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Extracorporeal Cardiopulmonary Resuscitation in the Pediatric Cardiac Population: In Search of a Standard of Care

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Abstract

Objectives: Although clinical and pharmacologic guidelines exist for the practice of cardiopulmonary resuscitation in children (Pediatric Advanced Life Support), the practice of extracorporeal cardiopulmonary resuscitation in pediatric cardiac patients remains without universally accepted standards. We aim to explore variation in extracorporeal cardiopulmonary resuscitation procedures by surveying clinicians who care for this high-risk patient population.

Design: A 28-item cross-sectional survey was distributed via a web-based platform to clinicians focusing on cardiopulmonary resuscitation practices and extracorporeal membrane oxygenation team dynamics immediately prior to extracorporeal membrane oxygenation cannulation.

Settings: Pediatric hospitals providing extracorporeal mechanical support services to patients with congenital and/or acquired heart disease.

Subjects: Critical care/cardiology specialist physicians, cardiothoracic surgeons, advanced practice nurse practitioners, respiratory therapists, and extracorporeal membrane oxygenation specialists.

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Interventions: None.

Measurements and Main Results: Survey web links were distributed over a 2-month period with critical care and/or cardiology physicians comprising the majority of respondents (75%). Nearly all respondents practice at academic/teaching institutions (97%), 89% were from U.S./Canadian institutions and 56% reported less than 10 years of clinical experience. During extracorporeal cardiopulmonary resuscitation, a majority of respondents reported adherence to guideline recommendations for epinephrine bolus dosing (64%). Conversely, 19% reported using only one to three epinephrine bolus doses regardless of extracorporeal cardiopulmonary resuscitation duration. Inotropic support is held after extra-corporeal membrane oxygenation cannulation “most of the time” by 58% of respondents and 94% report using afterload reducing/antihypertensive agents “some” to “most of the time” after achieving full extracorporeal membrane oxygenation support. Interruptions in chest compressions are common during active cannulation according to 77% of respondents.

Conclusions: The results of this survey identify wide variability in resuscitative practices during extracorporeal cardiopulmonary resuscitation in the pediatric cardiac population. The deviations from established Pediatric Advanced Life Support CPR guidelines support a call for further inquiry into the pharmacologic and logistical care surrounding extracorporeal cardiopulmonary resuscitation. (*Pediatr Crit Care Med* 2018; 19:125–130)

Keywords

cardiac arrest; cardiopulmonary resuscitation; congenital heart disease; extracorporeal membrane oxygenation; pediatrics

Extracorporeal cardiopulmonary resuscitation (E-CPR) is the rapid deployment of extracorporeal membrane oxygenation (ECMO) during cardiac arrest to provide immediate cardiovascular support for patients unresponsive to conventional cardiopulmonary resuscitation (CPR). Effective and efficient E-CPR requires a complex interplay of care made up of dedicated personnel, equipment, and clinical expertise. Although E-CPR has evolved from its origins in the management of pediatric postcardiotomy cardiac arrest patients to include noncardiac and adult patient populations (1–7), it remains commonly used by patients with congenital and acquired heart disease (8–18). Many retrospective reports of E-CPR use in the pediatric cardiac population have investigated risk factors for mortality and neurologic outcome; yet, our understanding of the inter- and intrainstitutional variability in the process of E-CPR is lacking.

Several domains of E-CPR performance would benefit from an analysis of practice variability and guideline adherence: vasoactive medication dosing and timing, team composition and training, and logistics of care/mobilization. Of particular interest to the authors is the use of vasoactive medications, a key component of conventional CPR. Although data are lacking on drug choice, timing, and overall efficacy during CPR, the American Heart Association’s Pediatric Advanced Life Support (PALS) guidelines recommend administering epinephrine (1:10,000 concentration) IV/intraosseously every 3–5 minutes for the treatment of asystole and pulseless electrical activity (19–21). To date,

consensus guidelines have not addressed vasoactive dosing regimens during conventional CPR escalating to E-CPR.

To understand self-reported extracorporeal resuscitation practices, we surveyed pediatric cardiac practitioners about institutional E-CPR resources and care patterns. We expect self-reports of E-CPR resuscitative practice patterns to be highly variable among providers caring for children with congenital and/or acquired heart disease.

MATERIALS AND METHODS

Study and Survey Design

A cross-sectional survey of E-CPR practitioners was created using a modified Delphi technique with members of the research group serving as content experts. Survey questions were designed by two authors (J.J.L., P.J.) and distributed for comments and modification within the study group. After revisions, the final questionnaire was approved and piloted by all authors. The questionnaire was not tested for reliability or generalizability. However, content validity is derived from the method of creation using the modified Delphi method among experts in the field. The questionnaire was anonymous, with personal data limited to title (MD, RN, RT) and an optional response for institution name. Institutional Review Board approval for the study was obtained from Texas Children's Hospital/Baylor College of Medicine (Houston, TX) prior to implementation.

