Virtual Reality in Surgical Training

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Abstract

Virtual reality promises to change the world of surgical training and practice. Just as flight simulators revolutionized pilot training, human simulators will become the medical classrooms of the future. Surgeons will be able to train on simulated human models, perfecting their techniques without even entering an operating room. Recent advances in computer technology have placed these exciting ideas within our reach.

“Virtual reality is the ultimate surgical simulator.”
– Dr. Robert Mann, 1991.

Introduction

Despite what many believe, “virtual reality” is not new. In fact, it dates back more than 35 years. In 1960 Morton Heilig patented an invention called the “Sensorama Simulator,” which was the first virtual reality video arcade machine. His system provided 3-D video (obtained through a pair of side-by-side 35mm cameras), motion, color, stereo sound, aromas, and a vibrating seat. Building on this, Robert Mann proposed the first medical virtual reality (VR) system in 1965 (Mann, 1965). His specific vision was to develop a rehabilitation application for virtual reality. The system he had in mind would allow the surgeon to try multiple surgical approaches for a given orthopedic problem. Then, in the virtual environment, the clock could be accelerated to predict the future outcome of the different surgical approaches. In effect the patient could leave the operating table, go through rehabilitation, and then return for outcome evaluation in the span of a minute or two. Thus, the surgeon could choose the best approach to the real operation. This approach, however, requires the model to be not only patient-specific but also provide an accurate representation of the deformity and its response to treatment over time. Despite its early stage this system identified three major benefits to surgical training: (1) It could be customized to the needs of the student; (2) the variety of the cases encountered during training increased significantly; and (3) the student could train on the most difficult parts of the surgery and repeat them as often as necessary. This would be much more time-efficient (comparable to just training take-off and landing on a flight-simulator). Such efficiency is the ultimate 21st century goal for a virtual reality system in medicine.

In the early years of medicine, the young physician was akin to an apprentice, learning a trade from a single master. Although developments in medical technology and surgical technique have inspired major breakthroughs in the last couple of decades, the manner in which we *train* surgical staff has undergone very little change. The contemporary junior surgeon develops his skill through literature, textbooks, lectures, observation, and ultimately by performing the procedure under the supervision of an experienced surgeon. Due to the nature of this progression, the quality of education is still quite unpredictable and mainly depends on the instructor and the particular cases to which the surgeon is exposed during his or her training. There are studies showing that the outcome of surgery is significantly worse on the first procedures performed by an inexperienced surgeon (Davies & Campbell, 1995). The management of many of the complications and variations which arise during a procedure cannot presently be taught as this would put the patients at an unacceptable risk (Bowen, 1999).

The need for a comparable assessment of the physician’s abilities and competence predicates even more problems, especially in surgical education. The typical surgeon gets certified by passing the Board Examination, which usually consists of a multiple-choice test and an oral examination. These two forms of assessment alone give an inadequate picture of the physician’s abilities. Standardized patients, first described by Barrows and Abrahamson (Barrows, 1964) have been added, leading to the so-called multi-station examination standardized patients (MSESP) and objectively structured clinical examinations (OSCE) (Harden, 1979). Nonetheless, these tools are still rather inadequate for certification and qualification in light of emerging new technologies in surgery like the introduction of laparoscopic techniques or microsurgery using laser-technology and surgical microscopes. Moreover, computer-assisted procedures like those involving fast-improving diagnostic and imaging tools and surgical robots require a high degree of technological proficiency. This simply cannot be tested by a multiple-choice exam or an oral examination.

A virtual reality surgical simulator could offer the possibility of having the surgical resident of the future perfect a procedure without harming a patient, learning surgical anatomy and repeatedly practicing technique prior to performing surgery on the actual patient. This would translate into a very objective exam for certification using the exact same machines.

Virtual Human: From Generic to Patient-Specific Models

To reach the goal of a truly realistic virtual human it is necessary to provide a test as a milestone for achievement. Fifty years ago Dr. Alan Turing devised a standard test called the Turing Test meant to determine if a computer could be created that responds the way a human would respond to a number of questions asked by a person interrogating both the computer and a human. If the human interrogator could not distinguish between the answers of the computer and the human, then the Turing Test parameters would be met (Bleich & Turing, 1995; Heiser, *et al.*, 1979; Turing, 1995). A virtual reality Turing Test would do the same in regard to a human interacting in a multidimensional way with both a virtual human and a real human. In other words, if the interrogating human could not tell the virtual human apart from the real human by sight, hearing, touch or feel—even dissection—then the parameters of the test would be met. We have a long way to go before we meet these goals with our present day virtual humans, interactive tools, and surgical simulation systems, but the Turing Test offers a reasonable means of assessment for the progress ahead.

