



Recent Advances in Simulation for Pediatric Critical Care Medicine

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Abstract

Purpose of Review This review highlights the emerging fields of simulation research by tying innovation into principles of learning and process improvement.

Recent Findings Advances have been made in both educational simulation and simulation for quality improvement, allowing this versatile modality to be more broadly applied to healthcare and systems.

Summary Simulation in pediatric critical care medicine continues to evolve. Although the majority of simulation is focused on learner education, emerging research has broadened to focus on patient- and system-centered outcomes, leading to improvement in the quality of care delivered in the ICU.

Keywords Healthcare simulation · Pediatric critical care medicine · Medical education · Quality and patient safety

Introduction

Simulation is defined as “an instructional process that substitutes real patient encounters with artificial models, live actors or virtual reality patients” (Table 1) [1]. This modality has been used in industries other than medicine such as aviation, for decades, wherein adequate training is vital for critical events that are high risk, low frequency, and costly, whether in economic or health-related currency. This review provides a brief theoretical background of simulation-based medical education (SBME) and then highlights research with translational implications to pediatric critical care medicine (PCCM) for education and training, evaluation and maintenance of skills, advancement of quality healthcare delivery, and patient safety (Table 2).

History of Simulation-Based Medical Education

In 1967, engineer S. Abrahamson and anesthesiologist J. Denson at the University of Southern California built and demonstrated the first computer-controlled patient simulator, “Sim One” [2, 3]. This was an interactive mannequin that could be intubated, and which responded to interventions and medications with appropriate vital sign changes. Anesthesia residents who trained on Sim One showed improved performance, as compared with conventional training methods. Despite this promising start, medical simulation would not be taken seriously until almost 20 years later, after the 1999 Institute of Medicine (IOM) report, “To Err is Human” [4], highlighted the recurrent types of errors leading to preventable patients deaths: diagnostic errors, treatment errors, preventive errors, and most often, communication errors at a systems level [5].

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Components of Simulation

There are three major components to healthcare simulation in the PICU: the prebriefing, the simulation, and the debriefing. Prebriefing is an important component of healthcare simulation as it sets the stage for a scenario, and assists participants in

Table 1 Specific terms used in this article

Term	Definition	References
Simulation	“An instructional process that substitutes real patient encounters with artificial models, live actors or virtual reality patients”.	Gaba et al., 2004
Prebriefing	“An information or orientation session held prior to the start of a simulation activity in which instructions or preparatory information is given to the participants. The purpose of the prebriefing is to set the stage for a scenario, and assist participants in achieving scenario objectives”.	Lioce et al., 2020
Debriefing	The point where participants can process, react to, reflect on, and analyze their actions, thoughts, and feelings to close performance gaps.	Rudolph et al., 2008
Moulage	“The makeup and molds applied to humans or manikins used to portray lesions, skin findings, bleeding, and traumatized areas”.	Levine et al., 2013 Lioce et al., 2020
Mastery learning	Learning with an eye towards achieving full competency; often taught through deliberate practice of feedback and correction.	McGaghie et al., 2015
Functional fidelity	The ability of the simulated equipment to function and respond as it would in reality.	Lioce et al., 2020
Physical fidelity	“The degree to which the simulation looks, sounds, and feels like the actual task”.	Alexander et al., 2005 Lioce et al., 2020
Psychological fidelity	The ability of the simulation to induce a psychological response in its participants.	Dieckmann et al., 2008
Translational simulation	“A functional term for how simulation may be connected directly with health service priorities and patient outcomes, through interventional and diagnostic functions, independent of the location of the simulation activity”	Brazil 2017
Directive feedback	Feedback given with the ‘intent of improving future performance’.	Sawyer et al., 2016 Eppich et al., 2015
Rapid cycle deliberate practice	Directive feedback that is given in a rapid and iterative manner to quickly acquire procedural and teamwork skills.	Hunt et al., 2014
Plus-delta	Point-counterpoint method whereby debriefing is focused on what went well and what could be change or improve upon in the future	Fanning et al., 2007 Eppich et al., 2015
Advocacy-inquiry	Inquiry into a learner’s rationale for behavior while advocating for the patient’s perspective.	Eppich et al., 2015
Debriefing with good judgment	Allows for contextual learning and change by understanding a learner’s frames.	Rudolph et al., 2007
Debriefing for meaningful learning	“The integration, assimilation or construction and transfer of prior cognitive knowledge with new conceptual knowledge”.	Dreifuerst et al., 2011 Schweitzer, 2008
PEARLS	Promoting Excellence and Reflective Learning in Simulation - Scripted debriefing framework.	Eppich et al., 2015

