Overview of Simulation in Surgery

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Simulation has long played a role in the acquisition of skills in healthcare [1]. Various modalities have been used to prepare the surgeon for the operating theater. Not surprisingly, some of the first simulation occurred with cadavers. However, preservation proved challenging. As a result, carved figures resembling human anatomy were used. Procedures were carried out in a manner similar to that performed in the operating theater of the day. As time passed, interest in realism exceeded that of the carved figures. More complex simulators were developed to recreate actual physiology. However, these rudimentary moveable models did not always appear outwardly consistent with human anatomy. For example, one of the earliest functional devices was an obstetric simulator that consisted of a glass uterus situated in a wooden pelvis with a flexible fetus [1]. Although over the years, multiple simulators were developed for multiple anatomic structures and medical disciplines, Abraham Flexner specifically singled out the importance of obstetric simulation in his landmark report in 1910 [2]. Over the years, detractors of the benefits of simulation have remained. William Osler is famously attributed to say that there is no better place to learn medicine than at the bedside.

The importance of simulation became more evident when the military and airline industry demonstrated the benefit of training pilots prior to actual flight [3]. Anesthesiology and surgical investigators began to evaluate the potential role of structured simulation and its impact on skill acquisition. As the research began to support the importance of simulation, options for training began to multiply. Further, as research began to support the importance of a protected environment in which a medical student or surgical resident can practice his or her skills, regulatory bodies began to expect these venues in medical schools and training programs (Fig. 1) [4]. The Association of American Medical Colleges has stressed the importance of simulation-based education and has invested in confirming its use within current curricula and ongoing curricular reform. Within surgery, there remains concern by some that simulation, although helpful, has yet to demonstrate a clear benefit [5]. However, the direction and standard are clear as suggested by Dietl and Russell who demonstrated that "simulation effectively reduces the surgeon's learning curve, improves communication, and reduces errors while increasing patient safety" [6–8]. Educators now see simulation as an integral part of training. Moreover, the public understands that through the use of simulation, basic skills can be honed prior to a trainee ever touching an actual patient [9, 10].

The use of simulation in surgical education can be divided into two main areas: technical skill/procedural and nontechnical skill/scenario-based. A review of the benefits and drawbacks of each type of simulation will demonstrate that the building blocks for a robust curriculum and eventual assessment of performance are available. The keys to a successful program that maximizes education outcomes based upon the investment of time and money are less clear [11]. Ultimately, there are endless combinations of training options that offer the opportunity to educate, assess, and practice in the lower stake confines of a simulated environment.

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Fig. 1 Department of Surgery Skills Laboratory at Indiana University School of Medicine

Validation, Fidelity, and Reliability

Before reviewing the types of simulation, one must consider the goals of simulation and the ways in which one can describe how each form of simulation meets those goals. Ultimately, simulation aims to recreate a scenario that a trainee will encounter in the treatment of actual patients. A measurement of the comparison of these simulated scenarios in reality and their proximity to reality is an assessment of their validity [12]. In other words, a scenario is valid if it approximates real life. Validity can be further defined. For example, an overall assessment of the simulation and how it compares to reality is considered face validity. A comparison of how the simulated environment allows the participant to complete tasks to an accurate level of his or her abilities is construct validity. Finally, it is important to know how performance on a simulator will predict a trainee's performance in reality. This is referred to as criterion-related validity.

Fidelity measures the degree to which a simulated environment more closely provides a picture of reality. As an analogy, compare a low-resolution image to a high-resolution image. Upon evaluation of the low-resolution image closely, one sees rough borders of the items within the image with blocklike configuration. The high-resolution image provides smoother boundaries and a more lifelike appearance. Within simulation, an example may be the difference between using a box trainer with reusable laparoscopic instruments to perform laparoscopic suturing versus a computer-based simulator with a virtual reality (VR) environment in which computer-projected instruments are used to sew computer-generated items together. While the two may allow one to complete the task and therefore are valid, the VR is clearly more complex and with the aid of complex computer software approaches a more realistic picture of what is seen in the operating room. Therefore, this VR simulator is considered high fidelity. Frequently, as in this scenario, higher fidelity generally means higher cost. Controversy remains over the benefits of high-fidelity simulator versus the clear financial implications. Many feel, when used appropriately, low-fidelity simulators provide as effective teaching as high-fidelity devices [13].

Reliability represents the ability of the simulation to be repeated consistently by different users at different times but yield similar results for similar performances [12]. For example, if the simulation is attempting to measure aptitude, an individual observing the simulation must consistently come to the same conclusion regarding a trainee's performance at completion of the simulation. This is referred to as test-retest reliability. Moreover, when two trainees perform the simulation in a similar fashion, the observer should come to the same conclusion with each trainee. This is referred to as internal-consistency reliability. And, two observers watching a similar performance of the simulation should come to the same conclusion regarding the assessment of that performance if completed by the same trainee or by different trainees. This is referred to as inter-rater reliability.

Types of Simulation

Technical Skill/Procedural Simulation

In surgical education, the timely acquisition of technical skills remains the focus. Simulation in technical skills training has included both biologic and synthetic models. Some of the first models used for training were biologic in nature. Although initially used to study anatomy, cadavers were then used to prepare for performing the actual procedure. The lack of consistent preservation techniques initially limited the usefulness of cadavers. However, a cadaver naturally provides the most realistic anatomic model, and they remain a consistent component of surgical training [14–17].

