Medical Virtual Reality Simulation:

Enhancing Safety Through Practicing Medicine Without Patients

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In 1999, the Institute of Medicine issued a report, *To Err is Human*.[1] The major finding from that report was that medical errors contributed to as many as 98,000 deaths annually in U.S. hospitals. In a similar report, it was estimated that 1,700 deaths and 9,458 injuries could be attributed to nursing errors.[2] To put these numbers in perspective, in the same year that *To Err is Human* was issued, the U.S. Department of Transportation reported 41,611 highway fatalities and the National Transportation Safety Board reported only 12 fatalities on scheduled airline flights.[3,4] Although not everyone agrees on the magnitude of the mortality numbers, most everyone agrees that the problem is more serious than was previously estimated.[5]

Obviously, it has never been more important to identify and eliminate factors that contribute to error in medicine. One novel approach to this problem may lie with medical virtual reality (VR) simulators. Medical VR simulators provide computerized training on a variety of procedures and incorporate visual, auditory, and haptic displays.

There are many advantages to using simulators in general. They provide:

- an environment to observe specific skills in the absence of uncontrollable influences.
- immediate performance feedback.
- the opportunity to examine performance under conditions that would be too dangerous in actual operational settings.
- the opportunity to examine interactions with rare or infrequent conditions.
- a cost-effective alternative to traditional methods.

In medicine, more specifically, they offer the additional advantage of decreasing the dependence on animals to practice procedures.

Medical VR Simulators

Although medical simulation devices have been around since the 1940s, most of them have been little more than physical models with very limited functionality. In the 1980s, computer technology made it possible to display more dynamic information on computer screens. Since then, the development of medical simulators has diverged and followed two paths. One class of simulators that has emerged are mannequin-based and provide a physical model of the patient as well as physiological responses to treatments (see *BI&T*, Vol. 37, No. 5; p. 364).[6] The second class uses VR to simulate interactions with anatomy and physiology.[7] Many of the original VR systems were primarily novelties and research prototypes. The promise of viable commercial systems, however, seemed elusive because so many medical procedures require physicians to use their hands.

In the mid-1990s, that began to change. Systems started to appear that incorporated haptic devices.[8] The handles, grips, and controls of these devices are identical to the actual tools used by surgeons or medical practi-

As computer technology has revolutionized the provision of health care, it has the potential—indeed is on the threshold—of revolutionizing the means of acquiring skills necessary to safely and effectively provide such care. This second of two articles addressing the value of computer based simulation in enhancing patient safety, focuses on the almost uncanny simulation that provides visualization of internal structures and feedback from actions inherent in performing certain procedures.

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tioners, but the operational ends are encased in a housing and modified to interact with a force feedback system and the corresponding visual renderings. The end result is that the instruments "feel" like they are contacting, probing, and penetrating the organic structures users see on their screens.

The number and variety of medical VR systems currently available has increased dramatically over the last five years and several commercial systems are now available. For example, Mentice, Inc. offers several systems including the Procedicus® MIST system for training minimally invasive laparoscopic procedures. Systems by Immersion Medical, Inc. provide training in upper and lower endoscopy procedures including flexible sigmoidoscopy, colonoscopy biopsy, and colonoscopy basic polypectomy procedures. They also offer systems for endovascular access and vascular access including IV catheter insertion and phlebotomy. These systems allow trainees to practice the fundamental psychomotor skills necessary for more challenging procedures (e.g. laparoscopy). Other systems enable training on entire procedures and can provide the trainee with performance feedback in the form of numerous metrics such as angle of insertion, economy of movement, speed and force of actions taken, subjective pain experienced by the patient, procedure completion time, and degree of success for the entire procedure.

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Efficacy. Despite the rapid growth of this technology, the efficacy of these systems has yet to be established. To date, much of the data supporting the benefits of these systems have been gathered on the systems themselves. Although evaluations based on system generated metrics are valuable, they are limited. They can demonstrate improvement over time and in some cases, distinguish between expert and novice performers. However, such evaluations fall short of establishing that simulation-based training on medical VR systems facilitates performance where it counts most—with genuine patients.

One study designed to measure the effectiveness of simulator-based training with genuine patients was performed by Seymour and his colleagues using the Procedicus® MIST system by Mentice, Inc.[9] They had one group of surgical residents receive their standard programmatic training and then practice with the MIST VR system. These residents were compared to another group who received only the standard programmatic training. Afterward, all residents performed a laparoscopic cholecystectomy and were rated on their performance by more senior surgeons. The ratings for the residents who trained on the MIST VR system revealed that they performed more quickly and accurately than those in the other group. Their data provide initial evidence that training on a medical VR simulator can improve performance on procedures with genuine patients.

The practice of medicine. Establishing the effectiveness of VR medical simulators is necessary to take the science and practice of medicine to the next level. Once we know the degree to which time spent on simulators predicts performance with genuine patients, we can begin to study the science and practice of medicine in a safe, controlled environment. Just as flight simulators allow us to examine pilot performance under a wide variety of conditions, medical simulators will allow us to study physicians, surgeons, anesthesiologists, and other medical personnel under an unlimited array of contexts.

