Impacts of a Pediatric Extracorporeal Cardiopulmonary Resuscitation (ECPR) Simulation Training Program

Taylor Sawyer, DO, MEd; Christopher Burke, MD; D. Michael McMullan, MD; Titus Chan, MD; Hector Valdivia, RN; Larissa Yalon, RN; Joan Roberts, MD

From the Division of Neonatology (T Sawyer), Division of Cardiac Surgery (C Burke and DM McMullan), and Division of Critical Care Medicine (T Chan, H Valdivia, L Yalon, and J Roberts), Seattle Children's Hospital, Wash
The authors have no conflicts of interest to disclose.
Address correspondence to Taylor Sawyer, DO, MEd, University of Washington School of Medicine, 1959 NE Pacific St, RR451 HSB, Box 356320, Seattle, WA 98195-6320 (e-mail: tlsawyer@uw.edu).
Received for publication February 12, 2018; accepted January 21, 2019.

Abstract

Objective: To examine the impacts of a large-scale simulation-based extracorporeal cardiopulmonary resuscitation (ECPR) training program in an academic children's hospital.

Methods: The study followed a quasi-experimental, mixed-method, time series design. Two-hour high-fidelity ECPR simulations were held monthly in the pediatric, cardiac, and neonatal intensive care units. Intensive care unit−specific cases were used in each unit. The learning objectives for all cases were the same. Each simulation included an average of 11 health care professionals, including nurses, physicians, respiratory therapist, and perfusionists. Impacts of training were examined using Kirkpatrick's 4-level model: reactions, learning, behaviors, and results. Participant surveys, semistructured interviews, facilitator observations, applied cognitive task analysis, and hospital code data were used to examine the impacts of training.

Results: From February 2014 to October 2016, a total of 332 health care professionals participated in 29 ECPR simulations. Participants enjoyed the simulations and reported learning gains. Applied cognitive task analysis revealed 2 specific behaviors, coordination of compressions with surgical cannulation and performing sterile compressions, that were targeted for further training. The rate of adherence to the ECPR activation protocol improved from 83% (48/58) before simulations started to 95% (92/97) after simulations ($P = .02$). ECPR activation time decreased from 7 minutes (interquartile range, 4−9 minutes) before simulations started to 2 minutes (interquartile range, 1−4 minutes) after simulations ($P < .01$).

Conclusions: Large-scale simulation-based ECPR training was associated with positive reactions, learning gains, behavioral change, improved adherence to the ECPR activation protocols, and faster activation times. Other children's hospital that perform ECPR should consider simulation-based training.

Keywords: extracorporeal cardiopulmonary resuscitation (ECPR); pediatric; simulation

Academic Pediatrics 2019;19:566−571

What's New?

Simulation-based extracorporeal cardiopulmonary resuscitation (ECPR) training was associated with positive reactions, learning gains, behavioral change, improved adherence to the ECPR-activation protocols, and faster activation times. These findings support the use of simulation training in pediatric hospitals that perform ECPR.

Extracorporeal membrane oxygenation (ECMO) has revolutionized the care of critically ill patients.[1] Since 1990, more than 50,000 patients who may have otherwise died have survived because of ECMO.[2] Extracorporeal cardiopulmonary resuscitation (ECPR) is the initiation of ECMO during cardiac arrest that is unresponsive to conventional resuscitation measures. During ECPR, cardiopulmonary resuscitation is provided while the surgical team places ECMO cannulas. Over the past 20 years, ECPR has proven its effectiveness. Reported survival to discharge rates for in-hospital arrests patients undergoing ECPR are approximately 40%.[1-13]

ECPR is technically challenging and requires a large-scale, well-orchestrated, interprofessional team effort. Centers providing ECPR must offer training in ECPR deployment to health care teams.[1] Simulation is one method to provide ECPR training. Previous studies have shown an association between simulation-based ECPR training and improvements in clinical outcomes.[14] These results are encouraging; however, they do not provide information on the impact of simulation-based ECPR training on other important educational outcomes, such as attitudes and knowledge.