Cadavers have generally been used in either a “fresh frozen” format or an “embalmed/preserved” format. The benefits of frozen cadavers are clear. Once adequately thawed, the tissues and the anatomic layers including tissue planes remain lifelike [18]. Unfortunately, natural processes do lead to deterioration of the tissue and a short window of usefulness exists. While the preservation process negatively affects tissue realism, it does significantly increase the timeline for use thereby allowing the cadaver to be used over repeated sessions. Recent trends have provided hybrid preparation techniques that attempt, somewhat successfully, to maximize the realism of fresh cadavers with the usefulness of a preserved one [14, 19]. In addition, some educators have created “live cadavers” connecting the blood vessels of cadaveric specimen to pumps, simulating circulation, and providing an even more realistic educational experience [19–21].

Although the benefits of using cadavers in simulation are clear, the drawbacks may be less obvious. Perhaps more obvious, a lack of flexibility prevents placement in the lithotomy position and limits the use of a cadaver in some procedures (e.g., proctectomy). Although this may be overcome by removal of the legs, some institutions, including the author’s, do not support sectioning of cadavers. In addition to inherent issues with a cadaver, there are less obvious environmental issues to address. The use of cadavers requires adequate ventilation and a method of collecting fluids that are commonly associated with the use of cadavers (i.e., intestines remain unprepped). This limits the locations in which cadavers can be used. At some institutions, this requires competing with undergraduate gross anatomy courses for lab space presenting yet another challenge to creating a robust curriculum.

In addition, as the number of medical schools continues to increase, the demand for cadavers has dramatically risen. Fortunately, there remains a continued understanding by the public that donation of one’s body to science is a very effective method of providing beneficence to society even after one has passed. Still, the cost of obtaining a cadaver may range from $1500 to more than $3000 depending on the venue and the source. In addition, if one elects to use frozen cadavers, infectious diseases may be transmitted postmortem (e.g., HIV or hepatitis C). So, each frozen cadaver requires these tests and increases costs by more than $500 per cadaver. In the end, the cost to obtain “safe” cadavers in an environment conducive to surgical training may be prohibitive for routine use in a skills curriculum in most programs.

Nevertheless, appropriate simulators for a number of surgical procedures (e.g., open inguinal hernia) are still not available requiring a cadaveric model to provide the best training experience [22]. The limited supply of cadavers and the cost associated with using cadavers have led to some programs using cadaver parts. The use of parts provides a potentially more efficient manner of using this limited resource. However, an interest in returning a collection of cremated ashes to the family members of individuals donating their bodies makes it challenging to offer cadaver parts. The parts must be tracked and returned for cremation. As a result, this option is generally offered at limited sites.

A beating heart and circulating blood with the potential for hemorrhage are helpful in creating a lifelike scenario that creates buy-in by the participant. Naturally, one of the biggest drawbacks for cadavers is the lack of bleeding and movement associated with a living being. Although some centers have overcome these obstacles with circulating pumps attached to sectioned cadaver parts as described above, the expense and regulatory challenges of obtaining cadavers remain major barriers to their use [16, 19]. Therefore, animal models have been identified as another biologic simulated environment for some common surgical procedures. Some of these models were initially identified as efforts to research the surgical treatment of diseases which demonstrated similarities to the human model. For example, canine stomachs have proved very similar to humans while bovine or porcine hearts share a significant resemblance to our own [23]. Animate models do provide actual bleeding, not simulated bleeding, with a beating heart and breathing lungs. This actual living environment clearly sells the benefits of the model. For example, Advanced Trauma Operative Management (ATOM) developed at the University of Connecticut and later adopted by the American College of Surgeons Committee on Trauma has demonstrated the role of the swine model in teaching the skill set necessary to manage traumatic injury [24].

There are also several challenges, however, working with animate models. Acquiring animals for educational sessions is largely dependent on the access to these animals. For the most part, comparative anatomy has helped to identify similarities between human organ systems and several other mammals. Animal size and availability, ease of administering anesthetic, and cost are also determining factors in this decision on which model to use. However, for primarily social reasons, the swine model is most commonly chosen.

In fact, the revolution of laparoscopy was significantly facilitated by the ability for practicing surgeons to practice laparoscopic cholecystectomy with the swine model [25].

Access to an animal holding facility necessary to receive and temporarily house these animals limits this option for some institutions. In addition, for some locations in large metropolitan areas, access to pig farms is quite limited. Therefore, while, in some areas, there is ample access to porcine models for training that are even less expensive than some lifelike synthetic inanimate models currently available for purchase, in some other settings, obtaining pigs can prove even more expensive than considering cadaver models. Over the years, ethical treatment of animals has raised concern regarding the use of animals for educational sessions. For example, bowel preparatory techniques are not used. Limiting the use of live animals in education is considered so important by some that the European Union has pushed to reduce, refine, and replace the use of animals in educational sessions [26]. In fact, the UK has eliminated the use of live animals for surgical training, but some trainees (e.g., military medical trainees) travel outside the UK to neighboring countries like Denmark to participate in trauma surgical training courses [27]. Still, access to pig farms likely offers access to food processing facilities where organs commonly disposed at the completion of processing can be used for training purposes. For example, an ex vivo pig liver has been used in comparison to virtual reality simulators and in the laparoscopic cholecystectomy verification of proficiencies developed at Southern Illinois University [28, 29].

