

# Current and Future Applications of Virtual Reality for Medicine

RICHARD M. SATAVA, ASSOCIATE MEMBER, IEEE, AND SHAUN B. JONES

## *Invited Paper*

*Virtual reality is just emerging as an accepted scientific discipline for medicine. The majority of near-term applications are in the area of surgical planning, intraoperative navigation, and surgical simulations. Its use in rehabilitative medicine and psychiatry has made significant progress. The immediate future holds promise for virtual endoscopy, which may replace standard endoscopic procedures for diagnostic screening. Viewing of these virtual images may be with head-mounted displays or true suspended holograms.*

*The most highly developed area is in surgical simulations. Current generations are approaching photorealistic representation of the anatomy, while measurement science is providing physical tissue properties and physiologic parameters. The types of simulations range from "needle-based" procedures, such as standard intravenous insertion, central venous placement catheter, and chest-tube insertion to more sophisticated simulations of full surgical procedures like laparoscopic cholecystectomy or hysteroscopic resection of interuterine myoma. In addition, haptic input devices are providing the sense of touch to the procedures. Soon there will be patient-specific models derived from computed tomography or magnetic resonance imaging scans that will permit a surgeon to practice a delicate surgical procedure on the patient's specific virtual anatomy before actually performing the procedure on the patient. These applications will afford the surgeon the opportunity to provide the highest surgical care possible through the use of advanced technologies.*

**Keywords**—*Endoscopy, surgical education, surgical simulation, virtual reality.*

We are now entering the second decade of practical implementation of virtual reality. The original research involved three-dimensional (3-D) scientific visualization in aerospace, geological survey, computer-aided design/manufacturing, transportation, and other nonmedical

fields. As computer power and the level of visual realism increases, there are more applications relevant to the medical profession. While not comprehensive, herein is contained a survey of representative applications, many of which were initiated for military medical applications for combat casualty care but have now migrated into civilian applications. The thread that ties these seemingly unrelated applications is the ability to represent a person as a 3-D data set, epitomized by the accomplishments of the Visible Human Project (discussed below). In accepting such a 3-D image as a representation of the real person (a "medical avatar"), there are enabled new applications in the areas of education and training (simulators), certification (simulators), and diagnosis (virtual endoscopy). Thus, those technologies that enhance the realism [visual, acoustic, and haptic (sense of touch)] of a simulation are in the direct pathway to new products in the twenty-first century. Problems that require solution to realize a fully interactive clinical system include real-time 3-D segmentation, registration, image fusion, image enhancement with digital signal processing, massive data base transmission (codec) and storage, and intuitive interfaces to interact with the data.

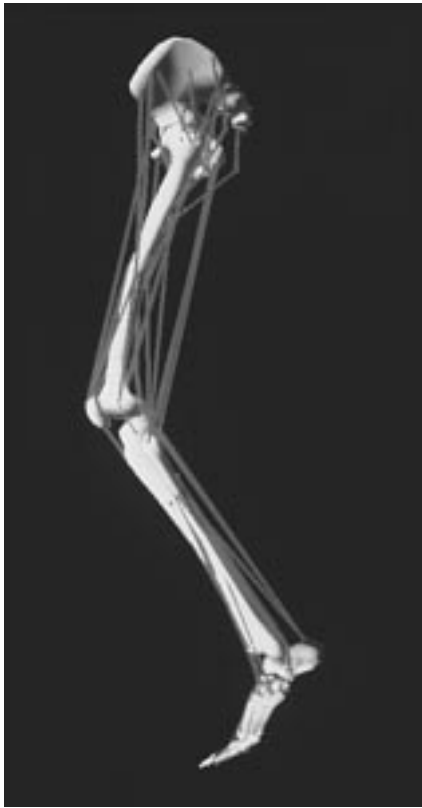
Out of the scientific accomplishments of flight simulators and 3-D graphics visualization, virtual reality for surgical simulation and medical training began in the late 1980's. Delp and Rosen [1] created one of the first virtual-reality systems to investigate alternative surgical procedures (tendon transplants) of the lower leg (Fig. 1). In 1991, Satava [2] created the first abdominal-surgery simulator, using images of organs created in a simple graphics drawing program (Fig. 2). They were neither realistic nor highly interactive, but the simulator provided the opportunity to fly around and through the anatomy and to "practice" a surgical procedure with virtual instruments. Within 18 months, Merrill [3] of High Techsplinations created a highly sophisticated graphic representation of the human torso, with organs that simulated physical properties such as bending or stretching when pushed and pulled or edges

