Title

Cardiac Tamponade: Innovative Sternotomy Simulation Model for Training Pediatric Cardiac Intensive Care Team

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Abstract

Introduction: Cardiac tamponade occurring after cardiac surgery is rare but life threatening and requires simultaneous resuscitation and emergent sternotomy by the intensive care team. A simulated scenario using innovative mannequin with sternotomy wound has the capability of reproducing cardiac arrest associated with postoperative tamponade. We evaluated the face validity of this innovative mannequin, the confidence level and crisis resource management skills of the team during sternotomy to manage postoperative cardiac tamponade.

Methods: The simulation case scenario was developed using innovative sternotomy mannequin for children's hospital cardiac intensive care unit (CICU) teams. The case involved a 3-year old male, intubated, mechanically ventilated after surgical repair of CHD, progressing to cardiac arrest due to cardiac tamponade. We conducted a structured, video debriefing following each scenario. We conducted a formative learner assessment before and after each scenario and analyzed the data using student t-test.

Results: Of the 72 CICU providers, a statistically significant proportion of providers ($p < 0.0001$) showed improved confidence in assessing and managing cardiac arrest occurring following postoperative cardiac tamponade. All the providers scored ≥ 3 for impact of the scenario on practice, teamwork, communication, assessment skills, improvement in CPR and opening the chest and their confidence in attending similar clinical situation in future. Most (96–100%) scored ≥ 3 for perception on realism of mannequin, the scenario, re-opening the sternotomy and level of stress.

Conclusions: Innovative adaptation of a high-fidelity mannequin for cardiac tamponade simulation can achieve a realistic and reproducible training model with a positive impact on multi-disciplinary team training.

Key words

Sternotomy, Chest re-opening, simulation, high-fidelity, cardiac tamponade, pericardial effusion, mannequin, Scenarios, training, Cardio-pulmonary arrest, CPR, Pediatrics, PICU, Emergency Medicine, Critical Care, Shock, Defibrillation.

Abbreviations

CICU = cardiac intensive care unit, CRM = Crisis Resource management.

Introduction

Congenital heart defect (CHD) is the commonest birth defect, affecting nearly 1% of—or about 40,000—births in the United States each year.[1,2] Palliative and/or corrective surgery for the CHD has been associated with improved life span.[3] But, palliative and corrective surgery for CHD often results in postoperative complications involving cardiovascular, respiratory, neurologic and other systems[4]. Postoperative cardiac tamponade is rare but a dramatic complication, which progresses to cardiac arrest if not recognized in time. The cardiac tamponade is characterized by accumulation of fluid around the heart, which leads to obstructive shock[5]. Therefore, an urgent drainage of the fluid helps reverse the shock.

