History of Simulation in Medicine: From Resusci Annie to the Ann Myers Medical Center

Medical and surgical graduate medical education has historically used a halstedian approach of “see one, do one, teach one.” Increased public demand for safety, quality, and accountability in the setting of regulated resident work hours and limited resources is driving the development of innovative educational tools. The use of simulation in nonmedical, medical, and neurosurgical disciplines is reviewed in this article. Simulation has been validated as an educational tool in nonmedical fields such as aviation and the military. Across most medical and surgical subspecialties, simulation is recognized as a valuable tool that will shape the next era of medical education, postgraduate training, and maintenance of certification.

KEY WORDS: History of simulation, Medical Education, Neurosurgery, Resident Training, Simulation, Simulation Models, Surgical Simulation

Simulation is an approach to education that is rapidly expanding across all professional realms. It provides the trainee the opportunity to realistically experience a given task or situation while minimizing or eliminating the normally associated risks to the operator, equipment, environment, or others involved. It has the advantage of providing a safe learning environment, standardized and reproducible content, and the ability to demonstrate problems of various levels of complexity. This is accomplished by fabricating any number of factors that play an important role in real-world tasks, including the surrounding environment, operator tools, personnel, and situational factors, via a dynamic interface.

It is this combination of safety and intensive education that has spurred the growth of simulation across many professions subject to high-risk events. Use of simulation in both medical and nonmedical fields is continually evolving to optimize the professional educational value and relevance to real-world challenges. In this article, we trace the origins and history of simulation as they pertain to medical and nonmedical fields and to neurosurgery in particular.

HISTORY OF SIMULATION IN NONMEDICAL FIELDS

War games have been used as simulations throughout history. In the 19th century, the Prussian army developed the war games known as Kriegsspiel, which are credited with the victory of the French in the Franco-Prussian War. Before this, Germans developed a board game, the Konigspiel, allowing the player to visualize the movement of his or her forces and those of the opponent on a board. These early systems of war planning persisted until the 1950s, when attempts were made to program the foundations of warfare via computer systems. Beginning with the Air Defense Simulation in 1948 and the Carmonette series of simulations in 1953, games eliminated much of the manual work of moving pieces, rolling dice, looking up results in a table, and calculating final results. The Rand Corporation is a leader in developing military simulation software for war games.

Simulation as we know it today is modeled primarily on those simulators initially implemented in the aviation industry in the early 20th century. The first reported simulator was the Antoinette biplane in 1909. This device consisted of a barrel suspended from pulleys and accompanying individuals with prodding rods to create responses to the trainee’s use of the controls. It was not until Edwin Link developed the Link simulator in 1929 that pilots were able to replicate the basic motion of a flight, including functioning in blinded environments like those experienced in poor weather conditions. This pioneering device went unnoticed until 1934 when, because of poor weather conditions, pilots were forced to rely on instruments to safely land their aircraft. By the late 1930s, simulators were being used widely in the aviation industry with the advent of the electronic computer in the 1940s allowing more complex simulations to be both created and of increased fidelity.

The first use of simulation in the military was World War II, when the Boxer Corporation was created to build the Red Sands Model to train U.S. military personnel. The simulation was used to train military personnel for their roles in the war. This was followed by the Carmonette series of simulations, which included the Air Defense Simulation in 1948 and the Carmonette series of simulations in 1953. These early systems of war planning persisted until the 1950s, when attempts were made to program the foundations of warfare via computer systems. Beginning with the Air Defense Simulation in 1948 and the Carmonette series of simulations in 1953, systems eliminated much of the manual work of moving pieces, rolling dice, looking up results in a table, and calculating final results. The Rand Corporation is a leader in developing military simulation software for war games.

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weather conditions, many postal carriers suffered crashes, forcing President Roosevelt to contract the US Army Air Corps to deliver US postal mail. As a result of the same issues of inadequate flying experience in bad weather conditions, these same “expert” aviators suffered devastating crashes. Subsequently, the US Army Air Corps purchased the trainers, and soon the device became a mandatory part of the training of pilots in many countries, including Japan, during the prelude to World War II.

Since the 1930s, flight simulation has become a mandatory part of pilot training for military, commercial, and amateur pilots. This process creates a controlled environment that implements the necessary variables to be declared an expert in any aspect of flight. Repeated exposure to rarely encountered settings and situations in a non–life-threatening environment prepares the pilot for actual flight. These features have made aviation simulation extremely successful. The successful use of simulation in both the military and aviation worlds prompted other disciplines to, in later years, consider the use of this tool.