The limited availability of cadavers and the ethical dilemma of using animals have led to a rise in the availability of inanimate synthetic alternatives that range in complexity from a piece of foam to a computer-simulated environment. The prior is an example of a low-fidelity model, while the latter is considered high fidelity. Controversy continues regarding the benefits and drawbacks of low-fidelity versus high-fidelity models. Innovative educators have generated numerous low-fidelity models that commonly represent bedside procedures, simple surgical tasks, or a single component of a much more complex procedure [5, 30]. Moreover, these low-fidelity models have demonstrated success in recreating these tasks or procedures in a low-stress environment during which feedback can be provided without risk to the patient. Examination of the benefit of these low-fidelity models has suggested that skills learned here transfer effectively to the operating room and are even preferred by instructors and learners to other forms of simulation including cadavers and animals [5]. These models are present throughout surgical education. For example, in thoracic and abdominal surgery, basic surgical techniques used in minimally invasive procedures can be practiced in what are commonly called “pelvic trainers” or box trainers (Fig. 2). These trainers are omnipresent and relatively inexpensive with an external hard plastic housing with several holes cut in the top surface that are covered by small thin diaphragms, or some trainers have a rigid plastic endoskeleton that is covered by a sheet of thin pliable material on top. The cut holes or the pliable sheet located on the top surface allows introduction of minimally invasive instrumentation while watched by a small posable camera that sends an image to a contained LCD screen or sends the image to a connected monitor or laptop computer. With availability of electronic materials in most major cities, one can construct a model like this at home [30]. These models have proven very effective, and one is used in the Fundamentals of Laparoscopic Surgery (FLS). FLS is an assessment program developed by the Society of American Endoscopic and Gastrointestinal Surgeons (SAGES) to demonstrate proficiency in basic laparoscopic surgery. It has two components: an assessment of knowledge through a multiple-choice examination and a technical assessment using five basic laparoscopic tasks with efficiency and accuracy benchmarks. In addition to the laparoscopic trainers, similar low-

Fig. 2 Example of a low-fidelity “box trainer” with camera, ports, and instruments used to practice basic laparoscopic surgical tasks or procedures

fidelity environments are used to recreate an endoluminal environment used to practice endoscopic procedures [31–33]. Even more rudimentary models are used to simulate tasks including basic suturing and knot tying.

Almost every medical student has benefited from using a piece of thread wrapped around some relatively immobile object [34]. From this basic model, the student has been able to practice knot tying. These rudimentary models have been embellished as well. For example, a box with pieces of cloth is fashioned to recreate an abdominal wall and can be used to practice laparotomy. In orthopedic surgery, the sawhorse has effectively provided an inanimate model from which many boney procedures can be practiced [35]. Despite the simplicity of materials used in creating these models, many learners ultimately do confirm similarity to patient care activities. For example, a model using ventilator tubing and a thick neoprene-type cloth can recreate a lifelike cricothyroidotomy. Residents trained with the model at the author's institution have made anecdotal comments that the model effectively recreates the anatomy of the region and offers a realistic comparison to human anatomy.

Unfortunately, to the untrained observer, the low-fidelity simulators do not measure up. The initial impression for most is that the high-fidelity models provide greater benefit. These high-fidelity models generally involve the use of audiovisual equipment and computers [36]. Still others use extremely high-tech computers modeling force feedback referred to as haptics. Simulators that provide haptic feedback add an additional element of realism with physical feedback representing instrumentation encountering or engaging tissue.

High-fidelity simulators may also use lifelike physical components to represent organs being manipulated during a procedure. For example, materials created by industry may mimic the abdominal right upper quadrant with a realistic liver and gallbladder generated from synthetic material that has come from exhaustive material science research. Using actual laparoscopic equipment with hardware mounted on a rolling tower, the trainee is able to initiate and perform an entire laparoscopic cholecystectomy with lifelike materials configured in realistic anatomical structures without using any biologic material. Similarly, some devices use segments of intestine either donated from a cadaver or retrieved from an animal during preparation for delivery to market. These are then mounted on a fixed stricture to represent the anatomically correct configuration of the human colon allowing an endoscope to be introduced and perform a screening colonoscopy or even a diagnostic procedure with interventions including biopsy or snare removal of polyps. Similarly, bones taken from cadavers or animals mounted to a fixed structure can be used to perform orthopedic surgical procedures [35]. Entire mannequins are available to offer the ability to perform multiple procedures on one device and during one scenario. The mannequin provides a lifelike configuration to a patient creating an element of realism of the trainee. Some simulators provide video recording that may be evaluated by computer software to measure outcomes including overall time, accuracy of movement, efficiency of movement, and potential untoward effects of errant movements. Although all of these lifelike models that simulate real scenarios represent high-fidelity simulators, the most commonly considered devices in this category are used to train technical skills and utilize virtual reality (VR).

VR simulators have limitations based upon the capabilities of computer programming and hardware to generate a lifelike environment. Although there are VR simulators for simplistic tasks like intravenous line insertion, the most common VR simulators cover laparoscopic and endoscopic tasks. Although under development, the ability to introduce one's hands into a box and simulate open surgery in a VR environment exists currently for orthopedic surgical procedures (Sim-Ortho, OSSimTech™) [37]. The greatest benefits of VR simulators are the ability to reproduce identical tasks for all trainees and generate measurements from which metrics are determined to demonstrate overall improvement in trainee movements and the acquisition of surgical skill [36]. In fact, at the author's institution, an attending surgeon commonly performs the tasks on the VR simulation to set a benchmark for trainees to exceed as they train toward proficiency.

