Implementation of an Extracorporeal Cardiopulmonary Resuscitation Simulation Program Reduces Extracorporeal Cardiopulmonary Resuscitation Times in Real Patients*

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Objective: To determine if development of an extracorporeal cardiopulmonary resuscitation simulation program reduced extracorporeal cardiopulmonary resuscitation times in real patients

Design: Before-after study.

Setting: Twenty-six bed pediatric cardiac ICU in a tertiary urban hospital.

Patients: Forty-three cardiac patients (aged 1 d to 16 yr) who received extracorporeal cardiopulmonary resuscitation.

Interventions: An interdisciplinary team collaborated to define the roles and clarify responsibilities of each individual involved in extracorporeal cardiopulmonary resuscitation. An "ideal rapid deployment" was defined and tested using simulation sessions. This included a task analysis, role creation, and multidisciplinary simulations, including structured debriefings and video review and the creation of a master checklist.

Measurements and Main Results: There were a total of 43 episodes of extracorporeal cardiopulmonary resuscitation during the study period, 16 (37%) of which occurred during the preintervention time period (from February 2009 to March 2010) and 27 (63%) during the postintervention time period (April 2010 to March 2013). The median deployment time in the preintervention time period was 51 minutes (interquartile range, 43–62 min), whereas the median deployment time in the postintervention time period was 40 minutes (interquartile range, 23–52 min) ($p = 0.018$).

Conclusions: There are no standard guidelines of how a team should coordinate the efforts of nursing, physicians, extracorporeal membrane oxygenation specialists, surgeons, respiratory therapists, patient care technicians, and unit clerks to emergently execute this complex procedure. Because time is of the essence, it is essential to develop a highly functioning and well-coordinated team with a standardized method of the procedure, its documentation, and communication. Simulation accomplished this for our program. Following these simulation exercises, not only was there a subjectively observed improved coordination and smoother deployment of extracorporeal membrane oxygenation in real-life extracorporeal cardiopulmonary resuscitation, but we have also demonstrated a significantly faster deployment of extracorporeal membrane oxygenation as compared with the presimulation era. (*Pediatr Crit Care Med* 2014; 15:856–860)

Key Words: cardiac arrest; extracorporeal life support; pediatrics; resuscitation; simulation; teamwork

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Venoarterial extracorporeal membrane oxygenation (ECMO) or cardiopulmonary bypass is being used increasingly for reestablishing circulation in witnessed in-hospital pediatric cardiac arrests that are refractory to the initial resuscitation interventions (1). Its use is currently recommended by the American Heart Association as a consideration for children in refractory cardiac arrest in a highly supervised environment with a potentially reversible cause of arrest (2). Despite the increased use of extracorporeal cardiopulmonary resuscitation (ECPR) in pediatric cardiac arrests, the proportion of children who survive has not improved over the years and varies quite significantly among institutions with reported survival to discharge rates ranging between 35% and 100% in several small single-center series (3–7). A recent multicenter analysis of 682 pediatric patients undergoing ECPR over a 13-year period showed a 38% survival to discharge (1). This could partly be explained by its expanded use in sicker patients, but it is also possible that the execution of ECPR plays a significant role in ultimate patient outcome and that can also vary greatly among institutions and have room for improvement. Certainly, in our institution, the perceived chaos and lack of process prompted a quality improvement initiative centered around simulation.

It is generally considered that patients with cardiac arrest and reversible disease etiologies who have only a brief period of no flow and subsequently undergo high-quality cardiopulmonary resuscitation (CPR) during the low-flow period and have a well-controlled postresuscitation phase tend to have good outcomes (8). Longer duration of conventional CPR before institution of ECPR and a higher pre-CPR serum lactate levels have been associated with poorer outcomes (9). However, rapid deployment of ECPR requires round-the-clock availability of personnel experienced with rapid assembly of ECMO circuit and 24/7 capability of the surgical, medical, and nursing teams to initiate and manage patients on ECMO, making such programs very resource intensive and expensive (6, 10).

Even with the round-the-clock presence of a well-staffed team, there are many factors that affect the timely deployment of ECPR and hence the potential outcomes. The team must prepare and drape the patient, assemble and prime the ECMO pump, and cannulate the patient while the medical team must continue the resuscitation. The inherent complexity of rapid deployment of ECMO combined with the stress of a dying child lends itself to a feeling of chaos and often the reality of disorganization and confusion.