Another area in which simulation is used is in driving and automobile design. Automobile simulators replicate the external variables and conditions encountered by the driver of the vehicle before the on-road experience. Various scenarios are replicated with sufficient reality, fully immersing the driver into the basic experiences and preparing the driver for the actual act of driving. This hands-on approach is considered a more thorough educational experience compared with observational and conventional book learning. The simulator provides a constructive experience for the novice driver and enables more complex exercises to be undertaken by the more mature driver. Developing technologies within the automotive industry also rely on simulation models for both the manufacturing and introduction of novel technology.7,8

Simulation often plays an important role in city planning. To understand how cities are likely to evolve in response to various human and natural phenomena, urban planners have used urban simulators to guide development of cities. AnyLogic, UrbanSim, and LEAM are examples of large-scale simulation modeling software systems used for urban planning. Aspects such as infrastructure planning, traffic flow patterns, and demographic positioning have been modeled with these software systems.9-11

In manufacturing, simulation has been used to engineer the processes of product development to increase quality, to maximize throughput, and to determine the lifecycle of the product. Nearly all best-in-class manufacturers use simulation early in the design process compared with 3 or 4 laggards that do not.12

Today, computer-based simulations are being used to predict weather, to improve ergonomics and biomechanics, to assess disaster preparedness, to chart the trajectory of a country’s economy, and even to predict the outcome of a basketball game. Simulation has become ubiquitous in the world today.

**TYPES OF MEDICAL SIMULATION**

Current surgical curriculum dates to William Halsted, who, at the turn of the 20th century, outlined an apprenticeship model of training dependent on a multiyear, single-institution, high-volume, hands-on training regimen with variable, graduated levels of supervision.13 This model was dependent on busy centers and a society with a high degree of tolerance for the mistakes associated with the trainee learning curve. The quality of training was highly subjective, based on primarily numbers and approval of qualitative metrics set by the attending surgeon. As society’s standards for quality and safety increased, the Institute of Medicine implemented a focus to improve safety in surgical training. This agenda, combined with the growth in the number of training programs, the implementation of decreased work hours, and a decrease in single-center surgical volume, highlighted the role of surgical simulation in surgical training and credentialing to create safe, competent surgeons. As a result, a universe of simulation aids have been developed, including standardized patients, task trainers, software-based models, and augmented/virtual reality models.

The process of using actors to portray different patient encounters and care situations was first reported in 1964 but was not widely accepted because of the cost and lack of validity at the time. However, the obvious benefits of hands-on interaction were eventually noted and led to the initiation of standardized patients for pelvic examination teaching in 1968.14-15 The role of the standardized patient eventually became that of an individual with stable chronic conditions used by training medical professionals for obtaining histories and performing physical examinations. Although studied carefully by the National Board of Medical Examiners, the Medical Council of Canada was the first to incorporate the standardized patient simulation into the examination for licensure in 1993. The Educational Commission for Foreign Medical Graduates formally adopted standardized patient assessment the following year. Two large review articles confirmed the validity, reliability, and utility of the Clinical Practical Examination,16,17 “These findings led to an endorsement by the National Board of Medical Examiners of a standardized patient examination to be implemented in 4 to 7 years. The first required standardized patient examination for US medical students, Step II Clinical Skills, was held in 2004 as part of the national licensing process.”18

The introduction of manikins and task trainers served as an adjunct to medical education in the 1960s. Resusci Annie, a manikin, was introduced in 1960 to teach mouth-to-mouth resuscitation and later evolved with the addition of a spring-loaded chest for the practice of cardiopulmonary resuscitation.19 Another manikin, SIM 1, was produced in the 1960s as a model with user feedback; its facial features included blinking eyes, pupils that were capable of changing size, and an opening jaw. A palpable carotid pulse and temporal pulse were built in, and chest rise and fall were indicative of the manikin’s airway.20 Moreover, SIM 1 was responsive to numerous medi-
augmented reality as software and hardware were able to interface to create meta-real scenarios. Visual (head-mounted displays), aural (3-dimensional audio), haptic (tactile), and vestibular (motion sensors) displays provided the user with a more immersive experience. One of the earliest known examples of this multimodal technology was the Sensorama. Several iterative new technologies have led to the use of handsets and virtual enhancing eyepieces. In Second Life, a virtual Internet-based world started in 2003, avatars are created to replicate a virtual life online. Several medical schools have created in-world learning forums where student avatars can role-play patient interaction scenarios. Medical simulations began to appear in Second Life in 2007 in the community known as Ann Myes Medical Center. Systems such as brain-computer interfaces offer the ability to further increase the level of immersion for virtual simulation users.

