The Utility of Simulation in Medical Education: What Is the Evidence?

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ABSTRACT

Medical schools and residencies are currently facing a shift in their teaching paradigm. The increasing amount of medical information and research makes it difficult for medical education to stay current in its curriculum. As patients become increasingly concerned that students and residents are “practicing” on them, clinical medicine is becoming focused more on patient safety and quality than on bedside teaching and education. Educators have faced these challenges by restructuring curricula, developing small-group sessions, and increasing self-directed learning and independent research. Nevertheless, a disconnect still exists between the classroom and the clinical environment. Many students feel that they are inadequately trained in history taking, physical examination, diagnosis, and management. Medical simulation has been proposed as a technique to bridge this educational gap. This article reviews the evidence for the utility of simulation in medical education. We conducted a MEDLINE search of original articles and review articles related to simulation in education with key words such as simulation, mannequin simulator, partial task simulator, graduate medical education, undergraduate medical education, and continuing medical education. Articles related to undergraduate medical education, graduate medical education, and continuing medical education were used in the review. One hundred thirteen articles were included in this review. Simulation-based training was demonstrated to lead to clinical improvement in 2 areas of simulation research. Residents trained on laparoscopic surgery simulators showed improvement in procedural performance in the operating room. The other study showed that residents trained on simulators were more likely to adhere to the advanced cardiac life support protocol than those who received standard training for cardiac arrest patients. In other areas of medical training, simulation has been demonstrated to lead to improvements in medical knowledge, comfort in procedures, and improvements in performance during retesting in simulated scenarios. Simulation has also been shown to be a reliable tool for assessing learners and for teaching topics such as teamwork and communication. Only a few studies have shown direct improvements in clinical outcomes from the use of simulation for training. Multiple studies have demonstrated the effectiveness of simulation in the teaching of basic science and clinical knowledge, procedural skills, teamwork, and communication as well as assessment at the undergraduate and graduate medical education levels. As simulation becomes increasingly prevalent in medical school and resident education, more studies are needed to see if simulation training improves patient outcomes. Mt Sinai J Med 76:330–343, 2009. © 2009 Mount Sinai School of Medicine

Key Words: graduate medical education, simulation, undergraduate medical education.

As educators in the field of medicine, we have a tremendous responsibility to our students, patients, and society as a whole. Participating in medical students’ professional development is truly a gratifying yet daunting task. We must help our students to develop the ability to recognize their own limitations and knowledge gaps and provide them with the tools to fill these voids. Simulation, in all its incarnations, is a tremendous tool for healthcare educators, in that it allows students to achieve these goals without our patients being put at risk. Simulation, as defined by
Dr. David Gaba,1 is an instructional process that substitutes real patient encounters with artificial models, live actors, or virtual reality patients. The goal of simulation is to replicate patient care scenarios in a realistic environment for the purposes of feedback and assessment. Properly conducted, simulation creates an ideal educational environment because learning activities can be made to be predictable, consistent, standardized, safe, and reproducible. This environment encourages learning through experimentation and trial and error with the ability to rewind, rehearse, and practice without negative patient outcomes. It is not our intent to suggest that simulation, in its present form, serves as an acceptable substitute for the actual clinical experience, and we agree that the ideal setting for clinical education remains the actual clinical environment, but unfortunately, the ideal is not always practical.

One might question the necessity of simulation in medical education when the apprenticeship model of training under experienced clinicians has served us well for so many years. However, the world of medicine is changing because of a variety of issues affecting medical education. Patients are now increasingly treated on an outpatient basis, and less time is afforded to patient interaction. Continuity of care has also decreased as time limits are placed on resident work hours. Simulation technology has begun to gain widespread acceptance in medical education because of the safety of the environment, the ability to demonstrate multiple patient problems, the reproducibility of content, and the ease of simulating critical events.2 Coupled with an aggressive medicolegal system in the United States, the idea of learning difficult and error-prone tasks by making errors on live patients is progressively less acceptable.3 It has been said that we remember from our failures, not our successes. Those events that end with an untoward outcome create “seasoned” veteran clinicians.

To date, there is a small but growing body of evidence that simulator training improves healthcare education, practice, and patient safety, but Gaba4 argues that “no industry in which human lives depend on skilled performance has waited for unequivocal proof of the benefits of simulation before embracing it.” Patient safety and medical errors have come to the forefront of healthcare since the Institute of Medicine released To Err Is Human: Building a Safer Health System in 2000.5 The effective integration of simulation into medical education and assessment can address this modern healthcare challenge.

Medical simulation is often divided into 4 areas by the educational tool: a standardized patient, a screen-based computer, a partial-task simulator, and a high-fidelity mannequin simulator.6 This article reviews the utility of simulation in medical education and focuses mainly on the latter 3 areas related to simulation technologies, as a vast body of literature already exists for standardized patients.7 We briefly discuss the history of mannequin simulation and types of simulators and then focus on the educational theory behind simulation as well as simulation as it applies to undergraduate medical education, graduate medical education, and continuing medical education (CME).