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R. M. Satava is with the Department of Surgery, Yale University School of Medicine, New Haven, CT 06510 USA and the Advanced Biomedical Technology Program, Defense Advanced Research Projects Agency, Arlington, VA 22225 USA (e-mail: richard.satava@yale.edu).

S. B. Jones is with the Uniformed Services University of the Health Sciences, Bethesda, MD 20814 USA and the Advanced Biotechnology Program, Defense Advanced Research Projects Agency, Arlington, VA 22225 USA.

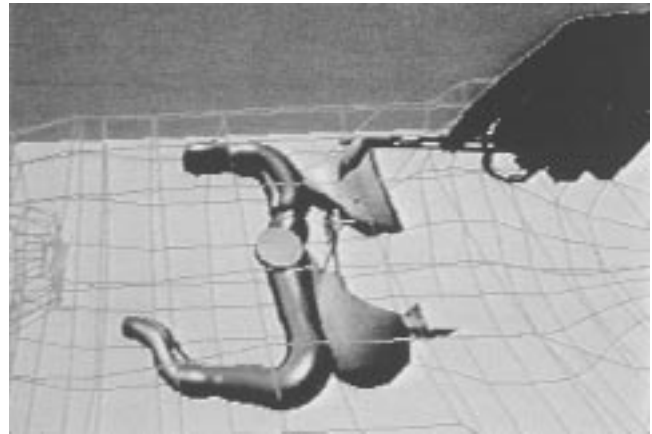
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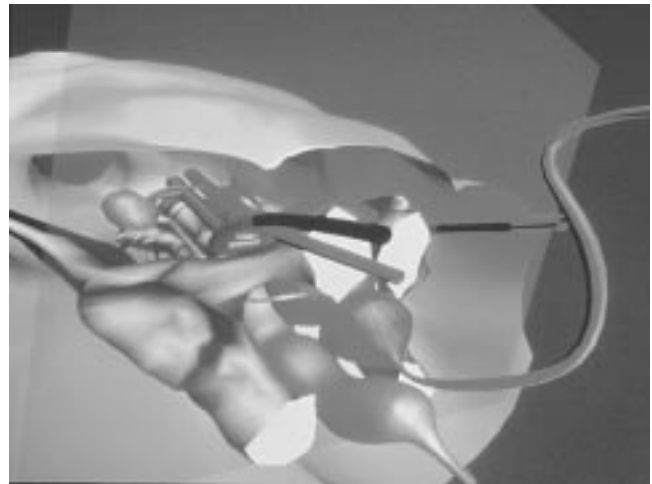
**Fig. 1.** Lower limb simulator to evaluate tendon transplant. (Courtesy of Dr. S. Delp and J. Rosen, MusculoGraphics, Inc., Evanston, IL.)

retracting when cut (Fig. 3). The landmark event was the 1994 release of the National Library of Medicine's "Visible Human" project under Dr. M. Ackerman, which provided images that were reconstructed from an actual person's data set. The virtual cadaver was created by Spitzer and Whitlock [4] of the University of Colorado from 1871 slices, 1 mm in thickness, that had been digitized and stored in the computer. In rendering the images, there was near photorealism (Fig. 4); however, there were no properties because the entire power of the computer was used in portraying the image. Later that same year, Delp [5] used the Visible Human leg to create a "Limb Trauma Simulator" (Fig. 5). The image did not look as realistic as the Visible Human because so much computer power was used for the tissue properties, bleeding, wounding, and instrument interaction that a less realistic visual image resulted. However, this model permitted debridement of the wound, removal of bone fragments, and stopping of hemorrhage. The purpose of this simulator is to decrease the number of animals that need to be wounded in order to train physicians and medics in the essentials of combat casualty care and trauma management.