achieving scenario objectives” [6]. This, in turn, facilitates a focus of psychological safety of the learners and sets the tone for the simulation [7]. It is defined as, “An information or orientation session held prior to the start of a simulation activity in which instructions or preparatory information is given to the participants. Debriefing, or facilitated feedback, represents the point where participants can process, react to, reflect on,

and analyze their actions, thoughts, and feelings to close performance gaps [8]. Using directive feedback with either individual or small group sessions has been shown to be efficacious, especially for highly technical, task-based skills [9]. Best practices in debriefing exist and a variety of methods have been described including directive feedback, plus-delta, advocacy-inquiry, debriefing with good judgment or

Table 2 Illustrative examples of using simulation to achieve translational outcomes

Simulation Topic	Study	Importance	Translation level	
Teaching and Learning	Task training	Kessler et al., 2015	•Translating simulation to success with infant lumbar puncture	T2
		Tofil et al., 2018	•Educating parents on tracheostomy care prior to discharge home	T1
		Barsuk 2009, Cohen 2010	•Central venous line training improves patient outcomes including complications	T2, T3
	Mock Codes	Hunt et al., 2014	•Rapid Cycle Deliberate Practice (RCDP) educational model improves CPR skills	T1
		Andreatta et al., 2011 Niles et al., 2017	•Simulated mock codes improve pediatric patient cardiopulmonary arrest survival rates •“Rolling Refresher” training improves retention of chest compression psychomotor skills	T3 T1
	Team Training	Colman et al. 2019	•Simulation-based team training improves behaviors and skills associated with patient survival	T1
		Sawyer et al. 2019	•Pediatric Extracorporeal Cardiopulmonary Resuscitation (ECPR) simulation training improves behaviors, protocol compliance, and activation time	T1, T2
Virtual reality	Badke et al. 2019	•Virtual Reality for patients improves subjective experiences in the PICU	T1	
	Zackoff et al. 2020	•Impact of an immersive virtual reality curriculum on medical students’ clinical assessment of infants with respiratory distress	T1	
Boot Camps	Nishisaki et al. 2009	•Boot camp is effective and subjectively valuable for learning basic PICU fellow skills	T1	
Patient safety and systems	Harwayne-Gidansky et al. 2019	•Using “Mirror patients” during simulation training helps identify latent safety threats	T3	
	Maa et al. 2019	•Simulating anaphylaxis events helps uncover common latent safety threats	T3	
Assessment	Calhoun et al. 2018	•The International Simulation Data Registry captures CPR quality metrics on simulated patients from multiple institutions	T1	
	Faudeux et al. 2017	•A resuscitation checklist helps to evaluate technical resuscitation skills	T1	
Debriefing	Dube et al. 2019	•Promoting Excellence and Reflective Learning in Simulation (PEARLS)	T3	
	Bajaj et al. 2018	•A debriefing tool focusing on systems-based simulations		
	Eppich et al. 2015	•A healthcare debriefing tool		
Research Networks	Cheng et al. 2018	•A debriefing framework	T3	
	Cheng et al. 2017	•The INSPIRE network		

debriefing for meaningful learning (DML) as defined in Table 1. [8, 10–15, 23]. With the publication of the Promoting Excellence and Reflective Learning in Simulation (PEARLS) framework by Eppich and Cheng in 2015, scripted debriefing by healthcare educators can be applied for a variety of goals ranging from teaching the “right thing”, to understanding team dynamics and cultural assumptions, with an eye towards both education and patient safety [12, 16–18]. All three elements are essential to ensure that learners are open to feedback, and that learning occurs.

