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Simulation in surgical education

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ABSTRACT

Simulation is becoming an important tool in surgical education. Surgical faculty have been forced to modify how they teach technical skills. Instead of a complete reliance on teaching in the operating room, a structured curriculum and dedicated time in the simulation center are being used in many centers. Some of the advantages of this approach include the ability to learn and practice new procedures in a safe and nurturing environment. The disadvantages include the significant cost of virtual reality simulators and the competition, between various training programs, to gain access to simulation.

Surgical education is being transformed from an old apprenticeship model to a new system that incorporates the latest teaching methods. It is no longer feasible to expect that graduates, fresh out of medical school, be placed in a surgery residency program for five years and come out as competent surgeons on the other end with minimal effort on the part of educators. In fact, older residency program models did not necessarily take into account that surgery residents do not all learn at the same pace, and many had different needs. In recent years, the importance of teaching trainees surgical skills, especially in the operating room, has been refined.[1] One model consisting of briefing, intraoperative teaching and debriefing was tested and validated as an educational tool for guided-discovery learning during participation in a surgical procedure.[2] At the outset, the resident selects learning objectives appropriate to their level of training. Faculty focus intraoperative instruction to help the resident achieve their objective. Postoperatively, a face to face debriefing takes place and immediate formative feedback is given by the faculty to supplement the resident's self-reflection. Patient safety, time and financial concerns have all exerted pressure on surgical faculty to modify their approach. In this review, we explore how simulation can help in teaching students and residents technical skills and the contemporary role it plays in surgical education.

History

William Stewart Halsted is credited with starting the first surgical residency training program in the United States. It is oft said that he modeled the surgery residency at Johns Hopkins after clinics he had visited in Germany.[3,4] A lot has changed in 130 years. Prior to the publication of the Flexner report in 1910, medical education in the U.S. lacked uniform standards. Similarly, surgical training was quite variable, and in many cases deficient. The American College of Surgeons was established in 1913 to confer the title of Fellow on properly trained surgeons who could demonstrate satisfactory outcomes.[5] In 1937, the American Board of Surgery was founded with the mission to certify surgeons who could meet its rigorous vetting process in order to protect the public.[6] Later, the ACGME was established to accredit surgery residencies that fulfilled its criteria for creating a proper learning environment for residents and ensure that faculty were held to high standards. Each specialty with an accredited training program has to be verified by its residency review committee (RRC) which is empowered to make sure that a program is following the rules. The main objective of these certifying and accrediting bodies is to ensure the proper education and training of surgeons. It is generally agreed that, if the desired end-product is a competent surgeon, a rigorous postgraduate training program with a comprehensive curriculum are essential.

For centuries, teaching and learning surgery were done through the apprenticeship model: the trainee follows the teacher (mentor) learning through observation and assisting, and in many instances no actual patient care took place in a hospital.[4] The Halstedian model is based on making the trainee work in a hospital setting

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under supervision. There was an obligatory time spent in the physiology or animal lab, however, surgical judgement and technical skills were learned on the job. The length of training, that was agreed upon by the regulatory bodies, was a minimum of 5 years. While this pre-defined period of training may be adequate for many residents, in recent years, some skeptics have questioned whether all graduating surgery residents were ready to launch into practice independently.[7] Over the last two decades, at least three out of four graduating surgery residents elected to pursue additional fellowship training, even if it did not lead to specialty board certification. The sheer number of surgical procedures and complexity of patients may be a driver for graduating chief residents to seek specialization in a defined “niche”, a trend also observed in other specialties like Orthopedics. Furthermore, there appears to be a distinction between the attributes of a general surgeon practicing in rural America, who by necessity needs to be more of a generalist, and the more specialized surgeon practicing in an urban area who feels the need to have a well-defined area of expertise.