By increasing the exposure and familiarity to rapid deployment ECMO during simulated ECPR sessions, the interdisciplinary team members can become better aware of the different roles and can practice them in a safe setting. This could also create a highly reliable process that is not dependent on particular knowledgeable individuals, but rather provide a clear delineation of role expectations, so that different individuals can step into roles at any given time and effectively execute the expected responsibilities.

By practicing these roles in high-fidelity scenarios in regular simulation exercises, we hypothesized that the development and implementation of an ECPR simulation program would lead to a faster deployment of ECMO in real patients.

METHODS

ECPR is offered at our institution only for any witnessed cardiopulmonary arrest that occurs in the cardiac ICU or cardiac operating room and is refractory to conventional CPR. At this time, noncardiac patients are not being cannulated because of previous poor survival rates for this population within our institution. In March 2010, a multidisciplinary team analyzed the process of ECPR and mapped over 90 tasks that need to be accomplished before a patient can be emergently deployed onto ECMO during CPR (Supplemental Flow Map, Supplemental Digital Content 1, http://links.lww.com/PCC/A117). These tasks do not include the actual assembly of the ECMO circuit and oxygenator or the ongoing conventional resuscitation. Based on the process map created by this analysis, three major teams were identified: 1) ICU team (consisting of nurses, ICU physicians, respiratory therapists, and support staff) focused on the resuscitation of the patient, alerting the rest of the teams, and preparing the ICU room to be turned into a make-shift operating room; 2) surgical team (consisting of cardiovascular surgeon, assistants, and nurses) focused on placement of the cannulas and initiation of ECMO; and 3) ECMO team (specialized nurses and respiratory therapists who can prime and run the ECMO pump) focused on preparing the ECMO circuit for deployment. Four different phases of the ECPR process were identified: 1) conventional CPR, 2) transition to ECPR, 3) ECMO preparation (nonsterile), and 4) ECMO deployment (sterile).

All the identified tasks were assigned to 16 different roles. Roles created included primary responsibility of standard tasks and an oversight and redundancy provided by nursing and physician leads. A laminated card was made for each of the 16 roles, and they contained a list of the role-specific tasks. These cards were worn by the respective members of the team on a lanyard during the simulation.

Based on the debriefing and feedback after each simulation session, modifications were made that included redistribution of tasks, elimination of the nonsterile ECMO phase, creation of a room diagram with predefined locations of equipment placement and creation of a master checklist for the nursing and physician leaders to track progress, and aid in decision to move to the next phase (Supplemental Master Checklist, Supplemental Digital Content 2, http://links.lww.com/PCC/A118).

In an effort to limit the artifacts associated with simulation, we modified the simulation scenarios in an attempt to recreate some of the more realistic issues with time. For example, if the participants asked for a blood prime of the pump, one participant had to retrieve a preplanted refrigerated box with "blood" from the blood bank and return with it before the ECMO team could prime with red-colored liquid. The surgeons were also

not allowed to enter the simulation room until the room was sterile, which meant that all participants had donned hat and masks and the surgical instruments pack was opened on the table and ready for use. Each simulation exercise was conducted in an actual cardiac ICU room and was videotaped and reviewed with the team immediately after the exercise.

Measurements and Definitions

We implemented this process in March 2010, and over the next 36 months, eight simulation exercises were conducted during both daytime and nighttime. We defined the 14-month period (February 2009 to March 2010) preceding the implementation of the simulation as the preintervention period and the 36-month period that followed the intervention (April 2010 to March 2013) as the postintervention period. There were no times recorded before February 2009.

The ECMO deployment time was defined as the time in minutes from the time the call was placed to the page operator to the actual start of ECMO flow as recorded by the ECMO specialist. No attempts have been made to determine the accuracy of these records. A retrospective chart review of all cases of ECPR from February 2009 to March 2013 was undertaken along with a review of the institutional ECMO database to identify all cases and to collect the required data elements.

Data Analysis and Statistical Methods

We collected the demographic and clinical data by a retrospective review of the identified charts. We compared the deployment time in the preintervention and postintervention periods. Further analysis was made between the two groups for confounding variables that could affect the deployment times. This included 1) the route of cannulation (transthoracic vs peripheral [groin or neck vessels]), 2) cannulation through open chest versus need for emergent sternotomy, 3) daytime versus nighttime cannulations, 4) presumed primary cause for cardiac arrest versus noncardiac, and 5) single ventricle physiology with partial or total cavopulmonary connections.

Deployment times between the pre- and postintervention time periods were compared using the Wilcoxon rank-sum testing. Type-1 error was set at 0.05. All calculations were performed using Stata/IC 12.1 (Stata Corporation, College Station, TX).

