Effect of High-Fidelity Simulation on Pediatric Advanced Life Support Training in Pediatric House Staff

A Randomized Trial

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Objectives: To assess the effect of high-fidelity simulation (SIM) on cognitive performance after a training session involving several mock resuscitations designed to teach and reinforce Pediatric Advanced Life Support (PALS) algorithms.

Methods: Pediatric residents were randomized to high-fidelity simulation (SIM) or standard mannequin (MAN) groups. Each subject completed 3 study phases: (1) mock code exercises (asystole, tachydysrhythmia, respiratory arrest, and shock) to assess baseline performance (PRE phase), (2) a didactic session reviewing PALS algorithms, and (3) repeated mock code exercises requiring identical cognitive skills in a different clinical context to assess change in performance (POST phase). SIM subjects completed all 3 phases using a high-fidelity simulator (SimBaby, Laerdal Medical, Stavanger, Norway), and MAN subjects used SimBaby without simulated physical findings (ie, as a standard mannequin). Performance in PRE and POST was measured by a scoring instrument designed to measure cognitive performance; scores were scaled to a range of 0 to 100 points. Improvement in performance from PRE to POST phases was evaluated by mixed modeling using a random intercept to account for within-subject variability.

Results: Fifty-one subjects (SIM, 25; MAN, 26) completed all phases. The PRE performance was similar between groups. Both groups demonstrated improvement in POST performance. The improvement in scores between PRE and POST phases was significantly better in the SIM group (mean [SD], 11.1 [4.8] vs. 4.8 [1.7], $P = 0.007$).

Conclusions: The use of high-fidelity simulation in a PALS training session resulted in improved cognitive performance by pediatric house staff. Future studies should address skill and knowledge decays and team dynamics, and clearly defined and reproducible outcome measures should be sought.

Key Words: PALS, education, simulation

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Resuscitations for pediatric patients are uncommon occurrences. Pediatric house staff have scant experience in leading actual patient resuscitations during their residency.[1] Educational exercises involving mock patients with critical illness, often referred to as mock codes, have been used for decades to train house staff in the principles of care of children with critical illness. Studies have shown these exercises to improve confidence and performance in pediatric house staff.[2]

High-fidelity simulation is a rapidly evolving technology that has been in use for years in a variety of medical fields. Within medicine, the most robust experience with this technology are in anesthesia, where it has been used for training and maintenance of competency and certification.[3] High-fidelity simulation is well suited to training for critical clinical situations that are uncommon but for which a level of preparedness is essential. The goal of a high-fidelity simulation experience is to allow the participants to suspend disbelief and perform in a manner that more closely reflects the way they would act in caring for a real patient in a comparable situation. Previous studies have examined the effect of simulation exercises on task performance, the dynamics of team interactions, and overall performance of trainees after training programs.[4–9] The child with critical illness or injury fits this educational paradigm well, and published literature on the effectiveness of simulation technology in pediatrics is beginning to emerge.[7,10]

We designed a study to evaluate the effect of a high-fidelity simulation milieu during a training session in Pediatric Advanced Life Support (PALS) algorithms targeted toward junior pediatric residents. The outcomes of interest centered on performance of critical cognitive tasks in a set of standardized mock code scenarios. Our hypothesis was that the use of high-fidelity simulation features would result in enhanced cognitive performance.

METHODS

Residents at 3 tertiary children's hospitals were invited to participate. Eligible participants were pediatric house staff at the level of postgraduate year 1 or 2 during the period from May 2006 through January 2007. All residents approached for the study must have completed at least 5 months but no more than 14 months of residency training; all residents meeting these criteria were reached by e-mail and invited to volunteer to participate. Baseline data collected on each participant included their prior participation in resuscitations, their clinical procedural experience, and their experience with mock code exercises in the past (with or without simulators). After written informed consent, participants were randomized within study site and postgraduate level to either the simulator (SIM) or mannequin (MAN) groups. Block randomization via a web-based random number generator (www.random.org) was used; neither investigators nor subjects were blinded to group assignment.