In 1995, Dr. J. Levy constructed a surgical simulator for hysteroscopy. This system incorporated a simple haptic device for the hysteroscopic instruments and imported patient-specific anatomy and pathology. Now for the first time, surgeons could practice on exactly the same virtual



**Fig. 2.** Early surgical simulation of the abdomen using simple graphics drawing programs.

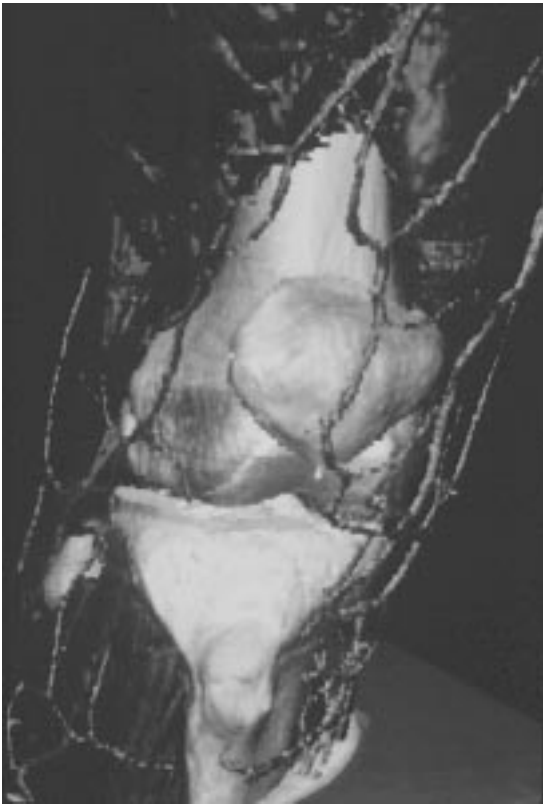


**Fig. 3.** Improved graphic rendering of human torso, which includes organ properties. (Courtesy of J. Merril, High Techsplana-tions, Inc., Rockville, MD.)

pathology that they would encounter in their patient. When the anatomy is not extremely complex, a near photorealistic image with full tissue properties and haptic input can be achieved, such as the central venous catheter placement simulator (Fig. 6) by Higgins [6] of HT Medical, Inc. In 1996, Boston Dynamics, Inc. [7] introduced their task-oriented surgical simulator with high-fidelity haptics with the Phantom Haptic Device, focusing upon individual tasks such as anastomoses, ligating and dividing, etc. rather than full procedures. And within the field of catheter-based endovascular therapy, simulators of catheter systems with balloon angioplasty and stent placement are being developed (Fig. 7).

There are four levels of simulators, and it is now time to begin implementing the simulators based upon matching capabilities of the simulators to the educational curriculum. The levels are:

- 1) needle-type simulators, as in spinal tap, intravenous needle insertion, central venous catheter placement,



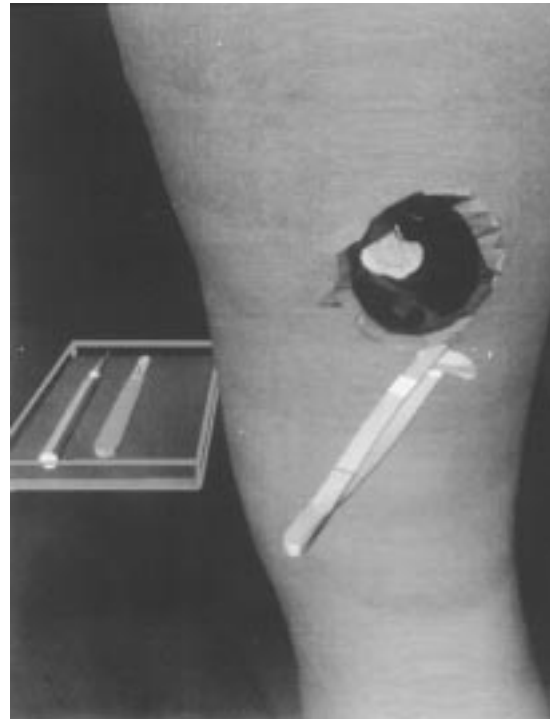
**Fig. 4.** The Visible Human Project: Full high resolution of the knee derived from actual patient data. (Courtesy of Dr. V. Spitzer, University of Colorado School of Medicine, Denver.)

