The use of simulation for pediatric training and assessment

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Purpose of review

Simulation has been widely adopted as a training and assessment tool in medical education. Conventional teaching methods may be inadequate to properly train healthcare providers for rare but potentially lethal events in pediatrics such as trauma and respiratory arrest. Recent studies suggest pediatric acute care providers have limited exposure to critically ill patients and also lack the skills to manage them. Simulation has the potential to fill this educational void. This review will highlight the role of simulation as an educational and assessment tool, with a particular emphasis on retention of knowledge and skills.

Recent findings

Simulation is currently used as an assessment tool to provide ongoing feedback during training (formative assessment) and is gaining popularity as an adjunctive method for demonstrating competency (summative assessment). Recent literature demonstrates increased retention of knowledge and skills after simulation-based training in the areas of resuscitation, trauma, airway management, procedural training, team training, and disaster management.

Summary

Simulation is an effective training tool for pediatric acute care providers. Further research is necessary to develop validated performance assessment tools and demonstrate improvement in clinical outcomes after simulation training.

Keywords

assessment, pediatrics, procedures, resuscitation, simulation

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Introduction

Simulation has been used as a teaching tool for nearly 40 years in fields as diverse as aviation and military training. However, integration of this technology into the arenas of medical education and assessment is a relatively recent development. The purpose of medical simulation is to emulate real patients, anatomic regions, and clinical tasks, or to parallel real-life situations in which medical care is provided. The widespread adoption of simulation technology marks a divergence from the traditional 'see one, do one, teach one' method of medical training, which for centuries has relied upon real patients.

Multiple factors have contributed to this revolution in training. Changing patterns in healthcare delivery have resulted in shorter hospital stays and clinic visits. Limitations on trainee work hours have contributed to decreased clinical experience. This has resulted in reduced patient availability for learning, decreased exposure to critically ill patients, and decreased time for clinical faculty to teach [1••].

In addition, technological advances in diagnosis and treatment, such as newer imaging modalities and endoscopic or laparoscopic procedures, require development of skill sets that differ from traditional approaches. Concurrent progress in simulation technology that enables increasingly realistic models offers advantages for such skill acquisition (Table 1).

Furthermore, the increasing drive to reduce medical errors and improve patient safety has fueled the impetus to incorporate simulation technology into training and assessment programs [2]. It has been described that pediatric residents have poor retention of skills and knowledge via traditional methods of learning [3•]. Simulation in pediatric education can teach the skills needed to manage rare or critical events, such as cardiopulmonary arrest or pediatric trauma. Trainees can make errors and

Table 1 Features of human patient simulator

Airway	Monitoring
Anatomical landmarks	Vital sign generation
Pharyngeal/tongue edema	Blood pressure
Trismus	Heart rate/telemetry rhythm generator
Laryngospasm	Respiratory rate
Response to positioning	Oxygen saturation
Sound generation (e.g., voice, cough)	End tidal CO_2
Cardiopulmonary	Procedures
Spontaneous and assisted ventilation	Bag-valve-mask ventilation
Breath sounds (e.g., wheezing, crackles)	Endotracheal intubation
Changes in lung compliance	Nasogastric tube placement
Accessory muscle use	Cricothyroidotomy
Heart sounds ± murmurs	Thoracostomy/needle decompression
Blood pressure auscultation	Cardioversion/defibrillation
Palpable pulses	Chest compression
Perioral cyanosis	Pericardiocentesis
Gastrointestinal	Venipuncture
Gastric distension	Lumbar puncture
Bowel sounds	Urinary catheterization
Neurologic	Software
Seizure-like movements	Programable clinical scenarios

Table 2 Simulation features as applied to best educational practice

Principles of best educational practice	Simulation features that lead to effective learning
1. Active learning	Opportunity for repetitive 'hands-on' practice Realistic learning as an active participant
2. Prompt feedback	Trainer provides real-time feedback Debriefing and reflection after learning
3. High expectations	Clearly defined objectives Tangible outcome measures Range of difficulty and complexity
4. Collaboration among students	Working together as a multidisciplinary team Crisis resource management skills
5. Emphasis on time on task	Time to intervention measured by simulator
6. Respect for diverse ways of learning	Complements multiple learning strategies
7. High level of student–faculty interaction	Teacher as coach/facilitator

learn to recognize and correct them in the simulated environment without fear of being penalized or causing harm to patients.