Each study session was divided into 3 phases (Fig. 1). The first phase (PRE phase) consisted of 4 case scenarios designed to require the performance of cognitive tasks pertinent to clinical assessment and intervention (hereafter referred to as critical tasks) according to different PALS algorithms. Each PRE phase

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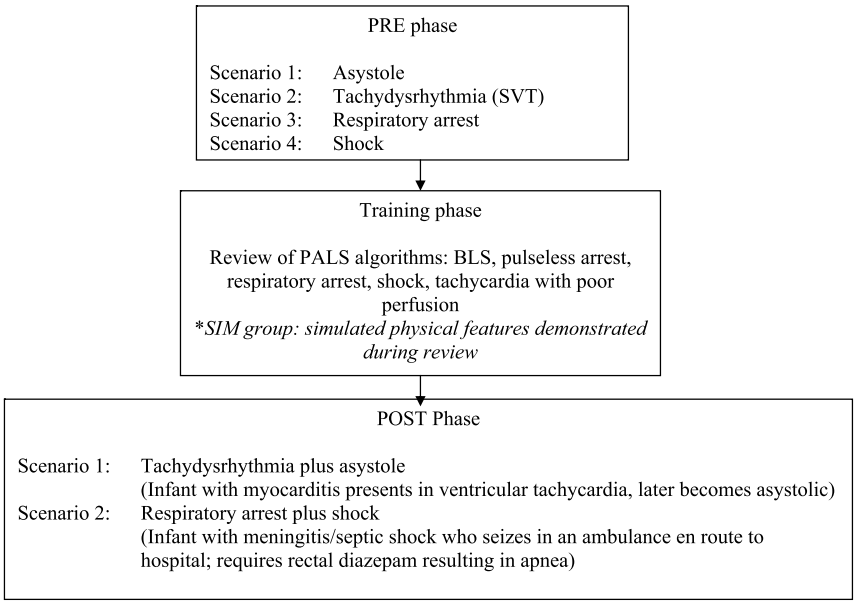

CRITICAL TASKS (listed by scenario)	
ASYSTOLE • Pulse check • CPR • Epinephrine • IV/IO access • Pulse recheck after ROSC	**RESPIRATORY ARREST** • Assess airway patency • Open airway • Assess respirations • 100% oxygen administration • Pulse oximetry • Bag-valve mask ventilation
TACHYDYSRHYTHMIA • Pulse check • Perfusion assessment • ECG monitor • Blood pressure measurement • Cardioversion	**SHOCK** • Pulse check • Perfusion assessment • Blood pressure measurement • IV/IO access • Fluid resuscitation • Blood glucose check

FIGURE 1. Schematic of trial phases and list of critical tasks.

scenario was allowed to run up to 5 minutes or until all critical tasks were performed, whichever occurred first. The second phase consisted of a scripted didactic review of the text and flow diagrams for PALS algorithms for basic life support, pulseless arrest, tachycardia with poor perfusion, respiratory arrest, and shock. Time was provided for questions and answers after the review. The third phase (POST phase) consisted of 2 additional scenarios designed to require the same set of tasks as the PRE phase scenarios but in an altered clinical context so as to maintain the perception of new cases. Each POST phase scenario was allowed to run up to 7 minutes or until all critical tasks were performed, whichever occurred first. Within each phase, scenarios were presented in a random order. During PRE and POST phases, the sessions were video-recorded. All 3 phases were performed in immediate succession, and total time to complete a study session was 90 minutes. All sessions at all 3 sites were conducted by the same investigator (A.J.D.) to assure uniformity of the educational experience.

For the intervention group, all 3 study phases were conducted using a high-fidelity infant patient simulator (SimBaby, Laerdal) connected to an air compressor and with audio speakers enabled, which provided physical signs that were visible (chest wall movement and cyanosis), audible (vocal sounds), auscultatable (breath and heart sounds), or palpable (central and peripheral pulses). For the control group, the simulator was disconnected from the air compressor and the audio speakers were silenced, thus rendering the simulator equivalent to a standard mannequin. For all study participants in both groups, scenarios were run using the simulator software and evolving vital signs were displayed in real time on a cardiorespiratory monitor interface. All sessions were video-recorded by 2 simultaneous webcam feeds, one of which was synchronized to the simulator event log and debriefing software (SimBaby Debrief Viewer, Laerdal). During the instructional session (second phase), the simulator remained operational so as to demonstrate physical findings pertinent to the PALS algorithms being reviewed.