In addressing the complex challenge of creating an accurate human model, most labs and research groups choose to focus on a specific system or part of the human body, i.e. skeletal biomechanics or the gastrointestinal pathway. Chen and Zeltzer presented a method that combines realistic computer animation and valid biomechanical simulation of muscle (Chen & Zeltzer, 1992). Taking human animation beyond simulating the surface geometry of skin, Chen models individual muscles. For instance, using computer reconstructed three-dimensional images from CT, MRI data, and the Swivel 3-D Professional Modeling Program, a polyhedral model of the human calf muscle (gastrocnemius) was constructed using the finite element method. By developing a model with the capacity to simulate actual muscle force and visualizing the dynamics of muscle contraction, Chen has created an animated image that changes shape accurately and realistically.

In a similar biomechanical project, McKenna has developed a system to simulate "complex human kinematics" (McKenna). His model of the human figure contains a total of 90 degrees of freedom with 28 degrees of freedom in each foot. It incorporates anatomical diagrams, a three-dimensional digitized skeleton, and biomechanical clinic and cadaver studies of limbs and joints. Simulated actions include walking, falling, reaching, standing on toes and rising from the knees, all under real gravitational constraints.

Satava has likewise created a "virtual abdomen" to teach medical students specific anatomic details of the abdominal organs and to instruct surgical residents in technique and operative procedure (Satava, 1993; 1994; 1995a). This computer model allows the viewer to see the anatomy from both outside the organs, as in a traditional open laparotomy, and inside the organs in a "fly-through" mode, as in an endoscopy. There are also laparoscopic tools in the mode, to perform simulated minimally invasive surgery.

Even with the new sophisticated tools used in surgical planning, a link to actual surgery has not yet been developed. When it comes to the operating room, the surgeon puts most of the newfangled tools away. There are already systems available that allow surgeons to superimpose the imaging data used during the planning-period onto the real-time pictures of a laparoscopic surgery or onto the view seen through a surgical microscope. This is called *datafusion*. A goal for the next forty years would be to enhance these first systems to such an extent that there would be no difference between the planning or training period and the actual surgery. Then the vision Dr. Mann had 30 years ago would become reality and the criterion of the Turing Test would be met.

Complete Systems: From Simulators to Telesurgical Performance Machines

With the beginning of the twentieth century, flight simulators were introduced and soon became a proven means of training pilots in complex maneuvers (Haber, 1986; Rolfe & Staples, 1986). Flight simulators provide an environment for learning and instruction, a tool for prediction, and an aid for experimentation. Their advantages include decreased costs and increased safety compared to real flight experience. The first simulators provided only a very vague representation of reality, using vector graphics without any texture and a very low number of picture-frames per minute. But with advancements in computer technology, these simulators have become a good deal more complex and realistic. So much so that telling the difference between reality and simulation is sometimes impossible.

For the most part, the advantages of flight simulators hold equally true for surgical simulation (Satava, 1995a; 1995b; 1995c; 1997). Surgical simulators provide a concentrated environment that lends itself to learning complex tactile maneuvers in a relatively quick and proficient manner. Moreover, simulation of infrequent but highly hazardous events provides experience in handling these scenarios that may not be available during a period of routine flight or surgical training.

Like flight simulation, surgical simulators allow the user to train to perform a complex task using an interactive computer environment. Over the last century, this interactive environment has progressed from a two-dimensional screen (i.e. photographs and radiographs) to a three-dimensional virtual reality. Two-dimensional sources of data were initially modified by hand using drafting tools. This two-dimensional data was subsequently introduced to a computer in order to facilitate manipulation and give the surgeon the ability to better plan and demonstrate the outcome of the proposed procedure. More recently, volumetric data obtained from computer-aided scans have provided three-dimensional information for the surgeon to assist in planning complex operations. Using a computer simulator for planning, a surgeon may "try out" many possible reconstructions on a patient-specific model prior to operating.