liver biopsy, etc., which have simple visual objects and minimal axis of a single haptic device;

- 2) catheter/scope type, in which the view on the video monitor will change in relation to movement of a control handle (in a scope) or catheter (as in angioplasty);
- 3) task-oriented simulations, such as cross clamping, ligate and divide, anastomoses, etc., with one or two instruments;
- 4) full operative procedures.

The lower level simulators exist today with rather high levels of visual and haptic fidelity and are capable of significant educational value, while the higher level simulations that exist have lesser fidelity, and the expectations of the educational content must be scaled back. The task-level procedures have been subjected to analysis, and the training transfer (the amount of time in the simulator that is equal to the time on actual animal or patient training) is about 25–28%. This means that every hour of simulator is equal to 15 min (25% of an hour) of operating time on an animal. Based upon current standards for flight simulators, it could be expected that the training transfer for surgical simulators should achieve about 50–55%.

While there is a significant improvement needed from a technology standpoint, it is time to begin implementing the simulators at the level that will provide added value.

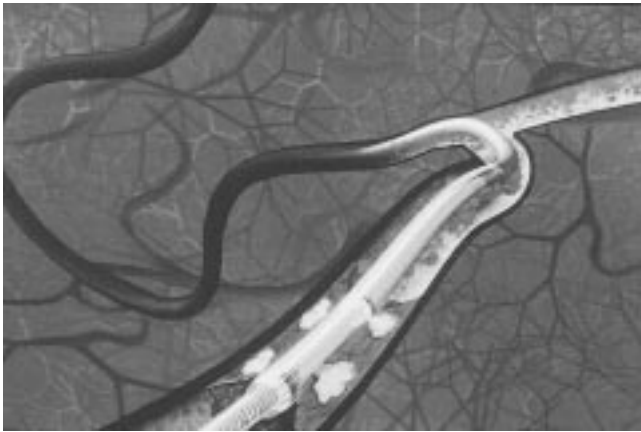


**Fig. 5.** The Visible Human leg, with less visual realism due to added properties, and accurate ballistic wounding model. (Courtesy of Dr. S. Delp, MusculoGraphics, Inc., Evanston, IL.)



**Fig. 6.** Central venous catheter placement simulator for training. (Courtesy of Dr. G. Higgins, HT Medical, Inc., Rockville, MD.)

The critical feature now is not the technology but matching the curriculum to the level of technology. For example, in a simulation of an anastomoses (task level), a blood vessel or ureter can accurately be visualized and physically modeled to teach medical students and beginning residents the essentials of surgical skills. The content focuses upon how to perform an anastomoses and basic instrument techniques. The expectation of the student is not that they will suture organs that are indistinguishable from a real structure but that the model will behave as realistically as a real structure—the educational content is tailored to the



**Fig. 7.** Angioplasty catheter in blood vessel. (Courtesy of G. Merrill, HT Medical, Inc., Rockville, MD.)



**Fig. 8.** Virtual colonoscopy with internal view of the transverse colon. (Courtesy of Dr. R. Robb, Mayo Clinic, Rochester, MN.)

technology. As computer power increases, so too will the level of realism.