The greatest drawback of high-fidelity simulators is their cost. Although these simulators also can occupy significant space, especially the mannequin-based devices, the cost of many of these simulators can reach and exceed $100,000 per device. Additionally, contracts to maintain the devices with complex computer hardware and software, as well as surgical instrumentation that interfaces with the hardware, can cost more than $20,000 per year. High costs generally place these simulators out of reach for smaller training programs, may require the cooperation of several programs at one institution, could necessitate the involvement of clinical entities or healthcare organizations, or demand the identification of a benefactor who can support the mission with philanthropic efforts. Packaging of VR simulators and the images provided on the screen do immediately engender interest from trainees and potential benefactors which draws trainees to the training center and helps encourage philanthropy. Furthermore, they provide an image of futuristic training where surgeons-in-training demonstrate proficiency prior to touching a patient, similar to the flight simulators used in pilot training today. Ultimately, there exist roles for both low- and high-fidelity simulators. A review of the literature suggests a consensus of surgical educators is that low-fidelity simulators remain effective in training basic tasks (e.g., basic suturing), while high-fidelity options are effective in the training of complex tasks including surgical procedures (e.g., total gastrectomy) [38].

Nontechnical and Scenario Simulation

Simulated scenarios like a clinic visit have been used in physician training for decades. Placing an individual who partakes in the role of a patient in an exam room can quickly create a lifelike scenario for someone in any level of training from medical student to surgical fellow. Creating a script and structured method of introducing the learner to the simulated scenario along with an assessment checklist for the actor to use provides an opportunity to demonstrate the acquisition of skills and even improvement from prior events. This objective structured clinical examination (OSCE) using a simulated and standardized patient has played a role in assessment of clinical skills since the 1980s [39]. As time has passed, these training environments have generally moved from an actual clinic to an area dedicated to simulation within the medical school of healthcare organization. These simulation centers can consist of rudimentary rooms with limited materials including an exam table, microphone, and video camera. However, in other locations, rooms are staged to represent an operating theater (Fig. 3), ambulance bay, emergency department, or even an entire hospital ward or intensive care unit [40]. Each room contains at least one audiovisual recording device, but sometimes there are several viewpoints captured for review. Not only do these simulated environments contain physical structures including gurneys, beds, beside tables, IV poles with IV pumps, and bedside chairs for actors to sit, but they also commonly contain VR mannequins that simulate movements of a real patient with eyes that open, speakers that provide breath sounds, abdominal and thoracic movements to simulate a beating heart or breath movements, and simulated telemetry tracings on a bedside monitor which provides vital signs and data just like that seen in the actual hospital room. All of these aids have provided an ability to insert the trainee into as lifelike of a scenario as possible [41, 42]. When an event takes place in one of these simulated venues, the trainees commonly remark on how they were made to feel the same level of stress as that of the actual hospital environment. In addition, these simulated environments provide an opportunity for not only an individual to partake in the training process but for groups of individuals from multiple disciplines or specialties to work together [43]. At the author's institution, simulated events involving medical and nursing students are part of the curriculum for both schools, while coordinated sessions involving surgical and anesthesiology residents in a simulated operating room have proven beneficial to train for stressful events during a simulated laparoscopic crisis.

Naturally, with the ability to record comes the ability to watch and listen to the recording. It has been shown that there is not only benefit of reviewing the checklist with the learner after the completion of an activity, but providing an audio and video recording of the learner and simulated patient partaking in the interaction is very beneficial for the learner [40]. Watching the video after the completion of the session provides an opportunity for review or debrief. In fact, this activity is now considered as important to assessment and improvement as the actual simulated interaction. It provides an opportunity to show specific areas for improvement and clearly shows the learner actions that he or she may not even recognize were performed.

Fig. 3 Simulated operating room arranged for an emergent Caesarean section session at the Indiana University Health Simulation Center

Incorporating Simulation into the Curriculum

The application of simulation in surgery has mainly focused on training and assessment. Dr. K. Anders Ericsson has suggested that mastery of any complex skill requires approximately 10,000 hours of deliberate practice. Although his initial discussions and evaluations revolved around playing the piano, the analogy has been drawn to surgery and the completion of surgical tasks [44, 45]. Almost immediately after this connection was drawn, many in surgical training broke down the average hours a week a surgical resident participated in clinical experience and multiplied that over the 5-year clinical residency. Ultimately, this seemed to justify the long hours and the overall time a young doctor dedicates to surgical training. However, there are at least four competing forces that have shaped the amount of time a resident is allotted for formative skills training under the time-honored Halsted training model of graduated responsibility in the operating room: work-hour restrictions, medicolegal environment, dwindling financial margins in the healthcare industry, and billing guidelines. When one adds that the public has come to expect that training happens prior to actual patient care, the need for a controlled and consistent environment in which education can occur without risk to human life was needed. Although simulation was clearly used prior to the quadripartite wallop to operating room training, it provided an opportunity to effectively expand the time residents train and ultimately worked to meet the standard set by Ericsson's theory [46, 47].