Recruitment

Several organizations assisted in the distribution of the survey including the Pediatric Cardiac Critical Care Consortium (PC⁴), the Extracorporeal Life Support Organization (ELSO), and the Pediatric Cardiac Intensive Care Society (PCICS). Survey web links were distributed over a 2-month period (March to April 2016) with each organization using their individual network. The leadership at PC⁴ assisted the authors by distributing the survey to 23 individuals identified as "clinical champions" for their respective institutions.

The survey takes approximately 15 minutes to complete and is available in the supplemental file (Supplemental Digital Content 1, <http://links.lww.com/PCC/A557>).

Statistical Analysis

All variables were categorical and expressed as frequencies and percentages. Where applicable, Fisher exact test was used to compare proportions between groups. Statistical significance was assessed at the 0.05 level.

RESULTS

Respondent Characteristics

A total of 150 responses were received during the study period. PCICS distributed the survey link four times to society members over the study period resulting in a total of 236 opened e-mails with 173 individuals initiating survey participation (480 total recipients received emails). Each physician representative from the 23 participating PC⁴ centers

responded to the survey request. ELSO emailed survey links to 1,600 participant members, directors, and data coordinators from 424 national and international centers. Both adult and pediatric centers received electronic newsletter invitations to participate in the survey. Due to the large number of adult-only centers subscribed to the ELSO email newsletter, as well as the inability to track opened newsletter links, a clear delineation of respondents with pediatric cardiac expertise from ELSO is unknown.

Critical care and/or cardiology physicians made up the majority of completed surveys (75%) with the remainder completed by advanced practice care providers (11%), registered nurses (8%), and ECMO specialists (2%). Nearly 97% report practicing at academic or teaching institutions. Forty-four percent (44%) reported greater than 10 years of clinical experience in the pediatric cardiac critical care arena. The majority of individuals reported up-to-date PALS certifications (78%). The majority of respondents reported working at U.S. or Canadian institutions. (Table 1)

Vasoactive Profiles

The majority of respondents (84%) reported using epinephrine as the only bolus-form vasoactive during CPR prior to ECMO cannulation. Additional vasoactive medications (either bolus or continuous infusion) were limited to epinephrine in the majority of respondents (Fig. 1). Although pharmacologic resuscitation occurs primarily via bolus dosing of vasoactive medications, 52% reported initiating continuous epinephrine infusions during CPR prior to ECMO cannulation.

More than 80% of respondents reported activating ECMO teams prior to the third dose of epinephrine. However, only one third of respondents (38%) reported ECMO team activation after one dose of epinephrine. During conventional CPR prior to ECMO cannulation, 64% of respondents reported administering unlimited boluses of epinephrine as compared with 19% who reported limiting epinephrine exposure to one to three total doses (Fig. 2). After achieving full ECMO support, 64% reported discontinuing vasoactive support “most” or “all of the time.” Conversely, 94% of respondents reported using afterload reducing/antihypertensive agents “some,” “most,” or “all of the time” in the post-ECMO cannulation period.

Although not statistically significant, administering unlimited epinephrine boluses until cannulation was more often reported by respondents from institutions without an in-house ECMO cannulator/surgeon as compared to those that do have an in-house team (69% vs 51%, respectively, $p = 0.07$).

E-CPR Logistics and Training

Approximately, 74% of individuals reported an ICU bed capacity of at least 20 beds in locations where E-CPR is performed (Table 2). The most commonly reported location of ECMO cannulation was the cardiovascular ICU (CVICU, 77%) followed by the PICU (51%), neonatal ICU (36%), emergency department (ED, 25%), combined PICU/CVICU (20%), and “other” (17%) sites which included the operating room, cardiac catheterization laboratory, and/or ward. Patient admission type was not specified in the survey (surgical vs medical). ECMO team activation occurs most commonly during the first 10 minutes after

CPR initiation according to 73% of respondents. Cardiothoracic surgeons perform the majority of ECMO cannulation (97% of respondents); however, general surgeons also participated in ECMO cannulation (41%). Only one respondent reported nonsurgical physicians performing ECMO cannulation. Most commonly reported E-CPR physical cannulation sites were peripheral sites (neck or femoral, 63%) in comparison to open chest/central cannulation (37%). Chest compressions were interrupted for cannulation or rhythm/pulse checks in at least 78% of respondents.