Hand in hand with the development of surgical simulation is the use of real patient data from computed tomography (CT) or magnetic resonance imaging (MRI) scans to perform diagnostic procedures on the data set instead of inserting invasive or minimally invasive instruments into the patients. The currently accepted term is “virtual endoscopy.” This can be applied to those areas where endoscopic procedures are performed but also has the opportunity to explore areas not amenable to endoscopic procedures—parts of the body that are too dangerous (inside the eye) or too small (inner ear) to be accessible to real instruments. The process of virtual endoscopy consists of performing a standard helical CT scan of the area of the body of concern and “segmenting” the various organs and tissues. By applying sophisticated “flight path” algorithms (derived from terrain following algorithms for military aircraft), the organ can be “flown through,” with the resulting image being comparable to performing the examination with a video endoscope [8]. Areas providing initial success are the lungs, colon (Fig. 8), stomach, kidney-ureters-bladder, uterus, sinuses, and ventricles of the brain. Other areas, such as the inner ear (Fig. 9) and ganglion, are being explored [9].

The level of resolution of structure is now at 0.3 mm, which is adequate for diagnosis of structural abnormalities that cause distortion of a surface, such as polyps, cancers, or ulcers. The surface renderings are generic texture maps; therefore, the many disease states that do not distort the anatomy (many infections, very flat and superficial cancers, ischemia, etc.) are not able to be diagnosed at this time. However, an attempt to provide a “look-up table” that correlates Hounsfield units of a CT scan to organ-specific color and texture has been successfully demonstrated. Thus, once the problem of accurate, real-time registration is solved, it will be possible for the virtual organs to not only be anatomically correct but have precisely accurate coloration. With these capabilities, virtual endoscopy can



**Fig. 9.** Virtual endoscopy of the inner ear with view of semicircular canals, cochlea, and associated structures. (Courtesy of Dr. R. Robb, Mayo Clinic, Rochester, MN.)

be used for diagnosis, not therapy. There are a number of energy-directed methods, however, such as high-intensity focused ultrasound or laser or cryotherapy, that will permit precise localization of diseases that can then be destroyed (through coagulation, protein denaturing, or freezing) totally noninvasively. By using the patient’s image during the procedure, by data fusion, the physician can intraoperatively augment precision localization in real time through data fusion and stereotaxis. The result is the ability to provide a higher level of patient care by enhancing the physician’s capabilities above frail human limitations.

The potential of these examples (and similar information and 3-D visualization-based innovative and nontraditional approaches to medicine) can be best illustrated by the results of a “blue sky” brainstorming session in late 1995. This rudimentary idea is referred to as the “doorway to the future” and touches upon how information representation of actual anatomy (referred to as “informa-



**Fig. 10.** Full 3-D suspended holographic image of a mandible. (Courtesy of J. Prince, Dimensional Media Associates, New York.)

tion equivalents” of the actual organs and tissues) tie together the fabric of medicine. It was inspired by the many technologies under investigation and integrates them into a meaningful system of complementary technologies. The following scenario is used to illustrate one possible portion of the future 20, 50, or perhaps 100 years from now.

A patient enters a physician’s office and passes through a doorway, the frame of which contains many scanning devices, from CT scan to MRI to ultrasound to near infrared and others. These scanners acquire not only anatomic data but also physiologic and biochemical (like the pulse oximeters) data. When the patient sits down next to the physician, a full 3-D holographic image (Fig. 10) of the patient appears suspended upon the desktop—a visual integration of the information acquired just a minute before by the scanners. When the patient expresses the complaint of pain over the right flank, the physician can rotate the image, make various layers transparent, and query the representation of the patient’s liver or kidney regarding the lactate dehydrogenase, serumglutamic-oxaloacetic transaminase, alkaline phosphatase, serum creatinine, or other relevant information. This information and more is stored in each pixel of the patient’s representative image (a medical avatar) such that the image of each structure and organ (such as the liver) stacks up into a “deep pixel” all the relevant information about the structure. Each pixel contains not only anatomic data but biochemical physiologic data, past historical data, etc. so that information can be revealed directly from the image rather than searching through volumes of written medical records or a prolonged computer data base search. Should a problem or disease be discovered, the image can be immediately used for patient education, instantly explaining to the patient on their own avatar what the problem might be. Should a surgical problem be discovered, this same image can be used by the surgeon for preoperative planning or imported into a surgical simulator to practice a variety of different approaches to a difficult surgical procedure that will be performed upon

the patient the next morning. At the time of operation, the image can be fused with a video image and used for intraoperative navigation or to enhance precision, as in stereotactic surgery. During the postoperative visits, a follow-up scan can be compared to the preoperative scan, and using digital subtraction techniques, the differences can automatically be processed for outcomes analysis. Since the avatar is an information object, it can be available and distributed (through telemedicine) at any time and any place. Thus, this single concept of replacing the written medical record (including X-ray and other images) with the 3-D visual record of a medical avatar permits the entire spectrum of health care to be provided with unprecedented continuity.

