EDITORIAL

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# Surgical Simulation and Virtual Reality: The Coming Revolution

In the past decade, the world has accelerated its transition from the Industrial Age to the Information Age. Around your office or home, this revolution is apparent everywhere, from your digital watch to your personal computer, in the video games that your children (or you) play, and the enormous control that computers exert on utilities, transportation, banking and finance, and news and information. The relentless pace has, thus far, validated "Moore's Law" first described by Intel Corporations cofounder Gordon Moore, who observed that the power of computer chips doubles every 18 to 24 months. Randall Tobias, former vice-president of ATT, put it this way: "Over the last 30 years, we have seen a 3,000-fold improvement in computing power. If we had had similar progress in the automotive industry, a Lexus would cost $2., it would travel at the speed of sound, and go 600 miles on a thimble full of gas."

In many aspects of life, computing power has been used beyond operations and computations, to run complex simulations and to create interactive virtual worlds. Predicting consumer behavior is currently being tackled by creating a data base of virtual people as unpredictable as real people.[1] Virtual shopping has the potential to transform the retail world.[2] The U. S. Department of Defense has determined, based on extensive experience, that combat soldiers who survive their first 10 combat experiences have a 95% likelihood of surviving any further encounter. Thus, the military uses simulated or virtual reality combat training to produce those first 10 combat experiences in a nonlethal environment. The aviation industry has achieved an impressive safety record through a process of standardized education, repetitive practice, and frequent proficiency testing using aircraft simulators.[3] Visualization software enables potential customers to operate an overhead crane in a virtual steel mill, or judge the ergonomics of a proposed front-end loader.[4] While far from perfect,[5] the progress has been substantial and the pace relentless.

This same progress, so evident elsewhere in the world, has been less rapidly adopted in medical practice and education. The convulsive transformation of medicine from the rules of a cottage industry to those of a trillion-dollar business will, however, force similar applications. Beyond the simple computerization of medical records, information technology can and will be applied to the practice of medicine and surgery and our educational programs.

In a landmark paper in this issue of **Annals of Surgery**, Marescaux and colleagues, a unique collaborative group of surgeons and computer scientists, present their work on the application of virtual reality to hepatic surgery and simulation.[6] The Revolution is here.

These authors make a compelling case for the use of virtual reality, a unique form of computer-driven simulation, for surgical education, preoperative planning and practice, and the possibility that such information might ultimately be optimized and then delivered with robotic assistance. Each of these points are unique and worth considering individually, but first a few definitions are in order. *Simulation* can be defined as a device or exercise that enables the participant to reproduce or represent, under test conditions, phenomena that are likely to occur in actual performance. There must be sufficient realism to suspend the disbelief of the participant. *Virtual reality* is an advanced human-computer interface that goes far beyond existing interfaces (e.g., a keyboard, mouse, or joy stick). Virtual reality implies a three-dimensional computer-generated world that mimics the real world and allows participants to interact with and navigate it, using components of their five senses in real time, and become immersed. *Haptics* is the study of the psychomotor experience of touch, and is an essential component if a meaningful surgical experience is to be created.

## PREOPERATIVE PLANNING

The authors have incorporated a three-dimensional reconstruction of the sliced image data from the Visible Human project, sponsored by the National Library of Medicine. This project created the one-millimeter sectional anatomy used to build the three-dimensional liver model, and demonstrates the power of the Visible Human project. Using simultaneous processing and graphics workstations (currents costs: less than $100,000.), a projectable liver surface model was created as a wire-mesh construct. Photographs taken during laparoscopic procedures were then "texture mapped" over this surface to create a model that has the visible and haptic characteristics of the liver, and is interactively palpable using a commercially available force feedback device, the Impulse Engine.

Such a reconstruction is a formidable task, but the authors have demonstrated the ability to move from the total-body data set of the Visible Human to a specific organ construction—the first step toward building other interactive surgical models. Using novel mathematic simplifications, a palpable and deformable organ has been created. Historically, it has been said that any computer-generated virtual world can possess any two of three properties: good, fast, and cheap. Marescaux and colleagues have demonstrated that all three are possible! In addition, they have thoughtfully constructed a model which allows for the insertion of tumor masses, creating novel educational opportunities.

## PREOPERATIVE SURGICAL PRACTICE

Preoperative surgical planning has changed enormously, as imaging technology has advanced; intraoperative imaging has also refined planning. Heretofore, however, the ability to practice a surgical procedure preoperatively has been inconceivable. This report demonstrates that this is now possible, which suggests that a surgical procedure could be practiced on an individual patient's specific data. Put another way, Mrs. Smith's liver tumor could be virtually resected the night before her operation, based on her CT scan. While historically many surgical procedures were devised and practiced on animals before human application, virtual reality reconstruction theoretically allows totally patient-specific practice.