The children who undergo surgery for CHD are often brought back to the CICU with either open or closed sternum. In case of closed sternal wound, any significant, intra-thoracic accumulation of blood and blood clots could lead to cardiac tamponade[5]. In such a scenario, re-opening the closed sternum by CICU team could be a life-saving measure. The other key management components in case of cardiac arrest caused by cardiac tamponade include cardiopulmonary resuscitation (CPR), volume expansion and direct cardiac massage, evacuation of blood, and clots from chest once the closed sternal wound is re-opened. In short, management of the postoperative cardiac tamponade in CICU involves a multi-disciplinary team approach for simultaneous resuscitation and re-opening the closed sternal wound. Cardiac surgeons are very well trained in re-opening the closed sternal wound, but the rest of the CICU team members are not formally trained in re-opening the sternum. This is an example of "pediatric training paradox"[6] - the skills most helpful for saving lives are the skills we get to perform, and practice the least. Simulation has been identified as an important method for improving patient safety, and quality of care[7,8]. With the reduction in apprenticeship hours, simulation can provide effective practical training with assessment of technical skills[9,10]. It has become an essential part of training in many hazardous specialties including cardiac surgery [11]. It is known that simulation-based education enhances the quality of care during cardiac arrest team responses[12]. It promotes procedural, and resuscitation technical skills [13,14] as well as teamwork, communication, and overall practice[15]. There is a lack of sufficient information on how simulation can be utilized to train the CICU team in delivering a high-quality resuscitation with effective teamwork and communication during postoperative cardiac tamponade after surgical repair of CHD. Our team has developed innovative mannequin with postoperative sternal wound to mimic postoperative CICU scenario and developed a simulation-based educational curriculum focused on training CICU team on crisis resource management (CRM) of cardiac tamponade. Our simulation scenario is uniquely suited to the CICU team in early recognition of cardiac tamponade, understanding the differential diagnosis of tamponade, early interventions such as volume expansion, titration of inotropes, and manipulation of chest tube drainage, re-opening the closed sternum and simultaneously delivering a high-quality resuscitation, CRM and effective team communication during management of postoperative tamponade. Prior educational curricula related to cardiac tamponade have focused on objectives such as improving diagnostic skills of the providers using bedside ultrasound, time to order chest re-opening by experienced versus new team leaders and performing an emergent pericardiocentesis for cardiac tamponade[16, 17, 18]. Our current study aims at assessing the participant perception and confidence in managing tamponade-associated cardiac arrest and delivery of a high-quality CPR during cardiac tamponade in postoperative period.

Methods

Study Design

We conducted a retrospective study on an innovative cardiac tamponade sternotomy simulation exercise. Ethical oversight was obtained at the participating simulation center while gaining informed consent from all participants.

Development of Innovative mannequin and Simulation-Based Curriculum

In case of a significant pericardial effusion leading to cardiac tamponade, an urgent pericardiocentesis would be sufficient to relieve the tamponade. But, in case of accumulation of blood and blood clots around the heart, which often leads to postoperative tamponade, an emergent re-opening of the closed sternal wound becomes an essential intervention. Cardiac surgeons are well trained in re-opening the closed sternal wound but the CICU physician is not formally trained in performing the intervention. In case of non-availability or delayed availability of a cardiac surgeon at the bedside, CICU physician should be trained to re-open the closed sternum in order to relieve the tamponade. Also, coordinating the simultaneous tasks of opening the sternotomy by CICU physician and delivery of high-quality CPR by CICU team members requires teamwork, efficient communication and CRM skills. Our team therefore developed an innovative mannequin capable of reproducing postoperative cardiac tamponade (Figure 1). The detailed scenario of the case, history and examination findings, vital sign trends, expected critical actions, and anticipated management mistakes are in the template (Appendix A).

Equipment/Environment

Scenarios were conducted in the hospital simulation center, which is not in the vicinity of the patient care area. This optimized recruitment of the study participants, and streamlined the study procedure without jeopardizing patient care, study participants' privacy, or confidentiality. Environment and mannequin were prepared according to the template (Appendix A). Medications and equipment were used as following the checklist. (Appendix B) to prepare all the medications and equipment; and used the details of the scenario to provide the information about the physical examination during the scenario. At the start of the simulation, bedside nurse was informed that a 3 year old male who had a significant bloody output through the chest tubes overnight following repair of Tetralogy of Fallot, now had sudden cessation of chest tube output and deterioration in vital parameters (Appendix A). Changes in vital signs were seen on the monitor using the standard software for SimJunior by Laerdal.

Selection of Participants

One ICU physician, one ICU nurse practitioner, five to six ICU nurses were selected for each scenario. Each scenario included 2 simultaneous life-saving interventions – opening of the chest and cardiopulmonary resuscitation. The simulations required the presence of at least 6 participants to conduct the scenario successfully. Each participant functioned in their expected roles within the health care team (physicians played the role of physicians, nurses played the role of nurses.). We collected the information about the participants (Appendix C) including the provider level, number of years in practice, the certification status, any previous experience in dealing with either the cardiac tamponade or sternotomy.

