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Simulation and education

Simulation training enables emergency medicine providers to rapidly and safely initiate extracorporeal cardiopulmonary resuscitation (ECPR) in a simulated cardiac arrest scenario

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Abstract

Background: Extracorporeal cardiopulmonaryresuscitation (ECPR) is emerging as a viable rescue strategy for refractory out-of-hospital cardiac arrest. In the U.S., limited training of emergency medicine providers is a barrier to widespread implementation.

Aims: Test the hypothesis that emergency medicine physicians and nurses can acquire and retain the skills to rapidly and safely initiate ECPR using high-fidelity simulation.

Study design: Prospective interventional study.

Setting: U.S. tertiary academic medical center.

Subjects: Emergency medicine physicians and nurses with no prior ECPR/ECMO experience.

Methods: Teams of three physicians and three nurses underwent a two-day ECPR training course including didactics, hands-on training, and simulation. Teams were videotaped initiating ECPR in a high-fidelity simulation scenario before and after simulation training. The primary outcome was the proportion of simulations in which full ECPR support was achieved within 30 min of patient arrival.

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Results: Five teams completed the entire study. Full ECPR support was achieved within 30 min of patient arrival in 11/15, 15/15, and 15/15 attempts at baseline (B), post-testing (PT) and 3-month post-testing (3-PT), respectively ($p = 0.06$). Intervals (mean $\pm$ sd) required to achieve full ECPR support at B, PT, and 3-PT were 25.8$\pm$5.3, 17.2$\pm$4.6, and 19.2$\pm$1.9 min respectively ($p < 0.05$ for B vs. PT and 3-PT).

Conclusion: High fidelity simulation training is effective in preparing emergency medicine physicians and nurses to rapidly and safely initiate ECPR in a simulated cardiac arrest scenario, and should be considered when implementing an ED-based ECPR program.

Keywords: Cardiac Arrest, Extracorporeal Cardiopulmonary Resuscitation, Simulation, Emergency Medicine, Emergency Department

Introduction

Approximately 242,000 people are treated for out-of-hospital cardiac arrest (OHCA) each year in the United States.[1] No new therapies have been proven effective in over a decade, and therefore survival rates have remained stagnant at approximately 10%.[1] The limiting factor for the majority of patients is failure to achieve sustained return of spontaneous circulation (ROSC).[1] For these patients, an alternative strategy is needed to make survival possible. Extracorporeal cardiopulmonary resuscitation (ECPR) using percutaneous veno-arterial extracorporeal membrane oxygenation (VA-ECMO) is emerging as feasible and effective for patients who fail to achieve ROSC with standard resuscitation. For witnessed refractory OHCA, reported survival rates with good neurologic outcome following EPCR range from 4 to 50%.[2–9]

In the majority of published case series of ECPR for OHCA, ECPR is initiated in the emergency department (ED).[2–4,6,7,10–13] The reason for this strategy is that the shorter the interval from cardiac arrest onset to initiation of ECPR, the better the chance for a favorable outcome, with a target likely under 60 min. A major barrier to implementation in the U.S. is that very few emergency medicine (EM) providers are trained to provide ECPR. Therefore, cardiac surgeons or intensivists must be called to the ED, or interventional cardiologists must receive patients in the cardiac catheterization laboratory with ongoing CPR. In both cases, there are challenges to creating a sustainable model that consistently achieves arrest onset-to-ECPR flow intervals of less than 60 min, especially if prehospital treatment and transport time approaches 30 min or more.

An alternative strategy that has been successful outside the U.S. is to have ED providers initiate ECPR within minutes of patient arrival.[3–6,10] In the U.S., EM physicians are immediately available on-site to perform time sensitive procedures 24 h/day, 365 days/year without relying on a call schedule. However, ECMO initiation and management are currently not part of EM physician or nurse training. EM providers have the most experience in managing OHCA, are the most familiar with the resources, equipment and personnel available in the ED, and are well-trained to perform arterial and central venous access in unstable patients. Therefore, it is reasonable to postulate that EM providers can be trained to rapidly and safely initiate ECPR.