A scoring instrument (Fig. 2) was designed by investigator consensus that granted a maximum score of 2 points for each critical task. Points could be deducted if tasks were done incorrectly, in the wrong sequence, or after an unacceptable amount of time had elapsed. A task was scored 0 points if it was

TASK	*0 points*	*1 point*	*2 points*
		ASYSTOLE SCENARIO	
Pulse check	• Not done	• >30 sec • Peripheral pulse • After CPR started or epi given	• <30 sec and in sequence
CPR	• Not done	• Done without pulse check • Done after epi given • >30 sec after pulselessness recognized	• <30 sec after pulselessness recognized and before epi
ECG	• Not done	• Done without clinical assessment of circulation • Done before CPR if pulselessness recognized • Done after epi • >60 seconds	• Done after CPR started for pulselessness and before other therapy
IV/IO access	• Not done • Only done once need for IV med recognized	• IV instead of IO • >60 seconds	• IO in less than 60 sec
Epinephrine	• Not done	• Done without pulse check • Done without CPR • Done via ETT • >30 seconds after pulselessness recognized	• Called for after pulse check and CPR within 30 seconds of pulselessness recognition
Pulse recheck after ROSC	• Not done (includes ROSC never achieved)	• >30 sec after ROSC • Peripheral pulse check	• Central pulse checked within 30s of ROSC
Defibrillation	• Done	• Not done	

FIGURE 2. Sample scoring instrument (for asystole scenario).

completely omitted or was performed at a time point where its impact on the initial state of the scenario was no longer present (eg, assessing perfusion for the first time after IV fluid resuscitation). This scoring system was adapted from a system used in a recently published article examining performance in neonatal resuscitation.[11] Specific items were chosen according to assessments, and interventions included in PALS algorithms and scores were determined by expert consensus opinion by pediatric emergency medicine and critical care medicine–trained faculty. For each subject, the video-recorded scenarios during PRE and POST phases were reviewed, and a summary score for both phases was generated using this instrument and expressed as a percentage of the maximum possible points (0–100).

Descriptive statistics consisting of score distribution for each task were performed across both groups. Univariate analyses between SIM and MAN groups with respect to baseline characteristics, scores for PRE and POST phases, were done using Wilcoxon rank sum testing. Univariate analyses between SIM and MAN groups with respect to score distribution for individual tasks were done by χ^2 testing for both PRE and POST phases. Univariate analyses were performed using STATA version 8.0, Corp, College, Tex.

The improvement in score between the PRE and POST phases was analyzed as our outcome of interest. Mixed modeling with the rescaled scores as the responses, and phases and study groups as independent variables, was used with a random intercept to account for the within-subject covariance. The difference between the 2 groups in improvement from PRE to POST was assessed by including an interaction term between the study phases and group assignments in the model. The analysis was done using PROC MIXED in SAS Institute, Cary, NC version 9.0.

RESULTS

Fifty-one subjects completed all 3 study phases (SIM: n = 25, MAN: n = 26). Twenty subjects were in postgraduate year 1 (SIM: n = 10, MAN: n = 10), and 31 were in postgraduate year 2 (SIM: n = 15, MAN: n = 16). Table 1 summarizes the baseline prior experience of both groups. No significant differences in baseline resuscitation, procedural, or mock code experience were present between SIM and MAN groups.

Mean scores for PRE and POST phases and the change in score are listed in Table 2. The PRE phase scores were similar for both groups. The POST phase scores were higher in the SIM

TABLE 1. Comparison of Background of Study Groups

	SIM Group	MAN Group
Patient events		
Resuscitations (nonneonates)	1 (0–12)	1 (0–19)
Neonatal resuscitations	3 (0–21)	4 (0–12)
Critical procedures		
Bag-valve mask ventilation	4 (0–20)	4 (0–25)
Endotracheal intubation	3 (0–20)	3 (0–20)
Chest compressions	0 (0–10)	0 (0–10)
Defibrillation	0 (0)	0 (0–2)
Interosseous access	0 (0–4)	0 (0–1)
Training events		
Mock codes	5 (0–14)	5 (0–18)
SIM exercises	2 (0–10)	2 (0–10)

All values listed as median (range).

