]
27. Aiyagari RM, Rocchini AP, Remenapp RT, Graziano JN. Decompression of the left atrium during extracorporeal membrane oxygenation using a transseptal cannula incorporated into the circuit. *Crit Care Med*. 2006; 34(10):2603–2606. [PubMed: 16915115]
28. Ortega-Deballon I, Hornby L, Shemie SD, Bhanji F, Guadagno E. Extracorporeal resuscitation for refractory out-of-hospital cardiac arrest in adults: A systematic review of international practices and outcomes. *Resuscitation*. 2016; 101:1–9. [PubMed: 26826564]
29. Barbaro RP, Odetola FO, Kidwell KM, et al. Association of Hospital-Level Volume of Extracorporeal Membrane Oxygenation Cases and Mortality. Analysis of the Extracorporeal Life Support Organization Registry. *American Journal of Respiratory and Critical Care Medicine*. 2015; 191(8):894–901. [PubMed: 25695688]
30. Kolla S, Awad SS, Rich PB, Schreiner RJ, Hirschl RB, Bartlett RH. Extracorporeal life support for 100 adult patients with severe respiratory failure. *Annals of Surgery*. 1997; 226(4):544–564. discussion 565–546. [PubMed: 9351722]
31. Napp LC, Kühn C, Hoepfer MM, et al. Cannulation strategies for percutaneous extracorporeal membrane oxygenation in adults. *Clinical Research in Cardiology*. 2015; 105(4):283–296. [PubMed: 26608160]
32. Reeb J, Olland A, Renaud S, et al. Vascular access for extracorporeal life support: tips and tricks. *Journal of thoracic disease*. 2016; 8(S4):S353–S363. [PubMed: 27195133]
33. Biscotti M, Bacchetta M. The “sport model”: extracorporeal membrane oxygenation using the subclavian artery. *The Annals of Thoracic Surgery*. 2014; 98(4):1487–1489. [PubMed: 25282228]
34. Grasselli G, Pesenti A, Marcolin R, et al. Percutaneous vascular cannulation for extracorporeal life support (ECLS): a modified technique. *Int J Artif Organs*. 2010; 33(8):553–557. [PubMed: 20872350]
35. Rupprecht L, Lunz D, Philipp A, Lubnow M, Schmid C. Pitfalls in percutaneous ECMO cannulation. *Heart, lung and vessels*. 2015; 7(4):320–326.
36. Ventetuolo CE, Muratore CS. Extracorporeal Life Support in Critically Ill Adults. *American Journal of Respiratory and Critical Care Medicine*. 2014; 190(5):497–508. [PubMed: 25046529]
37. Foley PJ, Morris RJ, Woo EY, et al. Limb ischemia during femoral cannulation for cardiopulmonary support. *Journal of vascular surgery*. 2010; 52(4):850–853. [PubMed: 20615644]
38. Kennedy JH. The role of assisted circulation in cardiac resuscitation. *JAMA*. 1966; 197(8):615–618. [PubMed: 5953090]
39. Mattox KL, Beall AC. Resuscitation of the moribund patient using portable cardiopulmonary bypass. *The Annals of thoracic surgery*. 1976; 22(5):436–442. [PubMed: 999368]
40. Hill JG, Bruhn PS, Cohen SE, et al. Emergent applications of cardiopulmonary support: A multiinstitutional experience. *The Annals of thoracic surgery*. 1992; 54(4):699–704. [PubMed: 1417227]
41. Mooney M, Arom K, Joyce L, et al. Emergency cardiopulmonary bypass support in patients with cardiac arrest. *The Journal of Thoracic and Cardiovascular Surgery*. 1991; 101(3):450–454. [PubMed: 1999938]
42. Younger JG, Schreiner RJ, Swaniker F, Hirschl RB, Chapman RA, Bartlett RH. Extracorporeal Resuscitation of Cardiac Arrest. *Academic emergency medicine : official journal of the Society for Academic Emergency Medicine*. 1999; 6(7):700–707. [PubMed: 10433529]
43. Chen Y-S, Chao A, Yu H-Y, et al. Analysis and results of prolonged resuscitation in cardiac arrest patients rescued by extracorporeal membrane oxygenation. *JAC*. 2003; 41(2):197–203.