How Simulation Facilitates Learning

The one-time standard medical pedagogy paradigm of “see one, do one, teach one” has not only proven less effective in training providers for infrequent but high-risk critical events, but has been shown to be impractical, expensive, and ultimately potentially unsafe [19]. Further, standardization and assessment of both skills and knowledge training can be difficult or impossible using this technique. Conversely, simulation can

provide for an educational and training environment that is safe, low risk, standardized, and reproducible, with frequency of events readily controllable for use; so much so, that providing “on demand” simulation-based medical education (SBME) has been part of the Accreditation Council for Graduate Medical Education (ACGME) training of core competencies for over 10 years [20].

Learner engagement is a critical component of simulation-based learning. Simulation enables learner engagement in a psychologically safe environment through several approaches: active, hands-on learning in an immersive environment, opportunities for repetitive, deliberate practice, and facilitated feedback. Psychological safety in simulation gives the learner “permission” to make errors or perform inadequately without patient harm or judgment from participants [21, 22]. Active, hands-on learning and emerging strategies to engagement such as gamification can be utilized to facilitate learner motivation [23, 24]. McKinnon et al. [25, 26] described early success with gamified learning to improve CPR practice frequency in a tertiary care children’s hospital. Mastery learning, through deliberate practice of skill

refinement with timely instructor feedback, is attainable before the task is done on a real patient [27]. One example of this is in improving chest compression performance. Several studies have demonstrated an improvement in chest compression psychomotor skills and resuscitation team performance utilizing the technique of “rapid cycle deliberate practice”, where the learner is stopped and corrected once a learning need is identified. These components are all believed to improve adult learning and skills acquisition, especially when compared with passive learning techniques like didactic teaching [28, 29].

Assessment and Evaluation

Assessment of either a learner, a team, or the system is a key component to understanding the effectiveness of a simulation-based intervention. Simulation is typically used for formative assessments of skills and knowledge to provide feedback to improve learner performance and less commonly for summative or high-stakes evaluations for ensuring competency. Evaluators can capture specific time-limited metrics, such as time to start chest compressions for cardiac arrest, or observable critical actions such as use of closed-loop communication. In the past 5 years, a variety of qualitative and quantitative assessment tools have been validated, including those for resuscitation, team hand-offs, invasive procedures and neonatal intubation [30–33].

Simulation Media and Clinical Fidelity

Simulation “is a technique, not a technology” [34]. Consequently, simulation techniques have diversified for different modalities and settings in healthcare education. Broadly, simulation modalities can be divided into low and high-fidelity simulation. Fidelity is the measure to which the simulator or the simulation matches the real environment the scenario is attempting to recreate [35]. Low-fidelity simulation includes partial task and procedural trainers, designed to teach specific skills and/or techniques such as infant lumbar puncture, or central venous catheter placement. High-fidelity simulation provides a more immersive scenario by involving several dimensions of fidelity, such as functional, physical, and psychological fidelity (Table 1) [6, 36–39]. High-fidelity manikins may provide feedback to learners, such as lung sounds, verbal cues, and additional moulage as fits the scenario (Table 1) [6, 40]. Standardized patients (SPs) may be used for one-on-one sessions to teach physical exam and communication skills acquisition, with directive feedback offered by the SP, facilitator, or both [41]. Both virtual and augmented reality (AR) simulations have the advantage of facilitating self-learning and feedback. Evidence of its efficacy, however,

is only starting to emerge. Topics such as airway intubation, patient monitoring, and infant respiratory distress have been taught through this technique, with positive results [33, 42–46]. In the case of VR/AR simulations, feedback is given through a computer program; there is often no human instructor used for debriefing.