Implementation

Every participant spent about 1 hour per simulation session - approximately 20 minutes for the scenario, and 40 minutes for debriefing. The simulation technician prepared the mannequin, all the simulation resources such as code cart, gowns, masks, monitor settings for the scenario according to simulation template (Appendix A and B). Before initiating the scenario, participants were informed about the ground rules of simulation, the educational project with details of pre-simulation and post-simulation questionnaires. Before starting the scenario, participants completed the pre-simulation questionnaire (Appendix D) to assess their confidence level in assessing and managing a child who has developed complication after the cardiac surgery. Subsequently, the nurse educator went over the innovative mannequin at the bedside and narrated the case scenario to the participants. The simulation team asked one of the nurse participants to be the bedside nurse. During the scenario, the simulation technician changed the monitor trends based on the simulation template (Appendix A) and the facilitator observed the participants through the control room and completed the expected critical actions checklist (Appendix G). At the end of the scenario, the facilitators conducted structured, video debriefing (Appendix F). After the video debriefing, participants completed the post-simulation questionnaire (Appendix E).

Debriefing

At the end of the scenario, we conducted video debriefing focusing on the teamwork, communication, medical management. We focused on early recognition and management of cardiac arrest, opening of the sternotomy by CICU attending, delivery of high-quality CPR during sternotomy, teamwork and communication. We specifically focused on leadership during initial phase of the scenario and leadership transition when CICU attending identified the need to open the sternotomy and got involved with the procedure; closed loop communication and CC interruptions while CICU attending was attempting to open the sternotomy.

Assessment

We utilized pre, and post-simulation questionnaire with Likert scale (1=not at all/no impact, 5=a lot/high impact) (Appendix D and E respectively) to assess their confidence before and after the simulation scenario in assessing and managing postoperative cardiac tamponade. Through the questionnaire, we estimated the same four elements as pre-study survey, in addition to the impact of the scenario on practice, teamwork, communication, and assessment skills. We evaluated their improvement in specific technique such as CPR, and opening the chest, and their confidence in attending similar clinical situation in future. Moreover, we asked them about their perception on realism of the innovative sternotomy mannequin, cardiac tamponade scenario, re-opening the sternotomy on the mannequin, and their level of stress experienced during the scenario. We checked their adherence to resuscitation guidelines during the simulation through the checklist for Facilitator (Appendix G), and also by reviewing the videos (Appendix H).

Data Collection

We collected data from the pre, and post assessments completed by the simulation teams, and from the observation checklist that the facilitator completed. CPR quality metrics were compared between the first session and 6-month follow-up session. The data was analyzed using student t-test and chi-square test (significant $p \leq 0.05$).

Results

Patient Demographics

A total of 72 participants completed the simulation exercise. Of these 54, 18 returned to complete the second session 6 months later, resulting in a total sample size of 72 participants. Among them, 78% (n=56) were nurses and 22% (n=16) were non nurses which included faculty, CICU intensivist, respiratory therapists (RT), physician assistants (PA). 56% (n=40) of the participants had been practicing for more than 5 years, 36% (n = 26) of the participants had previous experience with treating cardiac tamponade, 36% (n=26) had experience with closed/open sternotomies and 99% (n=71) of participants were certified in Pediatric Advanced Life Support (PALS). Demographic and clinical data of the entire cohort are summarized in Table 1.

Pre- and Post- Study Confidence Comparison

In analyzing the survey results, answers greater than or equal to 3 were considered confident. Before completing the simulation exercise, 76% (n=55) said they were confident in assessing the patient, 65% (n=47) said they were confident in taking care of the patient, 63% (n=45) said they were confident in performing medical interventions and 42% (n=30) said they were confident in performing surgical interventions.