Although using simulation for education has demonstrated clear advantages for years, there are best practices by which simulation has provided different outcomes and arguably can be used in a more effective manner [5, 11]. Specifically, effective use of simulation requires performance review, mandatory participation, and a delicate balance of timing and repetition. First, simulation requires a timely review of the performance. An effective teaching strategy previously introduced is referred to as the BID technique: brief, intraoperative teaching, and debrief [48]. In this strategy, prior to the surgical procedure, the attending surgeon and resident discuss the expectations of the procedure. This may include which portions of the procedure the resident will perform or if the resident will perform all portions of the operation. It should also include a discussion of which portions the resident hopes to focus improving his or her performance. Then, during the procedure, the surgical attending provides immediate feedback regarding resident performance. Although immediate feedback comes in many forms, the expectations here are formative feedback that helps the trainee understand immediately what he or she is doing well and where he or she must improve. Finally, during the debriefing, the resident and faculty member discuss what went well and what can improve, and a comparison is drawn to prior performances. In this regard and to utilize the BID model in simulation, prior to the session, preparation must take place. This should include aligning a resident's reading with his or her simulation experience. At the author's institution, a module from the Surgical Council on Resident Education (SCORE) web-based materials is developed for each simulation session. The module provides not only a book chapter or article to review, but there are also procedure descriptions and when available even a video. It is expected that the trainee arrives to the simulation having completed this preparation. At the beginning of the simulation session, a very brief review of the task or event is performed. Then, the simulation commences. Depending on the session, use of immediate feedback should be consistent with the overall goals. Feedback may be offered, or trainee performance without direction can be assessed to determine a level of autonomy. Finally, upon completion of the session, a review of what went well, areas where the trainee struggled, and an assessment of the end result should occur. This debrief can be added with the benefit of video recording if available.

Second, simulation training must be mandatory. The draw to the clinical environment is strong. The end result is that a trainee will consistently choose to continue clinical duties rather than retreating to the simulated environment for an educational experience. If voluntary participation is encouraged, in general, and not surprisingly, trainees will engage in the simulation infrequently, if at all [49]. If trainees attend simulation sessions infrequently, faculty participation will naturally trail as well, creating a spiral of nonparticipation. Trainees won't participate as a lack of faculty presence suggests a lack of importance, while the lack of trainee participation will suggest a lack of importance of the sessions to the faculty.

At the author's institution, since the development of a comprehensive skills lab curriculum, the sessions are considered mandatory. This requires that the schedule is available well in advance. Moreover, it requires that the trainees prepare in advance and arrange coverage for clinical responsibilities by other trainees or advanced practice providers. Despite the preponderance of electronic scheduling tools with alarms and reminders, trainees still sometimes miss their simulation sessions. Creating a successful skills lab curriculum remains an uphill climb and is dependent on department leadership support.

Finally, effective scheduling of simulation sessions is a delicate balance of timing and repetition. Effective timing would suggest that a teaching session occurs immediately before the skill is required in clinical practice. For example, teaching tube thoracostomy immediately before a resident takes trauma call would provide the best opportunity for the trainee to remember the key components of performing the skill before application of the skill. However, arranging this type of timing creates an element of complexity that is likely not obtainable or sustainable in most training programs. For example, it would require that every rotation for every resident at every level has a simulation-based training program. Even if rotations at a program are 2 months long, that would require 30 simulation programs covering multiple disciplines. In general, this level of complexity requires a bandwidth and financial investment that few, if any, program possesses. However, there are variations on this theme that provide some proximity of skills practice prior to application. A curriculum that calculates the most common procedures performed by trainees per year allows the simulation curriculum to focus on those procedures during the preceding 6–12 months. For example, if laparoscopic cholecystectomy is most commonly performed on rotations during the second year of residency, it would be reasonable to introduce that procedure in the simulated environment during the completion of the first year of residency or the very beginning of the second year [8, 11]. An even closer link between simulation and clinical use could be established by initiating simulation training of laparoscopic cholecystectomy at the beginning of the rotation or immediately prior. This technique, referred to as "just in time" training, has proven effective for simple tasks including endotracheal intubation and lumbar puncture [50, 51].

In addition to timing simulation sessions to maximize skill retention, it is important to identify a time when attendance is maximized. Each residency training program has accommodated the changes in work hours differently. Night float, midweek days off, and staggered vacations have had an impact on all facets of training including didactic and simulation sessions. Choosing a day of the week and a time of day that allows the most trainees to attend is key.

Although the focus of most simulation activities is surgical residents and medical students, simulated surgery remains a major component of training practicing surgeons in new procedures. Hands-on courses that draw practicing surgeons from afar have long incorporated cadavers and live animal sessions. Choosing the best timing for these courses must consider common times for family vacations and surgical meetings. Although industry has commonly sponsored such courses, interest has waned over the years. In addition, willingness of practicing surgeons to travel from home for work purposes has diminished. Moreover, recruiting faculty for these courses can be a challenge if the course is timed poorly. Finally, conflict of interest policies have been introduced by most medical schools and healthcare organizations making travel to industry-sponsored courses untenable. In fact, although eventually repealed, Massachusetts passed a law that prevented physicians from participating in such events. Ultimately, whether one is training medical students, residents, or practicing surgeons, event timing is key to ensuring participation and allowing for participants to focus on the event.

In addition to the intricacies of timing events, establishing the role of repetition within a simulation curriculum is important. As proposed by Ericsson, repetition is a core component of deliberate practice and key to the current goal of proficiency-based training [45]. However, as mentioned, the time that a medical school or surgical residency can devote to simulation events is limited. Therefore, incorporating deliberate and repetitive practice into the curriculum may be challenging and costly. Besides the significant initial capital investment needed for high-fidelity simulators, cadaver sessions are frequently associated with the highest cost per session and, therefore, are infrequently used in most programs. In contrast, inanimate simulations with low-fidelity simulators or even sessions that incorporate computer-based VR simulators can be repeated frequently with limited per use supply costs. As a consequence, high-fidelity simulators that recreate human anatomy have come to replace cadavers and animate models in many facilities. Although material science has allowed these anatomical models to effectively recreate human tissue, these developments have not come without a cost. For example, mannequins commonly used in team-based scenarios commonly have neck, chest, and abdominal skin inserts that may be used more than once but generally not more than three times. The use of these materials can quickly add up and may call into question the role of low fidelity or even animate models which may be available in some environments at comparatively lower costs.

