Simulation-based medical education emerged from efforts begun in the 1920s by anesthesiologists to improve patient safety. Interest in this technology has expanded in the past decade. More medical schools and hospitals are building simulation programs, and credentialing bodies are beginning to require the addition of simulation to both educational and certification processes. This article discusses the history of simulation, the role of anesthesiologists in simulation, and future uses of this technology. It is meant to provide an overview of a field that incorporates a wide spectrum of educational tools and techniques and is not intended to be an exhaustive review.

Simulation Defined

Simulation, as defined by David Gaba, MD, of Stanford University, is an instructional process. It is a “technique not a technology, that replaces or amplifies real experiences with guided experiences that evoke or replicate substantial aspects of the real world in a fully interactive manner.” The goal of simulation is to create patient-care scenarios in settings that are similar to or that recreate the clinical environment. Simulation is a term that encompasses a wide range of applications and groups both technological devices and educational modalities that are revolutionizing medical education. At the forefront of this new technique are expensive, computer-driven machines that can mimic an entire patient or a specific procedure or skill.

Simulators and the simulation scenarios themselves may vary in their relation or fidelity to the real clinical experience. Low-fidelity simulation might involve using a partial-task trainer to practice a clinical examination or procedure, such as an intubation mannequin, while high-fidelity simulation often involves expensive computer-driven mannequins that mimic the physiology of a real patient in an operating room (OR) setting. Simulation experiences may involve a single learner or a full patient-care team. Matching the equipment and environment to the learning objectives and goals for the educational program is critical, as expensive equipment and programs are not always the correct solution.

The technology and the realistic clinical environment, along with video-recorded experiences, allow for immediate feedback to the students and also may be used to assess students as they progress through their training. Educators can choose the appropriate simulators and educational techniques to create a realistic clinical environment in which activities are predictable, consistent, standardized, safe, and reproducible. The students are...
History of Simulation: Anesthesiology at the Forefront

Anesthesiologists were the first to develop simulation technology and incorporate simulation into medical education. The earliest record of the use of modern simulation to train physicians can be traced to the anatomy laboratory launched by John Lundy, MD, head of anesthesiology at Mayo Clinic, in the 1920s. Dr. Lundy developed a method to educate surgical fellows about anatomic structures to improve their performance of regional anesthesia and as part of an effort to interest them and other physicians. He created the anatomy laboratory of cadavers so residents would be able to practice procedures. Initially this clinic was used primarily by surgical residents, but it ultimately became a multidisciplinary laboratory.

The anatomy laboratory grew at a rapid pace. Dr. Lundy observed that surgical fellows who studied in the laboratory before assisting with patients in the OR were better able than those who did not to understand the anatomy and technique on real patients. Dr. Lundy also developed a simulation program that recreated the OR environment so residents could learn about performing procedures under conditions similar to those in the OR. This allowed the surgical fellows to practice procedures, learn anatomy and receive feedback about their performance, which was not possible in the OR.

CPR

Interest in patient safety and efforts to improve outcomes after cardiac arrest as early as the 1950s led Peter Safar, MD, an anesthesiologist and intensivist, to develop a new mouth-to-mouth technique that made it possible to oxygenate and ventilate arrest victims. Dr. Safar worked with Bjørn Lind, MD, also an anesthesiologist, and with Asmund S. Laerdal, a toy manufacturer, to create the simulator “Resusci Anne.” Evidence of the importance of closed chest massage prompted Dr. Safar to advise Laerdal to add an internal spring mechanism to permit training in proper cardiac compression. This simulator is still in use as a platform for training in life-support skills.

Sim One

In the 1960s, engineer and medical educator Stephen Abrahamson and anesthesiologist Judson Samuel Denson, MD, worked with a team from Sierra Engineering and Aerojet-General Corporation to construct the Sim One anesthesia simulator. This device, which was a computer-controlled mannequin simulator of the entire patient, initially was constructed to simulate the functions of an anesthesia machine. Sim One evolved to become a fully lifelike mannequin simulator. It had an anatomically shaped chest that moved with respiration, eyes that were able to blink, pupils that dilated and constricted, and a jaw that opened and closed. Sim One was used for airway training and for educating residents in critical anesthesia-related events. The mannequin required a separate room for the computer and was never copied.

Patient Safety

In the 1980s, two mannequin simulators were developed independently. Both were inspired by the research of Jeffrey Cooper, PhD, and his colleagues into error and human factors. This research was among the influences that led to the formation of the Anesthesia Patient Safety Foundation (APSF), which funded simulation research, specifically the creation of physiologic patient mannequins. Dr. Gaba and colleagues at Stanford and the Veterans Affairs Palo Alto Health Care System developed the prototype of a mannequin simulator. This new mannequin combined waveform generators and virtual instruments to create a simulator with vital signs that could be manipulated to simulate critical events. It was housed in a real OR, surrounded by actual equipment to create a highly realistic simulation environment to investigate human performance in anesthesia.