In this study we tested the hypothesis that ED physicians and nurses with no prior ECPR/ECMO experience can acquire and retain the skills to rapidly and safely initiate ECPR using high-fidelity simulation. To the best of our knowledge this is the first study to quantify the initial and sustained effect of ECPR simulation training for OHCA in adults.

Methods

This was a prospective, interventional cohort study of simulation as a training tool for acquisition and retention of technical skills. Our Institutional Review Board approved this study for exemption from informed consent. Training and testing took place in the University of Michigan Clinical Simulation Center.

A multidisciplinary group including intensivists with ECPR/ECMO experience, cardiac surgeons, and ECMO specialists convened to define the procedure in detail, develop a list of critical actions and safety violations pertinent to cannulation, circuit priming, circuit connection, and initiating ECPR flow, and develop a two-day training curriculum (Fig. 1 and Supplemental Table). This group consensus reflected the techniques and equipment already used at our institution.

Fig. 2 illustrates the training model. To simulate the bilateral femoral arteries and veins, inferior vena cava, and abdominal aorta, ½″ silicone tubing was looped over the surface of a full-size CPR mannequin. The vessels at the groin were covered with ballistic gel molds to simulate ultrasound-guided vessel access and serial dilation through tissue. The vessels were filled with warm water from a reservoir to create the effect of back-bleeding during vascular access and cannulation. Once the model was cannulated and connected to an ECMO circuit, forward flow could be established with realistic flow rates and inlet and outlet pressures. In addition, we simulated an active resuscitation with monitor alarms and a mechanical CPR device (LUCAS-II, Physiocontrol, Lund, Sweden) to create noise and patient movement during the procedure. The room layout simulated the environment of a typical emergency department resuscitation area to enhance realism.

The training circuit replicated the adult VA-ECMO circuits in clinical use at our institution, consisting of a Centrimag centrifugal pump motor and console (Thoratec, Pleasanton, CA) and a Quadrox oxygenator (Maquet, Wayne, NJ). We used Bio-Medicus ECMO cannula kits (Medtronic, Minneapolis, MN): 23 French single-stage or 25 French 60 cm multistage venous cannulae and 15 French arterial cannulae. For initial vascular access, we used a Cook 5 French 15 cm single lumen catheter kit (Cook Group, Bloomington, IN), 180 cm 0.035″ Amplatz Superstiff J-tip wires (Boston Scientific, Marlborough, MA), and an Avalon Elite Vascular Access Kit (Maquet, Wayne, NJ) or LivaNova Vascular Dilator Kit (LivaNova, London, UK), all of which reflect the current clinical practice at our institution. Ultrasound was performed using a Mindray TE7 (Mindray, Mahwah, NJ).

Teams of three EM residency-trained physicians and three ED nurses were recruited on a voluntary basis. Prerequisites were[1] time commitment to complete all phases of the study within the assigned team, and[2] no prior experience with ECPR/ECMO cannulation, initiation, or circuit priming. Each physician rotated through each of three roles: primary ECPR cannulator (“MD1”), assistant (“MD2”), and ultrasound/equipment helper (“MD3”). Each nurse rotated through each of three roles: nursing team leader (“RN1”) and two circuit primers (“RN2” and “RN3”), one of whom guided the other through tasks using a checklist, analogous to pilot/co-pilot roles on an airliner. Each individual role was responsible for an exact sequence of critical actions, the end results of which were correct vascular access, ECPR cannulation, and circuit connections by the physician team, and correct circuit priming and titration to full ECPR support (3 L/min) by the nursing team.