Each simulation tool has its strengths and weaknesses. For each, initially, time, money, and effort must be devoted to the development of exercises that allow accurate re-creation of the task of interest. Physical simulators such as cadavers and sawbones require a physical space for the simulator to be housed in and tools to perform the operation. Although the costs are much greater for virtual simulators, they do not require a traditional operating room environment complete with instruments. Although the current generation of virtual simulators is quite sizable, one can envision a future in which these simulators are more compact and portable. At present, it would appear that a multimodality approach to simulation is warranted in which simulators, whether physical or virtual, are used because of their fidelity to the operation of interest.

HISTORY OF SIMULATION IN VARIOUS MEDICAL FIELDS

The utility of simulation is widely recognized and becoming a greater part of medical education across fields. Each major specialty in medicine has worked to shape and optimize the use of simulation in ways that not only address common medical challenges but also specifically address competencies unique to a given specialty. To better understand simulation as a changing entity across medical fields, we briefly survey key components of the use of simulation in each of 5 major medical specialties outside neurosurgery: anesthesia, emergency medicine, surgery, obstetrics, and pediatrics.

The nature of certain medical fields in which spontaneous emergent intervention is required (eg, anesthesia, surgery, and emergency medicine) is such that learning opportunities in critical cases may be sporadic and somewhat limited given the rapidity with which intervention must be implemented. Unacceptable consequences may occur should care be delayed or errors take place during training.

Procedural simulation has been demonstrated to improve clinical implementation of advanced cardiac life support protocols. Therefore, given the often high-acuity environments of anesthesia, simulations have provided a natural supplement to clinical anesthesia training, with >70% of medical schools using some form of simulation for teaching. Additionally, the American Board of Anesthesiology certification guidelines even require a component of simulation-based education and consider it a core element of certification. Similarly, emergency medicine education has adopted simulation training in crew resource management during crisis situations, with >90% of emergency medicine programs in the United States using simulation to train residents. However, definitive evidence has yet to be produced showing whether the use of simulation in emergency medicine effectively modifies clinical skills, behaviors, or performance.

In surgical training, continuous learning is required to gain and maintain proficiency with continually evolving and improving surgical technology. Indeed, most surgical residents view simulation as an essential component of the surgical education curricula. Studies suggest simulation to be particularly effective in developing surgical skills when efficient command of devices under the unique perspective of video guidance is necessary such as laparoscopy and endoscopy. Although the generation of realistic tactile feedback (haptics) has remained a significant challenge in virtual surgical simulation, soft-tissue force feedback is an active area of bioengineering research with new advancements that continue to enhance the realism of virtual training.

Simulation in obstetrics has been demonstrated in recent years to benefit technical proficiency in uncommon procedures and to improve coordination among obstetric teams. Simulation is being used for education on a variety of obstetric topics, including determination of fetal heart station, amniocentesis, management of shoulder dystocia, trauma, and other obstetric emergencies. In particular, simulation training for the management of shoulder dystocia has demonstrated a 4-fold reduction in the rate of neonatal injury.

In pediatrics, much simulation work has focused on neonatal resuscitation. Appropriate conformity to neonatal resuscitation guidelines is a known challenge to neonatal teams. In 2000, Halamek et al proposed a neonatal resuscitation training paradigm that used high-fidelity simulation training as a major component to enhance teamwork and technical skills. Although trainees reported subjective improvement of skills and clinical thinking, data demonstrating effective transfer of these simulation-enhanced skills to real patients are lacking.

Given the extensive track record of simulation in many medical specialties, for neurosurgical educators, the challenge is identifying the means and methods by which simulation can augment traditional neurosurgical training. For a field such as neurosurgery, with high-risk but low-volume procedures, simulation can be effective in providing the surgeon an environment in which to perfect his/her skills.