HISTORY OF THE MANNEQUIN SIMULATOR

The first mannequin used to teach airway and resuscitative skills was developed by 2 anesthesiologists, Dr. Peter Safar, an American, and Dr. Bjorn Lind, a Norwegian, during the 1950s.8 Lind worked with a toy manufacturer to develop what has been known for over half a century as Resusci-Annie. Some 10 years later, Dr. Stephen Abrahamson, also from the United States, presented the advantages of training anesthesiologists with his full-scale, computer-controlled human patient simulator.9 Toward the end of the 1980s, 2 teams of anesthesiologists, one from the University of Florida (Dr. Michael Good and Dr. John Gravenstein) and the other from Stanford (led by Gaba), developed a realistic mannequin simulation. They combined engineering skills and the idea of using simulation in education for team training and with the aim of improving patient safety. The result was an interactive, realistic patient simulator that could replicate the human response to various physiological and pharmacological interactions.10 At the same time, Dr. Hans-Gerhard Schaefer and his colleagues in Basel, Switzerland developed full-scale simulators for crisis resource training of operating room teams.11 Today, these high-fidelity mannequin simulators are capable of recreating physical examination findings, including normal and abnormal heart and lung sounds, pupil diameter, sweating, and cyanosis, as well as physiological changes, such as changes in blood pressure, heart rate, and breathing.

TYPES OF SIMULATIONS

Simulation, as defined earlier, is the replacement of real patient encounters with either standardized patients or technologies that replicate the clinical scenario. These technologies range from simple demonstrations through screen-based video game–type...
simulations, such as fiber-optic bronchoscopy, to partial-task trainer devices designed to allow learners to practice procedures, including chest tube insertion and intubation, to full environment simulation (FES) using high-fidelity mannequin simulators.

Flight simulators are perhaps the most highly developed form of FES: full cockpit environments undergo all of the movements associated with real flight. High-fidelity mannequin simulators are typically used to recreate real patient encounters in a simulated clinical environment. Even the highly advanced mannequin simulators in use today can be used along a continuum of fidelity, reflecting the time and resources available to the instructor. Students participating in an anesthesiology-based curriculum may be run through a simple anesthetic induction and evaluated on their performance with a checklist of required tasks in a particular order. On the other end of the spectrum is the simulation theater, in which details, both subtle and overt, are embedded, creating emotion, confusion, and distraction and adding that element of reality which helps to enhance the experience. Instead of simply completing the tasks on an anesthesia checklist (eg, start an intravenous line, apply monitors, pre-oxygenate, induce anesthesia, and intubate), participants may face a difficult or inappropriate patient, may have to deal with an obnoxious or verbally abusive family member, or may have to address an inappropriate comment from a consultant. Standardized patients, played by actors, can be used in conjunction with FES to lend an even greater level of reality to simulation. This theater, which adds so much to the reality of the simulation experience, can be laced with emotional content to enhance the learning experience.

The ingredients of a full-environment simulation include the patient (high-fidelity mannequin simulator), other healthcare professionals, and ancillary equipment and supplies designed to replicate the clinical environment. Current mannequin-based simulator designs are computer- and model-driven, full-sized infant, child, or adult patient replicas that are capable of delivering “true-to-life” scenarios that simulate reality. The incorporation of the mannequins into a simulated clinical environment complete with monitors and medical equipment commonly found in real clinical scenarios allows participants the ability to suspend disbelief, thus creating a highly effective learning environment. The lessons learned can be perceived as more realistic in comparison with simpler screen-based simulators.

FES provides the unique opportunity to not only practice procedures but also allow educators the ability to stage realistic settings in which the principal focus can be human behavior and interaction. In this environment, participants can be allowed to make mistakes and experience bad outcomes without patient harm. These adverse outcomes can facilitate the generation of negative emotions among the participants, as no healthcare professional wants to be responsible for contributing to patient harm through a bad clinical outcome, especially when witnessed by colleagues. One of the major manufacturers alleges that its device “exhibits clinical signals so lifelike that students have been known to cry when it ‘dies.’” We theorize that the effectiveness of the simulator as an educational tool not only depends on the ability of the simulator to realistically emulate human physiology and physiological responses but also depends on the specially designed facilities and the expertise of the educators to accomplish FES that triggers these emotions.

SIMULATION AS AN EDUCATIONAL TOOL

The medical learner at any stage—undergraduate, graduate, or postgraduate—is truly an adult learner. Defined in various ways by education theorists, the adult learner, by all accounts, is seen to learn by different methods and for different reasons in comparison with earlier stages in his education. In 2008, building on the work of other education scholars (including Knowles, the father of andragogy, or adult learning theory), Bryan et al. described 5 adult learning principles that apply to the medical learner (Table 1).