Changing the paradigm

Two decades ago, several events converged to force surgical educators to rethink how to train residents.[1] {Table 1}. A new mandate issued from the ACGME to all training programs included emphasis on teaching six core competencies: patient care, medical knowledge, interpersonal communication skills, professionalism, systems-based practice and practice-based learning & improvement.[8] It was also recognized that not all trainees are able to master the required skills at the same pace. The Milestones Project outlined a developmental framework for residents as they progressed through months of training. Competency-based medical education (CBME) emerged as a concept to ensure that trainees are able to master the competencies required to function effectively at their level.[9] An example would be that an intern is capable of evaluating a patient with right lower quadrant pain, order appropriate tests and initiate treatment. The American Board of Surgery, in collaboration with a number of surgical educators, is evaluating whether entrustable professional activities (EPA) can be used for assessing a trainee's performance.[10] EPAs can be defined as daily workplace activities that an individual can be entrusted to perform independently. In the U.S., EPAs were first formulated for medical students by the AAMC as the Core EPA for entering residency.[11] A subset of EPAs is currently being piloted in 26 surgery residency programs in the US. The acquisition of technical skills to perform procedures independently is an essential part of surgery residency training. Also, regular performance feedback to the resident, focusing on specific tasks or parts of an operation, is desired. In the past, performance feedback for a resident was quite subjective, unstructured and variable. Most experts agree that effective feedback should be timely and based on direct observation.[12]

Theory to practice

Resnick and MacRae reviewed the educational theories that underpinned teaching surgical skills.[3] The learner goes through three stages, namely: cognitive, integrative and autonomous. When residents are exposed to a new skill or procedure, they go through the cognitive stage to intellectualize the task and understand the steps. In the integrative stage, the motions are smoother as they gain familiarity with the procedure. Finally, in the autonomous stage, there is no hesitation so that performance becomes smooth and efficient.

Many experts have made the analogy that surgical training is similar to fighter pilot training.[8,13] Dreyfus and Dreyfus were commissioned by the U.S. Air Force to study fighter pilot training. They concluded that skill development in fighter pilots, was based on pattern recognition, intuition and reflection to develop skills. When specifically applied to the development of a physician's competence, the Dreyfus model identifies five stages that are self-explanatory: novice, advanced beginner, competent, proficient, expert and master. In a simplistic fashion, the surgery training program is charged with taking a naïve individual and through a series of proctored events, teach the trainee how to manage a surgical patient and perform an operation or procedure. The simulation laboratory is the ideal place to introduce residents to these operations and permit them to practice in a relaxed and nurturing environment.[13–15] Furthermore, it allows the faculty and program directors to evaluate the performance and gauge the progress of trainees in an objective manner using a validated instrument such as objective structured assessment of technical skills (OSATS).[16] In an ideal world, before participating in a surgical procedure, the trainee would read about it in a textbook, watch a video and practice the steps of the operation in a relaxed environment without the fear of failing or making a technical error. The trainee could also practice, as many times as necessary, to get comfortable with the steps and conduct of the operation.

Simulation

Simulation is the recreation, partly or in toto, of a real-life situation, so that it is as close to reality as possible. Before the personal computer era, there were a few tools available for surgeons to simulate an operation namely: cadavers, bench and animal models.[17] The beginning of the 1990's saw the early prototypes of augmented (AR) and virtual reality (VR). The entertainment industry latched on to this innovation and grew exponentially in a few short years. The gaming industry, with its sophisticated software and computer graphics, exceeded $18 billion in 2017, and is expected to surpass $200 billion in revenue in 2022. In medicine and surgery, the use of VR and AR to train on new procedures is increasing with time. The da Vinci surgical system was first introduced in the US in 1999. Several robot-assisted laparoscopic surgery simulators are now being used to train surgeons how to perform robotic surgery.[17] VR simulators are widely used to teach endoscopy, laparoscopy and endovascular procedures.[18–24] Three-

Table 1
Reasons to consider Simulation.

- 80-h work week
- Increasing cost of operating room time
- Decreasing reimbursement
- Patient safety concerns
- Fear of litigation
- Rapid advances in technology (laparoscopy, endovascular procedures)
- ACGME outcomes project
- Change in societal expectations

dimensional rapid prototyping takes a patient's own DICOM (Digital Imaging and Communication in Medicine) data to create a model that faithfully resembles the patient and enables the surgeon to practice on a given case.