HISTORY OF SIMULATION IN NEUROSURGERY

Although simulators can take the form of physical models, cadavers, or virtual simulators, neurological surgery, as a field, has an intimate relationship with the 3-dimensional aspect of the nervous system and tools to help navigate safe corridors to pathology. Therefore, neuroimaging and neuronavigation have been available for many years; the real challenge has been how to
model the tissue interfaces accurately to provide a realistic surgical environment for the trainee. Further challenges have included the desire to import patient-specific data into such a virtual simulator, allowing preoperative surgical practice.

Virtual simulation in neurosurgery was fueled by the introduction of computed tomography and magnetic resonance imaging, which provided the images for creating 2-dimensional models used for intraoperative navigation and stereotactic surgery. Since then, simulation in neurosurgery has focused primarily on creating 3-dimensional interactive models with superb realism allowing the user to navigate through the complicated anatomy of the cranial, cranial base, and intracranial contents.47-49

In the 1990s, the Dextroscope became the prototype of a virtual surgical field. It allowed, through the use of a mirror reflecting an image of a monitor and stereoscopic shutter glasses, the creation of a 3-dimensional holographic image.48,49 Combined with the software program VizDexter, this model gave users the tools to manipulate and navigate difficult-to-access spaces. The Virtual Temporal Bone model followed shortly thereafter. Using photographs of 1-mm slices of an actual human cadaver and tomographic data from the Visible Human Project, this model was able to re-create, in a higher degree of neuroanatomical detail, the cranial nerves, vessels, and contents of the temporal bone. Several models simulating cranial base anatomy were developed next, including the Interactive Virtual Dissector. The ROBOSIM, however, took the next steps of providing real-time deformation of virtual tissue and adding the same robotic arm, NEUROBOT, that is used during live surgery.

As recently as 2004, Apuzzo and colleagues48,50,51 noted that the stage was set for virtual simulation in the field; less than a decade later, the number of virtual simulators has increased dramatically. Devices and platforms exist for every conceivable neurosurgical intervention, including aneurysm clipping;52 microvascular decompression,53 tumor surgery,54,55 endovascular procedures,56 and spinal instrumentation.57

In an attempt to overcome the limited sensory interaction of virtual models, ImmersiveTouch was introduced for ventriculotomy, providing the user with tactile sensation and re-creating the “popping” sensation felt as a catheter penetrates the ependymal ventricular lining.58,59 NeuroSim, created in Germany, is a virtual simulator that allows open surgical interventions on the human brain, including aneurysm clipping.52

More recently, NeuroTouch, a virtual simulator developed by Canadian neurosurgeons working with the National Research Council of Canada, allows trainees the opportunity to practice cranial microneurosurgery skills; tasks developed include tumor debulking and cauteryization. At the present time, 7 Canadian teaching hospitals are performing beta testing of the device.54,55

**UTILITY OF SIMULATION IN MEDICAL EDUCATION**

Simulation in medical education serves several purposes, including procedure planning, visual-spatial learning, skill acquisition, and minimizing errors that occur during the early phases of training. Simulation training has the possibility, if implemented correctly, to maximize a surgical resident’s training in the setting of reduced resident work hours and increasingly complex procedures.

There has been wide support from both surgical program directors and residents for the implementation of simulation in the curricula.50,61 However, there is concern regarding lack of evidence for its efficacy. Reznick and colleagues52,53 at the University of Toronto introduced in the mid-1990s the objective structured assessment of technical skills, an assessment tool that they validated. Briefly, for any given task, use of the objective structured assessment of technical skills allows an evaluator to assess the trainee’s skill using both a task-specific checklist and a global rating scale.

In determining the value and effectiveness of simulation training, outcomes must be assessed at different levels. In a review of simulation education, Griswold et al.64 referenced a system by which to measure simulation outcomes (T1, T2, T3, Tvalue). At the T1 research level, simulation outcomes are measured in a laboratory setting. At the T2 level, transfer of skills acquired from simulation training is measured by clinical performance outcomes. T3 level studies assess patient safety. Finally, T4 value studies measure the cost-saving benefits of simulation training. In this review, we focus primarily on the T1 and T2 levels to demonstrate the value of simulation in a resident’s medical education.

**T1 Studies: Simulation Outcomes**

Simulation provides a novice with a safe environment to navigate and to become familiar with the underlying anatomy, providing the foundation for developing spatial awareness, motor skills, and technique mastery. Initial studies of simulation in surgery have demonstrated improvement and retention of skills acquired during simulation training when retested in a similar setting, demonstrating the ability to accelerate the learning curve.