Starting in February 2014, Seattle Children's Hospital began a large-scale interprofessional simulation-based ECPR training program. The purpose of this study was to examine the impacts of the training program on each of the 4 levels of organizational learning described by Kirkpatrick: reactions, learning, behaviors, and results.[15] We hypothesized that the training program would have a positive impact on all 4 of Kirkpatrick's levels.

METHODS

STUDY DESIGN

The study followed a quasi-experimental, mixed method, time series design. The conceptual model of the study was deliberate practice.[16] The 2 time periods in the study were *before ECPR simulations started* (December 2012 to January 2014) and *after ECPR simulations started* (February 2014 to October 2016). The study was approved by the Seattle Children's Hospital Institutional Review Board and received a waiver for signed informed consent.

SIMULATION TIMING, LOCATION, AND SETUP

ECPR simulations were held once or twice per month for 10 months per year in each of the 3 intensive care units (ICUs): the pediatric intensive care unit (PICU), cardiac intensive care unit (CICU), and neonatal intensive care unit (NICU). Each simulation session lasted 2 hours. The time was roughly divided into a 30-minute introduction, 30 minutes of simulation, and 60 minutes of postevent debriefing.

All simulations were conducted in situ, in one of the hospital's ICU rooms. This allowed for maximal fidelity, including accurate ECPR team response times and equipment arrival times. The room in which the simulations were conducted was set up to emulate the room of a critically ill pediatric patient and included a pediatric manikin, monitors, intravenous fluids and pumps, and a mechanical ventilator.

SIMULATION SCENARIOS

Each ECPR simulation involved an interprofessional team of health care professionals. ICU-specific ECPR scenarios were developed for the training. Cardiomyopathy with refractory ventricular fibrillation arrest was used in the PICU and CICU. Meconium aspiration with refractory hypoxemic bradycardia was used in the NICU. Each scenario was standardized to assure a consistent approach to the simulation and debriefings during every simulation. The learning objectives were the same for all scenarios:

1. Accurately identify ECPR candidates.
2. Activate the ECPR system in accordance with hospital policy.
3. Provide effective cardiopulmonary resuscitation.
4. Demonstrate good teamwork and communication.

SIMULATION SESSIONS

Simulations were conducted using either the SimMan (Laerdal Medical, Inc, Stavanger, Norway) or the SimNewB (Laerdal Medical, Inc) simulators, depending on the scenario. The manikins were equipped with a specially developed ECMO neck patch that had simulated skin, tissue, and vessels (Figure). The vessels within the patch were connected to a bladder system that provided realistic circulation of artificial blood within the ECMO circuit. This neck patch allowed the surgical team to perform a life-like ECMO cannulation during cardiopulmonary resuscitation.

IMPACT MEASURES

The impacts of the ECPR simulation program were examined using the 4-level model described by Kirkpatrick: reactions, learning, behaviors, and results.[15] Because previous studies have shown an improvement in clinical outcomes with simulation based ECPR training, we felt it was important to report on attitudes and knowledge as these are also important learning outcomes.[15] Table 1 provides a summary of the outcome metrics and measurement methods used.

KIRKPATRICK LEVEL 1 OUTCOMES (REACTION)

Participant reactions were evaluated using anonymous e-mail surveys sent to all participants at 8 and 22 months after the start of the training program. Training value was rated on a 3-point Likert-type scale of "very valuable," "somewhat valuable," and "not valuable."