A formal “ECMO team” was sponsored at home institutions according to 89% of respondents. The proportion of respondents reporting an ECMO specialist in-hospital 24 hours per day, 7 days a week was different as compared to the in-hospital presence of an ECMO operator/surgeon (Fig. 3). Only 62% of individuals reported formal multidisciplinary training programs for E-CPR performance at their home institution. Of those that reported training programs, only 59% reported the use of simulation-based training that occurs at least yearly.

DISCUSSION

The results of our survey reveal multiple aspects of practice variation in the use of E-CPR in the pediatric cardiac population which were previously unreported in the literature. First, a high degree of variation in vasoactive medication administration was observed with nearly 20% of respondents reporting deviation from established guidelines for epinephrine bolus dose administration during E-CPR. These results were not anticipated as the authors expected a higher degree of adherence to consensus guidelines for the administration of vaso-active medications during conventional CPR while awaiting ECMO cannulation. The use of epinephrine during CPR has been considered an essential element of pediatric resuscitation for over 50 years (22, 23). Recommendations by the American Heart Association and International Liaison Committee on Resuscitation (20, 21) with regards to use of epinephrine and additional vasoactive medications have been challenged recently as several reports have demonstrated poorer hospital survival and neurologic outcomes in the adult out-of-hospital cardiac arrest population receiving epinephrine (24–28). Contrary to the recommended dosing of epinephrine until return of spontaneous circulation (every 3–5 min intervals), nearly one third of respondents in our survey reported limiting epinephrine doses, regardless of CPR duration (Fig. 2). Although no additional questions were provided to seek insight into the reasons for this important difference in practice, we postulate that epinephrine dosing frequency may vary due to philosophical differences in the end-result of E-CPR: achieving return of spontaneous circulation per PALS guidelines regardless of ECMO cannulation or effects on afterload (unlimited epinephrine) versus committing to high-quality chest compressions and ventilation until ECMO cannulation in order to avoid excessive elevations in afterload which can impact ECMO flow rates (limited epinephrine).

ECMO team deployment timing was also variable in our study. Nearly all reports of E-CPR outcomes have used CPR duration prior to ECMO cannulation as a variable influencing survival and neurologic outcomes (14, 29–33). Yet, time from CPR initiation to ECMO cannulation is clearly influenced by the timing of ECMO team activation (34). Waiting greater than 10 minutes prior to calling for ECMO can lengthen time to ECMO cannulation,

especially when ECMO teams (surgeon) are not available in the hospital. The majority of respondents to our survey reported activating ECMO teams for pediatric cardiac patients within the first 10 minutes of CPR. An additional 38% reported activating their institutional ECMO team after just one dose of epinephrine. Reports quantifying the timing of ECMO team activation during active CPR are limited in the literature. Huang et al (31) reported their institutional experience for E-CPR in the pediatric population and were able to link prolonged ECMO activation times with poorer survival outcomes in univariate analysis. However, multivariate analysis revealed only era effect and postresuscitation renal injury as significant markers of mortality. Researchers from the Hospital for Sick Children in Toronto have also reported on their experience with rescue E-CPR in the pediatric cardiac population and describe an institutional guideline for activation of ECMO “within 5–10 minutes of initiating CPR.” Although not quantified in their analysis, the authors describe an explicit institutional goal of “initiating mechanical support within a short period of time (usually 25–40 min).” (32) In contrast to other studies in the literature, these authors were unable to demonstrate a significant effect of CPR duration on survival or neurologic outcomes in their study population, postulating that witnessed in-hospital cardiac arrest patients are more likely to receive CPR quickly with rapid and effective perfusion of vital organs.

The ability to institute mechanical support in such a short time requires the participation of key personnel such as surgeons and ECMO specialists/cardiovascular perfusionists who must be available when E-CPR is initiated by the critical care or ED teams. Our analysis is the first to report the perceived availability of ECMO team personnel (surgeon vs ECMO specialist) in the hospital, or “in house,” 24 hours a day/7 days a week. Although not surprising, ECMO specialists were more often in-house than surgeons. Nearly one third of respondents (27%) reported that surgeons were not available “in-house” and, although we did not delineate between training level of “in-house” surgeon (i.e., attending vs fellow vs resident), we suspect that the absence of a qualified operator to initiate cannulation for ECMO may impact duration of CPR and therefore resuscitative practices during the pre-ECMO CPR period.