The study was reviewed and given exempt status by the institutional review board.

RESULTS

The demographic and clinical characteristics of the patients in the preintervention and postintervention phase are shown in **Table 1**. There were a total of 43 episodes of ECPR during the study period, 16 (37%) of which occurred during the preintervention time period (from February 2009 to March 2010) and 27 (63%) during the postintervention time period (April 2010 to March 2013).

Of the 16 cases of ECPR during the preintervention period, three patients had transthoracic cannulation through a preexisting open sternum, whereas another six patients had an emergent sternotomy to place the transthoracic cannulas. The remaining seven patients were cannulated peripherally using neck or groin vessels. In this group, there were two patients with Glenn physiology and one with Fontan physiology, and all of these patients were placed on ECMO using a single venous cannula.

Of the 27 patients who underwent ECPR since the intervention with simulation sessions, seven patients were cannulated transthoracically using a preexistent sternotomy, whereas 10 patients were cannulated transthoracically through an emergent sternotomy. The remaining 10 patients were cannulated peripherally using neck or groin vessels. In this group, three patients had Glenn physiology and one had Fontan physiology. One patient with Glenn physiology received both inferior and superior vena cavae venous drainage cannulas.

Although a larger proportion of the preintervention ECPR (81%) were during the nighttime and weekend hours as

TABLE 1. Characteristics of Patients Requiring Rapid Deployment Extracorporeal Membrane Oxygenation Stratified by Time Period

Characteristic	Preintervention ($n = 16$), n (%)	Postintervention ($n = 27$), n (%)	p
Age (mo)	2 (IQR, 14 d to 17 mo)	1 (IQR, 11 d to 12 mo)	0.72
Female gender	8 (50)	12 (44)	0.72
Deployment time (min)	51 (IQR, 43–62)	40 (IQR, 23–52)	**0.018**
Nighttime or weekend deployment	13 (81)	13 (48)	0.052
Method of cannulation			0.92
Transthoracic (in open chest)	3 (19)	7 (26)	
Transthoracic (with emergent sternotomy)	6 (37)	10 (37)	
Peripheral	7 (44)	10 (37)	

IQR = interquartile range.
The boldface value is statistically significant.

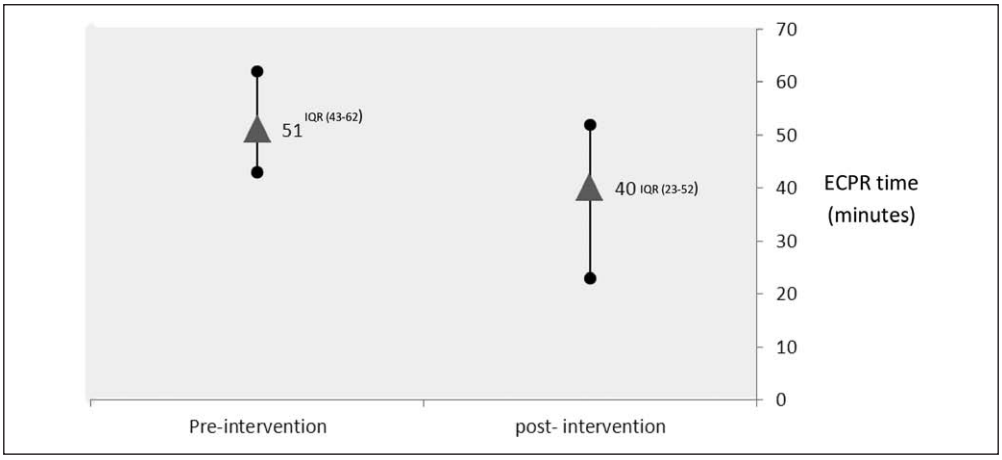

Figure 1. Extracorporeal cardiopulmonary resuscitation (ECPR) times decreased ($p = 0.018$) after implementation of our ECPR simulation program.

compared with the postintervention period (48%), this difference was not statistically significant.

The median deployment time in the preintervention time period was 51 minutes (interquartile range, 43–62 min), whereas the median deployment time in the postintervention time period was 40 minutes (interquartile range, 23–52 min) ($p = 0.018$) (**Fig. 1**). In the postintervention period, there were 10 deployments that occurred in 30 minutes or less. The times did seem to decrease each year (mean, 41.67 min for fiscal year [FY]11, 40.5 min for FY12, and 35 min for FY13), but given the small numbers, their relationship to each other was not analyzed for statistical significance. We also did not compare the survival and other clinical outcomes between the two groups due to the small sample size.