Nesbitt et al.55 compared fourth-year medical students’ and senior general surgery residents’ proficiency in performing a coronary anastomosis using a porcine heart model. The students underwent a period of 4-month training using deliberate practice methodology and one-on-one instruction. In contrast, the senior general surgery resident group received only a single tutorial before performing the anastomosis. No statistically significant difference was seen when the 2 groups’ final scores and mean times to completion were compared. The authors conclude that the physical simulator allowed deliberate practice and mastery of the task at hand.

Zendejas et al.66 further demonstrated how simulation training “jump starts” the learning process in laparoscopic totally extraperitoneal inguinal hernia repair by reducing the number of procedures needed to achieve technical proficiency. Residents taught with the apprenticeship model eventually reached the same performance level, although at a slower rate. Similar results have been seen in pediatric ileocolonoscopies with virtual endoscopy training.67
T2 Studies: Clinical Performance Outcomes

Clinically relevant benefits resulting from simulation training in a laboratory setting have largely been seen in laparoscopic surgery training. Initial studies demonstrated the ability of simulation training to increase accuracy, performance scores, participation, and self-confidence while decreasing procedure time, errors (used commonly as a surrogate measure for patient outcomes), complications, and training time. Unfortunately, many studies are underpowered, using small sample groups of 10 to 20 residents.

The laparoscopic totally extraperitoneal inguinal hernia repair is a relatively new procedure that has not gained much popularity among surgeons because of its steep learning curve; it is estimated that an average of 250 repairs are required to fully master the procedure.66 Zendejas et al66 designed a resident simulation curriculum for this procedure, comparing it with standard practice by assessing operative time/percentage of resident participation in procedure, operative performance measured by a global rate scale, and intraoperative and postoperative complications. The simulation-based curriculum decreased operative time (stimulation-based mastery learning group was 6.5 minutes shorter at the first postrandomization procedure), increased resident participation (5% vs 35%), and decreased postoperative complication rate (3% vs 30%).

DISCUSSION

Graduate medical education has undergone a major transformation since the days of Halsted and Cushing. The days of “see one, do one, teach one” are becoming a relic of the past. A number of factors are leading the revolution in medical education. With the reduction in work hours, without an increase in the length of training, residents are at risk of not obtaining the training they need to practice independently. Simulators would allow for deliberate practice on skills outside the hospital and operating room.

Beginning in 2013, all neurosurgical training programs are required to provide qualitative and quantitative measurements of their trainees. Specifically, the Accreditation Council of Graduate Medical Education Milestone project requires that all trainees be evaluated regularly as to their proficiency in the 6 competencies. A second initiative, the Senior Neurosurgical Society Matrix, requires that all trainees be evaluated regularly on their performance in 20 index cases. Surgical simulation would provide a means for providing metrics in the assessment of trainees. Finally, although the maintenance of certification process currently involves only a written test and practice data, it is possible that, in the future, maintenance of certification will require surgical simulation to be completed.

Neurosurgery, with its rich history of 3-dimensional navigation of the nervous system, has a history of dependence on image acquisition and guidance. It is not a far stretch to envision neurosurgeons using patient specific data to practice independently. Simulators would allow for deliberate practice on skills outside the hospital and operating room.

How can neurosurgeons, as a group, make sure that we develop and use these tools in the most effective and efficient way possible?

Medical and surgical simulation has the ability to ensure the competence of the next generation of surgeons. Although the current generation of simulators still requires refinement, advances are being made rapidly as surgeons, computer scientists, and educators work together to achieve this public safety goal. The Congress of Neurological Surgeons has taken a first step of attempting to create models and curricula for the teaching of neurosurgical skills. In this supplement, readers will appreciate the obstacles encountered and lessons learned as the neurosurgical education community attempts to advance and improve neurological training.

KEY POINTS

- Simulation has a rich history in nonmedical fields; it is particularly useful in fields that carry high risk and cost in the event of errors.
- Medical and surgical education is constantly being pushed to meet the demands of the public and society for excellent results with minimal morbidity and mortality.
- Neurological surgery, because of its high-risk and complex procedures that affect quality and quantity of life, may augment traditional training with multimodality didactic tools.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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