These are an adaptation of the assumptions of andragogy, which emphasizes the role of experience and self-direction as well as the need to know the benefits of knowledge and its potential applications before one embarks on the instructional journey. The challenge then is to create effective educational pathways within this paradigm. The complexity

<table>
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<tr>
<th>Table 1. Five Adult Learning Principles That Apply to the Medical Learner.</th>
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<td>1. Adult learners need to know why they are learning.</td>
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<td>2. Adult learners are motivated by the need to solve problems.</td>
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<td>3. The previous experiences of adult learners must be respected and built upon.</td>
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<td>4. The educational approach should match the diversity and background of adult learners.</td>
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<td>5. Adults need to be involved actively in the process.</td>
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NOTE: The material for this table was taken from Bryan et al.
grows, however, when the technical aspects of clinical instruction are introduced. Clinical skills, on the simplest level, are psychomotor skills learned via reinforcement and requiring straightforward instruction. In some ways, clinical skills would seem easier to master because students tend to remember 90% of what they do yet only 10% of what they read. However, clinical skills consist of more than motor memory. They require the integration of problem-solving skills, communication skills, and technical skills in the setting of a complex medical context, and they require practice.

The ultimate goal in medical education is expertise or mastery of one’s trade. Deliberate practice is an educational technique used to produce expert performance contingent upon 4 conditions: intense repetition of a skill, rigorous assessment of that performance, specific informative feedback, and improved performance in a controlled setting. The true goal of deliberate practice, similar to the true goal of medical education, is to produce an expert or master of any trade. As Eppich et al. explained, unless the goal is improved performance, merely participating in the activity will not lead to mastery. It would appear then that one way to improve medical education is to seek a mechanism for deliberate practice. A recent study by Wayne et al. assessed the value of using simulation technology and deliberate practice to enhance acute resuscitation skills. This study of 41 second-year internal medicine residents using deliberate practice to teach advanced cardiac life support (ACLS) showed statistically significant improvements in education outcomes, including compliance with standard ACLS protocols as well as retention of skills and knowledge after 14 months.

In evaluating simulation as an educational tool, Issenberg et al. and McGaghie et al. described the features enhancing its utility (Table 2). Simulation provides the tools and the paradigm to enhance medical education, but it depends on intense preparation and support from faculty as well as buy-in from the participants. The ability to provide immediate directed feedback is the primary advantage of simulation. This opportunity is typically lacking in the clinical setting. It also effectively addresses the diversity of both learners and situations with its adaptable, programmable structure. The main limitation of simulation is learner-dependent, as it requires full participation and engagement by the individual.

FES addresses many of the challenges in today’s medical education. First, it provides a medium and mechanism for clinical skill instruction. Everything from basic interview skills to lung auscultation to emergent cricothyrotomies can be practiced in a simulated environment. That environment allows for relevant, active learning with feedback, these being important components of clinical skill development. Next, it creates a safe environment for practicing with new technologies and, importantly, ensures that practice occurs without endangering patient or practitioner safety. Traditional practice of “see one, do one, teach one” may no longer be ethical. FES is also an ideal environment for the promotion of teamwork and communication. Many clinical problems cannot be solved simply by identification of the diagnosis; they often require resource management and teamwork, 2 practical skills well suited to simulation education. A study by Ottestad et al. demonstrated that simulation could be used to reliably assess nontechnical skills such as interpersonal communication and task management. In Ottestad et al.’s study, house staff were videotaped managing a standardized simulated septic shock patient in teams, and a benchmark checklist of clinical and nonclinical skills was developed. The tapes were reviewed by 2 of the study authors pretrained in skill review, and interrater reliability was found in the assessment of both clinical and nonclinical skills ($r = 0.96$ and $r = 0.88$, respectively). Lastly, training with high-fidelity mannequin simulation improves knowledge consolidation. Wayne et al. demonstrated by both retrospective case log review and simulator testing that comparing the acute cardiac arrest management of residents trained by simulation and those not trained on the simulator showed that students learning new material with the use of simulation retained knowledge further into the future than students studying with more traditional methods.