After completing the simulation exercise, 99% (n=71) said that they were confident in assessing the patient ($P < 0.0001$), 94% (n=68) said they were confident in taking care of the patient ($P < 0.0001$), 94% (n=68) said they were confident in performing medical interventions and 86% (n=62) said they were confident in performing surgical interventions. All these results were significantly higher than pre-survey answers ($P < 0.0001$).

Additionally, in the post-simulation survey, every participant said that they were confident enough to attend to a real-life situation and that the exercise had a positive impact on practice and teamwork and improved their communication and assessment skills. All participants also said that the model, clinical scenario, and procedure performed were realistic. 99% (n=71) said that the simulation exercise improved their technique in skills necessary in treating cardiac tamponade, and 96% (n=69) said that the level of stress experienced was similar to real life. Survey results are summarized in Table 1 and Figure 2 & 3.

Comparisons of CPR Quality between the two sessions

Treating cardiac tamponade requires proper CPR technique, which involves identification of cardiac arrest, initiation of chest compressions, and placing a backboard in a timely and uninterrupted manner. In the first session the average time to recognize cardiac arrest was 9.5 seconds, in the second session this time decreased to 8 seconds ($P = 0.22$). Time to initiate chest compressions decreased from 15.5 seconds to 12 seconds (P= 0.44) and time to place the backboard stayed the same at 16.5 seconds in both sessions. In the first session the median number of interruptions during chest compressions (CC) was 22, this number significantly decreased to 10 in the second session ($P = 0.006$). These findings are summarized in Figure 4 & 5.

Additionally, administration of epinephrine in a timely and efficient manner is important to CPR. Time to administer first dose of epinephrine significantly decreased from Session 1 to Session 2 (176 vs 88; $P = 0.045$). There was also significant improvement in administration of subsequent doses of epinephrine. In Session 1, only 38% of teams administered subsequent doses of epinephrine every 3-5 minutes after start of CPR. In Session 2, 100% of teams administered subsequent doses of epinephrine, a significant improvement ($P = 0.02$). These findings are summarized in Figure 6 & 7.

Teamwork Metrics

Teamwork is very important in treating cardiac tamponade, as there are simultaneous tasks to treat the condition that require proper communication. Teamwork metrics were recorded and timed by the observer and are detailed in Table 2. 50% of the groups appointed a clear team leader to lead the simulation exercise. 75% of groups used closed-loop communication. The median (IQR) time for the bedside nurse to recognize deterioration and call for help was 16 seconds (14-19 second range). These findings are summarized in Table 2.

Discussion

This report describes a novel sternotomy simulation exercise for cardiac tamponade and shows that there is significant educational benefit associated with the use of this simulation exercise. Most importantly, this study showed a significant improvement in key cardiac tamponade treatment metrics. The second sessions which were conducted 6 months after the first session showed that there was a significant improvement in: CPR quality, epinephrine administration, and CC interruptions. In treating cardiac tamponade providers must be able to recognize and start CPR quickly, administer epinephrine quickly and consistently through treatment, and must be able to perform these tasks without interruptions. After performing inadequately in the first session, CICU teams in their second session showed improvements in all metrics showing that the simulation was successful in improving CICU teams' performance in recognizing and treating cardiac tamponade. The skills they learned in the first session transferred over in the second session and will hopefully transfer over into the ICU.

As postoperative cardiac tamponade is a very time-sensitive condition that needs fast recognition and treatment, it is important that providers have a method to train on becoming faster and more efficient in treating this condition. The sternotomy simulation exercise provides ICU teams a safe and realistic learning environment to improve their skills in treating tamponade and our results show by using the simulation exercise, ICU teams were able to improve their treatment of postoperative cardiac tamponade as seen in the decreases in time to recognize and treat, and improvements in administration of epinephrine and the other benchmarks published in the results.