And finally, ethical questions arise concerning the appropriateness of using real patients as training resources. Much of this debate centers on sensitive tasks (i.e., pelvic examinations) or those that involve potential risk of harm to patients (endotracheal intubation or other invasive procedures).

All of these factors driving the increased use of simulation are part of a paradigm shift toward outcomes-based medical education. The consensus calls for research to explore the methods of assessment and the correlation of simulated assessments with clinical performance [4]. The following review will attempt to answer this call by quantifying the effect of simulation-based educational interventions on retention of knowledge and clinical performance, as applied to acute care pediatrics.

Simulation as an educational and assessment tool

The principles of best educational practice provide the basis for traditional methods of learning. The features of simulation adhere to and enhance these principles, as shown in Table 2 [5,6]. Simulation, as an educational tool, mirrors, anticipates, and amplifies real-life situations with guided and interactive experiences [7]. Simulation has the added benefit of creating the optimal level of productive anxiety for learning. Errors can occur in simulated cases without adverse outcomes or fear of retribution. These errors are more valuable to learning than successes, and raise awareness of aspects of performance that need improvement. The teacher can then deconstruct the providers' performance, correct errors, and provide immediate feedback until the trainee masters all components [8].

Simulation also has the potential to be an effective assessment tool. Assessment can either be formative, giving learners ongoing feedback on their progress toward the development of knowledge, understanding, and skills; or summative, providing evaluation to assess competency.

An essential aspect of formative assessment is feedback or debriefing. This technique is effective in describing what was done well and where improvement is needed to develop an individualized learning plan. Rudolph *et al.* [9••] suggest a four-step model of debriefing: identifying performance gaps related to predetermined objectives, providing feedback describing the gap, investigating the basis for the gap, and helping to close the gap through discussion and targeted instructions.

Formative assessments and debriefing help to prepare providers for summative assessments that may have potential impact on career advancement (e.g. in-service and board examinations). Simulation is currently being used as a summative assessment tool on the board examination for Israeli anesthesiologists and vascular surgeons in the United States [10]. In addition, the Accreditation Council for Graduate Medical Education recommends the use of simulation for teaching and testing of providers' competencies [11]. Several programs have already used simulator-based assessment to differentiate skill levels of acute care providers [12•,13••,14••].

There are potential barriers to simulation-based assessment. A recent Academic Emergency Medicine consensus statement reports that a broad range of evaluation tools has been developed, but few of these tools are well validated or reliable. One exception is the assessment tool created by Quan *et al.* [15], who developed and validated a checklist to evaluate pediatric resuscitation skills related to pediatric advanced life support (PALS).

Evidence-based review of simulation in pediatric acute care

Over the past decade, there have been an increasing number of studies evaluating the effectiveness of simulation as an educational tool [6]. Simulation has been used in various aspects of pediatric acute care training, including

(1) resuscitation,
(2) trauma management,
(3) airway management,
(4) procedural skills,
(5) crisis resource management/team training, and
(6) disaster/mass casualty training.

Resuscitation

Pediatric acute care providers undergo formal resuscitation training ((neonatal advanced life support (NALS), PALS, and advanced cardiac life support (ACLS)) every 2 years, yet a growing body of evidence suggests poor retention of these skills and knowledge [3•]. In addition, pediatric residents are exposed to fewer critically ill patients during their training [1••]. Simulation training may potentially fill this educational void and improve the resuscitation skills of pediatric healthcare professionals. It has been demonstrated that residents who received additional training on a human patient simulator performed significantly better on the PALS written examination as well as during a mock resuscitation [16]. Two other studies reported a mean improvement in overall ACLS performance by medicine residents after implementation of simulator training sessions [17,18].

Although many studies have utilized artificial mock code scenarios in the evaluation of knowledge retention, there is a dearth of literature evaluating clinical outcomes of actual patients. An exception is a retrospective case–control study of resident team performance during cardiac arrest [19••]. Residents who received human patient simulator training in addition to ACLS showed significantly higher adherence to American Heart Association (AHA) standards as compared with those who received ACLS alone. Another case reported by Smith *et al.* [20•] noted that two anesthesia providers successfully resuscitated a patient with bupivicaine-induced cardiac arrest after recently undergoing a similar scenario using a human patient simulator. Both commented that the prior training positively impacted their skills during the resuscitation, including rapid problem recognition, correct choice and dosage of specific therapy, and coordination of team efforts.