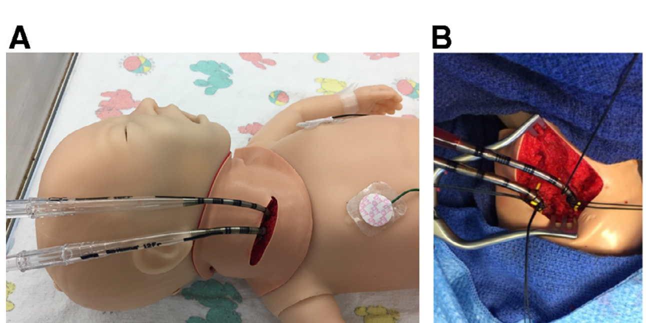

Figure. *(A) ECPR neck patch on a SimNewB simulator (Laerdal Medical, Inc). (B) Surgical dissection into ECPR neck patch. ECPR indicates extracorporeal cardiopulmonary resuscitation.*

Table 1. Outcome Measures of ECPR Simulation Training

Kirkpatrick Level	Outcome Metric	How Measured
1. Reactions	Self-perceived value of the simulations training	Surveys of participants
2. Learning	Self-perceived knowledge gains	Surveys of participants
3. Behaviors	CPR coordination	Facilitator observation
	Dawning sterile attire for chest compressions	Semi-structured interviews
4. Results	Appropriate ECPR activation	Analysis of hospital "code blue" and ELSO data
	Time to ECPR cannulation	
	Duration of cannulation procedure	
	Survival outcomes	

ECPR indicates extracorporeal cardiopulmonary resuscitation; CPR, cardiopulmonary resuscitation; and ELSO, Extracorporeal Life Support Organization.

Kirkpatrick Level 2 Outcomes (Learning)

Learning outcomes were evaluated on the same surveys used for Kirkpatrick Level 1. Learning outcomes were evaluated via "yes" or "no" responses to the following questions: "*The simulation was effective in teaching skills appropriate to my level of experience*" and "*The simulation was effective in teaching teamwork and communication skills.*"

Kirkpatrick Level 3 Outcomes (Behavior)

We used applied cognitive task analysis (ACTA) to evaluate specific behavioral related to ECPR. As described by Militello and Hutton,[17] ACTA is a streamlined method of cognitive task analysis intended for use by instructional designers. ACTA provides a method to elicit critical cognitive elements from subject matter experts and the means to transform those data into instructional design recommendations. ACTA was performed using 2 complementary methods; interviews conducted as part of the postsimulation debriefings and a cognitive demands table (Table 2).[17]

Kirkpatrick Level 4 Outcomes (Results)

Retrospective chart review of hospital "code blue" records and local Extracorporeal Life Support Organization data were used to evaluate the clinical results from the ECPR simulation training. Clinical data from the period before ECPR simulations started were compared with clinical data from the period after ECPR simulations started. The analysis was limited to the first ECPR event for each patient.

Statistical Analysis

Data were summarized as percentages and standard deviations for normally distributed variables, and median with interquartile range (IQR) for non-normally distributed variables. Kirkpatrick level 1 and 2 outcomes were examined using descriptive statistics. Kirkpatrick level 4 outcomes were analyzed using the Chi-square or the Fisher exact test for normally distributed data and Mann−Whitney U test or Kruskal−Wallis test for non-normally distributed data. Data were analyzed using Stata SE 12 software (StataCorp LLC., College Park, Tex). Statistical significance was defined as a $P < .05$.

Results

ECPR Simulation Participation

From February 2014 to October 2016, a total of 332 health care professionals participated in ECPR simulations. Participants included 243 (73%) nurses, 34 (10%) attending physicians, 21 (7%) respiratory therapists, 14 (4%) ICU and surgical fellows, and 20 (6%) ECMO specialists. During that period, a total of 29 ECPR simulations were conducted; 15 (52%) in the PICU, 7 (24%) in the CICU, and 7 (24%) in the NICU. The average number of participants at each ECPR simulation was 11 ± 3.

Level 1 Outcomes: Reactions

Surveys of reactions (Level 1) and learning (Level 2) were received from 283 (85%) simulation participants. Response breakdown by work location was: 41% PICU, 34% NICU, and 27% CICU. Eighty-one percent of respondents found the simulation to be "very valuable."

Level 2 Outcomes: Learning

Ninety-five percent replied that "yes," the simulation was effective in teaching skills appropriate to their level of experience. One hundred percent replied that "yes," the simulation was effective in teaching teamwork and communication skills.