While performing animal experiments involving cardiopulmonary bypass, Dr. Gaba had begun to consider decision making during patient emergencies. He adapted “crew resource management,” an approach to team training used in aviation, to the anesthesia environment, and called it Anesthesia Crisis Resource Management (ACRM). The ACRM course comprises a series of highly realistic simulation scenarios, which are followed by a detailed video-debriefing session (Table 1). The course addresses medical and technical issues relevant to the simulated scenarios, but concentrates on basic principles of crisis management. These principles include leadership, teamwork, distribution of workload, communication, use of all available information and resources, and constant re-evaluation of the clinical situation. Dr. Gaba’s group used this combination of a highly realistic environment, mannequin, and crisis resource management skills to explore clinicians’ actions and decision making in dynamic environments.

Effective ACRM requires the use of debriefing, oral discussions during which students, guided by teachers, reflect on the scenarios and their actions and behaviors. Debriefing is a crucial element of simulation education, as it allows learners to consider what they know and how they performed in the scenario.

Gravenstein’s GAS

While Dr. Gaba and his colleagues were working on ACRM, a multidisciplinary team at the University of Florida also received funding from the APSF to develop its own simulation program. This effort arose from an interest in improving the clinical skills of anesthesia residents. Led by anesthesiologists Michael Good, MD, and J.S. Gravenstein, MD, the project spawned the Gainesville Anesthesia Simulator, or GAS. The project began as part of a plan to educate residents about the diagnosis and management of anesthesia machine faults, and
ultimately developed into a complete mannequin. The device had a sophisticated lung model that was able to mimic uptake and distribution of anesthetic gases. Later versions of the mannequin incorporated a system to recognize drugs as they were injected.26

**TECHNOLOGICAL ADVANCES**

Mathematical models of the physiology and pharmacology of drugs in anesthesia initially developed by a group at the University of California San Diego (UCSD), as well as others, led to the creation of both the mannequins described above and to the development of screen-based computer simulations.27-29 Howard Schwid, MD, a former UCSD fellow working in the lab of N. Ty Smith, MD, simplified these models and developed interactive flat-screen anesthesiology computer simulations that allowed users to manage a wide variety of complicated cases and patient complications with readily available computers.30 Although these inexpensive and highly portable simulation programs do not require the presence of instructors, they are not realistic recreations of patient-care settings.

In January 1994, the Boston Anesthesia Simulation Center (BASC) became the first dedicated center to teach ACRM, which Dr. Cooper had brought from Stanford with the help of Dr. Gaba and others earlier in the decade. BASC evolved into the Center for Medical Simulation and the ACRM program continues: all Harvard anesthesia faculty take the course every 3 years as a requirement for a substantial reduction in their malpractice premium and also for hospital credentialing.31

**PROCEDURAL SIMULATION**

Full-scale human patient simulation is favored for practicing team skills and responses to rare clinical events. There also is a need to improve educational methods for acquiring clinical skills, as procedures become ever more complex and painful for patients, while carrying greater risk for harm.32,33 Such skills, formerly taught primarily on animals or people, now are increasingly taught and rehearsed using “task trainers.” As materials and anatomic models improve, these trainers are becoming more realistic. An advantage of these models is the relative ease of measuring outcomes of educational efforts with and without simulation-based practice.5,32

Physicians never have been required to formally demonstrate competence with procedures before performing them on patients. In recent years, changing attitudes among patients and educators have made it more difficult, especially for beginners, to learn these skills on real patients.4 The decrease in patient care during medical school has pushed the burden of practical training into residency.4,33 However, concurrent changes in resident work hours, and a real reduction in reimbursement for clinical teaching, also have reduced the ability of residents to gain adequate practical experience during this period of their training.4

Virtual reality devices now incorporate haptic, or hands-on modeling to provide a realistic response and sense of touch based on the actions of the trainee. Other specialties beyond anesthesiology, including emergency medicine, surgery, and cardiology, have adopted these task and virtual reality trainers to study simulation-based teaching. Studies show that the initial learning curve for many procedures can be shortened through the use of simulation training.5,32,34

**Best Evidence Medical Education Review Of Simulation**

Issenberg and McGaghie conducted a systematic review of the literature regarding medical simulation from 1969 to 2003.35,36 The authors categorized the available evidence to identify gaps or flaws in the existing literature. They also identified the features and uses of medical simulation that are associated with effective learning (Table 2).