Without doubt, not all of these technologies will be developed in precisely the manner indicated above, and many other technologies not mentioned will have an even greater impact than those currently envisioned. We now have information tools that can fundamentally and totally revolutionize our approach to patient care—tools that are existent today and are based upon known and provable science. While it is true that we must stringently evaluate the technologies and concepts with all known scientific rigor, we must not discard these powerful ideas because of our Industrial Age preconceptions.

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**Richard M. Satava** (Associate Member, IEEE) received the B.S. degree from The Johns Hopkins University, Baltimore, MD, and the M.D. degree from Hahnemann University, Philadelphia, PA. His fellowship, with a master of surgical research degree, was with the Mayo Clinic, Rochester, MN.

His internship was with the Cleveland Clinic and his surgical residency was with the Mayo Clinic. He currently is a Professor of surgery at the Yale University School of Medicine, New Haven, CT. Until recently, he was a Professor of surgery in the U.S. Army Medical Corps assigned to general surgery at Walter Reed Army Medical Center, Special Assistant in Advanced Technologies at the U.S. Army Medical Research and Materiel Command, and Special Assistant to research at the Defense Advanced Research Projects Agency. He has been continuously active in surgical education and surgical research, with more than 125 publications and book chapters in diverse areas of advanced surgical technology, including surgery in the space environment, video and three-dimensional imaging, telepresence surgery, and virtual-reality surgical simulation. He is a Member of the editorial boards of numerous surgical and scientific journals. During 20 years of military surgery, he has been an active Flight Surgeon, an Army Astronaut Candidate, a MASH Surgeon for the Grenada invasion, and a Hospital Commander during Operation Desert Storm, all the while continuing a full-time clinical surgical practice. While striving to practice the complete discipline of surgery, he is aggressively pursuing the leading edge of advanced technologies to formulate the architecture for the next generation of Medicine—Medicine: 2001. He is active in numerous surgical and engineering societies.

Dr. Satava is a member of the White House Office of Science and Technology Policy Committee on Health, Food and Safety. He is a member of the Emerging Technologies, Resident Education, and Informatics Committees of the American College of Surgeons, the Society of Laparoendoscopic Surgeons, and the Board of Governors of the Society of Minimally Invasive Therapy. He is the past President of the Society of American Gastrointestinal Endoscopic Surgeons.



**Shaun B. Jones** received the M.D. degree from the Uniformed Services University of the Health Sciences, Bethesda, MD.

He completed a residency in otorhinolaryngology at the National Naval Medical Center and was a Resident Research Fellow in the divisions of Cytokine Biology and Monoclonal Antibodies at the Center for Biologics Evaluation and Research of the Food and Drug Administration (FDA). He is the Program Manager for Unconventional Pathogen Countermeasures in the Biological Warfare Defense Program at the Defense Advanced Research Projects Agency. He is aggressively pursuing the application of today's most advanced technologies to counter biological warfare. He is on active duty in the U.S. Navy and is Assistant Professor of surgery at the National Naval Medical Center and the Uniformed Services University of the Health Sciences. He is an FDA Consultant, Division of Ear, Nose and Throat Device Evaluation. He is the author of numerous book chapters and publications. He is an internationally invited speaker and active participant on multiple editorial boards for peer-reviewed journals on advanced medical and surgical technologies and biological warfare defense. He is also a regularly invited Consultant to a variety of Department of Defense visioning panels, e.g., the Military Health Services System 2020 Biotechnology and Nano Technology Study Group.

Dr. Jones is a diplomate of the American Board of Otolaryngology and a fellow of the American Academy of Otorhinolaryngology—Head and Neck Surgery.