There is evidence to support inadequate teamwork during resuscitation, but it is unknown if additional complex task of sternotomy during resuscitation further impairs teamwork and communication. Important components of teamwork are role assignment, team leadership, effective communication and closed loop communication between the team members, effective hand-off during transition of care or transition of leadership. Table 2 shows that there were impairments in teamwork and communication during this exercise as not all groups used closed-loop communication, and only 50% of groups had a clear team leader. These results confirm that the complex task of performing an emergent sternotomy to relieve postoperative cardiac tamponade during an arrest is associated with inadequate teamwork, especially team leadership.

There is no literature to support the face validity of simulation mannequin for interprofessional CRM training in the resuscitation of acute cardiovascular collapse, and cardiac arrest in children with a median sternotomy wound after surgical repair of their congenital heart defects. To our knowledge, the mannequin with closed sternotomy, capable of reproducing postoperative cardiac tamponade and the simulation scenario focused on opening of the sternotomy for management of cardiac tamponade while performing CPR were innovative and helpful in improving provider confidence in managing cardiac tamponade. There are other studies that highlight the effectiveness of simulation training in pediatric ICUs but none that were used specifically for acute treatment of cardiac tamponade.

This simulation-based educational session was well received by participants. It allowed the providers to learn and reinforce knowledge and skills in early recognition and management of cardiac arrest related to cardiac tamponade occurring in a patient following cardiac surgery. The high-fidelity patient simulation case was created to simulate a low frequency but high-acuity scenario for CICU team members. Participation in future scenarios may help identify knowledge gaps in the identification and management of patients in postoperative cardiac tamponade. This scenario allowed for simulation-based learning of early recognition and management of cardiac tamponade, cardiac arrest, opening of the sternotomy, delivery of high-quality CPR during sternotomy, application of CRM principles during management of postoperative tamponade, teamwork, and communication. A limitation of the high-fidelity simulator is that it does not demonstrate the physical fidelity of jugular vein distention or muffled heart tones. Key components of Beck's Triad in Cardiac Tamponade. Staff must verbalize these as the learner evaluates the neck and listens to heart tones.

Conclusion

Post-operative cardiac tamponade is a rare and severe complication that must be treated quickly and efficiently by the CICU team. Simulation-based training of tamponade-associated arrest improved quality of CPR, especially epinephrine administration and number of CC interruptions. Simulation mannequin training can help improve CICU team confidence in treating cardiac tamponade by allowing for proper training and feedback in a real-life practice simulation. Future studies needed on cardiac tamponade outcomes in CICUs with hands-on open sternotomy training to analyze the clinical outcomes of simulation training.

Disclosures
None to report.

Funding/Support
None to report.

Ethical Approval
Reported as not applicable.

Figure 1: Innovative Sternotomy Mannequin

Figure 1. Innovative Sternotomy Mannequin

from inside out (from left to right) – artificial heart and lungs inside the thoracic cavity of the mannequin, the artificial Blood bag added, plastic sternum with ribs, median sternotomy with sternal wires, view of median sternotomy and sternal wires through the median open chest wound, mannequin with median chest wound and chest tubes, the external view of the sternotomy scar and chest tubes and pacing wires

Table 1: Demographic Data of Providers & Pre- and Post-Study Comparison

Parameters	**Pre-study survey ≥3**	**Post-study survey≥3**	**p- value**
Total number of subjects	72	72	
Confident in assessing the patient	55 (76%)	71 (99%)	<0.0001
Confident in taking care of the patient	47 (65%)	68 (94%)	<0.0001
Confident in performing medical interventions	45 (63%)	68 (94%)	<0.0001
Confident in performing surgical interventions	30 (42%)	62 (86%)	<0.0001
Positive impact on practice		100%	
Positive impact on team work		100%	
Improvement in communication skill		100%	
Improvement in assessment skill		100%	
Improvement in specific technique		99%	
Confident enough to attend the similar situation after training		100%	
Model realistic		100%	
Clinical scenario realistic		100%	
Procedure performed realistic		100%	
Level of stress experienced similar to real life		96%	
Experience of sternotomy scenario in ICU			
Demographic details			
Provider level		78% RN, 22% non nurse	
> 5 Years in practice		56%	
Experience with cardiac tamponade		36%	
Experience with closed/open sternotomy		36%	
Certified in PALS		99%	

ICU- Intensive care unit

Table 1: Survey data on experience in medical practice and treating cardiac tamponade. Additionally, pre-study and post-study survey data on managing cardiac tamponade. Pre & Post Study Questionnaire were scored: 1 = not at all/no impact to 5 = a lot/high impact.