Of the five senses, the sense of touch is unique because it is interactive. When one looks at an object, the object does not look back, but when one lifts an object, an interaction immediately begins: the object is lifted with muscular force in direct proportion to the mass of the object and our intent. Thus, a five-pound object is lifted with a far different force than one would apply to a 50-pound object.

Using a commercially available force feedback device, the Impulse Engine, which is used to simulate laparoscopic surgery, a palpable surgical manipulation is now possible. Real-time deformation is perceived in a surgical range of forces (25 g/meter with maximal forces of 8.9 Newtons), collision detection is done at the point of the tool, and deformation and resistance are updated 1,000 times per second for the force feedback and 50 images per second for the visual display. *This represents true, real-time surgical virtual reality.* The implications of this technology are enormous. Heretofore, our surgical education, at all levels, has remained locked in the age-old apprenticeship model, best described as "see one, do one, teach one." What this report suggests is the evolution of a surgical procedure curriculum. Basic surgical skills could be learned in a systematic and logical fashion by *doing*, and a student's or resident's proficiency could be safely assessed and demonstrated. Only after a demonstration of such skill and proficiency would those skills then be refined in the operating room. Such a concept has real potential for providing more effective, less expensive, and safer surgical education.

## ROBOTIC ASSISTANCE

The third essential point that Marescaux and colleagues make is the ingenious and innovative suggestion that a pre-practiced surgical procedure might then be optimized as a stored data set of movements and replicated intraoperatively with robotic assistance. Consider the analogy of making a movie: in the film industry, the participants perform a given scene and repeat it until the director is satisfied; many scenes are then spliced together, edited, and optimized to produce the movie the director envisioned. Looking ahead with this technology, a surgical procedure could be rehearsed and stored as a computer data set. This data set could then be optimized, false moves eliminated, and the perfect surgical procedure delivered by computer-driven and -enhanced robotic arms. This is a bold projection, but it is by no means ludicrous—consider the current availability of the voice-controlled robotic arm to control the video camera during laparoscopic surgery.

Interest in the use of virtual reality in medicine in the United States has been supported by the Advanced Research Projects Agencies (ARPA) of the Department of Defense and championed by its former director, Col. Richard Satava, MD, now a professor of surgery at Yale. The annual Medicine Meets Virtual Reality Congress and Surgical Robotics Congresses, and the Technology Demonstration at this year's Clinical Congress of the American College of Surgeons, sponsored by the Committee on Emerging Surgical Technologies and Education, are clear evidence that the technology is compelling. The field of anesthesia[7] has been an important early adopter in crisis resource management; basic science curricula have also considered virtual reality methodology.[8] It is important to remember that all of these early efforts are very much the equivalent of the "Model T" of the automobiles that we take for granted today.

Where will this all go? Dr. Harold Varmus, NIH Director, has announced plans to direct increased support toward accelerating bioengineering research.[9] It seems clear that unique partnerships between surgeons, engineers, and computer scientists, like the Marescaux group, will be needed to drive this field in the most appropriate and useful direction, and to demonstrate educational validity. It does seem likely that future generations of surgeons will be selected, trained, credentialed, and recredentialed using simulation and virtual reality devices like the one discussed here and others yet to be developed. The mantra of the Information Age as it applies to surgery is probably best stated by Col. Satava: "It's no longer blood and guts, it's bits and bytes."

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## References

1. Playing the game of life. Forbes Magazine. April 7, 1997.
2. Burke RR. Virtual shopping: breakthrough and marketing research. Harvard Business Review. March-April 1996.
3. Lessons Learned. Army devises system to decide what does, and does not, work: the real value of experience. Wall Street Journal. May 23, 1997.
4. Dvorak P. Engineering puts virtual reality to work. Machine Design. February 20, 1997.
5. Still a virtual reality. The Economist. October 12, 1996.
6. Marescaux J, Clément J-M, Tassetti V, Koehl C, Cotin S, Russier Y, Mutter D, Delingette H, Ayache N. Virtual reality applied to hepatic surgery simulation: the next revolution. Ann Surg 1998; 228:627–634.
7. Burt DER. Virtual reality in anaesthesia. Br J Anaesth 1997; 75:472–480.
8. Hoffman H, Vu D. Virtual reality: teaching tool of the twenty-first century? Academic Medicine 1997; 72:1076–1081.
9. Agnew B. NIH plans bioengineering initiative. NIH 1998; 280:1516–1518.