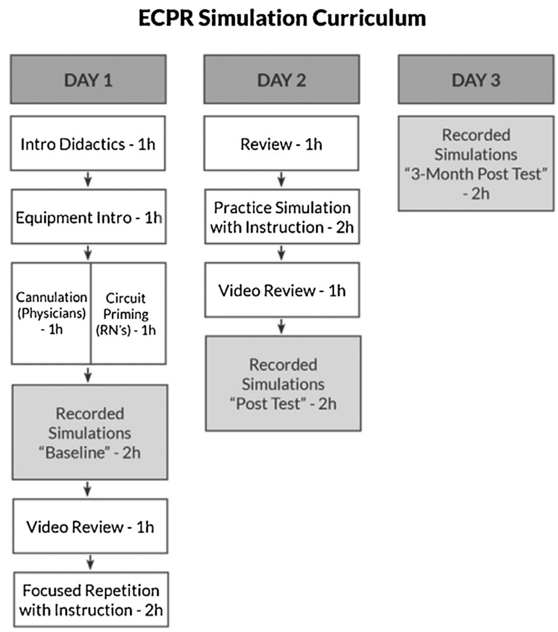

Fig. 1 – ECPR simulation curriculum. Two-day curriculum for emergency medicine physicians and nurses included didactics, hand-on training, simulation pre-test and simulation post-test. Followup post-testing occurred 3 months after training session.

The training course started with introductory didactics and orientation to the ECPR circuit, after which the physicians and nurses split up for hands-on primers on technique of cannulation and circuit priming, respectively. Following this *non*-simulation instruction, the full team conducted three video-recorded ECPR simulations for baseline timing and scoring. Each simulation started with the "patient" arriving on a stretcher in cardiac arrest and ended with establishing 3 L/min of ECPR flow. The remaining portion of the course consisted of repeated simulation with video review and hands-on instruction. Three more recorded simulations were timed and scored at the conclusion of the course (post-test) and again after three months (3-months post-test). Physicians and nurses rotated roles, with no debrief or instruction, between each scored simulation.

Data collection

Each scored ECPR simulation was video recorded onto a protected server maintained by the Clinical Simulation Center. Data collection occurred in person and by video review by the authors,

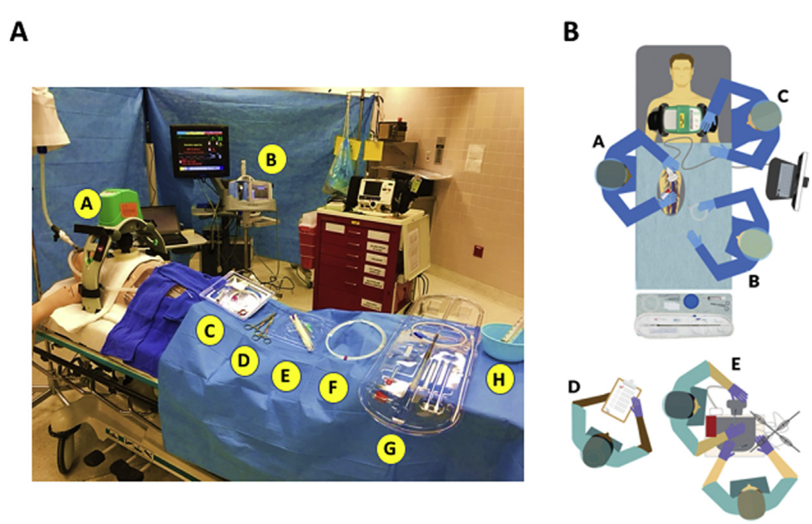

Fig. 2 – ECPR simulation. A. Labeledphotograph of ECPR simulation setup including a full-scale resuscitation simulation space, CPR mannequin, resuscitation cart and typical simulation software. (A), mechanical CPR device; (B), vascular ultrasound; (C), central line kit; (D), tubing clamps; (E), vascular dilator kit; (F), long guidewire; (G), ECMO cannula kit; (H), catheter-tip syringe and bowl of saline flush. B. ECPR trainee roles. A, cannulating physician; B, cannulation assistant; C, ultrasound and equipment runner; D, ECMO lead nurse; E, two-person ECMO circuit priming.

using de-identified critical action scoring sheets (Supplemental Table) for each physician and nurse role. All collected data were stored on a spreadsheet saved on a password protected university cloud server.