Trauma management

Pediatric trauma has the potential to benefit from simulation training, as it is a highly stressful, relatively uncommon disease entity. The advanced trauma life support (ATLS) training course, mandatory for emergency care providers, is offered every 4 years, but only a small component is devoted to pediatrics. Consequently, several pediatric residency and fellowship programs have adopted simulation training to reinforce the various skills needed to manage pediatric trauma.

One institution described a self-reported improvement in management of pediatric trauma, understanding roles, familiarity with the resuscitation room, and comfort with procedural skills after implementing a simulation-based educational session for residents [21•]. Although the authors found no change in overall team performance, a validated team performance assessment tool was not used. In contrast, another study evaluating the performance of a pediatric trauma team consisting of 160 house, faculty, and nursing staff reported significant improvement in overall performance after simulation training [22•]. One possible explanation for this finding may have been the inclusion of nursing staff in the simulated scenarios, which is often cited as a vital aspect of mock code training [23]. Hunt *et al.* [24••] reported similar performance gains after conducting an unannounced simulated pediatric trauma code followed by a debriefing and didactic session at 18 emergency departments. A second trauma scenario performed 6 months later to evaluate retention of skills and knowledge resulted in significantly improved performance by emergency department personnel.

It is difficult to infer from these studies whether the improvement in team performance was secondary to the implementation of any type of educational intervention, or if it was due specifically to the simulation training. One study comparing didactic and simulation training randomized surgical residents to receive 10 h of trauma education by either scenario-based didactic sessions or scenario-based simulator sessions [25••]. After training, the simulation group had higher performance scores for crisis management skills, specifically with regard to teamwork.

Airway management

Although basic airway management is a major component of resuscitation, it has been reported that pediatric residents lack basic airway skills [2]. Mayo *et al.* [26] examined the impact of a basic airway skills simulation program and found that simulation-trained residents performed significantly better on most elements of basic airway management during mock codes. Trained residents also showed improved performance on actual patients during a 10-month follow-up period.

Another study analyzed whether the experience of the trainer affects resident performance [27]. Medicine interns randomized to receive basic airway simulation training from either an experienced attending or a senior resident had no difference in performance scores during a simulated scenario. As in the previous study, all residents who received simulator training also performed well on actual patients. This suggests that teaching simulation is a skill that can be acquired across various levels of training.

In addition to mastering basic airway skills, management of the 'difficult airway' is critical for pediatric acute care providers. Kuduvalli *et al.* [28•] evaluated difficult airway skills (laryngeal mask airway intubation, fiberoptic intubation, needle and surgical cricothyroidotomy) of anesthesiologists after a simulation-based educational intervention. Improvement in skills was demonstrated at 6–8 weeks, although many of these skills returned to baseline at 6–8 months. This emphasizes the importance of training at regular intervals to ensure knowledge retention.

Another study of fiberoptic intubation (FOI) evaluated emergency medicine residents after receiving a virtual reality simulation session [29]. A significant reduction in time to intubation was noted in two out of three pediatric difficult airway scenarios.

Procedural training

Simulation has been used as a training tool to improve procedural skills such as chest tube thoracostomy, central line placement, and nasogastric and foley catheter insertion. Although there are no clinical outcome studies of chest tube thoracostomy of which we are aware, two studies report increased resident satisfaction after simulation-based training sessions [30,31].

Central venous access is a skill that is predominantly taught to pediatric residents by didactic methodology. Currently, there are several simulation models available for adult central line placement, but few pediatric options are available. Canadian investigators utilized a self-built femoral vein simulator to teach pediatric femoral vein catheterization to pediatric and emergency medicine residents [32]. Residents who underwent training with the simulator had significantly higher mean confidence levels for femoral vein catheterization than residents who received didactic teaching alone. Another study used clinical performance as an outcome measure [33]. Twenty-six medicine residents were randomized to receive central venous catheterization training either by the 'traditional' method of observing and then practicing on patients under supervision, or by the 'course' method in which the residents received training on a human simulator. The residents were subsequently evaluated on their central line placement technique on critically ill adult patients. The 'course' group outperformed the 'traditional' group on the majority of clinical aspects of central venous catheterization, including fewer attempts to find the vein, identification of anatomical landmarks, and total overall performance score. The 'course' group also scored higher on a multiple-choice test, supporting a correlation between knowledge gain and improved clinical performance.