Table 2: Teamwork Metric Results

Clear Team Appointed Leader	**50%**
Used Closed-Loop Communication	**75%**
Median (IQR) time for the bedside nurse to recognize deterioration and call for help	**16 (14-19) seconds**

Table 2: Teamwork metrics were recorded and timed by the observer, overall poor teamwork, and leadership quality by teams.

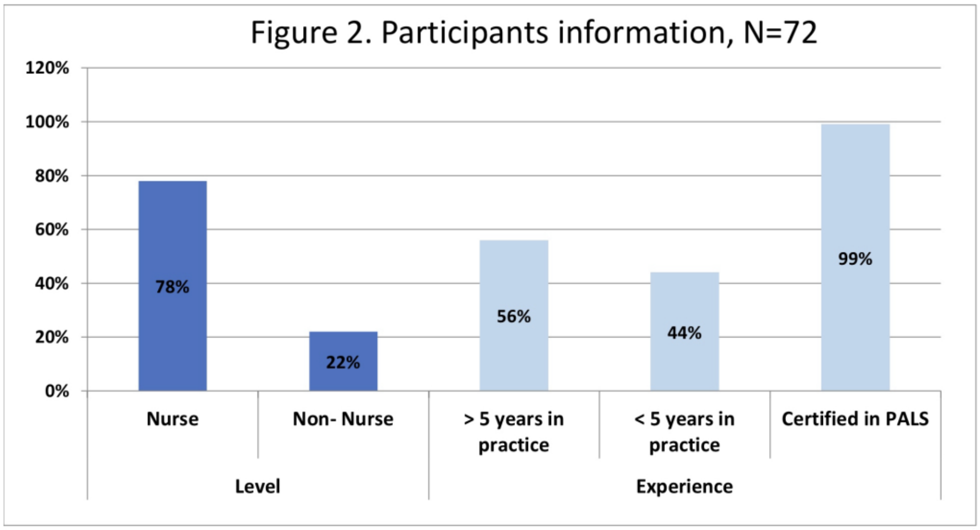

Figure 2. Bar diagram representing distribution of participants based on level/discipline and experience. "Non-nurse" includes faculty member, and respiratory therapist.

