SPECIAL ARTICLE

Simulation and Virtual Reality in Surgical Education

Real or Unreal?

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Rapid change is under way on several fronts in medicine and surgery. Advances in computing power have enabled continued growth in virtual reality, visualization, and simulation technologies. The ideal learning opportunities afforded by simulated and virtual environments have prompted their exploration as learning modalities for surgical education and training. Ongoing improvements in this technology suggest an important future role for virtual reality and simulation in surgical education and training. *Arch Surg. 1999;134:1203-1208*

Rapid change in most segments of society is occurring as a result of increasingly more sophisticated, affordable, and ubiquitous computing power. One clear example of this change process is the Internet, which provides interactive and instantaneous access to information that was scarcely conceivable only a few years ago. The increasing importance of the Internet is but one example of the effect of technology on our lives.

Advances in instrumentation, visualization, and monitoring have enabled continual growth in minimally invasive techniques in surgery, radiology, and cardiology, among others. The operating room is becoming an increasingly complex environment as technology affects the ways in which surgery is practiced, with marked change during the last 10 years and little to suggest otherwise for the future.[1] The advent, growth, and development of virtual reality (VR) and simulation as adjunctive educational, training, and certification modalities in surgery will likely affect current surgical practice in ways that may be difficult to predict. The purpose of this article is to explore the concepts of surgical education, simulation, and VR and to determine how and to what extent they overlap and affect the way we train and learn as surgeons.

SURGICAL EDUCATION

Surgical education and training as a subset of graduate medical education has drawn increasing interest in recent years. Prior to the 20th century, medical education in the United States was erratic, lacking in standardization, and poorly regulated. Advanced surgical training was often obtained in Europe in the mid 19th century.[2] The effects of ether anesthesia and aseptic techniques on surgical practice radically increased the number of operations performed during the latter half of the 19th century. Combined with the surgical training system instituted by Dr William Halsted of The Johns Hopkins University School of Medicine in the 1890s, these advances laid the groundwork for the future of surgical science and training at the turn of the century.[3,4]

The original Halstedian approach to surgical training sought to produce surgeon clinicians, researchers, and teachers (3 domains often identified as core values of the modern academic health center). Dr Halsted's program of apprenticeship, with graded responsibility and emphasis on laboratory investigation, has formed the basis of most American surgical training programs.[2] During the past 50 years, the original pyramidal structure of the surgical residency has evolved into the rectangular, 5-year programs that are standard today.[4,5]

Traditional surgical teaching has been based on the preceptor or apprenticeship

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model, in which the resident surgeon learns with small groups of peers and superiors, over time, in the course of patient care. A variety of more or less formal educational practices, such as bedside teaching rounds, case conferences, morbidity and mortality conferences, and grand rounds, have evolved over time.[6,7] The operating room provides a venue to demonstrate technique and place the operation in the context of overall patient management. Indeed, the operating room has been termed "the surgeon's classroom and laboratory extraordinaire."[8]

Various efforts have been undertaken to improve surgical education and training. Problem-based learning, the single-observer method of evaluation, and organized strategies for teaching in the ambulatory setting have been described as educational modalities for third- and fourth-year medical students.[9-11] Another innovative educational tool, the objective structured clinical examination, has proven useful in the evaluation of clinical competence of surgical residents.[12,13] As interest in the development of technical skills training laboratories has grown in recent years, several investigators have worked to develop methods to objectively evaluate surgical skill.[14-18]

Multiple external factors are exerting pressure on the traditional surgery residency training structure. The funding of graduate medical education in surgery is threatened while the per capita workload increases, due to plateaus in the number of postgraduate training positions available.[19,20] Several authors have suggested that the next step in surgical education, given these forces, is the adoption of computer-based simulators for surgical education and training.[21,22] Bridges and Diamond[23] estimate that the annual cost of training chief residents in the operating room amounts to $53 million per year (for general surgery alone). They suggest that adjunctive training environments that use traditional and virtual teaching aids may serve to alleviate this cost over time. Further alternatives include distributed education via the Internet, although little is known about this growing area.[24]

SIMULATION

The concept of simulation in training is not unique, and its utility in education has been recognized for some time. Perhaps it is most well known for its role in civilian and military pilot and astronaut training. The idea of simulation in action may evoke images of game- or role-playing, though it may be most instructive to consider a simulation as a case study, with the participants "on the inside." From a functional standpoint, a good simulation represents simplified reality, free of the need to include every possible detail.[25]