Deliberate practice involves repeated performance of psychomotor skills in a setting where those skills are rigorously assessed to provide feedback to the trainee. Deliberate practice has been shown to be extremely important in the development of expertise.37 This learning style may be viewed as a strategy to help the student work through Miller’s domains of competence: knows (knowledge), knows how (competence), shows how (performance), does (action). Students may use deliberate practice with simulation to help them work through these stages to learn to perform as competent professionals.38

Simulation education generally involves the education of professionals and requires an understanding of the adult learner. Adults have a set of life experiences and are often self-directed. They prefer problem-centered

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**Table 1. Key Points of Anesthesia Crisis Resource Management**

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<th>Know the environment</th>
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<td>Anticipate and plan</td>
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<td>Call for help early</td>
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<td>Exercise leadership and followership</td>
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<td>Distribute the workload</td>
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<td>Mobilize all available resources</td>
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<td>Communicate effectively</td>
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<td>Use all available information</td>
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<td>Prevent and manage fixation errors</td>
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<td>Cross-(double-)check</td>
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<td>Use cognitive aids</td>
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<td>Reevaluate repeatedly</td>
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<td>Use good teamwork</td>
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<td>Allocate attention wisely</td>
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<td>Set priorities dynamically</td>
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Adapted from references 21 and 22.
Feedback: MOST important
Repetitive practice with the use of feedback to allow for deliberate practice
Varying degrees of difficulty needed to allow the learner to progress
Multiple learning strategies should be employed
There should be good clinical variation
The environment should be controlled
Opportunities for individualized learning should exist
Defined outcomes/benchmarks are necessary
The environment for the simulations should be realistic
Simulation should be integrated into a curriculum

Adapted from references 35 and 36.

Medical Malpractice
The use of simulation has had a significant and growing impact on medical malpractice insurance for anesthesiologists. The Consolidated Risk Insurance Company (CRICO) is a patient safety and medical malpractice company that is owned by and serves the Harvard medical community. In 2001, the CRICO Risk Management Foundation began offering insurance premium incentives for anesthesiologists who participated in simulation-based crisis resource management. After several years of simulation courses, CRICO analyzed malpractice claims and concluded that the program had reduced the number and cost of malpractice claims. The company subsequently increased the amount of premium incentives for anesthesiologists who participated in these courses. The benefit was large enough that CRICO worked with the simulation experts to create a similar program in obstetrics and gynecology; it now is extending the program to other surgeons.

Other malpractice insurance companies have now made this type of training a component of a group of patient safety provisions that can lead to a reduction in premiums.

Future Directions: Simulation for Assessment Of Clinical Competency
Although anesthesiologists initiated the use of simulation in medical education, medical schools and residency programs have begun to incorporate the use of simulation in educational and certification processes. Simulation is becoming a useful tool to assess clinical competence and is beginning to be used for credentialing and certification. The United States Medical Licensing Examination first integrated computer-based case simulations, and in 2005 added a clinical skills assessment using standardized patients for all allopathic medical graduates. Osteopathic medical graduates participate in a similar examination process overseen by the National Board of Osteopathic Medical Examiners, the Comprehensive Osteopathic Medical Licensing Examination.

The American Board of Family Practice expanded its board certification examination in family practice to include computer-based case simulations. The Royal College of Physicians and Surgeons of Canada has long incorporated standardized patients into its comprehensive objective examination in internal medicine.

The Israeli Board of Anesthesiology Examination Committee fully integrated simulation into its board-certification examination. It created standardized scenarios to assess trauma management, advanced cardiac life support, crisis management in the OR, mechanical ventilation, and administration of regional anesthesia. A combination of high-fidelity mannequin simulators and standardized patients was used in the testing environment. The Israeli Board of Anesthesiology examination was the first such test to incorporate the use of simulation in an anesthesiology certification exam.

In 2010, the American Board of Anesthesiology instituted a new requirement for the Practice Performance Assessment and Improvement (Part IV) component of its Maintenance of Certification in Anesthesiology (MOCA) process. Diplomates in the MOCA process must attend a simulation-based course in a program endorsed by the American Society of Anesthesiologists.

Conclusion
Simulation allows students to make errors and to learn from those errors without harming patients. It thus has great potential to improve patient safety. Although early evidence suggests that this method of education leads to increased patient safety, it has not been fully adopted and incorporated into all levels of medical education and training. Greater collaboration among medical educators in simulation education and research could potentially lead to broader, more widespread acceptance and use of simulation.

Many believe that simulation-based training will gain acceptance only when there is definitive proof that its use leads to improved patient outcomes and decreased costs. Research is under way to identify those educational efforts in the simulation laboratory that succeed in changing physician practice and improve patient outcomes. In recent years, some evidence has emerged to indicate that education using simulation, particularly surrounding procedural skills, leads to improved patient outcomes and decreased costs. Dr. Gaba has noted many obstacles to obtaining proof that simulation
enhances patient safety and outcome, including the need to study long-term applications of the technology and curricula rather than only studying one intervention.\textsuperscript{51} He further has observed that “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.”\textsuperscript{52}

References