The Future of Medical Education Is No Longer Blood and Guts, It Is Bits and Bytes

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In the United States, medical care consumes approximately $1.2 trillion annually (14% of the gross domestic product) and involves 250,000 physicians, almost 1 million nurses, and countless other providers. While the Information Age has changed virtually every other facet of our life, the education of these healthcare professionals, both present and future, is largely mired in the 100-year-old apprenticeship model best exemplified by the phase "see one, do one, teach one." Continuing medical education is even less advanced. While the half-life of medical information is less than 5 years, the average physician practices 30 years and the average nurse 40 years. Moreover, as medical care has become increasingly complex, medical error has become a substantial problem. The current convulsive climate in academic health centers provides an opportunity to rethink the way medical education is delivered across a continuum of professional lifetimes. If this is well executed, it will truly make medical education better, safer, and cheaper, and provide real benefits to patient care, with instantaneous access to learning modules. At the Center for Advanced Technology in Surgery at Stanford we envision this future: within the next 10 years we will select, train, credential, remediate, and recredential physicians and surgeons using simulation, virtual reality, and Web-based electronic learning. Future physicians will be able to rehearse an operation on a projectable palpable hologram derived from patient-specific data, and deliver the data set of that operation with robotic assistance the next day. ***Am J Surg.*** **2000;180:353–356. © 2000 by Excerpta Medica, Inc.**

The practice of surgery is a learned art, built upon a strong foundation of didactic learning, reading, observation, doing under guidance, and repetition. This apprenticeship model has changed little over the years. Surgical education today is carried out within the context of teams that comprise the surgical resident body of an organized residency program. Core surgical residencies in the United States (general surgery, orthopedics, otolaryngology, neurosurgery, and urology) consist of a minimum of 5 years of full time clinical training, with progressive responsibility as the years pass.

This time-honored model, which has successfully avoided significant evolution and innovation for the past 75 years, is now experiencing considerable strain. 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 impact of technology on our lives. It has been said that if advances in the automotive industry had kept pace with the computer industry, cars would cost $2 and would travel at the speed of sound on a thimbleful of gas.

HISTORICAL OVERVIEW

Prior to the 20th century, medical education in the United States was erratic and poorly regulated. Indeed, advanced surgical training was often obtained in Europe in the mid-nineteenth century.[1] The effects of ether anesthesia and aseptic techniques upon surgical practice radically increased the number of operations performed during the latter half of the nineteenth 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.[2,3]

The standard of training in the early 1900s across the country was weak. In 1912, the Committee on the Standardization of Surgery defined a "minimum standard of requirement . . . to perform independent operations."[4] With the development of specialty examining boards in the 1930s and 1940s,[5] interest in the analysis of surgical education outcomes increased. In 1934, the Committee on Graduate Training for Surgery began to develop criteria for graduate surgical training.[4]

Through this process, the traditional surgical teaching method that has developed is based upon the preceptor or apprenticeship model, in which the resident surgeon learns with small groups of peers and superiors, over time, in the course of patient care. Surgeons have always acquired most of their operative and judgment skills through "learning by doing."[6] Although an essential portion of surgical practice, the majority of technical skill instruction occurs through fairly unstructured operating room exposure.

The "learning by doing" approach, though, fails to provide skill acquisition in an organized fashion. Teaching opportunities are dependent upon the random flow of patients through the office, clinic, emergency unit, and op-

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erating room. The operating room itself 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."[7] However, the variability in patient flow results in significant unpredictability in the educational content provided to the trainees, and precludes any organized curriculum. The Holy Grail for the surgical education community would be a valid, reliable, and sensitive measuring system, easily administered, allowing for the preemptive evaluation of residency candidates, and providing analysis of a given resident's progress throughout his or her training.

With the laparoscopic revolution of the last decade and rapid structural and financial change within the American health care system, traditional educational methods in surgery have come under increasing scrutiny. Radical change in the "see one, do one, teach one" methodology of surgical education has been proposed by integrating skill laboratories and surgical trainers into the curriculum.[8]

Why are these issues important? Multiple external factors are exerting pressure upon 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.[9] Time in the operating room, the traditional learning ground for surgical residents, has become more precious and costly.[10] These economic changes have important secondary effects, such as shorter inpatient stays, further diminishing a traditional learning resource. Surgical residents thus take care of higher acuity inpatients,[11] which has the effect of hindering the educational process by decreasing the amount of time available for formal teaching.[5]

Recognizing these forces, several authors have suggested that the next step in surgical education is the adoption of advanced computer-based simulators for surgical education and training.[12] Bridges and Diamond[13] estimate that the annual cost of training chief residents in the operating room amounts to $53 million dollars a year (general surgery alone). They suggest that adjunctive training environments employing traditional and virtual teaching aids may serve to alleviate this cost over time. Over the last several years, many medical schools have begun to utilize computers in problem-based learning, thereby decreasing required faculty time. Results with this approach have been promising.[14] Studies in other specialties have shown that developing and measuring problem-solving skills with a computerized decision analysis model is feasible.[15] Further alternatives include distributed education via the Internet.[16]