Simulation, loosely construed, is the act of assuming the outward qualities or appearances of a given object(s) or process or series of processes. Application areas for real-time simulation (which involves the computer modeling of events so that they proceed within a defined range of their natural occurrence) include training, testing, analysis, and research into and development of new products.[26] In addition to air and space flight training, training simulators for military and commercial vehicles, mechanical system maintenance, and nuclear power plant operation exist. Transport companies use simulators to prototype and test ground and air transport vehicles, primarily because they provide testing environments that are controllable, secure, and safe. The cost-effective use of simulators as described has demonstrated the utility of real-time simulation as a training tool, and has sparked interest in the development of simulators for other potentially dangerous environments (ie, new or complex medical procedures).[26]

Simulation in medical education has been undertaken in a variety of settings. Paramedical personnel are taught triage and assessment skills with this technique, and advanced trauma life support and advanced cardiac life support courses rely on simulated scenarios to teach and test skills. Screen- and mannequin-based simulators have been used in anesthesia training to ensure that clinicians will be exposed to unusual situations that they would not otherwise routinely experience, such as malignant hyperthermia, anaphylaxis, and cardiac ischemia.[27] Efforts to show that these simulators improve clinical performance have been equivocal. Chopra et al[28] showed that anesthesiologists trained on a "high-fidelity anesthesia simulator" responded more quickly and appropriately when handling crises on the simulator. Controlled studies involving human patients to validate this finding would present an unacceptable risk, however.

Further development of the simulation concept evolved out of recognition that two thirds of all accidents or incidents in anesthesia can be attributed to human error. To counter this, Howard et al[29] developed a training program, Anesthesia Crisis Resource Management, to optimize anesthesiologist and team performance during stressful incidents. Success in this arena has led to the use of mannequin-based simulators in surgical training as an alternative to "real" trauma resuscitations for teaching teamwork and crisis management skills.[30,31]

VIRTUAL REALITY

Ivan Sutherland wrote that the computer "screen is a window through which one sees a virtual world. The challenge is to make that world look real, act real, sound real, feel real."[32(pvii)] While much has been made of VR in the media, it is important to realize that it basically represents a unique interface to a variety of 3-dimensional (3D) computer applications.[32] The term *virtual reality* was coined by Jaron Lanier, founder of VPL Research (Palo Alto, Calif), in the late 1980s. Virtual reality has also been variously defined as a human-computer interface that simulates realistic environments while enabling participant interaction, as a 3D digital world that accurately models actual environments, or simply as cyberspace.[33,34]

Sutherland's work on interactive head-mounted displays (HMDs) in the mid 1960s set the tone for further development in 3D graphical visualization, though it was not until the mid 1980s that evolving components allowed Lanier and others to develop viable HMDs, body suits, and gloves.[35] Earlier inspiration can be attributed to the Sensorama, a unique immersive environment built by Morton Heilig in the early 1960s, which used 3D video linked to a motorcycle mockup to simulate inner-city travel.[36] Virtual reality development was also supported by efforts to build better flight simulators, particularly in the human factors and input design areas (eg, HMDs for NASA).[35,37]

A realistic sense of immersion is one key element in the design of a VR system. Optimal interpretation of the graphical image(s), perhaps through an HMD, in a given virtual environment (VE) enables a fuller understanding of that VE. This experience is enhanced by high-resolution display devices and high frame refresh rates (24-30 frames per second).[32,33,38] Auditory and other sensory cues can be added to enhance the overall sense of immersion.

User interactivity is another important concept in VR/VE design, as it allows the user to navigate. This can be achieved with hand tracking devices, motion-coupled HMDs, and motion-tracking body suits.[32,39] The haptic (touch, or having to do with touch) and kinesthetic (sensing orientation and position in space) components of the environment complete the interactive experience. These can be provided through tactile and force feedback devices that are in varying stages of experimental and commercial development.[33,40] A variety of hardware, software, and peripheral configurations are available to create and support VR environments.

Virtual reality has been used in a variety of educational, training, and entertainment settings.[32] The highly visual and interactive nature of VR has proven to be useful in understanding complex 3D structures and for training in visuospatial tasks.[41] Recognition of this has led to increasing interest in developing VR-based applications for surgical education and training.

APPLICATIONS

Virtual environments have been created and used in many areas of medicine. Early developments in the surgical field included the virtual abdomen created by Satava[42] and the hip arthroplasty planning application by Rosen et al.[43] Virtual endoscopy, interactive anatomy teaching modules, acrophobia treatment modalities, and soft tissue modeling have all been described.[44-47] A series of dedicated conferences have sparked interest in this field, and reports on VR applications in medicine can be found in the medical, computer science, engineering, and popular lay literature. Both VR and VE applications in surgery can be subdivided as follows: training and education, surgical planning, image guidance, and telesurgery.