Simulation Settings

Choosing which setting to perform your simulation should be based upon your objectives and available resources. Simulation may be lab-based, in situ, mobile (where a laboratory is brought outside of the institution), or remotely accessed. Many institutions have “on site” simulation centers fully equipped for high fidelity simulation, with video recording capabilities, functioning patient rooms and operating rooms, and full body, computerized manikins or SPs [47]. Simulation centers are good for skill development and minimizing distractions but are costly to build and maintain. In contrast, in situ simulation may enhance the physical fidelity by bringing the experience to workplace teams in actual clinical environments [48]. The benefits of in situ simulation include greater access to providers, enhanced realism, as well as direct parallels and responses to patient care incidents, e.g., just-in-time training [49]. Finally, in situ simulation can allow for systems-based issues and latent safety threats to be discovered and addressed without harm to real patients [50, 51]. In situ simulation may also be made mobile with a simple cart, such as with rolling refreshers for CPR [52, 53]. Truly mobile simulation refers to the ability to take a simulator, or even a full simulation lab from one place to another such as in a vehicle. Finally, telesimulation has recently emerged as a viable method of teaching learners. Telesimulation occurs with either (1) one learner group remotely watching a simulation being performed by another group of learners and debriefing together, or (2) a remote instructor watching the learners and facilitating a debrief. This approach allows for extension of expensive and limited resources to help educate healthcare providers without access to traditional simulation [54, 55]. During the SARS-CoV-2 pandemic, due to constraints on social gatherings, telesimulation was used in some institutions [56, 57]. Finally, a system’s resources and limitations can inform the approach taken when considering which setting to use for simulation.

Translating Simulation to PICU Care

McGaghie and coauthors [58–60] proposed that just as translational science involves moving research discoveries from a basic science bench to the bedside, SBME research can be translated from the simulation lab to the clinical setting. The

term “translational simulation” was introduced by Brazil in 2017 to describe the use of simulation to target improved patient safety and system-level outcomes, not necessarily involving educational interventions (Table 1) [61]. Figure 1 shows the different levels of translation as categorized by overall targeted outcomes, participants, and application to PCCM. The levels of translational outcomes follow: classroom or simulation laboratory (T1), moving downstream to improved and safer patient care practices and processes (T2), and ultimately to improved patient outcomes (T3). McGaghie et al. [28, 60] later added a fourth impact level to describe outcomes such as cost savings, skill retention, systemic educational value, and health care system improvements (T4). Examples of each of these are found in Fig. 1.

Below we discuss recent advances in simulation research within pediatric critical care medicine and how they can relate to improving different levels of outcomes. These simulations may be applied for education alone or for process improvement, and can focus on individuals, groups, groups of groups (such as interdisciplinary teams), or hospital systems.

The Individual Learner

SBME is a standard part of pediatric resident and fellow training, especially in the pediatric intensive care unit (PICU). Individual, learner-focused education may be used to teach both technical skills and nontechnical skills [18, 41, 52, 62]. Technical skills are improved by SBME on all translational levels.

For example, Johnson et al. [63] demonstrated a subjective improvement in nontechnical skills such as confidence and preparedness with a simulation-based course utilizing standardized patients for PCCM fellows for giving bad news

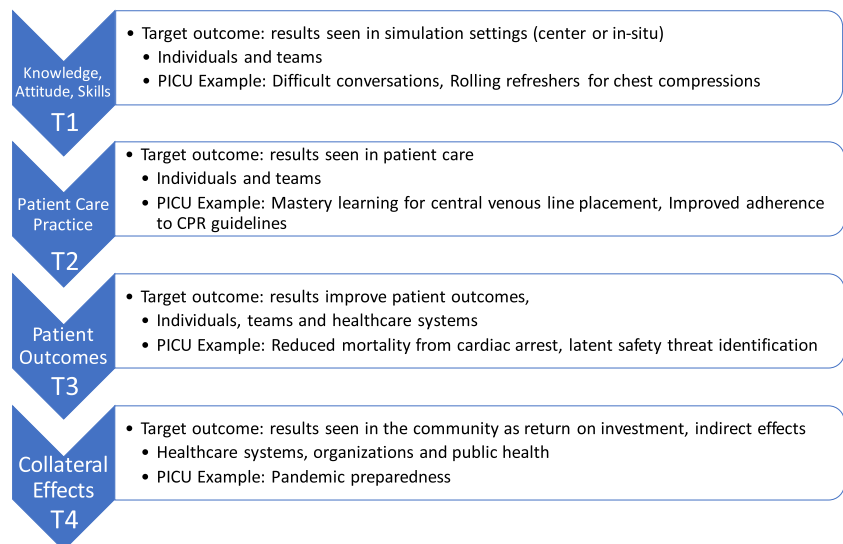
(T1). “Boot camps” provide focused training often during orientation and use deliberate practice to facilitate individual skill acquisition, such as advanced airway management, ultrasound guided central venous line placement, or chest tubes placement, as well as team training in crisis management principles and dynamics [64–66]. Individual technical skills such as CVL placement and thoracentesis are retained longer, and have fewer complications than those trained traditionally, thus demonstrating levels 3 and 4 translational outcomes (Table 2) [67–70].