Medical learners may also benefit from experiential learning, a model explained by David Kolb

### Table 2. Features and Uses of High-Fidelity Medical Simulations That Lead to Effective Learning.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
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<tr>
<td>1. Mechanism for repetitive practice</td>
<td>Simulation provides the opportunity for learners to practice tasks repeatedly.</td>
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<tr>
<td>2. Ability to integrate into a curriculum</td>
<td>Simulations can be easily integrated into existing educational programs.</td>
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<td>3. Ability to alter the degree of difficulty</td>
<td>Simulations can adjust the difficulty level to match the learner’s skill level.</td>
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<td>4. Ability to capture clinical variation</td>
<td>Simulations can replicate a wide range of clinical scenarios.</td>
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<td>5. Ability to practice in a controlled environment</td>
<td>Learning environments can be controlled to ensure safety and focus on learning.</td>
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<td>6. Individualized, active learning</td>
<td>Simulations allow for personalized learning experiences.</td>
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<td>7. Adaptability to multiple learning strategies</td>
<td>Simulations can adapt to various teaching methods.</td>
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<tr>
<td>8. Existence of tangible/measurable outcomes</td>
<td>Simulations provide quantifiable outcomes for assessment.</td>
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<tr>
<td>9. Use of intra-experience feedback</td>
<td>Learners receive feedback while engaged in the simulation.</td>
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<tr>
<td>10. Validity of simulation as an approximation of clinical practice</td>
<td>Simulations can accurately mimic real-world clinical scenarios.</td>
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NOTE: The material for this table was taken from Issenberg et al. and McGaghie et al.
that emphasizes a process of learning building on concrete experience. His model describes 4 stages: (1) concrete experience, (2) observation and reflection, (3) abstract concept formation, and (4) active experimentation in which generalizations are tested and new hypotheses are developed to be tested in future concrete experiences. The simulation experience affords an excellent opportunity to expand on this model. Learners are thrown into a simulated concrete experience that allows them to progress through the cycle, ideally developing skills and knowledge to be applied in future simulated or actual concrete experiences. One of the most important parts of the experiential learning cycle is debriefing, a process that is often difficult to perform in the typical clinical learning experience. In a simulated environment, debriefing can be successfully accomplished. A study by Savoidelli et al. found simulation without debriefing showed no improvement in nontechnical skills in comparison with simulation with either oral or videotape-assisted oral feedback, which showed significant improvement ($P > 0.005$).

**UNDERGRADUATE MEDICAL EDUCATION**

The recent growth of interest in simulation has led to a cascade of applications as a supplement to or replacement for current models of undergraduate medical education. The reason for this is the strong belief in its efficacy as an addition to and sometimes replacement of the current models of education. Traditional modes of education rely on noninteractive classroom lectures and more recently problem-based learning formats to relay basic science concepts and disease processes. Simulation-based training seeks to teach these concepts as well as cognitive and motor skills in an interactive way that more accurately reflects the clinical experience.

Many studies have shown that simulation is a valuable educational tool in undergraduate medical education. Simulation has been used as an evaluation tool to assess knowledge gaps in medical students and residents in the management of acutely ill patients. A study by Young et al. tested medical students and residents in the management of high-risk scenarios and sought to show differences in performance for each level of training with a steady increase in performance as training increased. Surprisingly, when the participants were assessed, all groups performed equally poorly in comparison with the expert-attending comparison group. This performance deficit signified that there might be a deficiency in the current model of the lecture-based and problem-based learning format of teaching. This also revealed potential dangers in the current medical system in which residents decide many critical actions.

As a teaching tool, simulation-based teaching has proved superior to the traditional problem-based learning format. A study by Steadman et al. randomized fourth-year medical students to receive a problem-based learning or simulation-based teaching training intervention for the management of acute dyspnea. Each group received the other intervention for the management of abdominal pain as a control. After a weeklong study period that included an initial assessment, intervention, and final assessment on a simulator, scores were tallied on the basis of standardized performance checklists. The results showed that the group receiving the simulation intervention performed significantly better with a greater improvement in scores from baseline than the problem-based learning group. Next is an overview of simulation use within the various levels of medical school education.

### Basic Science

Medical student educators have used simulation in basic science education. Online computer-based simulators and, more recently, high-fidelity mannequin simulators have been used to teach physiology and have been well received by both students and educators as an effective educational tool. Via et al. used a full-scale human simulator to demonstrate changes in cardiac output, heart rate, and systemic vascular resistance in response to volatile anesthetics for second-year medical students learning pharmacology. Student acceptance was high, with 95% of the students feeling that it was a valuable use of their time and 83% of the students preferring this method over didactic lectures. In another study by Seybert et al., students underwent cardiac scenarios including dysrhythmias, hypertensive urgency, and myocardial infarction. On the basis of preintervention and postintervention scores, students demonstrated improvement of knowledge, ability, and self-confidence in pharmacological management. Simulation in basic science education is often conducted in small-group sessions with the reasoning that it is more effective in such settings. However, Fitch showed that it was possible to teach large groups basic neuroscience concepts with simulation in large settings. High-fidelity patient encounters were presented with physician actors in front of a large group of first-year and second-year medical students to demonstrate basic neuroscience concepts.

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A review of the videotaped large-group sessions showed extensive interactions within the groups, and student feedback revealed that 98% of students felt the correlation to basic science concepts was good or outstanding.