For example, consider shift work. Research has shown that the time of one's shift, the number of consecutive hours worked, the number of consecutive days on and off work, as well as the rotation schedule can all affect subjective levels of fatigue and worker performance.[10] Moreover, these effects are moderated by time of day, body temperature, and age. The effects of shift work and fatigue are complex and are not always negative. In a review of the literature on sleep deprivation and junior doctors, Spurgeon and Harrington found that motivation was a key factor in maintaining performance;[11] however, these data were gathered from subjective impressions. More recently, Taffinder and his colleagues reported that errors and completion times increased on a laparoscopic simulator with increases in sleep deprivation.[12]

At present, objective data regarding the effects of shift work, fatigue, and sleep deprivation on surgical performance obtained in a controlled laboratory environment are still scarce. The effects of workload and other sources of stress and how they interact with psychomotor and cognitive task complexity have yet to be studied. More important, research on potential moderating factors and countermeasures need to be addressed as well.

Virtual reality and prototyping. Not only does medical VR simulation technology allow us to examine the conditions that affect the practice of medicine, it can also help us identify alternative and more efficient device designs. For example, MacKenzie, Lomax and Ibbotson have reported on the numerous challenges faced by surgeons who perform laparoscopic or minimally invasive procedures.[13] In laparoscopic surgery, instruments and a miniature video camera are inserted through small incisions in the patient's body. As such, they do not permit full range of movement. Further, the surgeon monitors performance of the procedure on a video screen mounted above the patient, not by looking at his or her hands. Also, the shafts of the instruments form a fulcrum at the point of incision where they rest and pivot. Thus, the surgeon must overcome the fulcrum effects of the instruments and the camera. Last, the shoulder, arm, and hand positions as well as the overall body posture needed to perform minimally invasive procedures can produce fatigue very quickly.[14] Medical VR simulators can provide a quick and efficient means for testing and evaluating alternative ergonomic designs to improve minimally invasive surgery without the need to study the surgeon in the operating room or to put patients at risk. In fact, Noakes and Dixon have used this approach to design a workstation to facilitate minimally invasive and robotic surgery.[15]

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Medical VR simulators typically simulate the area of the body where the surgeon operates; VR technology can also be used to simulate the environment in which the surgeon operates. In fact, the use of virtual environments affords the opportunity to observe both individuals and teams of health care providers interacting with virtual patients. Further, VR can be used to simulate the tools, equipment, and devices within the operating environment. For example, mannequin-based simulators can be incorporated into fully immersive virtual environments making it possible to train individuals or teams to perform procedures under a variety of conditions. These can include the urgent and stressful conditions often present in emergency rooms; however, they are not limited to the emergency room. They can also include field environments typically encountered by emergency first responders, paramedics, or even military medics out in the battlefield. Moreover, in a virtual environment not all team members need be present. Virtual intelligent agents can simulate the role of the nurses, anesthesiologists, or senior physicians in the way that telemedicine is used today.

In addition, VR is not restricted to current technology. VR opens up the possibility to design and evaluate medical equipment and technology within the context it will be used before it is actually created. Thus, the interfaces for typical medical devices (e.g., for x-ray, ultrasound, and physiological recording systems, etc.) can be simulated allowing them to be tested under a variety of environments and conditions. Moreover, the same rapid prototyping methods that are typically employed to study user interaction with mock-ups of individual devices can also be applied in immersive environments to examine the interactions of multiple users with the full complement of emergency/operating room equipment. Thus, VR technology enables sources of errors related to both training and equipment design to be identified and addressed simultaneously.

Research currently under way at the National Center for Collaboration in Medical Modeling and Simulation is aimed at addressing this broad range of uses for simulation technology.[16] Several medical VR simulators have been incorporated into the curricula of a number of courses at Eastern Virginia Medical School in Norfolk, VA, and performance on the simulators is being compared to traditional forms of instruction and assessed with genuine patients. In addition, simulation technology is being used to examine the efficacy of medical training as well as instrument design for use in unique environments and contexts.

Conclusion

Medical VR simulation technology is likely to have a profound impact not only on the way medicine is taught, but also on the design and development of medical devices. There are increasing pressures to train physicians and surgeons to higher levels of competency in shorter periods of time while simultaneously improving safety.[17]

In fact, the American College of Surgeons is currently considering how simulators might be used to screen potential surgeons, provide initial and ongoing training of surgeons, and enable periodic assessment of surgical skills.[18]

Medical VR simulators offer the opportunity to structure training to provide more efficient skill acquisition and assess performance with standardized metrics. Instructors can establish objective criteria and students and residents can train to meet those criteria. Thus, the potential for error can be addressed before procedures are attempted with actual patients. Moreover, the ability to couple plug-in computer peripherals with simulation modules accessible over the Internet will afford any student, resident, or practicing physician access to training 24 hours a day, seven days a week.

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Although medical VR simulators hold much promise, one should not view this technology as a panacea. Simulators are unlikely to ever replace traditional "apprenticeship" training in medicine.

First, the simulations available today address only a small fraction of those medical or surgical procedures for which even a first or second year resident would be exposed. Further, most of the current simulators are geared toward training basic skills. They do not address the needs of practicing physicians, surgeons, or even more senior residents. In addition, many do not incorporate a representative range of procedural complications or patient characteristics and histories. Creating a virtual environment to evaluate individual or team performance is still expensive and may not be a cost-effective approach.

Last, no virtual simulation can substitute for the unique experience of manipulating the anatomy and physiology of another human being under the careful guidance of a more experienced physician. Medical VR simulation technology is simply another tool that can be used to help make the practice of medicine safer, but it is a powerful tool whose time has come. ■

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