In recent years, SBME has moved beyond the practitioner learner to also prepare patients, parents, and caregivers for ICU procedures or to transition between the ICU and their home [71]. Families of technology-dependent children exposed to simulation scenarios of tracheostomy-related emergencies reported increased confidence and preparedness to handle these situations at home, a T1 level outcome [71–73]. Virtual reality (VR), albeit a newer technology, has been used in several different ways for critically ill children. One promising use is for distraction during painful procedures such as burn dressing changes [74], lumbar punctures, and blood draws [75] which results in decreasing the amount of sedative or opiate required to complete the task (T3 level outcomes). Some preliminary studies have explored the association between VR and the ICU experience with results showing the potential for decreasing postintensive care syndrome, mitigating anxiety and delirium from prolonged hospitalizations [76], and encouraging early mobilization [77].

Team-Based Learning

Patient care in the PICU is inherently team based, thus simulation training goals tend to focus on development of intact

Fig. 1 Translational simulation framework and applications relevant to PCCM [58–60]



interprofessional teams and improvement of their approach to critical situations, problem-solving, process improvement, and questioning of cultural norms [18, 78]. Code-team simulations are a common focus of PCCM simulation, with several studies showing both technical skills improvement and improvement in team-dynamics [79–85].

Performance of in-hospital cardiopulmonary resuscitation has benefitted from using simulation to assess performance, refine processes, and improve team training in hopes of translating gains to real patient care [81, 82, 84, 85]. Hunt et al. [81] used simulation to develop, refine, and train with a “CPR Coach” role as part of a resuscitation quality bundle, which resulted in increased compliance with the American Heart Association’s CPR guidelines during in hospital cardiac arrest, a T2 level outcome. Specific time-limited metrics, such as time to start chest compressions for cardiac arrest, and other critical actions can also be captured and used for performance evaluation and improvement [86]. Moreover, SBME for pediatric resuscitation has shown improvement in actual pediatric patients’ survival rates of in-house arrest, translating to the patient-outcomes (T3) level [87].

Interdisciplinary and Multiple Teams

The management of a difficult pediatric airway, for example, typically involves several disciplines—PICU, anesthesiology and otolaryngology—who are not routinely educated together, yet often need to practice together posttraining. Lind et al. [88] developed a workshop to teach trainees from each of these subspecialties to work and communicate as a cohesive team-of-teams in order to successfully manage a deteriorating patient. The benefits of rehearsing in the real clinical environment and of using in-place medical equipment include providing a platform for testing how well healthcare sites and services will function as a system when faced with more complex challenges that cut across disciplines and department. Studies have shown simulating such processes as the activation of ECMO plans, can lead to process assessment and identification of latent safety threats, process improvement and refinement, and continual team training on these new processes [89, 90].