Physical Examination
Simulation has also been used to help teach physical examination skills such as the heart and lung examination. The cardiology patient simulator (CPS), developed by Dr. Michael Gordon in 1968, can be used to teach 30 different cardiac conditions, reproducing abnormal and normal findings such as respiratory sounds, heart sounds, pulses, jugular venous pulsations, and precordial pulsations. This part-task simulator was developed because of the limitations of relying on patient exposure to teach all abnormal cardiovascular examination findings to medical students. A multicenter study, involving 208 medical students, demonstrated significant improvement in clinical skills and knowledge when students were trained on a CPS during a fourth-year cardiology clerkship in comparison with standard bedside teaching.6,35 Students on a cardiology clerkship were divided into a control group using standard bedside teaching and a CPS group using both standard and CPS training. Pretests between the 2 groups were not statistically significant. Upon completion of the training, the students in the CPS group showed statistically significant improvement on a written multiple-choice test and a clinical skills examination with both a CPS and a real patient. Issenberg et al.36,37 showed similar findings in medical house staff.

Clinical Clerkships
The clinical clerkships are a period during which medical students begin to apply preclinical knowledge to the care of real patients. Simulation can help bridge this gap. Medical students have been placed in a variety of simulated scenarios, including airway management in anesthesia cases,38 trauma management,39 and critical care management.40 Murray et al.39 used trauma simulation to explore measurement properties of scores. Third-year and fourth-year medical students and first-year residents underwent a trauma simulation exercise and were subsequently scored on the basis of item-checklist completion, thought process, action performance, and care prioritization. Results from the study showed that timing and sequencing of actions distinguished high-ability examinees from low-ability examinees and correlated with the training level. This and other studies such as that of Boulet et al.40 have shown that simulation is a valid measure of performance.41 As a tool for performance improvement, Morgan et al.12 had 299 fourth-year medical students undergo simulation sessions that involved working through 4 clinical scenarios that resulted in an unstable cardiac arrhythmia. Subsequent testing of knowledge and a review of actions showed statistically significant improvement in written test scores, global ratings, and completion of performance checklists.

Skills Training
Simulation-based training has also found utility in procedural and surgical skills training. Medical student training with virtual reality simulation has similarly led to greater knowledge acquisition and improved performances in simulated surgeries.42 In one study by Van Sickle et al.,43 medical students training with a laparoscopic suturing part-task simulator were able to learn advanced technical skills comparable to those of senior level residents in a short amount of time. For nonsurgical procedures such as cricothyrotomies, central lines, and chest tubes, medical students with simulation training felt more comfortable with and more willing to perform these procedures on their own than those trained without simulation.45 In obstetrics, simulation has been used to teach management of shoulder dystocia and simple delivery.46 Graber et al. demonstrated that patients are more willing to allow medical students to perform procedures such as venipuncture, lumbar puncture, or central lines on them after they have undergone simulation training.47

GRADUATE MEDICAL EDUCATION
In 1999, the Accreditation Council for Graduate Medical Education (ACGME) and the American Board of Medical Specialties defined competency in terms of 6 domains: patient care (including clinical reasoning), medical knowledge, practice-based learning (including information management), interpersonal and communication skills, professionalism, and systems-based practice (including health economics and teamwork). During the following decade, the ACGME identified common requirements for all residency programs. These common requirements mandate that programs must educate, evaluate, remediate, and determine that their graduates are competent in terms of these 6 domains. It is expected that the residency programs will document these processes. Because teaching and assessing some of these domains is complex and imperfect, the ACGME furnished a

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“tool box” with recommended teaching and evaluation modalities. The ACGME considered the use of simulation, including standardized patients and mechanical simulators, to be extremely effective for teaching and evaluating some of the so-called light competencies such as communication skills, professionalism, and systems-based practice. However, all 6 of the ACGME core competencies can be addressed through simulation.

Anesthesiology

Anesthesiologists such as Dr. David Gaba of Stanford Medical School have led the way in anesthesia simulation since the 1980s. Given the nature of anesthesiologists’ practice environment, opportunities for learning are often sporadic. When adverse or crisis events do occur, little teaching takes place, and ubiquitous legal concerns often prevent debriefing and discussion among colleagues. Simulation enables learners to witness such events in a safe environment and creates learning opportunities.

A 1999 survey by Morgan and Cleave-Hogg found that 71% of medical schools used some form of mannequin or simulator to teach anesthesia to medical students. Eighty percent of these institutions also used simulation for postgraduate training. This widespread use has been prompted by evidence that medical decision making and the occurrence of errors can be effectively examined in simulation labs and that improved performance can result from simulator training. There is also evidence that simulation training improves provider and team competence on mannequins and that procedural simulation improves actual performance in clinical settings with respect to implementing ACLS protocols.

It is not surprising that governing bodies have taken notice. Indeed, the American Board of Anesthesiology now requires simulator-based education to fulfill maintenance of certification in anesthesia requirements, and Ziv et al. reported the use of simulation by the Israeli Board of Anesthesiology Examination Committee as a crucial element in credentialing and certifying anesthesiologists. It is likely that the role of simulation will only grow in the field of anesthesiology, in which rare events and resource management training are so crucial.