Improvements in Assessing and Treating Cardiac Tamponade

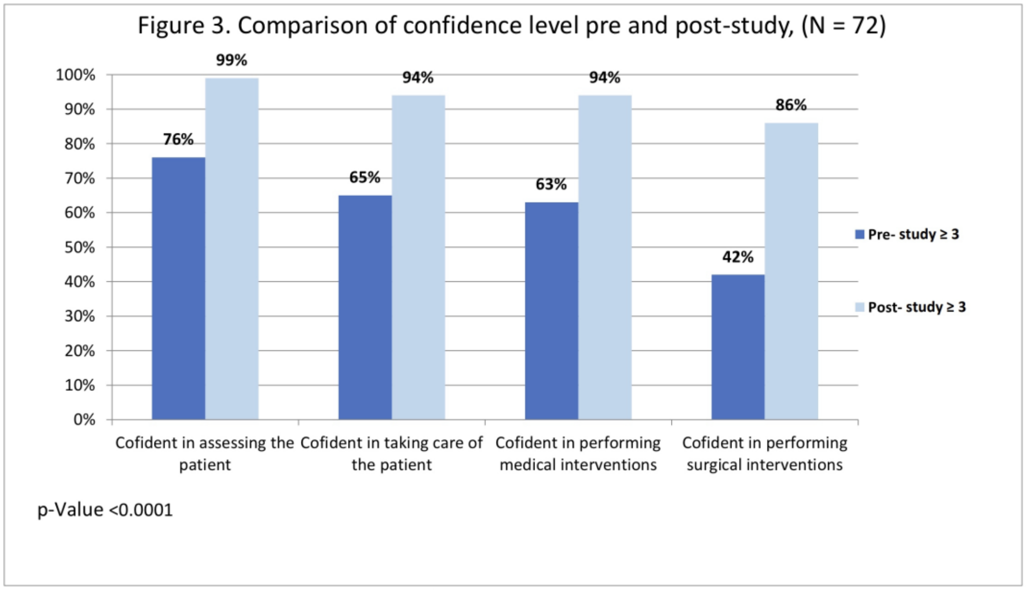

Figure 3. Comparison of confidence level before and after the simulation regarding assessment and management of patient with postoperative cardiac tamponade, including performing medical and surgical interventions; For all comparisons, p-value <0.0001.

Improvements in Simulation Training Metrics

Figure 4: Comparison of CPR quality between sessions

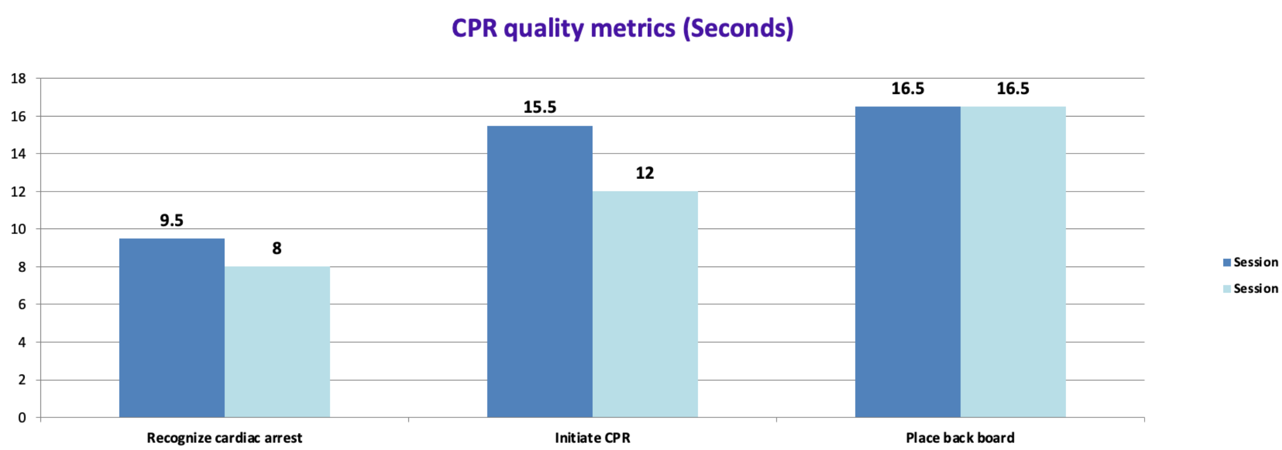

Figure 4: CPR quality metrics improved from Session 1 to Session 2. Time to recognize cardiac arrest decreased by 1.5 seconds, time to initiate CPR decreased by 13.5 seconds. Time to place backboard did not change between sessions.