As many work to create the best educational opportunities and utilize the mandated simulation environments in their own facilities, the secret to success of medical student and resident simulation training is not having the best simulators or the most robust curriculum but the unconditional support of the institution and department leadership. Published literature has demonstrated the educational value of cadavers [22], animate models [13, 23, 24], and low- and high-cost simulators [5, 11]. Nevertheless, it is the enthusiasm that the teaching faculty bring to each session and the importance leaders have placed on student, resident, and faculty member presence at each session that mark the key ingredients for a successful program.

In addition to education, simulated scenarios have come to play a role in assessing both technical and nontechnical skills. Likely the most common simulated setting that has been used to assess and certify an individual skill set has been the cardiac resuscitation in Basic Life Support and Advanced Cardiac Life Support programs. Advanced Trauma Life Support was added to these as required certification for individuals entering surgical residency. More recently, Fundamentals of Laparoscopic Surgery (FLS) and Fundamentals of Endoscopic Surgery (FES) have proven effective in demonstrating proficiency in basic laparoscopic and endoscopic skills and completion of these certificates are now necessary components to sit for the

American Board of Surgery Qualifying Examination [52]. Besides providing evidence of technical proficiency in technical skills, FLS certification has also been used for reduction in professional liability insurance premiums. The newly developed FES curriculum has been shown to improve proficiency and quality of diagnostic and therapeutic endoscopy and has the potential to be used also for privileging [53].

Similar high-stakes assessments in a simulated environment have been created for nontechnical skills. The OSCE has proven to be an extremely effective method to assess patient interaction skills. In fact, the US Medical Licensing Examination Step 2 Clinical Skills assessment relies heavily on this tool. Several additional assessment tools have been developed and validated for the assessment of nontechnical skills such as NOTECHS and NOTSS [54]. As curricular change has swept medical schools and milestones have come to replace competencies in postgraduate training, it is likely that simulation will play a bigger role in assessing skill competency.

Finally, in addition to education and assessment, simulation has been adapted directly into clinical practice as a method of preparing not for a general event but a very specific event and procedure. For example, computer software is currently available to gather all radiologic imaging data to create three-dimensional image of a patient's anatomy. This allows for a practicing surgeon or even teams of surgeons in many specialties to prepare for the delicate and coordinated efforts needed in challenging cases [55–59]. For example, hepatobiliary surgery has embraced this concept in approaching liver tumors [60]. With the increasing availability of 3-D printers, not only will virtual images be available, but physical models will be an option for surgeons to practice and prepare for these challenging scenarios [61].

Conclusion

As simulation curricula have demonstrated success in educating and assessing trainees, the number of simulation centers and skills labs has risen dramatically. Each institution uses these valuable resources differently. Literature demonstrates the benefits of simulation for both technical and nontechnical skills. The logistics of putting together simulation sessions including determining their ideal timing and duration will vary based on the needs of the individual program. Financial investment is important to the success of simulation programs as each of these resources has a capital investment and an ongoing replacement expense. However, support by institutional and department leadership and enthusiastic faculty is key to the overall success of a simulation program.

References

1. Owen H. Early use of simulation in medical education. Simul Healthc. 2012;7(2):102–16.
2. Medical education in the United States and Canada; a report to the Carnegie Foundation for the Advancement of Teaching. [S.l.]: New York; 1910.
3. Satava RM. Historical review of surgical simulation--a personal perspective. World J Surg. 2008;32(2):141–8.
4. Britt LD, Richardson J. Residency review committee for surgery: an update. Arch Surg. 2007;142(6):573–5.
5. Sutherland LM, Middleton PF, Anthony A, Hamdorf J, Cregan P, Scott D, et al. Surgical simulation: a systematic review. Ann Surg. 2006;243(3):291–300.
6. Dietl CA, Russell JC. Effects of technological advances in surgical education on quantitative outcomes from residency programs. J Surg Educ. 2016;73(5):819–30.
7. Piromchai P, Avery A, Laopaiboon M, Kennedy G, O'Leary S. Virtual reality training for improving the skills needed for performing surgery of the ear, nose or throat. Cochrane Database Syst Rev. 2015;9:CD010198.
8. Dawe SR, Windsor JA, Broeders JA, Cregan PC, Hewett PJ, Maddern GJ. A systematic review of surgical skills transfer after simulation-based training: laparoscopic cholecystectomy and endoscopy. Ann Surg. 2014;259(2):236–48.
9. Institute of Medicine (US) Committee on Data Standards for Patient Safety, Aspden P, Corrigan JM, Wolcott J, Erickson SM. Patient safety achieving a new standard for care. [S.l.]. Washington (DC): National Academies Press (US); 2004.
10. Institute of Medicine (U.S.). Committee on Quality of Health Care in America. Crossing the quality chasm : a new health system for the 21st century. Washington, D.C: National Academy Press; 2001. xx, 337 p. p
11. Stefanidis D, Sevdalis N, Paige J, Zevin B, Aggarwal R, Grantcharov T, et al. Simulation in surgery: what's needed next? Ann Surg. 2015;261(5):846–53.
12. Tavakol M, Mohagheghi MA, Dennick R. Assessing the skills of surgical residents using simulation. J Surg Educ. 2008;65(2):77–83.
13. AdAdams AJ, Wasson EA, Admire JR, Pablo Gomez P, Babayeuski RA, Sako EY, et al. A comparison of teaching modalities and fidelity of simulation levels in teaching resuscitation scenarios. J Surg Educ. 2015;72(5):778–85.
14. Adams AJ, Wasson EA, Admire JR, Pablo Gomez P, Babayeuski RA, Sako EY, et al. A comparison of teaching modalities and fidelity of simulation levels in teaching resuscitation scenarios. J Surg Educ. 2015;72(5):778–85.
15. Anastakis DJ, Regehr G, Reznick RK, Cusimano M, Murnaghan J, Brown M, et al. Assessment of technical skills transfer from the bench training model to the human model. Am J Surg. 1999;177(2):167–70.
16. Sundar SJ, Healy AT, Kshettry VR, Mroz TE, Schlenk R, Benzel EC. A pilot study of the utility of a laboratory-based spinal fixation training program for neurosurgical residents. J Neurosurg Spine. 2016;24(5):850–6.
17. Camp CL, Krych AJ, Stuart MJ, Regnier TD, Mills KM, Turner NS. Improving resident performance in knee arthroscopy: a prospective value assessment of simulators and cadaveric skills laboratories. J Bone Joint Surg Am. 2016;98(3):220–5.
18. Sheckter CC, Kane JT, Minneti M, Garner W, Sullivan M, Talving P, et al. Incorporation of fresh tissue surgical simulation into plastic surgery education: maximizing extraclinical surgical experience. J Surg Educ. 2013;70(4):466–74.
19. Cabello R, Gonzalez C, Quicios C, Bueno G, Garcia JV, Arribas AB, et al. An experimental model for training in renal transplantation surgery with human cadavers preserved using W. Thiel's embalming technique. J Surg Educ. 2015;72(2):192–7.