Surgery

The role of simulation in surgical education is rapidly changing the traditional apprenticeship model, which often suffers from poor reliability when applied to performance assessment and teaching. Surgeons need to learn new procedures and become proficient with new tools throughout their careers. The acquisition of new knowledge and skills can be especially challenging for surgeons, who often work under tremendous time constraints. Although surgical simulation can be thought to start on the first day of gross anatomy class, high-fidelity, computerized models are replacing and augmenting traditional training.

An impressive array of simulators is now available for use in the teaching, learning, and assessment of surgical competencies (from part-task trainers to virtual reality). The continuum of surgical care may be simulated through interconnected stations, each one focusing on a phase in the care of the surgical patient. A review of surgical simulation showed that computer simulation generally showed better results than no training at all. Most surgical trainees feel that simulation is essential to their current surgical training curricula. Furthermore, data suggest the potential for clinical benefits from simulation-based skills development, especially in laparoscopic and endoscopic procedures (upper endoscopy and colonoscopy). Studies by Aggarwal et al., Stefanidis et al., and Korndorffer et al. demonstrated that laparoscopic surgery simulation proved effective for surgical residents in training, maintaining skills, and improving performance in the operating room.

Obstetrics

A number of part-task trainers have since been created for training in common tasks (eg, determining the degree of cervical dilation), and high-fidelity birthing simulators now have motor-driven mechanics that can move a mannequin fetus out of the birth canal. The extant literature supports simulation for practicing routine and uncommon procedures and events, for improving technical proficiency, and for fostering self-confidence and teamwork among obstetricians as measured by self-report. Many articles have been published describing simulators for teaching ultrasound-guided amniocentesis, determining fetal station, managing shoulder dystocia, and managing obstetric emergencies and trauma. A recent retrospective study by Draycott et al., which looked at neonatal outcome before and after shoulder dystocia training on a simulator, showed a reduction in neonatal injury from 9.3% to 2.3%.

Emergency Medicine

The use of simulation in emergency medicine has expanded since the late 1990s. A recent survey of
emergency medicine residencies by Okuda et al. showed that 91% used simulation in training their residents. Of those using simulators, 85% used mannequin-based simulators. Of the emergency medicine residencies using simulation, many of the programs are using simulation to train skills and algorithms such as intubation and resuscitation. To this end, one study demonstrated that simulation-based rapid-response team training correlated with improved team functioning and adherence to American Heart Association guidelines in real in-hospital emergencies.

Crew resource management, in particular, is important in the emergency department, and much of the work done with emergency medicine simulation revolves around this concept. Crew resource management was a concept developed by the National Aeronautics and Space Administration to evaluate the role of human factors in high-stress and high-risk environments such as aviation. This model was adapted into medicine as crisis resource management. Currently, Stanford Medical School runs a compulsory crisis management course for its emergency medicine residents, with increasingly complex scenarios presented as residents progress through their training. Numerous studies have concluded that participants in similar courses viewed their crew resource simulations favorably and believed that their knowledge and skills had been improved. In a study by Bond et al., emergency medicine residents were exposed to scenarios in which they were expected to fail and later examine the decisions that led to their errors. The participants stated that they learned from their errors and ranked the experience second only to actual patient care in terms of educational benefit. Although the current evidence does not conclusively support whether simulation training can change behaviors, skills, or performance in emergency medicine, the increased interest in these possibilities means more research in coming years.

Pediatrics

Although much of the simulation work in general pediatrics has been focused on standardized patient encounters, high-fidelity simulation in pediatrics has focused on neonatal resuscitation. Numerous studies have highlighted deficiencies in providers’ conformity to neonatal resuscitation guidelines. Hence, there exists a need for better training in the skills and teamwork involved in handling pediatric resuscitation and emergencies. Halamek and his group at Stanford University developed a neonatal resuscitation program in the mid-1990s. The program used high-fidelity pediatric simulation and emphasized teamwork and technical skills. Trainees reported that the simulations enhanced their critical thinking, behavioral, and technical skills. Although data are lacking on the transfer of these skills from the simulator to real patients, it is likely that the confidence gained through simulation augments the knowledge gained through actual patient encounters.

Critical Care

The critical care setting is highly dynamic and necessitates many skills that can be taught or honed through simulation. As in many other fields, teamwork and leadership skills are crucial to critical care and can be rehearsed in a simulation environment. Procedures such as central line placement can also be practiced. Central line simulation before actual performance on patients was well received by participants in one study. Still, no long-term outcome evidence exists about whether simulation training improves outcomes.