TABLE 2. Overall Scores (by Group)

	SIM	MAN	*P*
Phase 1 score, mean (SD)	49.5 (10.7)	51.0 (8.8)	0.56*
Phase 3 score, mean (SD)	60.5 (9.1)	55.1 (10.4)	0.14*
Change in score, mean (SD)	11.1 (1.8)	4.8 (1.7)	0.007†

*Univariate analysis, Wilcoxon rank-sum.

†Analysis by mixed modeling, PROC Mixed.

group compared with the MAN group, but the difference did not achieve statistical significance. The improvement in score between PRE and POST phases was significantly greater in the SIM group (11.1 [1.8] vs. 4.7 [1.7], $P = 0.007$).

DISCUSSION

The addition of high-fidelity simulation features to an educational session given to pediatric residents resulted in a greater increase in scores on an instrument measuring cognitive task performance. The educational session resulted in increased scores for both groups, but the increase was significantly greater in the SIM group.

Our results suggest that residents experiencing high-fidelity simulation perform cognitive and decision-making tasks more accurately than those using less realistic models. We believe that some of this improved performance results from the more active role that is required from the participant. For the SIM group, their focus is completely on the assessment and interpretation of vital signs followed by an intervention. Using the standard mannequin, the resident must interrupt this critical triad by asking questions of the facilitator, making their role more passive in interaction.

The use of high-fidelity simulation in medicine has been suggested as a useful teaching method for clinical situations that, although infrequent, are critical in nature and require the maintenance of a high level of skill and preparedness. In this regard, pediatric resuscitation is very well suited to simulation education, given that actual pediatric codes are more infrequent than similar events in adult patients and that outcomes from pediatric cardiopulmonary arrest in both the prehospital and inpatient arenas are poor.[12–14] In addition, pediatric codes tend to be managed in many cases by trained subspecialists when they do occur, potentially resulting in trainees being marginalized and receiving less direct resuscitation experience. Current PALS instruction frequently makes use of partial task trainers for procedural skill training and standard mannequins for case exercises, but the use of simulators is less frequent.

Studies in pediatric simulation have begun to emerge in recent years in a variety of clinical venues and with varying outcomes of interest under study. Halamek et al[10] published the results of a neonatal resuscitation training program including simulation-based experiences and video debriefing that was rated by participants as highly realistic and effective. Hunt et al[7] used simulated pediatric trauma patients in unannounced mock resuscitations to assess gaps in preparedness at 35 emergency departments in North Carolina and also found a high level of positive response from participants. Of note, these studies used standard mannequins as the patient, and in the case of the Halamek article, a notable difference was present in survey responses regarding the realism of the experience using the mannequin, with 50% of respondents not agreeing that the mannequin itself was not consistent with a real-life patient experience. To our knowledge, our study is the first report of an experimental study design in pediatric resuscitation education specifically examining the effects of high-fidelity simulation features of a patient's physical signs, as distinct from simply a simulated environment or vital signs.

The most recent set of recommendations for resuscitation training from the International Liaison Committee on Resuscitation included the specific recommendations that training should move toward "scenario-based, facilitated, interactive teaching" and that "high-fidelity simulation-directed training should increasingly supplement instructor-directed training" in Advanced Life Support courses.[15] Experimental studies examining the effect of a simulation modality on trainee learning in mock adult resuscitations have begun to emerge. Lee et al[6] demonstrated a beneficial effect on performance by surgical residents in a mock trauma resuscitation training session when conducted using a high-fidelity simulator as opposed to a moulage patient actor. Wayne et al[4] conducted a crossover study in internal medicine residents where the inclusion of simulator practice sessions in Advanced Cardiac Life Support algorithms was shown to improve performance on an instrument measuring cognitive task performance. In a 3-armed randomized trial comparing high-fidelity simulation to mannequin trainings and to computer-based microsimulation training, Owen et al[5] showed that trainee medical officers had improved cognitive performance and were rated more highly by expert evaluators about their behavior as code team leaders when trained on a high-fidelity simulator. Although all of these studies suggest a benefit from the use of a higher level of fidelity in the simulated patient, as our own results also suggest, they are illustrative of the continued inconsistency in study design and outcome measurement that is prevalent throughout simulation research.