Outcome measures

The primary outcome was the proportion of recorded simulations in which full ECPR support (3 L/min) was established within 30 min of "patient arrival," with the individual simulation as the unit of analysis (n = 15). Secondary outcomes were time intervals required to complete cannulation, prime the circuit, and achieve full ECPR support, as well as critical action checklist adherence and incidence of safety violations, with the team as the unit of analysis (Supplemental Table).

Statistical analyses

Hypotheses for binary outcomes were tested with McNemar's test for dependent proportions, and hypotheses for continuous outcomes were tested with a series of repeated measures analyses of variance (ANOVAs) comparing changes in all three endpoints over time from pre-to post-test, pre-test to 3-months, and from post-test to 3-months follow-up. Procedures suggested by Agresti and Coull were used to estimate 95% confidence intervals for binomial proportions.[14] Analyses were conducted with the SAS software package.[15]

Results

Seven teams were recruited for the study, and complete data were collected from five teams. One team completed the course but could not be scheduled for follow-up within three to four months. One team of physicians only completed the course but could not be scheduled with nursing or follow-up. Reported results are derived from the five teams that completed the entire study.

ECPR was successfully initiated within 30 min in 11/15 (73.3% [95% CI 47.6%–89.5%]) baseline simulations, 15/15 (100% [95% CI 76.1%–100%]) post-test simulations, and 15/15 (100% [95% CI 76.1%–100]) 3-month post-test simulations. Although the improvement between baseline and post-testing did not reach statistical significance ($p = 0.06$), the magnitude of the improvement (73%–100%) is clinically important. Results from analysis of time interval data are summarized in Fig. 3. For the team-level data, results from a repeated-measures ANOVA showed that the effect of time was statistically significant, $F(2, 8) = 6.9$, $p = 0.02$, and follow-up contrasts showed that the interval from patient arrival to full ECPR support (mean ± sd) decreased significantly from 25.8 ± 5.3 min baseline to 17.2 ± 4.6 min post-test, $\Delta = 8.6$ min, $F(1, 4) = 10.1$, $p = 0.03$. This decrease from baseline remained statistically significant at 3-month post-testing with a mean interval of 19.2 ± 1.9 min, $\Delta = 6.6$ min, $F(1, 4) = 8.7$, $p = 0.04$. There was no statistically significant difference in the time from patient arrival to full ECPR support between the post-test and 3-month follow-up, $F(1, 4) = 0.8$, $p = 0.42$.

Primary ECPR cannulator performance was assessed by time to cannulation (Fig. 3) and by critical action checklist adherence (Fig. 3). Repeated-measures ANOVA showed that the effect of time was statistically significant, $F(2, 8) = 13.8$, $p = 0.003$, and follow-up contrasts showed that the interval from patient arrival to completion of cannulation (mean ± sd) decreased significantly from 20.2 ± 3.7 min at baseline to 13.4 ± 3.6 min during post-testing, $\Delta = 6.8$ min, $F(1, 4) = 12.5$, $p = 0.02$. This decrease from baseline remained significant at 3-month post testing with a mean interval of 13.3 ± 1.5 min ($\Delta = 6.9$ min, $F(1, 4) = 37.6$, $p = 0.004$). There was no significant change in the interval from patient arrival to completion of ECPR cannulation between the post-testing and 3-month post-testing period, $F(1, 4) = 0.002$, $p = 0.96$.)

Finally, we observed a statistically significant effect of time on the interval from patient arrival to circuit primed, $F(2, 8) = 4.4$, $p = 0.05$, and follow-up contrasts showed a statistically significant decrease from 18.8 ± 5.4 min at baseline to 13.3 ± 2.7 min during post-testing ($\Delta = 5.5$ min, $F(1, 4) = 10.0$, $p = 0.03$) (Fig. 3). However, interval from patient arrival to circuit primed at 3-month post-testing was 16.0 ± 1.6, which was not statistically different from baseline ($F(1, 4) = 1.4$, $p = 0.30$). There was no statistically significant change in time to circuit primed from initial post-test to 3-month post-testing, $F(1, 4) = 4.6$, $p = 0.10$.