Systems, Quality Improvement, and Patient Safety

Simulation lends itself well as an investigative methodology into quality improvement and patient safety practices [91]. Dewan et al. [79] align simulation methodology with 5 key components of high reliability organizations: (1) preoccupation with failure, (2) reluctance to simplify, (3) commitment to resilience, and (4) sensitivity to operations, (5) deference to

expertise. Even a simple simulation-based method to test new technology, such as different video laryngoscopy systems for intubation of Pierre Robin Sequence, prior to purchase or introduction into the patient care environment, may have broader implications for streamlining these processes [79]. Other applications of simulation for advancement of safe care include testing new clinical spaces prior to patient occupation or evaluating the preparedness of an existing space for a pediatric emergency or disaster such as Ebola or COVID-19 [79, 92]. Hospital-based simulation programs are partnering with patient safety experts to integrate simulation into the routine practices and structures of healthcare to fully leverage benefits at the systems level. Our own experience with entering simulation-discovered latent safety threats (LSTs) into our institution’s safety event reporting system has resulted in process improvement and equipment changes [50].

Simulation provides the opportunity to probe a system for vulnerabilities and immediately debrief participants, thus allowing for learning from both success and failure while maintaining psychological safety. A standardized scenario of pediatric anaphylaxis performed in 28 international hospitals identified a high medication error rate, and the postevent debriefings revealed a common LST across institutions related to decision support aids [51]. Learning opportunities from these system-focused simulations can be maximized by using a specific debriefing framework such as PEARLS for system integration [16] which is based on Systems Engineering Initiative for Patient Safety (SEIPS) 2.0, a human-factors model of patient safety and the healthcare system [93].

Pandemic preparedness affords a particularly timely lens by which to illustrate the utility of simulation as a means to improving system-based care and incorporating this into routine practice. During the SARS-CoV-2 pandemic, simulation training was used on many levels for pandemic preparedness. For example, Ramanathan et al. described using simulation training on a team level in full PPE during provision of ECMO services during a pandemic [94–96]. Dieckmann et al. detailed how simulation might be used in the future to prepare for a pandemic response using simulation on several different scales to practice different coordinated responses. This may be on a team level, such as with intubations or simulated code events with the added complexity of donning and doffing PPE, or simulating process changes necessary to accommodate surge capacity within a hospital system. These simulations can allow debriefers to hone in on potential barriers to process implementation and to share good ideas that may arise.

Research Networks

As simulation research has moved away from answering the question “is simulation effective?” for educating healthcare

workers and towards measuring patient level outcomes and other innovative uses, larger research collaboratives have shown benefits. The International Simulation Data Registry (ISDR) was created in 2014 to capture similar metrics to the AHA's Get with the Guidelines registry to compare simulation performance to real patient benchmark data [86]. The international simulation data registry (ISDR) allows for the assessment of mock codes by collecting such time-based data on simulated code events from multiple institutions in a similar manner to the American Heart Association's Get with the Guidelines registry (GWTG) which collects data on live patients [86]. Pediatrics has led the field of healthcare simulation with the creation of networks such as the International Network for Simulation-based Pediatric Innovation, Research and Education (INSPIRE). These registries and networks can facilitate the development of simulation-based multicenter collaborative research projects [97–99]. For example, the Improving Pediatric Acute Care Through Simulation (ImPACTS) program brings simulation to community hospitals to improve their preparedness to manage pediatric emergencies through combining education and assessment of the systems of care at these institutions [53, 100].

Conclusions

Throughout the past 5 years, the use of simulation has greatly expanded, broadening from simple task trainers and mock codes, to multidisciplinary, multifaceted simulations for teams of teams, to the use throughout hospital systems. Emerging technology has enabled a broader use of novel simulation techniques such as VR and telesimulation to expand access beyond large academic institutions.

Simulation is an exemplary educational model because it utilizes the principles of adult learning theory: involvement, experience, relevance, and problem centeredness [101]. It covers a broad swathe of learning topics and learner configurations, thus providing the flexibility needed to teach most adult learners. Simultaneously, simulation provides an ideal medium for understanding larger systems within the pediatric ICU through creation or recreation of vulnerable systems and processes. Simulation provides a modality by which the objectives of individual learning and systems testing converge towards the common goal of sustainably improving patient care.

Pediatric ICU simulation has been on the forefront of these changes, with PICU simulation research outcomes informing research into both other pediatric areas, as well as adult ICUs. Simulation has a tremendous capacity to effect change for the better by improving not only the knowledge base of our learners and the processes through which we work every day, but ultimately the care and lives of our patients.

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- Of major importance

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