Limitations

We studied the performance of individual residents running mock resuscitations in an unassisted manner. We chose to study individual as opposed to team performance so as to isolate the effect of a one-on-one educational intervention and to use the availability of trained assistants at the bedside to maintain enough realism to allow the subjects to function as code team leaders. Participants were told that the setting would be somewhat unrealistic in so far as a team of caretakers would not be physically present. This incomplete realism is not in perfect keeping with the goal of suspension of disbelief a simulation exercise is meant to achieve. The most recent revision of PALS guidelines has intensified the focus on effective resuscitation team dynamics, and the current PALS course is designed to allow participants to practice the role of a code team leader in addition to other roles within the code team and to rehearse the specific concepts pertinent to team communication and decision making. Studies in mock adult resuscitations have been published, documenting the effect of simulation on team performance and crisis resource management as separate entities from end points pertaining to knowledge or clinical skill.[8,9] As simulation research in resuscitation continues to expand, it will be necessary to design and validate instruments to measure team and individual performances to be used as reproducible outcomes of interest for future studies.

Our scoring system was designed by investigator consensus and was designed to account for whether tasks were performed, in addition to whether they were done quickly, correctly, and in the right sequence. We also attempted to account for certain errors of commission (eg, defibrillation for asystole/pulseless electrical activity). Our instrument is limited in its scope to examine cognitive performance and not psychomotor skill. In addition, the items are not designed to account for their specific

clinical impact if done improperly. We believe that using concrete definitions based on PALS algorithms with respect to performing basic assessments and the sequence of assessments and interventions contributes to face validity of the instrument; furthermore, both groups performed better in the POST phase than in the PRE phase after one-on-one teaching sessions with an attending, which speaks to some degree of construct validity. The future goal with our current data set and additional data still under collection will be to compare a global assessment of competency by an experienced academic physician to the result of our instrument; this technique was used by Nadel et al[2] in their mock code trial and was shown to demonstrate reasonable construct validity.

Our outcome measurement was performed immediately after the training session. This approach was chosen to ensure uniformity of timing and completeness of postinstructional evaluation. Prior studies of the immediate response to PALS training have shown improvement even in brand-new pediatric residents with no clinical experience.[16] Despite this, knowledge and psychomotor skills pertinent to resuscitation guidelines have been shown to decay rapidly after any training endeavor, and a recent study by Grant et al[17] showed that pediatric residents had a significant time-dependent decline in technical and cognitive performances during PALS testing for the course of a year of residency. The present data set does not reflect knowledge retention or decay, but our methodology would be well suited to assess residents' performance at remote time points to examine this further.

Each group went through both the baseline and outcome assessments on their group-specific medium, that is, the simulator or the mannequin. It is possible that, by experiencing the simulator during PRE phase, the SIM subjects were becoming acclimated to the features of the simulator and that this may result in an artificially inflated estimate of their performance. This was considered carefully in the experimental design, and it was with this potential limitation in mind that the list of critical tasks was designed to focus on cognitive skills and not psychomotor skills. The scoring of a particular task was based not on how it was or was not physically performed but rather based on whether a step was taken by the subject to indicate that they recognized the need for its performance (eg, a pulse rate check could consist of asking the facilitator "Do I feel a pulse?" or by physically placing a finger on a pulse point). We believe that this design with respect to our outcomes minimized the effect that familiarity with the teaching medium had on scoring.

Finally, despite a rapidly growing interest and enthusiasm for simulation as a method of optimizing training and patient safety, evidence clearly documenting a positive effect on patient safety and improved patient outcomes remains elusive.[18] Many hospitals and medical schools have begun using high-fidelity SIM medicine in their educational curriculum. However, the equipment is cumbersome, expensive to purchase and maintain, and requires additional training in programming and setup when used to its maximal potential and additional support personnel and space. For institutions to continue to support such an endeavor, it is crucial to understand its benefits and its limitations through thoughtful research and collaboration among educators.

CONCLUSIONS

The use of high-fidelity patient simulation enhanced a training session in pediatric resuscitation, as measured by the change in cognitive performance in relatively novice providers. Future studies in this area should examine the effect of a simulation modality on knowledge and skill retention and the effect of simulation on team performance in addition to individual performance. In addition, simulation researchers should continue to delineate clear, reproducible outcomes for skill and knowledge acquisitions for both individuals and teams. The ultimate goal of documenting improved operational performance on real patients and improved patient outcomes from pediatric simulation education remains elusive owing to the rarity of the clinical events in question, but with longitudinal multicenter studies, this may be possible.

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