**Figure 1.** Adult Emergency Department ECMO Programs in the United States



**Figure 2.**  
Services Involved in the Emergency Department ECMO Process



**Figure 3.**  
Anticoagulant Laboratory Monitoring Ranges for Emergency Department ECMO

Abbreviations: PTT--Activated Partial Thromboplastin Time; ACT-- Activated Clotting Time; IU--international unit, mL--milliliter

Notes:

3a:

#14: Dashed Line: If patient bleeding

#13: Dashed Line: If patient tolerates lower range

#6: Dashed Line: Two ranges given, not defined

3c:

#2: Dashed Line: Two ranges given, not defined



**Table 1**

Demographics and Program Characteristics (total n=36)

Variables	Level	%	N
<b>Academic / teaching vs non-teaching hospital(missing obs.=3)</b>	Non-teaching hospital	6.1	2
	Academic	93.9	31
<b>Formal Program for ED ECMO, or no formal program but ability to place patients in cardiac arrest on ECMO in the Emergency Department</b>	No Formal ED ECMO Program	66.1	22
	Formal ED ECMO Program	38.9	14
<b>Age of ED ECMO Program (missing obs.=4)</b>	<1	15.6	5
	1–3 years	31.3	10
	4–5 years	21.9	7
	6–10 years	15.6	5
	>10	15.6	5
<b>Historical rate of eCPR Cannulations per year in the Emergency Department (missing obs.=5)</b>	0–1 patients / year	41.9	13
	2–3 patients / year	19.4	6
	4–6 patients / year	25.8	8
	7–12 patients / year	12.9	4
<b>Was ICU-based ECMO functioning at your institution prior to ED ECMO program?</b>	Yes	88.9	32
<b>Was salvage ECMO/eCPR available for inpatients before the ED ECMO program start? (missing obs.=4)</b>	Yes	90.6	29
<b>Locations where eCPR has been performed at the institution</b>	Inpatient Hospital Setting	91.7	33
	Emergency Department	100.0	36
	Operating Room	83.3	30
	Other	16.7	6
<b>A mechanical CPR device used during the cannulation process (missing 4)</b>	Yes	37.5	12
	Occasionally	9.4	3
<b>Vascular access is obtained via</b>	Percutaneous	72.2	26
	Cut-down	36.1	13
	Modified (Cutdown+Percutaneous)	25	9
<b>Role of the cannulator (check all that apply)</b>	Emergency Medicine	11.1	4
	CT Surgery	77.8	28
	Cardiology	16.7	6
	General Surgery	8.3	3
	Vascular Surgery	2.8	1
	Other	11.1	4
<b>Does a separate person cannulate for ECMO than the person running the resuscitation? (missing =4)</b>	Yes	93.8	30
<b>Does the ACLS portion of our ECMO resuscitations utilize more protocol than a typical resuscitation (missing =5)</b>	Yes	35.5	11
<b>The ACLS portion of our ECMO resuscitations are run by (missing =4)</b>	A nurse	9.4	3
	A physician	90.6	29

Abbreviations: ED--Emergency Department; ECMO--Extracorporeal Membrane Oxygenation; eCPR--Extracorporeal Cardiopulmonary Resuscitation; ICU--Intensive Care Unit; CPR--Cardiopulmonary Resuscitation; ACLS--Advanced Cardiac Life Support

**Table 2**

Inclusion/Exclusion Criteria and Services Involved (total n=36)

Variables		%	N
<b>Typically included patient phenotypes</b>	Cardiac arrest with VF/VT initial rhythm	75	27
	Cardiac arrest with any initial rhythm	61.1	22
	Respiratory arrest (not otherwise specified)	50	18
	Hypothermia	55.6	20
	Drug Overdose	47.2	17
	Cardiogenic shock with pulses	55.6	20
	Other	2.8	1
<b>Exclusion criteria (any)</b>	Age >60	8.3	3
	Age >70	27.8	10
	Obesity	5.6	2
	Cachexia	13.9	5
	Apparent dialysis access/fistula	11.1	4
	Concomitant major trauma	44.4	16
	Suspected/Presumed Drug Overdose	5.6	2
	Unwitnessed	55.6	20
	Non-Shockable Initial Rhythm	13.9	5
	No bystander CPR	38.9	14
	>5min of no bystander CPR	5.6	2
	>10min of no bystander CPR	25	9
	Other	22.2	8
<b>Services involved throughout entire ECMO Process</b>			
Emergency Medicine (missing obs. =5)	Yes, always	41.9	13
	Yes, as needed	29	9
	No, but available	3.2	1
	No	25.8	8
Cardiothoracic Surgery (missing obs.=4)	Yes, always	68.8	22
	Yes, as needed	25	8
	No	6.3	2
Cardiology (missing obs.=7)	Yes, always	17.2	5
	Yes, as needed	41.4	12
	No	41.4	12
Interventional Cardiology (missing obs. =8)	Yes, always	17.9	5
	Yes, as needed	35.7	10
	No	46.4	13
Vascular Surgery (missing obs. =10)	Yes, always	3.9	1
	Yes, as needed	23.1	6
	No, but available	23.1	6
	No, not available	3.9	1
	No	46.2	12