Figure 5: Comparison of CC interruptions between sessions

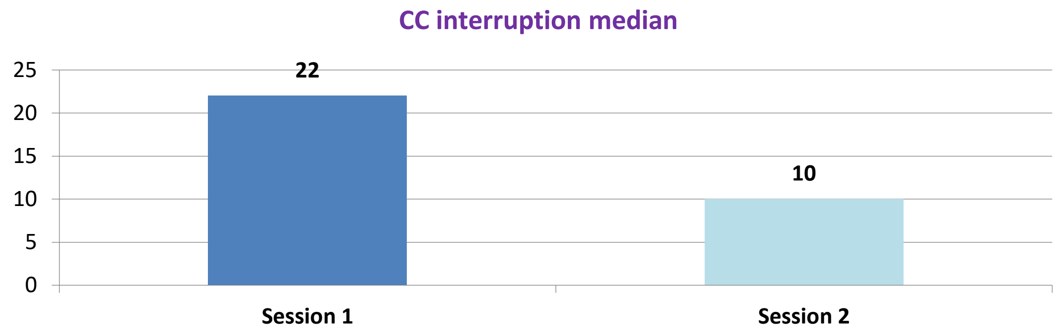

Figure 5: A significant decrease in number of CC interruptions after simulation training, (P=0.006).

Figure 6: Comparison of in time-to-first-epinephrine between sessions

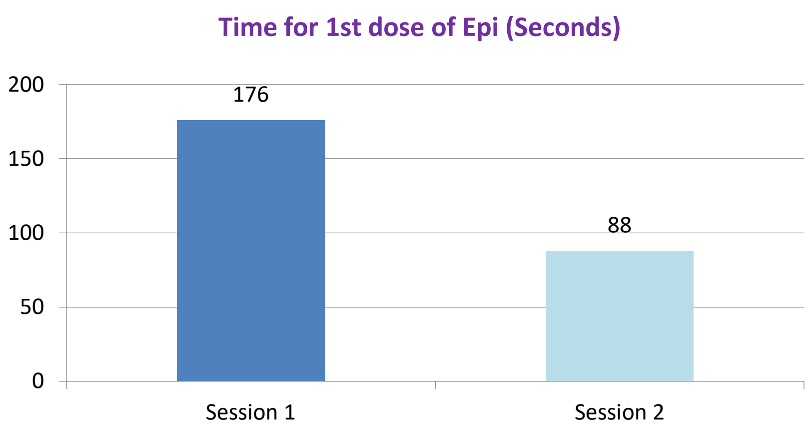

Figure 6: A significant improvement in time to deliver first dose of epinephrine (p=0.045).

Figure 7: Comparison of subsequent doses of epinephrine (for every 3-5 min) between sessions

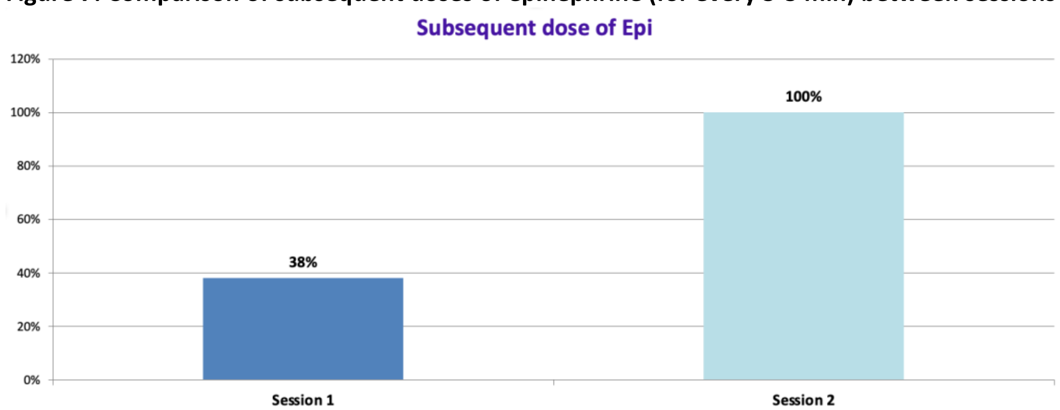

Figure 7: A significant improvement in subsequent doses of epinephrine (for every 3-5 min) after simulation (p=0.02).

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