A 2008 study compared 'low-fidelity' versus 'high-fidelity' simulation on nursing students' ability to successfully perform nasogastric and urinary catheter placement [34••]. The low-fidelity mannequin consisted of a relevant body part model that allowed for tube insertion, in contrast to the high-fidelity simulator (anatomically correct mannequin that reacts to tube insertion with physical responses such as change in vital signs, gagging/coughing sounds, etc.). Students who received high-fidelity training scored significantly higher than students trained by the low-fidelity simulator.

Crisis resource management/team training

Crisis resource management (CRM) is a method of team training that focuses on behavioral skills, resource utilization, communication, leadership, and teamwork. These skills are essential for effective clinical care, yet few medical personnel are exposed to formal training in these areas. Team training has been found to decrease medical errors [35]. Simulation offers an ideal setting to practice methods of CRM in a safe learning environment. A systematic review of team training studies found that 85% of the studies utilized simulation [36•].

Reznek *et al.* [37] described a specific program to teach simulation-based team training to 13 emergency medicine residents. These residents completed a scenario-based course on team training using a computer-enhanced mannequin and standardized patients. Although the effect on clinical outcomes was not measured, resident feedback was universally positive.

Another study evaluated nursing–physician collaboration during three pediatric scenarios using a human patient simulator [38•]. A panel of nonparticipating nurse experts measured levels of nurse–physician collaboration using validated scoring systems. Physicians and nurses showed increased levels of collaboration and competency during the third scenario after working together for the first two scenarios.

Leadership is often cited as a key aspect of CRM. A 2007 study evaluated the effectiveness of a mock code-based educational intervention on the leadership skills of pediatric residents [39•]. Residents who participated in the training session displayed significantly improved leadership skills compared with residents who did not undergo training.

Disaster/mass casualty training

Institutions use mass casualty drills, incorporating actors and moulage, to prepare for mass casualty events. A recent systematic review concluded that disaster training increases familiarity with procedures, identifies components of response, and provides opportunity to improve disaster response [40]. Several studies have assessed the use of advanced simulators (human patient simulators, virtual reality) in disaster drills, thereby decreasing the resources and training needed to utilize human actors. A study of disaster drills using live actors and human patient simulators found similar execution of critical actions on both groups [41•]. Participants in the drills agreed that simulators closely mimicked real-life scenarios, accurately represented disease states, and heightened realism of patient assessment and treatment.

Two recent studies of virtual reality-based disaster drills demonstrate the potential of using this novel technology. One study utilized a high-resolution computer-generated three-dimensional world (Cave Automatic Virtual Environment, 'CAVE') integrated with a human patient simulator to evaluate first responders during a simulated mass casualty event [42•]. This drill helped to identify several critical errors made by first responders, including incorrect triage, inability to assess number of victims, and failure to notify local hospitals. Participants agreed that the virtual reality simulator was effective at conveying images of injured victims. Another study analyzed medical student skills during three simulated mass casualty drills, using a virtual reality head-mounted display and motion-tracking sensors [43•]. These novice learners demonstrated improved triage and intervention scores after each virtual reality disaster drill.

Conclusion

Simulation has great potential as a teaching and assessment tool for pediatric acute care providers. There is ample evidence that simulation-based educational interventions increase retention of knowledge for resuscitation, trauma care, airway management, procedural skills, team-training, and disaster management. Simulation-based training, by enhancing provider skills, can subsequently decrease medical errors and increase patient safety.

At present, there is a lack of evidence regarding the benefit of simulation as measured by actual patient outcomes, with the exception of resuscitation and central line placement studies. Other limitations of current simulation studies include small sample size and lack of validated instruments to measure performance. Despite the lack of clinical evidence, the face validity of simulation is strong enough to support its implementation into pediatric acute care training programs. As Gaba [44] stated, 'no industry in which human lives depend on the skilled performance of responsible operators has waited for unequivocal proof of the benefits of simulation before embracing it' [45••].

There is considerable debate about the benefit of advanced simulators (human patient simulators, virtual reality) versus 'lower fidelity' simulators. It is important to remember that the simulator itself is only one component of a simulation program. Many institutions are unable to afford the high cost of advanced patient simulators, but by simply incorporating a scenario-based curriculum these programs can successfully increase provider skills and performance.

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Additional references related to this topic can also be found in the Current World Literature section in this issue (pp. 000–000).

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