Competency Assessment and Physician Impairment

Public pressure on physician performance is increasingly compounding the dilemma of assessing competency. Traditionally, physicians were assessed while delivering care to live patients in real clinical situations. This method is growing increasingly unpopular because of public demand for an error-free learning environment. In fact, some malpractice suits have attempted to shift blame to the inadequacies of residency programs. Bond and Spillane outlined how simulation could be used to assess the ACGME core competencies in emergency medicine residents. Other work in the field of emergency medicine has elaborated on the evaluation of specific core competencies and ethical dilemmas. This expands assessment beyond the evaluation of clinical care and into the realm of human rights and morality. Although few will argue that simulation is a convenient tool for competency assessment, many will question the transferability of this assessment in the simulation laboratory to the clinical environment. Two studies addressed this issue. In the first study, a group of emergency medicine residents at various levels of training were assessed on the basis of observable, objective events and time to completion of a surgical airway. The simulation-based evaluation was able to discern novice residents from more advanced residents. A separate study compared anesthesiology residents at different levels of training with board-certified anesthesiologists. These groups

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were exposed to 12 unique, simulated intraoperative emergencies. Again, the simulation-based assessment distinguished the junior trainees from more experienced trainees and anesthesiologists.

Assessment using medical simulation can also be applied to evaluating impaired clinicians for continued practice or promotion. One article outlines the use of a human patient simulator in evaluating an anesthesiologist identified as having substandard medical skills. In this report, the candidate underwent a psychological inventory, oral examinations, and a written test. These were performed to assess medical knowledge and suitability for remediation. The evaluation was enhanced by 4 simulated cases on a human patient simulator that was relevant to the candidate’s practice. The simulation allowed an assessment of technical proficiency within the candidate’s practice environment. In a separate report, some dentists with medical disabilities were evaluated in a simulated environment to determine their ability to perform clinically.

CONTINUING MEDICAL EDUCATION

This past century has witnessed an explosion in medical knowledge. With the ever-changing landscape of medicine, there must be a mechanism by which clinicians can stay current in their medical knowledge and practice. Most state medical licensing boards and specialty boards require some form of CME. Over the years, CME programs have evolved into many forms. Despite its wide acceptance as a requirement for ongoing medical practice, there is little evidence that participation in CME improves patient care or outcomes. However, several trends exist regarding CME activities. Marinopoulos and colleagues performed an exhaustive review regarding the effectiveness of CME. They found 3 common themes: live media are more effective than print media, interventions with multiple media are more effective than interventions with single media, and multiple exposures are more effective than a single exposure. Simulation-based CME programs fulfill the first 2 themes on this list. Simulation-based CME is usually offered in combination with didactic lectures. Because of the cost and logistics of performing simulation, high-fidelity simulation-based CME is not as common as part-task training CME exercises. One study describes the use of high-fidelity simulation for crisis resource management in anesthesia. Blum and colleagues proposed that simulation-based courses should be more widely used. A separate study examining the use of a simulation-based course for difficult airway training suggests that this type of program is more conducive to affecting clinical practice. Offering simulation-based CME requires a fair amount of resources. Simulators are costly, and a greater amount of time is necessary to perform simulations as opposed to lectures. Therefore, having sufficient faculty familiar with performing simulations can also be a problem. Several professional medical societies have recently begun accrediting simulation-based educational centers. Although each group has its own criteria for accreditation, they set standards for necessary equipment, space, and faculty. Theoretically, these centers would be adequately equipped to offer CME programs in their respective specialties.

FUTURE OF SIMULATION IN MEDICAL EDUCATION

Board Certification and Credentialing

The use of simulation technologies for undergraduate and graduate medical assessment has become well established in multiple specialties. However, use of these technologies for credentialing and certification is in its infancy. The United States Medical Licensing Examination (USMLE) was the first testing organization to integrate computer-based case simulations. Examinees are provided a chief complaint and a brief history and are required to care for the virtual patient. These simulations include changes in the patient’s status requiring multiple interventions. In 2004, the USMLE also added a clinical skills assessment using standardized patients. Examinees are required to participate in 12 encounters while the standardized patient records progress on a case-specific dichotomous checklist. Several specialty boards incorporate oral case presentations as part of the board certification process. The American Board of Family Practice expanded its board certification examination in family practice to include simulation. This examination includes computer-based case simulations that are uniquely generated from a knowledge-base database for each examinee. The system uses population distributions for disease states to create patients that evolve in response to candidate interventions, such as pharmacological and nonpharmacological therapies. A third-party application uses Bayesian theory to analyze the participant’s progress and manipulate the clinical case. This is a significantly more advanced system than the prefabricated cases on the USMLE examination. The Royal College
of Physicians and Surgeons of Canada (RCPSC) has long incorporated standardized patients into its comprehensive objective examination in internal medicine. However, the RCPSC quickly recognized the limitations of standardized patients in producing accurate physical examination findings. In 2003, it augmented its examination with digitized cardiac auscultation videos.\textsuperscript{107} By including simulation, the RCPSC was able to include an element of high-stakes assessment that is not otherwise possible with standardized patients alone. The Israeli Board of Anesthesiology Examination Committee fully integrated several simulation platforms into its board certification examination.\textsuperscript{108} The Israeli Board of Anesthesiology Examination Committee integrated a simulation-based objective structured clinical examination component into the board examination process. It created 5 standardized scenarios to assess trauma management, ACLS, operating room crisis management, mechanical ventilation, and administration of regional anesthesia. A combination of high-fidelity mannequin simulators, standardized patients, and an artificial lung was used in the testing environment. To date, the Israeli Board of Anesthesiology examination is the first to incorporate such a robust use of simulation technologies. Its results yielded only adequate interrater correlation, and thus further investigation is needed to improve this model of examination. As new evaluation tools are tested and validated, the various medical specialties may be more likely to adopt the use of simulation for board certification and credentialing. Simulation offers reproducibility and realism.