Surgical simulators consist of three basic components similar to those of a flight simulator: the computer, the interface, and the physical model. The physical model for the surgical simulator is a realistic computational representation of the patient, the operating room, and the surgical instruments (Foley, 1987; Pinciroli & Valenza, 1995; Sturmin, *et al*., 1989). The interface uses either a mouse or glove so the user can manipulate surgical instruments three-dimensionally, and it uses internal motors to give the user a sensation of force-feedback. Through this feature, the user can move a "scalpel" into the virtual tissue and actually feel its resistance, all simulated according to real patient information.

Medical Media Systems (West Lebanon, NH) has developed a prototype performance machine for computer-aided arthroscopic surgery of the knee. In this system, previously obtained MRI data of the knee is reformatted into a 3-D virtual model and superimposed on a patient's limb in the operating room. Co-registration of these two data sets allows the surgeon to compare the detailed, but narrow, arthroscopic view with the wide-angle, but low resolution, MRI data. Electromagnetic or infrared tracking is used to register instruments in the virtual model. This system uses patient-specific data, so the surgeon can plan the operation and set landmarks on the computer model. In the same manner, the surgeon is able to measure the length of the prospective anterior cruciate ligament (ACL) graft. Optimal placement of the graft using computer calculations helps to achieve isometry and to improve the outcome. Furthermore, it has been shown that using the same model during the actual operation shortens the operation time (Rosen & Robbie, 1998).

Conclusions

Because the systems for virtual reality are improving so rapidly and because this new technology is quickly moving into the operating room, we must reassess the role of VR in surgical training and planning. The systems and possibilities discussed above are only the beginnings of fascinating future technology and its potential use in medicine.

As indicated, the biggest hurdle we face today is designing an improved model of the human body for VR surgery. Further work also needs to be done on the tools used to interact with this model. One must realize, however, that many fields are developing the ideas relative to a simulated, realistic human. Despite its centrality in the medical field, the virtual human has practical applications in areas like transportation for crash testing, the military for ballistics research on tissue injury, and commerce for ergonometric design studies.

One of the key lessons to be learned is that while virtual reality will enhance training, it will not replace the existing methodology. A considered integration of the two, however, will inevitably require that we redefine the idea of what constitutes a complete medical education. Even though years of experience have proven that most aspects of surgical training can only be learned by exposure to real patients in real physical environments, there are other things that can be more easily learned on VR simulators available today, such as perfecting manual skills and treating rare disorders. Furthermore the VR systems introduce the alluring possibility of a completely objective measurement and assessment of the trainee's ability. An optimal perspective will balance the two training platforms (See Table 1).

For more advanced tasks, a robust model of the human body is needed to aid in the planning of surgery. From the leaf template for forehead-flap nasal reconstruction employed by Indian surgeons to plastic templates milled from CT scan reconstructions, all may be regarded as an attempt to "simulate" the operation in a medium other than the patient. More work is needed to refine this particular computer model and validate its results. The future will have computers not only involved in the training of surgeons, but also in the planning of surgery and the aiding of performance in the operating room. Ultimately the acceptance of these simulators and trainers depends heavily on the realism of the virtual human body models on which they are based. These models will need to be multi-dimensional, specific, and temporal, accurately predict-

Feature	Benefit
1) Real-time display of 3D human anatomy	2) Allows students to learn the spatial relationships of human anatomy. 3) Students learn wound management skills on human anatomy. 4) Optimizes the use of cadavers and laboratory animals.
5) Virtual surgical tools, including forceps, hemostats, and intravenous (IV) catheters.	6) Lets students interact with the 3D anatomical models in a realistic manner.
7) Physiological modeling (e.g., bleeding and tissue deformation)	8) Adds realism and sense of urgency to the simulation.
9) Repeated training and rehearsal	10) Teaches the student the requisite skills needed to treat medical problems - including time management and hand-eye coordination skills - in a self-paced environment.
11) Force feedback	12) Lets students feel the anatomy and develop manual skills prior to actual patients.

Table 1: This chart outlines the proposed features and subsequent benefits of a simulated surgical system used as a virtual training tool.

ing the outcomes of surgery and the healing process over time as first suggested by Dr. Robert Mann over thirty years ago.

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Acknowledgments

I would like to thank Dr. Joseph Rosen, MD, and Tim Lange, 4th year medical students who acted as advisors for the paper.

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