DISCUSSION

Simulation has become an increasingly common method of training medical and nursing personnel in acquiring certain technical skills. In addition, high-fidelity simulation has been used to train team-based learning for accomplishing complex tasks that require smooth coordination and effective communication (11). Despite the accepted role of this method in adult learning in other fields, there has been a limited evaluation in the medical literature of its impact on clinical outcomes (12).

Placing a child emergently on ECMO during an ongoing resuscitation is a complex process that requires many subprocesses and steps to be performed in coordinated fashion by multiple team members (9). It is a high-risk low-frequency situation, and often, the individual members of the assembled ad hoc team may not have worked together previously. Many people have compared the rapid deployment of ECMO in a child undergoing CPR to the performance required by the pit stop crew in car racing, where timeliness, coordination, and safety are all very critical.

We improved our ECPR using an iterative process centered around simulation. Our analysis shows that the actual deployment time of ECMO in children with ongoing CPR reduced significantly after the start of this program, thereby implying a better coordinated process and team function.

The deployment time can be dependent on many factors that we could not control or change with any amount of ECPR simulations—namely, the surgical experience and speed and the patency and accessibility of the patient's blood vessels. These will always limit the impact of our simulation program's effect on ECPR times. We analyzed some patient-related factors and did not find any significant differences between the preintervention and the postintervention groups. The peripheral and the transthoracic cannulations requiring emergent sternotomy took a longer time than those with a preexistent open sternum for obvious reasons. However, we did not find any significantly disproportionate representation of these subpopulations between the two groups. There was the addition of new clinical personnel over the 4 years that we studied, and this could have contributed to a difference in the observed deployment time. Many of the new additions including a new cardiac surgeon were all relatively less experienced and recent graduates of training programs. Consequently, this is less likely to shorten the deployment time based on the experience level of the operators. There were also differences noticed in the frequency of the ECPR done during weekends and nighttime, with the conventional wisdom dictating that deployment times are likely to be longer during the off-hours. However, we have an on-site dedicated team of ECMO specialists and nurses, as well as cardiac surgical team around-the-clock, and consequently, this is unlikely to be a major confounding factor.

One important limitation of this study is that because of the retrospective nature of the study and incomplete documentation of all the responders to the real ECPR deployments, we have no way of matching simulation participants with ECPR providers in the actual events. We will also admit that eight simulations itself do not seem like they should have a real impact, but the simulation program included more than just the simulations. Each simulation event took 4–5 hours. It required 1–2 hours for setup, 30–40 minutes for the simulation, an additional 60 minutes to review the video and debrief, and then an hour for cleanup. This limited our ability to have more frequent simulations and instead capitalized on the insight gained during the simulations by having extensive debriefing sessions. After each event, the multidisciplinary quality improvement team met to redefine roles and tasks. In addition, we incorporated the simulation videos in annual skills days for the nurses and

in fellow education. The value of the simulation program is likely attributable to the sum of all these factors. Since we implemented them all as part of the same process, it is impossible to isolate one factor such as the simulations themselves.

It is also possible that the faster deployment time is a natural function of general improvement of performance over time, and this possibility is difficult to rule out due to the lack of a control group. We did not study the clinical outcomes in our analysis due to our small numbers and the fact that we were doing a retrospective analysis and matching for the disease severity and underlying lesions would have been difficult.

Currently, there are no published manuals or textbooks that describe how a clinical team should deploy ECMO emergently in a patient in active cardiac arrest. There are no standard guidelines of how a team should coordinate the efforts of nursing, physicians, ECMO specialists, surgeons, respiratory therapists, patient care technicians, and unit clerks to emergently execute this complex procedure. Because time is of the essence, it is essential to develop a highly functioning and well-coordinated team with a standardized method of the procedure, its documentation, and communication (9). We were able to develop an algorithm that standardized and allocated the various tasks in a logical sequence among all the team members. Additionally, we were able to simulate this multiple times in the actual cardiac ICU with the care providers. Following these simulation exercises, not only was there a subjectively observed better coordination and smoother deployment of ECMO in real-life ECPR but we have also demonstrated a significantly faster deployment of ECMO as compared with the presimulation era. We believe that there are no previously published studies that have shown simulation in this setting to make a measurable impact on one of the potential outcome predictors in patients undergoing ECPR. Further prospective studies with patients matched for disease severity and lesions will be needed to study impact on survival and other outcome variables.

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