Medical-Legal Applications
The use of simulation also has a growing impact in the medical-legal arena. The Consolidated Risk Insurance Company (CRICO) is the patient safety and medical malpractice company owned by and serving the Harvard medical community. In 2001, CRICO began offering insurance premium incentives for anesthesiologists who participated in simulation-training programs.\textsuperscript{109,110} Upon analyzing its malpractice claims after several years of implementing this incentive, CRICO concluded that the program was effective in reducing the cost of malpractice claims. The benefit was so significant that CRICO implemented a similar program in obstetrics and gynecology.\textsuperscript{70,110} It is conceivable that other insurance companies will make this type of training required for other specialties. In the book \textit{Practical Health Care Simulations},\textsuperscript{11} Eason provides a theoretical rendering of using simulation in the courtroom. He discusses using medical simulation as evidence in a medical malpractice case. In his example, the medical case is recreated on a simulator for the jury. The intent is to prove or refute wrong doing by the physician. Although there are several legal considerations in using simulations as evidence, this is potentially a very interesting application of medical simulation.

CONCLUSION
Simulation in medical training is here to stay. From the learners’ perspective, simulation affords the ideal opportunity to practice patient care away from the bedside and to apply the principles of adult learning and the principles of deliberate practice toward knowledge and skills mastery. From the patients’ perspective, having students and residents pretrain with simulation increases the likelihood of a minimum competency level prior to clinical interaction and medical decision making. Patients are more willing to allow students to perform procedures on them after they have undergone simulation training.\textsuperscript{47}

There are various practical limitations to implementing simulation-training programs. One recent study, which surveyed all emergency medicine residencies using simulation, found faculty time constraints to be the top barrier to simulation use followed by a lack of faculty training and cost of equipment.\textsuperscript{3} Many of the technologies implemented by simulation educators are expensive. Depending on the fidelity of a simulator, the price for equipment alone can range from $6000 to $250,000. When this is coupled with the cost of equipment maintenance, space for educational labs, and personnel, the budget for a simulation center can be quite large. Many of these expenses can be minimized by the development of multidisciplinary centers in which funding is provided across various departments in an institution. Identifying qualified faculty skilled in simulation use and debriefing is another significant barrier. This includes availability in terms of protected time as well as those faculty trained to teach. This technology does not obviate the need for faculty trained in solid educational principles and teaching techniques. In other words, simulators do not replace good educators.

As the field of medical simulation continues to grow, an increasing number of educators are being formally trained to employ simulation. Currently, 4 emergency medicine programs offer fellowship training in simulation after residency.\textsuperscript{3,112} Ultimately, to increase the availability of simulation...
for students and residents, institutions must prioritize simulation in their hospitals and medical schools by properly rewarding educators through promotions and compensating them with protected time to teach and do further research in this area.

The field of medical simulation continues to grow. In a past publication, Gaba predicted that simulation would be “embedded in the fabric of care” by the beginning of the 21st century. Advanced Initiatives in Medical Simulation (AIMS) was established to accomplish just that. AIMS is a coalition of individuals and organizations committed to promoting the use of medical simulation to improve patient safety, reduce medical error, and lower healthcare costs. With the efforts of AIMS, Rep. Randy Forbes (R-VA) and Rep. Patrick Kennedy (D-RI) introduced bill HR 4321, the Enhancing SIMULATION (Safety in Medicine Utilizing Leading Advanced Simulation Technologies to Improve Outcomes Now) Act of 2007. This bill would advance the use of medical simulation in research and healthcare training and would create medical simulation centers of excellence. Indeed, it is very likely that the future will bring the widespread use of simulation in all aspects of our healthcare infrastructure.

DISCLOSURES

Potential conflict of interest: Nothing to report.

REFERENCES

Y. OKUDA ET AL.: UTILITY OF SIMULATION IN MEDICAL EDUCATION

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