Types of simulation

Bench models

The simplest and cheapest form of surgical simulation is the bench model.[3,17] The suture tying board is a simple tool for students and residents to practice tying square knots. It is possible to take simple tasks, such as tying a knot, and gradually making the task more challenging. First the resident learns how to tie a silk suture. The degree of difficulty increases by using finer sutures, such as 5.0 Prolene, or directing that the knot be tied in the bottom of a long cylinder. There are many examples of home-made suturing boards that teach accuracy and consistency of suturing. Learners can practice sewing on a Dacron patch or perform an end to end or end to side anastomosis on a prosthetic graft. Similarly, the basics of instrument handling are taught. The resident progresses from suturing Penrose drains to practicing a vascular anastomosis with 5.0 Prolene on an ePTFE graft.[19]

Laparoscopic box simulators such as the McGill Inanimate System for Training and Evaluation of Laparoscopic Skills (MISTELS) is another example of a simple trainer to teach and assess basic laparoscopic skills such as peg transfer, cutting, suturing and placing an endoloop.

There have been many inanimate models in use to teach specific operations, such as carotid endarterectomy or femoro-popliteal bypass for vascular surgery trainees.

Manikins

In 1960, the toy maker Asmund Laerdal was tasked to build a life-size doll to teach students how to perform mouth to mouth resuscitation. *Resusci Anne* was thus born. Thousands of nurses, EMTs, students, residents and even lay people have practiced performing CPR on these manikins. Students can learn and practice how to intubate and to correctly perform chest compressions. Advanced Cardiac Life Support (ACLS) is a program sponsored by the American Heart Association to teach medical professionals how to recognize and treat cardiac and respiratory arrest and promptly treat potentially fatal arrhythmias. The course has been updated several times to incorporate technological advances, such as the automatic external defibrillator, and the latest evidence-based practices. One of the features of the course is teaching team performance and communication. Similarly, the American College of Surgeons sponsors the Advanced Trauma Life Support (ATLS) program to teach medical professionals the early recognition of shock in injured patients and initiation of resuscitation. When the time to act is critical, minutes for a cardiac arrest, or the golden hour after traumatic injury, it is ideal to have all members of the team working together to achieve a successful outcome. Both ACLS and ATLS currently use manikins to teach and simulate the human body. Students can practice procedures, such as placing a chest tube or performing a cricothyrotomy in a controlled environment. Manikins have been used as models in many specialties. In vascular surgery for example, there are perfused models for open aortic aneurysm repair and carotid endarterectomy.[22,23]

Live animals

The use of live animals has been a part of surgical residency training since Halsted introduced it.[4] A variety of large animal models have been used, such as swine or dogs. The animal model offers many advantages such learning tissue handling and hemostasis. Animals are anesthetized, so in many ways, the animal lab resembles the operating room, and residents can work together in teams. An additional benefit is that trainees learn how to help one another and communicate effectively. The main drawback of the animal lab is the need for a complicated infrastructure to comply with regulations. Despite the fact that animals have been used humanely, there has been significant pressure exerted on universities by PETA (People for the Ethical Treatment of Animals) to limit any form of animal vivisection.

Human cadavers

For centuries, cadavers have been used to teach human anatomy and surgical exposures.[17] Cadavers are expensive and difficult to procure. Another drawback is that the tissues lack turgor and the blood vessels are empty. There have been models of perfused cadavers, however, this adds another degree of complexity that is not readily available. In vascular surgery boot camps, cadavers have been used to teach various surgical exposures. Other surgical specialties have used cadavers to practice unusual and difficult exposures, such as the skull base.

Human performance simulators

These models and others have been used for the purpose of team training.[25–27] Videotaping the exercise and then reviewing the performance of team members, a technique used extensively in professional and collegiate sports, enables each participant to self-critique and understand what needs to be improved upon. In recent years, inter-professional team training, and simulating a crisis scenario have been used to highlight how functional teams should behave.

In assessing technical skills of trainees, specifically laparoscopic skills, many published reports fall short of adhering to contemporary frameworks of validity. Korndorffer et al. reviewed the literature and evaluated 47 studies that used simulators for laparoscopic training.[28] They found that many papers failed to report on important validity concepts.[29,30] {Table 2}

Virtual reality

Virtual reality (VR) or augmented reality (AR) are the digital recreations of real life.[31,32] In the past few years, this technology has been adapted in medical education. VR holds a lot of promise because it is able to incorporate clinical scenarios, so theoretically, an infinite number of lessons can be designed. In the virtual endoscopy simulators, the student is taught the basics of performing the procedure with real-time feedback and simulation of the patient's vital signs. Learning how to deal with emergent situations, such as depressed respiratory status from over-sedation, makes the exercise and the test more life-like.