Training and Education

The similarities between pilot and surgeon responsibilities are striking: both must be ready to manage potentially life-threatening situations in dynamic, unpredictable environments. The long and successful use of flight simulators in air and space flight training has inspired the application of this technology to surgical training.[48] Perhaps because of the number of complications resulting from the uncontrolled growth of laparoscopic procedures in the early 1990s, many groups have pursued simulation of minimally invasive and endoscopic procedures. Tendick et al[49] have developed laparoscopic camera handling and cholecystectomy simulations based on a graphics workstation, while Tseng et al[50] have built a real-time force feedback cholecystectomy simulator based on a personal computer.

Advances in tissue modeling, graphics, and haptic instrumentation have enabled the development of open abdominal and hollow-tube anastomosis simulators.[51,52] Initial validation studies using these and other simulators have shown differences between experienced and novice surgeons, that training scores improve over time, and that simulator task performance is correlated to actual task performance.[53-55] Training applications for retinal, arthroscopic, neurosurgical, and otolaryngologic procedures have also been described.

Virtual reality technology has been used to create several learning environments. Anatomy education using interactive 3D graphics has recently been undertaken at the University of California–San Diego School of Medicine, and early evaluation of virtual bronchoscopies suggests that it may prove useful in prebronchoscopy planning and training.[56,57] A recent report on VR-based flexible sigmoidoscopy simulator training has shown significant improvements in examination times and hand-to-eye skill measures.[58] Medical students and residents using a VR-based module for intravenous catheter placement showed improvement in the VE, but were unable to transfer that improvement to physical reality.[59]

Surgical Planning

Virtual reality technology can serve as a useful adjunct to traditional surgical planning techniques. Basic research in image processing and segmentation of computed tomography and magnetic resonance scans has enabled reliable 3D reconstructions of important anatomical structures.[60,61] These 3D imaging data have been used to further understand complex anatomical relationships in specific patients prior to skull base surgery, and also to examine and display the microsurgical anatomy of the basilar artery bifurcation.[62,63] Three-dimensional reconstructions have proven particularly useful in planning stereotactic and minimally invasive neurosurgical procedures.[64,65] Modeling of deformable facial tissues has enabled simulation of tissue changes and the postoperative outcome of craniofacial surgery.[66] Other soft tissue applications include planning liver resections on a 3D, deformable liver model with the aid of a virtual laparoscopic tool.[67]

Image Guidance

The integration of advanced imaging technology, image processing, and 3D graphical capabilities has led to great interest in image-guided and computer-aided surgery. Navigation in surgery relies on stereotactic principles, based on the ability to locate a given point using geometric references.[68] Most of the work done in this field has been within neurosurgery. An image-guided operating robot has been developed by Lavallee et al,[69] and Shahidi et al[70] have described a microsurgical guidance system that allows navigation based on a 3D volumetric image data set. In one case, the intraoperative mapping of 3D image overlays on live video provides the surgeon with something like "x-ray vision." This has been used in conjunction with an open magnetic resonance imaging scanner to allow precise, updated views of deformable brain tissue.[71] Other researchers have focused on applications for orthopedic and otolaryngologic procedures.[72,73] Improvements in sensor and imaging technology should eventually allow updates of the patient's position and intraoperative shape changes in soft tissues within a reasonable time frame.[74]

Telesurgery

Telesurgery allows surgeons to operate on people who are physically separated from themselves. This is usually done through a master-slave robot, with imaging supplied through video cameras configured to provide a stereoscopic view. The surgeon relies on a 3D virtual representation of the patient and benefits from dexterity enhancement afforded by the robotic apparatus.[75] A prototype telemanipulator has been used to successfully perform basic vascular and urologic procedures in swine.[76,77] More advanced systems have been used to perform coronary anastomoses on ex vivo swine hearts and in humans undergoing endoscopic coronary artery bypass grafting.[78-80]

CONCLUSION

Though in its infancy, the field of VR and simulation in surgical education and training is gaining recognition. The Committee on Emerging Surgical Technology and Education of the American College of Surgeons sponsored a demonstration of various simulation and VR-based educational environments at the 1998 Clinical Congress, and reports on these evolving modalities are beginning to appear in the mainstream surgical literature.[81]