Level 3 Outcomes: Behaviors

Two tasks came to light because of the simulation as having a high cognitive load: coordinating chest compressions with ECPR cannulation and donning sterile attire to perform sterile chest compressions during ECPR. Through a series interviews and discussion with subject matter experts, these 2 areas were examined in detail to determine why the tasks were difficult and the common errors for each task. Table 2 shows the results of the investigation and the strategies developed to address the identified issues.

Level 4 Outcomes: Results

From December 2012 to October 2016, a total of 155 cardiac arrests occurred in the 3 ICUs, with 58 events before starting simulations and 97 after starting simulations. In that period, a total of 27 patients underwent ECPR, with 11 before starting simulations and 16 after

Table 2. Cognitive Demands Table Developed Using ACTA From Observations Made During ECPR Simulations

Difficult Cognitive Element	Why Difficult?	Common Errors	Strategies Developed Through ACTA
How to coordinate chest compressions during surgical procedure	Unclear who coordinates the pauses in compressions Lack of clinical experience	Long pauses in compressions Frequent interruptions of compressions Poor-quality CPR	Surgeon instructs compressor to pause compressions based on surgical needs. Instruct compressor to count seconds out loud in 15-second intervals from the stop of compressions. Surgeon instructs compressor to restart compressions with goal of <1-minute pause in compressions
How to put on sterile gown for chest compressions during ECPR	Multiple steps Lack of nurse training in donning sterile attire	Delays in start of sterile compressions OR techs tasked to help nurses don sterile attire Violations of sterile precautions	All ICU nurses received education on donning sterile attire during nursing skill days Area established in room for sterile compressors to stand to avoid contamination

ACTA indicates applied cognitive task analysis; ECPR, extracorporeal cardiopulmonary resuscitation; CPR, cardiopulmonary resuscitation; OR, operating room; and ICU, intensive care unit.

starting simulations. Adherence to the ECPR activation protocol improved from 83% (48/58) before simulations started to 95% (92/97) after simulations started ($P = .02$). Table 3 provides an overview of clinical outcomes of ECPR before and after simulation training.

DISCUSSION

We examined the impacts of a large-scale interprofessional pediatric ECPR simulation training in an academic children's hospital using Kirkpatrick's 4-level model. We found a positive reactions and individually reported learning gains from participation. Using ACTA, 2 cognitively challenging behaviors during the ECPR process were identified and made the focus of additional educational interventions. The simulation-based training was associated with improvement in adherence to the ECPR activation protocol and a decrease in ECPR activation time. These findings support the use of interprofessional simulation-based training in children's hospitals that perform ECPR.

Health care providers in our study enjoyed participating in simulation training. This is not surprising, as simulation-based ECMO training programs are generally well liked by participants.[18-20] This generalized enthusiasm makes simulation a powerful method for training health care teams. As noted by Lateef, [21] teamwork training conducted in the simulated environment offers additive benefit to the traditional didactic instruction and can result in enhanced performance and error reduction. Simulation works well for experienced health care professionals because it conforms to the principles of adult learning theory.[22,23] Our study used deliberate practice[16] as a conceptual model. Deliberate practice is a regimen of effortful activity designed to improve the acquisition of performance.[16] Features of deliberate practice include motivated learners, well-defined learning objectives, repetitive practice, measurement of performance, and formative