Variables		%	N
Perfusion (missing obs.=6)	Yes, always	76.7	23
	Yes, as needed	16.7	5
	No	6.7	2
Neurology (missing obs.=9)	Yes, always	3.7	1
	Yes, as needed	33.3	9
	No	63.0	17
Palliative Care (missing obs.=10)	Yes, always	19.2	5
	Yes, as needed	19.2	5
	No	61.5	16
Pharmacy (missing obs.=8)	Yes, always	75	21
	Yes, as needed	10.7	3
	No, but available	3.6	1
	No	10.7	3

Abbreviations: VF--Ventricular Fibrillation; VT--Ventricular Tachycardia; CPR--Cardiopulmonary Resuscitation

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**Table 3**

Devices/Equipment/Post ECMO care (total n=36)

Variables		%	N	
<b>Cannula Selection: For a 70kg male, typical arterial cannula size range (missing obs.=5)</b>	15–17F	51.6	16	
	19–21F	48.4	15	
<b>Cannula Selection: For a70kg male, typical venous cannula size range (missing obs.=5)</b>	19–21F	19.4	6	
	23–25F	58.1	18	
	27F+	22.6	7	
<b>Routine console for ED ECMO</b>	Maquet Cardiohelp	27.8	10	
	Maquet Rotaflow	41.7	15	
	Thoratec Centrimag	19.4	7	
	Sorin Revolution	19.4	7	
<b>Routine use of utilize distal limb perfusion catheters? (missing obs.=4)</b>	Yes	93.8	30	
<b>Distal limb perfusion catheter placed by (total n=30)</b>	CT Surgery	86.7	26	
	Vascular Surgery	20	6	
	Cardiology	30	9	
	Critical Care	10	3	
	Other	3.3	1	
<b>Timing of initial anticoagulation</b>	Upon dilation/cannulation	38.7	12	
	Upon initiation of ECMO flow	6.5	2	
	Vascular access (with catheter/sheath/wire)	54.8	17	
<b>Do you take ED ECMO patients to the cardiac catheterization lab after cannulation?</b>	Always	12.5	4	
	Yes	6.3	2	
	As needed	62.5	20	
	No	18.8	6	
<b>Routine anticoagulation for ED ECMO patients with -</b>	Unfractionated Heparin (UFH) - Use	Exclusively	60	18
		Routinely	36.7	11
		Occasionally	3.3	1
	Unfractionated Heparin (UFH) – Monitoring (missing obs.=9)	ACT	37.0	10
		ACT & TEG	3.7	1
		ACT & Xa	3.7	1
		PTT	40.7	11
		Xa	14.8	4
	Molecular Weight Heparin (LMWH) – Use (missing obs.=19)	Occasionally	5.9	1
		Never	94.1	16
Low Molecular Weight Heparin (LMWH) – Monitor (missing obs.=19)	PTT	2.8	1	
Bivalrudin – Use (missing obs.=17)	Exclusively	10.5	2	
	Occasionally	52.6	10	
	Never	36.8	7	
Bivalrudin – Monitoring (missing obs.=28)	PTT	87.5	7	
	Xa	12.5	1	

Variables		%	N
Argatroban - Use(missing obs.=19)	Occasionally	29.4	5
	Never	70.6	12
Argatroban – Monitoring	PTT	5.6	2
Coumadin - Use	Never	47.2	17
<b>Do you use a blender with the sweep gas flow? (missing obs.=4)</b>	Always	87.5	28
	Rarely	3.1	1
	Never	9.4	3
<b>Does your program routinely assess for LV over-distension or unloading? (missing obs.=4)</b>	Yes	81.3	26
	Occasionally	6.3	2
	No	12.5	4
<b>What do you use to decompress the LV? (if applicable)</b>	Atrial Septostomy	30.6	11
	LV Impella	33.3	12
	Reduce ECMO flow	11.1	4
	We do not decompress the LV	5.6	2
	Other	44.4	16

Abbreviations: kg--kilogram; F--French