Out of a total of 44 critical actions in the procedure for the primary ECPR cannulator (Supplemental Table), there was a statistically significant effect of time, $F(2, 8) = 4.6$, $p = 0.04$, and follow-up contrasts showed a statistically significant increase in the number of

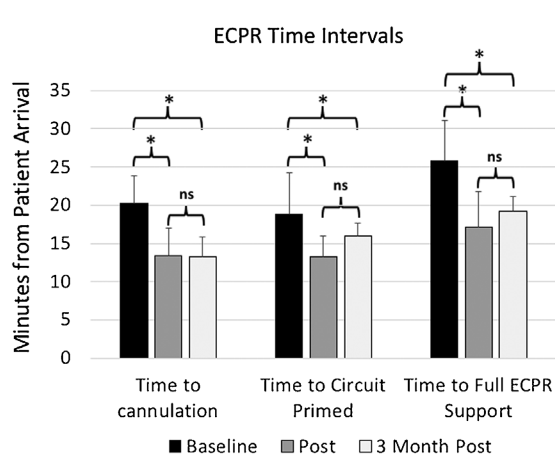

Fig. 3 – Intervals from patient arrival to ECPR cannulation, ECPR circuit primed, and full ECPR flow (3 L/min) for baseline, post-test, and 3-month post-test periods (mean ± sd). * indicates $p < 0.05$ based on follow-up contrasts for repeated measures ANOVAs.

critical actions performed correctly between baseline ($M = 40.3 \pm 1.8$) and post-test ($M = 43.6 \pm 0.6$), ($D = 3.3$ actions, F (1, 4) = 13.2, $p = 0.02$). However, the number of critical actions performed correctly did not differ between baseline to 3-month post-testing ($M = 40.9 \pm 2.7$), F (1, 4) = 0.2, $p = 0.67$).

A limited number of safety violations were observed. Of 15 pre-test cannulations, we noted two breaks in sterility, one failure to heparinize, and one arterial air embolism upon circuit connection. Of 15 post-test cannulations, the only safety violations noted were two breaks in sterility. Of 15 3-month post-test cannulations, we noted three failures to confirm correct wire placement by ultrasound prior to dilation and three instances of venous cannula being inserted beyond a safe depth. There were no instances of incorrect vessel cannulation or mismatched cannula-circuit connections. There were no statistically significant differences in the average number of safety violations over time, F (2, 8) = 1.2, $p = 0.35$.

Discussion

In the U.S., ECPR is currently outside the scope of training for EM physicians and nurses. The use of ECPR in the ED for refractory cardiac arrest is a "low-frequency, high-complexity" event, for which clinical volume alone is not sufficient to train the EM workforce going forward. Therefore, simulation is essential if EM providers are to acquire and retain these skills. ECMO training courses sponsored by international organizations such as the Extracorporeal Life Support Organization (ELSO) do provide didactic and simulation training, but ECPR is not generally the primary focus, and these courses do not emphasize cannulation or test individual and team performance. Finally, there is no standard approach to assess skill retention and need for refresher training. To overcome these barriers, we created an ECPR training and testing program focused specifically on the skills that EM physicians and nurses need to initiate ECPR. In this study, we demonstrate that a high-fidelity ECPR simulation training course is effective in training emergency medicine physicians and nurses with no prior ECPR/ECMO experience to rapidly and safely initiate ECPR in an adult cardiac arrest simulation. We also demonstrate these skills are maintained for at least three months.

Simulation is a staple of medical education for technical skill acquisition, particularly in EM.[16] Benefits include individualized real-time feedback to the learner, repetition, and standardized assessment. In a 2011 meta-analysis, McGaghie et al. showed that simulation with "deliberate practice"— that is, the focused repetition of a well-defined skill with ongoing feedback, error correction, and rigorous measurement — is superior to traditional training in terms of skill acquisition.[17] In more than 600 learners spanning multiple skills, including advanced cardiac life support, surgical techniques, and central line placement, simulation training consistently resulted in measurably improved skill performance with an effect size of 0.71 ($p < 0.001$) versus "apprenticeship" bedside training. Simulation training may translate into improved patient care as well; for example, central line simulation training is associated with fewer attempts, fewer arterial punctures, fewer pneumothoraces, fewer bloodstream infections, and higher overall success rate in critically ill patients.[18–21]