Virtual simulators have been used extensively in teaching

Table 2
Types of validity of surgical simulation program.

VALIDITY	
Face	does is resemble the "real" thing
Content	does it contain all elements
Construct	can it separate the novice from the expert
Concurrent	if it is compared to another instrument, is there concordance
Predictive	can it predict "real life" performance

Adapted from Barsom et al.[31]

laparoscopy, robot-assisted surgery, and endovascular procedures. There are four simulators used with the da Vinci system: SEP-robot, RoSS, dV-Trainer and the da Vinci skills simulator.[17] The Lap mentor (manufactured by 3D systems, formerly Simbionix, Haifa, Israel) system features 19 training modules and over 80 tasks and cases, including general, gynecology, urology, bariatric, colorectal, and thoracic surgery. The Angio mentor teaches endovascular skills, from simple balloon angioplasty to endovascular aortic aneurysm repair. The company has been a leader in simulation and its website lists 13 different simulators that span many medical and surgical specialties. The purported advantages of such systems are that they allow trainees to be directly observed by faculty as they perform a task, and are able to simulate clinical scenarios and anatomy. The systems can be used to teach, practice and to test a candidate's skills. It also allows for practicing certain procedures or steps of procedures so that the operator can become more familiar and facile with instrument or wire manipulations.

Patient specific simulators are currently used in multiple specialties. Surgical oncologists can plan pancreatectomies and hepatectomies. Urologists use it for renal resections. In vascular surgery, a resident can upload patient specific DICOM data from a CTA of an aortic aneurysm and practice performing EVAR (endovascular aortic aneurysm repair) before the actual operation taking place. As previously mentioned, the advantages of patient specific simulators are the ability to plan and practice an unusual or complicated procedure, not only for the surgeon, but also potentially for the resident or fellow, and the entire operative team. In a review of the literature, 13 studies have been published using patient specific surgical simulation.[15] The authors concluded that this technology is useful to help learners acquire technical proficiency in multiple specialties.

3-D printing

This technology is just beginning to be used by surgeons to simulate a patient's particular anatomy. In our hospital, before performing the first *trans*-carotid stent, the surgeon reproduced the carotid anatomy, based on the patient's own CT angiogram. The 3-D model was used in our simulation laboratory to bring together the entire surgical team to practice the steps of the procedure before it actually took place. This simple exercise helped to reduce the anxiety of all involved and allowed trouble shooting and anticipating potential problems. 3-D printing is being used in other specialties like Neurosurgery. This technology has proved to be extremely helpful in reproducing patient specific anatomy so that the surgeon can plan the approach, such as an intracranial aneurysm. Congenital heart surgeons are also using this to plan complicated procedures.

The acquisition of superior reproducible expert performance, in surgery as in other fields, such as typing, playing music or chess, is tied to the ability for deliberate practice.[33] Most performers, even the talented ones, need 10 years of intense practice before reaching a mastery level.

Boot camps

Medical school curricula are constantly being updated with added classroom instruction in medically related fields, such as ethics and the business of medicine. The length of surgery clerkships is constantly being whittled away by other priorities. This has led to an average of 6–8 weeks of surgery for junior students. Most students matching in surgical specialties are woefully unprepared for the tasks expected of a new intern, such as placing a central line or a chest tube.[34–37] In 2014, the American College of Surgeons (ACS), Association of Program Directors in Surgery (APDS) and the Association for Surgical Education (ASE) came out in support of a surgical pre-residency preparatory course. The latter was piloted in 39 institutions in 2014 and 47 in 2015. These "boot camps" have had varied success, but most interns reported an increase in confidence after participation. Many residencies, such as neurosurgery, cardiothoracic and vascular surgery, send trainees to these events, either before officially starting training or just after, so that residents get a concentrated dose of instruction. It remains to be seen if this is an effective way to prepare trainees.

Simulation center

Surgical simulation centers are being developed across the world to help train residents and fellows in all specialties.[38–40] In the U.S., all general surgery residents are required to pass the Fundamentals of Laparoscopic Surgery (FLS), and the Fundamentals of Endoscopic Surgery (FES) programs in order to complete their residencies and sit for board exams. Most surgical subspecialties including vascular surgery, colorectal surgery, otolaryngology, plastic surgery and cardiothoracic surgery have developed robust simulation programs as integral parts of their training programs. To meet these requirements, as well as provide simulation training for other medical specialties and healthcare workers, dedicated areas for simulation are needed. A few models exist for these simulation centers and depend on the available space, financial support and the goals of the institution.