20. Aboud E, Aboud G, Al-Mefty O, Aboud T, Rammos S, Abolfotoh M, et al. "Live cadavers" for training in the management of intraoperative aneurysmal rupture. J Neurosurg. 2015;123(5):1339–46.
21. Carey JN, Rommer E, Sheckter C, Minneti M, Talving P, Wong AK, et al. Simulation of plastic surgery and microvascular procedures using perfused fresh human cadavers. J Plast Reconstr Aesthet Surg. 2014;67(2):e42–8.
22. Ahmed K, Aydin A, Dasgupta P, Khan MS, McCabe JE. A novel cadaveric simulation program in urology. J Surg Educ. 2015;72(4):556–65.
23. Zenati MA, Bonanomi G, Kostov D, Svanidze O. A new live animal training model for off-pump coronary bypass surgery. Heart Surg Forum. 2002;5(2):150–1.
24. Jacobs LM, Burns KJ, Kaban JM, Gross RI, Cortes V, Brautigam RT, et al. Development and evaluation of the advanced trauma operative management course. J Trauma Inj Infect Crit Care. 2003;55(3):471–9; discussion 479.
25. Bailey RW, Imbembo AL, Zucker KA. Establishment of a laparoscopic cholecystectomy training program. Am Surg. 1991;57(4):231–6.
26. Gruber FP, Dewhurst DG. Alternatives to animal experimentation in biomedical education. ALTEX. 2004;21(Suppl 1):33–48.
27. Gala SG, Goodman JR, Murphy MP, Balsam MJ. Use of animals by NATO countries in military medical training exercises: an international survey. Mil Med. 2012;177(8):907–10.
28. Sanfey H, Ketchum J, Bartlett J, Markwell S, Meier AH, Williams R, et al. Verification of proficiency in basic skills for postgraduate year 1 residents. Surgery. 2010;148(4):759–66; discussion 766–7.
29. Van Bruwaene S, Schijven MP, Napolitano D, De Win G, Miserez M. Porcine cadaver organ or virtual-reality simulation training for laparoscopic cholecystectomy: a randomized, controlled trial. J Surg Educ. 2015;72(3):483–90.
30. Al-Abed Y, Cooper DG. A novel home laparoscopic simulator. J Surg Educ. 2009;66(1):1–2.
31. Desilets DJ, Banerjee S, Barth BA, Kaul V, Kethu SR, Pedrosa MC, et al. Endoscopic simulators. Gastrointest Endosc. 2011;73(5):861–7.
32. Wais M, Ooi E, Leung RM, Vescan AD, Lee J, Witterick IJ. The effect of low-fidelity endoscopic sinus surgery simulators on surgical skill. Int Forum Allergy Rhinol. 2012;2(1):20–6.
33. King N, Kunac A, Merchant AM. A review of endoscopic simulation: current evidence on simulators and curricula. J Surg Educ. 2016;73(1):12–23.
34. Gomez PP, Willis RE, Schiffer BL, Gardner AK, Scott DJ. External validation and evaluation of an intermediate proficiency-based knot-tying and suturing curriculum. J Surg Educ. 2014;71(6):839–45.
35. Atesok K, Mabrey JD, Jazrawi LM, Egol KA. Surgical simulation in orthopaedic skills training. J Am Acad Orthop Surg. 2012;20(7):410–22.
36. Willis RE, Gomez PP, Ivatury SJ, Mitra HS, Van Sickle KR. Virtual reality simulators: valuable surgical skills trainers or video games? J Surg Educ. 2014;71(3):426–33.
37. Davies J, Khatib M, Bello F. Open surgical simulation--a review. J Surg Educ. 2013;70(5):618–27.
38. Johnston MJ, Paige JT, Aggarwal R, Stefanidis D, Tsuda S, Khajuria A, et al. An overview of research priorities in surgical simulation: what the literature shows has been achieved during the 21st century and what remains. Am J Surg. 2016;211(1):214–25.
39. Sloan DA, Donnelly MB, Johnson SB, Schwartz RW, Strodel WE. Use of an objective structured clinical examination (OSCE) to measure improvement in clinical competence during the surgical internship. Surgery. 1993;114(2):343–50; discussion 350–1.
40. Pucher PH, Aggarwal R, Singh P, Srisatkunam T, Twaij A, Darzi A. Ward simulation to improve surgical ward round performance: a randomized controlled trial of a simulation-based curriculum. Ann Surg. 2014;260(2):236–43.
41. Pena G, Altree M, Field J, Sainsbury D, Babidge W, Hewett P, et al. Nontechnical skills training for the operating room: a prospective study using simulation and didactic workshop. Surgery. 2015;158(1):300–9.
42. Briggs A, Raja AS, Joyce MF, Yule SJ, Jiang W, Lipsitz SR, et al. The role of nontechnical skills in simulated trauma resuscitation. J Surg Educ. 2015;72(4):732–9.