Table 3. Clinical Outcomes of ECPR Before and After Simulation Training

Demographics and Outcomes	Before Simulation (n = 11)	After Simulation (n = 16)	*P* Value
Age, mo, median (IQR)	7 (3.25–15.75)	6 (1.625–78.5)	.83
Weight, kg, median (IQR)	6.3 (4.45–8.1)	6.4 (3.2–12.25)	.88
Female sex, n (%)	4 (36)	7 (43)	.72
Location, n (%)			
CICU	9 (82)	12 (75)	.66
PICU	2 (18)	3 (19)	
NICU	0 (0)	1 (6)	
ECPR activation time, min, median (IQR)	7 (4–9)	2 (1–4)	<.01
ECPR response time, min, median (IQR)	18.5 (15–23)	25 (18.5–27.75)	.36
ECPR deployment time, min, median (IQR)	37 (30.75–41.25)	46 (39.5–49.75)	.52
Nighttime or weekend deployment, min, n (%)	7 (64)	14 (88)	.25
Surgical cannulation time, min, median (IQR)	17 (15–21)	22 (14.5–27.5)	.65
ECLS 24-h survival, n (%)	5 (45)	9 (56)	.56
Survival to discharge, n (%)	3 (27)	6 (38)	.38

ECPR indicates extracorporeal cardiopulmonary resuscitation; IQR, interquartile range; CICU, cardiac intensive care unit; PICU, pediatric intensive care unit; NICU, neonatal intensive care unit; and ECLS, extracorporeal life support.

feedback. We believe the use of deliberate practice helped to achieve the improvements in knowledge and clinical outcomes we observed.

The 2 behaviors identified through ACTA as cognitively difficult were unique to ECPR. Thus, it is not surprising that these behaviors were challenging for the participants. As noted by Thompson et al, [19] simulation can be used for the identification and reduction of anxiety-related issues associated with ECMO. We found that ACTA provided an easy method for analyzing cognitive load and developing focused interventions. We believe other centers may benefit from applying ACTA techniques to pinpoint areas of cognitive difficulty for their staff around ECPR and to develop targeted interventions to address them.

Our findings of an association between ECPR simulations and improvements in clinical performance during ECPR are supported by previous research. Su et al [14] reported the impact of a simulation-based training intervention on ECPR initiation times using a similar pre-post study design. In that study, simulation training was associated with an 11-minute reduction in ECPR deployment times (51 minutes presimulation, IQR, 43−62 minutes vs 40 minutes postsimulation, IQR, 23−52 minutes; $P = .018$). We did not find a decrease in ECPR deployment time in our study; however, our 37 minutes' average presimulation deployment time was faster than the 40 minutes postsimulation deployment reported by Su et al. Therefore, we believe there was little room for improvement in that specific metric at our institution. Our main clinical finding was a decrease in ECPR activation time. The results of these 2 studies suggest that each hospital may have different opportunities for improvement in the ECPR process and that ECPR simulations can have positive effects on different metrics at different sites. Other measures of ECPR performance in our hospital did not change after simulation training. Our small sample size likely made it hard to show statistical changes in those measures. Our average ECPR deployment time was slightly longer after starting simulation training. We believe this was due to a greater number of nighttime or weekend deployments after starting simulations (Table 3).

This study has several limitations. First, learning outcomes were limited to self-assessments. Evaluation of knowledge outcomes could have been improved by using a multiple-choice test or other methods. Second, because of the rarity of the event, the number of ECPR cases was low. This puts the results of our clinical outcomes at risk for type II error. Further research over a longer duration, or using multiple centers, is indicated. Third, there was no washout period between the before simulation and after simulation data collection periods. Thus, during the postsimulation period, some people were trained whereas others were not. This could bias the results. Finally, due to the quasi-experimental study design, we cannot prove a causal relationship between the simulation training and the clinical results reported. We can only confirm a temporal association.

CONCLUSIONS

We conclude that large-scale interprofessional simulation-based pediatric ECPR training is well liked by health care teams and is associated with self-reported learning gains. Using simulation and ACTA, we identified behaviors that were difficult for the health care team to carry out, and specific measures were instituted to improve performance. Simulation training was associated with improved adherence to the ECPR activation protocols and faster ECPR activation. These findings support the use of interprofessional ECPR simulations in children's hospitals that perform ECPR.

ACKNOWLEDGMENTS

We acknowledge the health care providers at Seattle Children's Hospital who participated in the ECPR simulations. We also acknowledge the other physicians and nurses who help to facilitate the ECPR simulations and debriefings in the PICU, CICU, and NICU.

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