The exact effect of this change on the surgical education process is impossible to predict, though evidence suggests positive outcomes will result. Adult learners seek to gain and understand skills and knowledge that will assist them in important activities. They learn by doing and are often most successful when the experience is self-directed.[82] When focused on practical applications, the adult learner gains insight as information is placed within a contextual framework. Providing this context within a rich visual, auditory, and touch-enhanced virtual world has enabled the transfer of VR-based training to actual skill.[83,84]

Simulation as a metaphor for authentic experience was used prior to the advent of computerized simulations, with role-playing in business training, war games, and paramedical training. Well-designed computer simulations, though unable to teach per se, can provide the needed context that provides for optimal learning. Certain environments cannot be replicated without the assistance of computers (eg, space travel), necessitating the creation of manageable, low-risk, computer-based alternatives. Simulation provides effective learning experiences in groups or alone, can suit learners of varying backgrounds, is interactive and fun, and is more compelling because one can immediately see the consequences of one's actions.[85]

Historically, mainstream educational systems have regarded learning as an individual process. Recent evidence suggests that doing so fails to prepare the learner for high achievement in the modern workplace, which is characterized by the need to successfully use technology to collect, analyze, and act on information.[86] To counter this, group or collaborative learning is increasingly used as a networked learning environment to enable students to work together on learning tasks.

Effective collaboration can create high levels of interdependence and ingenuity among group learners, and it allows enhanced learning not easily attained using other methods.[87] Companion et al[86] suggest that integrating simulation-based learning into the educational experience is crucial to further develop collaborative learning environments. Incorporation of networked VR-based simulations into the surgical curriculum would leverage the collaborative strength of the present team-based structure of most surgical residency and clerkship programs.

It has been reported that information management comprises 80% to 90% of a physician's daily workload.[88] Failure to adapt to the increasing dependence on information (of all kinds) would be a mistake. Use of the new technologies described in this article may help prevent such an outcome, in part, by enhancing the current educational process. In short, for reasons of educational quality, safety, and cost, simulation and VR can provide real value now, and their role will almost certainly expand as computer power and availability increase.

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The Effect of Raloxifene on Risk of Breast Cancer in Postmenopausal Women: Results From the MORE Randomized Trial

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Context: Raloxifene hydrochloride is a selective estrogen receptor modulator that has antiestrogenic effects on breast and endometrial tissue and estrogenic effects on bone, lipid metabolism, and blood clotting.
Objective: To determine whether women taking raloxifene have a lower risk of invasive breast cancer.
Design and Setting: The Multiple Outcomes of Raloxifene Evaluation (MORE), a multicenter, randomized, double-blind trial, in which women taking raloxifene or placebo were followed up for a median of 40 months (SD, 3 years), from 1994 through 1998, at 180 clinical centers composed of community settings and medical practices in 25 countries, mainly in the United States and Europe.
Participants: A total of 7705 postmenopausal women, younger than 81 (mean age, 66.5) years, with osteoporosis, defined by the presence of vertebral fractures or a femoral neck or spine T-score of at least 2.5 SDs below the mean for young healthy women. Almost all participants (96%) were white. Women who had a history of breast cancer or who were taking estrogen were excluded.
Intervention: Raloxifene, 60 mg, 2 tablets daily; or raloxifene, 60 mg, 1 tablet daily and 1 placebo tablet; or 2 placebo tablets.
Main Outcome Measures: New cases of breast cancer, confirmed by histopathology. Transvaginal ultrasonography was used to assess the endometrial effects of raloxifene in 1781 women. Deep vein thrombosis or pulmonary embolism were determined by chart review.
Results: Thirteen cases of breast cancer were confirmed among the 5129 women assigned to raloxifene vs 27 among the 2576 women assigned to placebo (relative risk [RR], 0.24; 95% confidence interval [CI], 0.13-0.44; $P<.001$). To prevent 1 case of breast cancer, 126 women would need to be treated. Raloxifene decreased the risk of estrogen receptor–positive breast cancer by 90% (RR, 0.10; 95% CI, 0.04-0.24), but not estrogen receptor–negative invasive breast cancer (RR, 0.88; 95% CI, 0.26-3.0). Raloxifene increased the risk of venous thromboembolic disease (RR, 3.1; 95% CI, 1.5-6.2), but did not increase the risk of endometrial cancer (RR, 0.8; 95% CI, 0.2-2.7).
Conclusion: Among postmenopausal women with osteoporosis, the risk of invasive breast cancer was decreased by 76% during 3 years of treatment with raloxifene. *(1999;281:2189-2197)* www.jama.com

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