Previous studies provide evidence that novice physicians and nurses benefit from simulation training by improving knowledge, confidence, and technical skills related to ECMO cannulation and management.[22–25] In a similar study by Allan et al, cardiothoracic surgery trainees without cannulation experience performed VA ECMO cannulation via cervical vessel cutdown in an infant cardiac arrest scenario.[25] They achieved a significant reduction in time to cannulation and increased performance scores after a baseline simulation followed by video debriefing and didactics, and this improvement was evident out to three months. Our findings parallel these, with notable differences being the patient population, percutaneous versus cutdown technique, and training specialty. In a recent randomized trial, Zakhary et al. compared ECMO simulation in which a mannequin is "cannulated" and attached to an ECMO circuit, mechanical ventilator, and standard ICU monitoring with continuous vital sign, ventilator, and circuit parameters, versus standard ECMO water drills which utilize a circuit in isolation. The authors found that for novice critical care trainees, simulation training resulted in improved timing of critical actions.[24]

Our findings support the hypothesis that simulation can enable EM physicians and nurses with no prior ECPR/ECMO experience to initiate ECPR within 30 min of patient arrival. We also demonstrate that these skills are retained out to three months. In our institution, we estimate 1–2 ECPR candidates per month or 12–24 per year present to the ED, translating to approximately one cannulation per provider per year in a group of 15 ECPR-trained faculty, who might otherwise perform a refresher simulation quarterly in between real ECPR cases.

In addition to evaluating the time-critical aspects of ECPR, we sought to evaluate our ability to train providers to safely perform the technique. We used a critical action list to score each participant in every step of the procedure, as well as a safety violation checklist to track critical errors. We found an overall high level of critical action adherence (99%) in initial post-testing, with some evidence of decay over 3 months that was not statistically significant. Safety violations were uncommon but also numerically more frequent at 3-month post testing, again not statistically significant. These observations suggest that more frequent refresher training may be needed to maintain cognitive skills related to the procedure.

There are several real-world implications of this study, foremost is that emergency medicine physicians can be effectively trained to cannulate for ECPR using high-fidelity simulation. This may apply to other physicians trained in vascular access, such as anesthesia, critical care, cardiology, or interventional radiology. We have also demonstrated that emergency medicine nurses can use a checklist to quickly and safely prime a circuit and establish flow without an ECMO specialist present. This model of training could greatly improve access to ECPR for out-of-hospital cardiac arrest patients in the U.S. and other nations with similar health care systems.

Limitations

We acknowledge several important limitations. While we attempted to isolate each provider in each role for data gathering, we presume there was an element of team cooperation and iterative familiarization with each simulation that may contribute to each individual's improved performance over time. Our study was limited to the simulation environment. Performance may be affected by an individual's comfort with their consistent team, and team composition is likely to be disrupted in an unplanned clinical emergency. Performance may also be markedly affected if providers were called to perform their tasks on minutes notice without advanced preparation, also likely in a clinical emergency. These questions could be addressed in future studies using unannounced in-situ simulations within the actual ED setting.

Team composition of three physicians and three nurses focused solely on ECPR may not be realistic in many clinical settings. This study does not address the indications/contraindications for ECPR initiation or post-cannulation management and troubleshooting, In both of these areas, close collaboration with experienced ECMO services remains essential.

Conclusion

A high fidelity ECPR simulation training course enables teams of emergency medicine physicians and nurses to acquire and retain the skills necessary to rapidly and safely initiate ECPR in a high-fidelity simulation scenario. This training strategy is a valuable resource for institutions initiating ED-based ECPR programs or planning to participate in ECPR clinical trials for out-of-hospital cardiac arrest.

Conflict of interest

The authors have no significant financial conflicts of interest related to this research.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.resuscitation.2019.03.002.

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