Reported ECMO cannulation sites (central vs peripheral) in our survey highlight additional heterogeneity in practice across centers. Current evidence in the pediatric literature describing the frequency of ECMO cannulation site and its impact on outcomes remains limited to a small number of retrospective single-center studies and ELSO registry analyses. These studies present conflicting conclusions regarding the impact of carotid versus femoral and/or central cannulation on mortality and CNS injury (6, 8, 9, 18, 35, 36). Furthermore, results in these investigations often describe a wide variety of patients undergoing veno-arterial (VA) ECMO (cardiac, respiratory, or E-CPR) further limiting our ability to distinguish associations with mortality and/or neurologic outcomes specifically within the E-CPR population (37–39). Although ELSO registry reports suggest carotid cannulation for combined etiology VA ECMO is associated with improved survival to discharge, neurologic injury is higher for patients cannulated via carotid artery in comparison to central (aorta) and femoral arterial cannulation sites (37). Polito et al (39) evaluated neurologic injury in neonates with congenital heart disease supported with VA ECMO between 2005 and 2010 and found no association of neck/carotid cannulation with intracranial hemorrhage/stroke as confirmed by head ultrasound or CT. The impact of age, weight, and presence of congenital

heart disease may ultimately have larger contributions to neurologic outcomes than cannulation site.

In comparison to the general ECMO population, specific analyses of cannulation site during E-CPR are lacking. Tsukahara et al reported their single-center experience with E-CPR in the pediatric population and describe a formulaic approach to cannulation site given patient weight (≤ 30 kg, thoracic; > 30 kg, neck or femoral); yet no evidence was presented in favor of either cannulation site (40). Chan et al (16) queried the ELSO registry for pediatric E-CPR recipients with heart disease and found improved survival to discharge for carotid cannulation patients in comparison to central cannulation or “other” sites. The interaction of cannulation site with neurologic injury was not delineated in this report. Although we may consider translating data gathered from the increasing adult E-CPR experience (2, 41–43), the high frequency of femoral cannulation and rare use of central/carotid cannulation limit our ability to make associations with mortality or neurologic outcomes.

The success of an E-CPR program is also dependent on the preparation and training for this high-risk yet low-frequency clinical event. Multidisciplinary, high-fidelity, and serial simulation-based E-CPR training at Children’s National Health System reduced deployment time of ECMO in children with ongoing CPR after implementing an iterative in situ multidisciplinary simulation training program (44). The role of formal E-CPR training programs (both simulation and traditional) has yet to be fully elucidated in the current era, and our survey results confirm this notion as only half of respondents participate in simulation-based continuing education training for E-CPR. This large gap in simulation training serves a potential target for quality improvement efforts moving forward.

Limitations of this study are related to the nature of an anonymous survey posted in an e-mail and newsletter format. The e-mail was written in English with no translation available and distributed across pediatric cardiac-focused membership platforms. Additionally, individual centers and/or ECMO directors were not targeted as part of the survey; hence, response rates were lower than might have been achieved with targeted recruitment. Biased results may have resulted if respondent’s interpretation of authored content and questions differed from its intent. Responses from individuals who reported that their home institutions did not sponsor formal ECMO teams may also have skewed results. Biases in patient selection for E-CPR likely exist and presumably play a role in ECMO team activation timing and resuscitative strategies. This report does not explore this important facet of E-CPR and future surveys/studies should include patient selection factors as a key variable to describe and include in outcomes analyses.

CONCLUSIONS

Despite these limitations, clear themes emerge from this study. Resuscitative practices during cardiac arrest escalating to E-CPR are highly variable across multiple dimensions and differ from established resuscitation guidelines (PALS). Vaso-active medication administration and ECMO team activation/training/availability were particularly heterogeneous and are potential targets for future investigations. The level of practice variation we have documented is not surprising given the lack of evidence to guide best

practice. This variability also supports a call for consensus building and standardization across centers. However, in order to achieve this goal with potential for clinical trial enrollment, further insight into E-CPR decision-making and logistics is required. Proposed E-CPR module additions to existing extracorporeal life support registries may add to our understanding of the effects of E-CPR variability on outcomes while encouraging standardization and future investigations. Ultimately, our study highlights opportunities to investigate E-CPR's best practices and to develop quality improvement efforts that can expand our understanding of advanced resuscitation practices and mechanical circulatory support.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.
Alternative medications used during extracorporeal cardiopulmonary resuscitation (bolus or infusion).

Figure 2.
Epinephrine dosing during extracorporeal cardiopulmonary resuscitation.

Figure 3.
Team member presence in-hospital 24 hr/d, 7 d/wk. ECMO = extracorporeal membrane oxygenation.

TABLE 1.

Distribution of Self-Reported Institution Geography

Geographical Location	% (n)
United States/Canada	89 (126/141)
Europe	3 (4/141)
Asia	3 (4/141)
Central/South America	3 (4/141)
Australia/New Zealand	1 (2/141)
Middle East	< 1 (1/141)

TABLE 2.

Reported Maximum Bed Capacity of ICUs Where Extracorporeal Cardiopulmonary Resuscitation is Performed

ICU Bed Capacity	% (n)
Beds	
< 10	3 (4/141)
10–20	23 (33/141)
> 20	74 (104/141)