43. Bearman M, O'Brien R, Anthony A, Civil I, Flanagan B, Jolly B, et al. Learning surgical communication, leadership and teamwork through simulation. J Surg Educ. 2012;69(2):201–7.
44. Krampe RT, Ericsson KA. Maintaining excellence: deliberate practice and elite performance in young and older pianists. J Exp Psychol Gen. 1996;125(4):331–59.
45. Ericsson KA. Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains. Acad Med. 2004;79(10 Suppl):S70–81.
46. Crochet P, Aggarwal R, Dubb SS, Ziprin P, Rajaretnam N, Grantcharov T, et al. Deliberate practice on a virtual reality laparoscopic simulator enhances the quality of surgical technical skills. Ann Surg. 2011;253(6):1216–22.
47. Hashimoto DA, Sirimanna P, Gomez ED, Beyer-Berjot L, Ericsson KA, Williams NN, et al. Deliberate practice enhances quality of laparoscopic surgical performance in a randomized controlled trial: from arrested development to expert performance. Surg Endosc. 2015;29(11):3154–62.
48. Roberts NK, Williams RG, Kim MJ, Dunnington GL. The briefing, intraoperative teaching, debriefing model for teaching in the operating room. J Am Coll Surg. 2009;208(2):299–303.
49. Gostlow H, Marlow N, Babidge W, Maddern G. Systematic review of voluntary participation in simulation-based laparoscopic skills training: motivators and barriers for surgical trainee attendance. J Surg Educ. 2017;74(2):306–18.
50. Nishisaki A, Donoghue AJ, Colborn S, Watson C, Meyer A, Brown CA 3rd, et al. Effect of just-in-time simulation training on tracheal intubation procedure safety in the pediatric intensive care unit. Anesthesiology. 2010;113(1):214–23.
51. Auerbach M, Fein DM, Chang TP, Gerard J, Zaveri P, Grossman D, et al. The correlation of workplace simulation-based assessments with Interns' infant lumbar puncture success: a prospective, multicenter. Obs Study Simul Healthc. 2016;11(2):126–33.
52. Zendejas B, Ruparel RK, Cook DA. Validity evidence for the fundamentals of laparoscopic surgery (FLS) program as an assessment tool: a systematic review. Surg Endosc. 2016;30(2):512–20.
53. Hazey JW, Marks JM, Mellinger JD, Trus TL, Chand B, Delaney CP, et al. Why fundamentals of endoscopic surgery (FES)? Surg Endosc. 2014;28(3):701–3.
54. Wood TC, Raison N, Haldar S, Brunckhorst O, McIlhenny C, Dasgupta P, et al. Training tools for nontechnical skills for surgeons-a systematic review. J Surg Educ. 2017;74(4):548–78.
55. Sariali E, Catonne Y, Pascal-Moussellard H. Three-dimensional planning-guided total hip arthroplasty through a minimally invasive direct anterior approach. Clinical outcomes at five years' follow-up. Int Orthop. 2017;41(4):699–705.
56. Xuyi W, Jianping P, Junfeng Z, Chao S, Yimin C, Xiaodong C. Application of three-dimensional computerised tomography reconstruction and image processing technology in individual operation design of developmental dysplasia of the hip patients. Int Orthop. 2016;40(2):255–65.

57. Ren J, Zhou Z, Li P, Tang W, Guo J, Wang H, et al. Three-dimensional planning in maxillofacial fracture surgery: computer-aided design/computer-aided manufacture surgical splints by integrating cone beam computerized tomography images into multislice computerized tomography images. J Craniofac Surg. 2016;27(6):1415–9.
58. Lin JC, Myers E. Three-dimensional printing for preoperative planning of renal artery aneurysm surgery. J Vasc Surg. 2016;64(3):810.
59. Zhang G, Zhou XJ, Zhu CZ, Dong Q, Su L. Usefulness of three-dimensional(3D) simulation software in hepatectomy for pediatric hepatoblastoma. Surg Oncol. 2016;25(3):236–43.
60. Zeng N, Fang CH, Fan YF, Yang J, Xiang N, Zhu W, et al. The construction of three-dimensional visualization platform and its application in diagnosis and treatment for hilar cholangiocarcinoma. Zhonghua Wai Ke Za Zhi. 2016;54(9):680–5.
61. Lichtenstein JT, Zeller AN, Lemound J, Lichtenstein TE, Rana M, Gellrich NC, et al. 3D-printed simulation device for orbital surgery. J Surg Educ. 2017;74(1):2–8.