The first model is to develop a large "Simulation Hospital" which incorporates space for mock ORs, in-patient hospital rooms, classrooms, task trainers and space for cadaver dissections. These centers can accommodate large groups of various backgrounds (interprofessional) including nursing students, medical students, residents and fellows of all specialties. They also can provide space to be rented by medical device companies and other vendors to train physicians on new technology. There are many examples of programs like this including the Center for Advanced Medical Learning and Simulation (CAMLS) at the University of South Florida in Tampa, Florida and the Center for Immersive Simulation-based Learning (CISL) at Stanford University. This approach is obviously quite costly as it involves building and outfitting a center of this size and diversity. There are additional expenses for staffing. Training programs may have to compete for time and access to the simulation center.[41] This may mean that a surgery program would be limited to 2–4 training sessions per year, depending on how many other nursing, medical and surgical programs are sharing the space, and access may be limited to certain simulators. By distributing the cost of the center to multiple services, each program's financial burden is proportionately decreased but the convenience of scheduling and unfettered access to simulators is sacrificed.

Another model is the development of a specific simulation center for the surgical programs at the institution. This approach places the financial burden on the smaller programs but allows for flexibility of training times, purchasing of simulators specific to surgery and can be the site of all educational conferences if classroom space is incorporated. Often these centers are smaller, require fewer personnel to run and the shared expenses can be split among the various surgical programs. An example of this is the Jacob and Lois Mol Cardiovascular Simulation Center at Spectrum Health. This is a 2100 square foot center dedicated to the training of the cardiovascular medicine fellows, cardiothoracic surgery fellows, vascular surgery fellows and integrated residents. The simulation center was built through a philanthropic drive and outfitted with high fidelity simulators specific to these specialties including a Kind Heart cardiac surgery simulator, Angiomentor endovascular simulator for cardiac and peripheral interventions, and Ultrasound Mentor simulator for transesophageal echocardiography (TEE), transthoracic echocardiography (TTE) and POCUS ultrasound training. The center is staffed by one part-time employee and the trainees and faculty of the programs have 24-h access to the center for use of the simulators, classroom space and lounge. Simulations can be scheduled and performed on a weekly basis during the educational times for the programs or at other times given the flexibility of the schedule.

The future

Surgical educators have started to adopt the principles of CBME. Surgical teaching and learning are being segmented into EPAs. Simulators and simulation centers will have to play a larger role in this paradigm change. There have been many factors that led to this necessary change, among them the need to find a substitute to teaching in the operating room. For years, pilots have used simulators to train and get certified, especially when newer planes were being manufactured and more advanced technology being adopted.[42] Pilots, civilians and military, are thus able to practice a variety of scenarios and reach the desired level of proficiency.

The full-scale adoption of simulation in surgery has been thwarted primarily by financial constraints, but also some critics who questioned whether performance in the simulator translated to performance in the operating room. Future studies on the benefits of simulation will need to adhere to the established concepts of validity to prove that its worthwhile. The ABS has already required FLS and FES for any graduating resident seeking general surgery certification. Since 2002, the European Board of Vascular Surgery (EBVS) has used technical skills assessment as part of their Fellowship certification exam. Currently, it is a 2-h open and endovascular surgical test consisting of prosthetic models (Open AAA, carotid, and lower extremity) to evaluate dissection, anastomosis, knot tying, and endovascular skills. In 2014, the Association of Program Directors in Vascular Surgery (APDVS) announced they were developing the Fundamentals of Vascular and EndoVascular Surgery (FVES). Currently, FEVS is being piloted in several programs before its widespread adoption by all vascular training programs.

Conclusion

Simulation in surgical education is becoming a necessity in teaching trainees technical skills. Advances in technology, such as new devices and new procedures, will need to be taught in a safe environment where patient safety concerns can be mitigated. The ability to practice a certain procedure before it is performed on a patient will be a great advantage of a simulation center. As simulation becomes more sophisticated and validated, it would not be unreasonable to use it as a test of a surgeon's skills, or a tool to grant a trainee or practitioner privileges to perform a specific procedure.

Declaration of competing interest

We have no conflicts of interest.

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