ADULT EDUCATION

Over the last 2 decades, educational research has attempted to define the critical aspects of adult learning. Adults usually act as self-directed, internally motivated, and experienced students who seek specific knowledge in their chosen area of study.[17] An adult learns by doing, and is often most successful when the experience is self-directed.[18] Focused upon practical applications, the adult learner gains insight as information is placed within a contextual framework. In contrast, traditional medical training is rigidly structured, lecture-based, and focuses on the memorization of facts, leaving little room for self-directed education. Therefore, many medical schools have begun to change their curricula and have introduced principles of problem-based learning.[19] Within the last 10 years, these methods have been integrated into surgical education.[20]

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. From a functional standpoint, a good simulation represents simplified reality, free of the need to include every possible detail.[21] It is important to realize that simulations are not completely identical to actual events. Rather, an effective simulation places the learner in lifelike situations that provide real-time feedback on decisions, actions, and questions.[22]

Application areas for real time include training, testing, analysis, and research into and development of new products.[23] In addition to air and space flight training, training simulators for military and commercial vehicles, mechanical system maintenance, and nuclear power plant operation exist. 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).[23]

Simulation in medical education has been undertaken in a variety of settings. Paramedical personnel are taught triage and assessment skills with this technique, and ATLS and ACLS courses rely upon 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 they would not otherwise routinely experience, such as malignant hyperthermia, anaphylaxis, and cardiac ischemia.[24] Chopra and others showed that anesthesiologists trained on a "high-fidelity anesthesia simulator" responded more quickly and appropriately when handling crises on the simulator.

Further development of the simulation concept evolved out of recognition that two thirds of all incidents in anesthesia can be attributed to human error. To remedy this, Howard and others[25] developed a training program entitled Anesthesia Crisis Resource Management in order to optimize anesthesiologist and team performance during stressful incidents. Success in this arena has led to the use of mannequin-based simulators in surgery training as an alternative to "real" trauma resuscitations for teaching teamwork and crisis management skills.[26,27] The use of high-fidelity simulators to model variable human conditions may enable deliberate practice and help fill the void created by reduced attending teaching time and the relative scarcity of inpatients.[22]

VIRTUAL REALITY

While much has been made of virtual reality (VR) in the media, it is important to realize that it basically represents a unique interface to a variety of three-dimensional computer applications.[28] Virtual reality has been defined as a human-computer interface that simulates realistic environments while enabling participant interaction or as a three-dimensional digital world that accurately models actual environments.[29]

Virtual reality has been used in a variety of educational, training, and entertainment settings.[28] The highly visual and interactive nature of VR has proved to be useful in understanding complex three-dimensional structures and for training in visual-spatial tasks.[30] Recognition of this has led to increasing interest in developing virtual reality based applications for surgical education and training.

The concept of developing and integrating computer-based simulation and training aids for surgical skills education has begun with VR simulators. Interest in controlling training risk and cost through VR simulation has appealed to surgical educators,[10] but owing to the complexity of surgical procedures and the limitations of direct interaction with computer-generated images, surgical simulators of this nature have only recently become available. Such devices allow for the simulation of tasks on virtual tissues created by high-end graphics workstations. The manipulation is performed through haptic interfaces, thus allowing measurement of the trainee's performance through precise movement analysis. For the first time, objective data regarding motion, tissue tear forces, precision and error rates can be acquired and can be compiled into a "surgical report-card."[31]

TRAINING AND LEARNING APPLICATIONS

Virtual environments have been created and used in many areas of medicine. 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. Interest in simulated environments for surgical training is growing. Issenberg and others suggest that simulators are ideal for mastering techniques that demand repeated practice, and that their use should be considered before allowing trainees to perform invasive maneuvers on actual patients.[22]

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.[32] Tseng and coworkers have built a real time force feedback cholecystectomy simulator based on a personal computer,[33] and Tendick and others[34] have developed laparoscopic camera handling and cholecystectomy simulations based on a graphics workstation Initial validation studies using these and other simulators have shown differences between experienced and novice surgeons, improvement in training scores over time, and that simulator task performance is correlated to actual task performance.[35–37] O'Toole and others[31] have further demonstrated skill improvement and construct validity with a VR-based needle-driving simulator.

Not surprisingly, there is movement toward the development of Web-based surgical training and learning applications. El-Khalili and others[38] have demonstrated a Web-based surgical training system for abdominal aneurysm stent graft deployment. This unique system includes instructional Web pages and measuring and other rudimentary interactive tools to teach and simulate this complex procedure. Although the question of focusing on realism versus accuracy remains unanswered, this system demonstrates the feasibility of creating Web-based surgical training applications. CardioOp represents another Web-based surgical learning system. This environment allows for the flexible composition of multimedia fragments, enabling the reuse of various data sets to suit the needs of individual learners in cardiac surgery.[39]

CONCLUSION

The exact effect of simulation technology upon the surgical education process is impossible to predict, although evidence suggests positive outcomes will result. The adult learner succeeds by "doing," particularly when the experience is self-directed.[18] Focused upon practical applications, the adult learner gains insight if 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.[40,41] 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.

If one assumes that information management comprises a large portion of the physician's daily workload, failure to adapt to this increasing dependence on information (of all kinds) would be a mistake. Use of the new technologies described above 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 virtual reality can enhance surgical training and learning now, and its role will almost certainly expand as computer power and availability increase.

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