STEPPING INSIDE THE VIRTUAL OPERATING ROOM

BY JOHN OST

PHOTOGRAPHS BY HANK MORGAN

At first, James Chung stands motionless in the middle of the room. He's wearing an oddly shaped headset—similar to a bicycle racing helmet with a rectangular visor that completely covers his eyes. Thick cables attached to the back of the headset tether Chung to a nearby computer. Today Chung only wears the helmet and street clothes. On other occasions, the computer specialist from the University of North Carolina in Chapel Hill wears a body suit and gloves similar to the uniforms worn by astronauts during liftoff. Thin fiber optic cables woven into the suit and gloves "feed back" or transmit precise information about his smallest movement—even a twitch of his pinky—to the computer. Even though Chung has only donned the head gear, he still looks like a convict in a science fiction movie—plunged into total darkness by a technology that has cut him off from all real-world stimuli.

But this futuristic scenario does not play in a science fiction film; it takes place in a medical research laboratory. Once immersed inside the helmet, Chung enters a virtual world—or a computer simulated world—where he literally steps inside a cancer patient's chest cavity. Software on the computer connected to Chung's helmet creates a virtual—or three-dimensional representation—of the patient's lung from the patient's x-rays.

Chung does not lack audio, visual, and tactile cues from the virtual world or the real world. In Chung's virtual lung, a doctor will see a three-dimensional picture because the computer generates multiple two-dimensional images of the lung from the patient's x-rays. Each view is taken at a slightly different angle and projected simultaneously on two stereoscopic eyepieces inside the headset. The stereoscopic view adds dimension and depth to the x-rays—a tiny "sense-around" movie for each eye. As Chung gazes out into space, the multiple images merge and he sees the living organ functioning inside the patient's body.

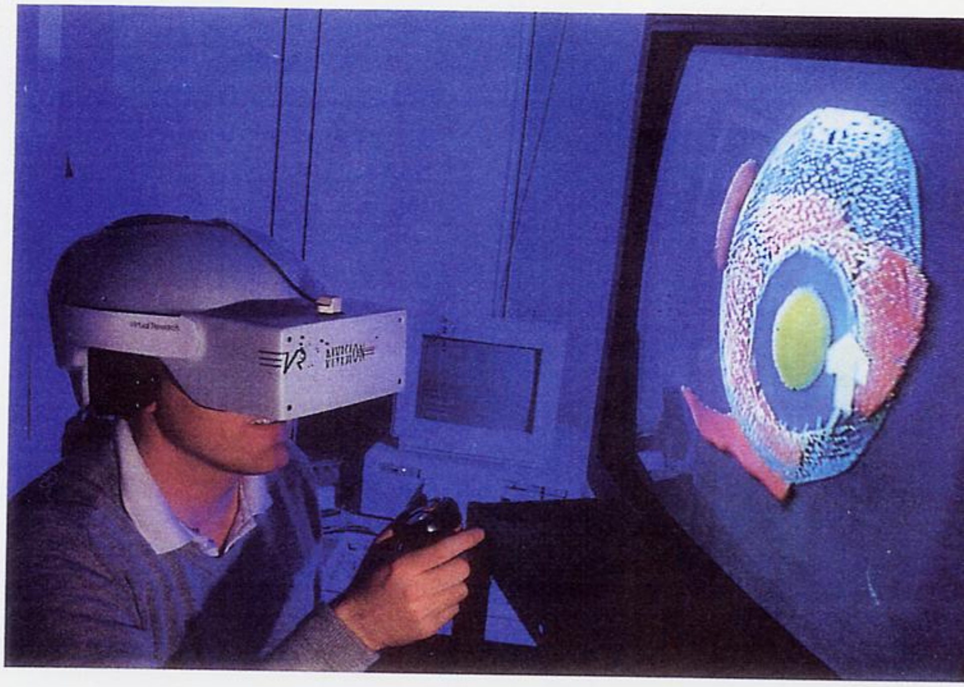
Special sensors on the helmet track Chung's movements about the room. The sensor data is then fed into a computer program, which mimics Chung's real-world movement in the virtual world. If a visitor watches Chung move about the room and, at the same time, views Chung's virtual world on a large television monitor—the spectator quickly realizes that Chung straddles two separate yet linked realities.

When Chung first puts on the headset, he finds himself standing before the chest cavity opening. Peering inside, he can see the heart beating off in the distance. Slowly, Chung begins to march about his real-world room, first forward and then a few steps to the left. Inside his helmet, his forward movement takes him deeper into the chest cavity, past the heart and within a few millimeters of the lump on the lung.

In essence, his forward movement in the real world repositions him in three-dimensional space inside the virtual world. If Chung wants to see the anterior heart chamber, he does not rotate an image on the computer screen. He walks to the back of the heart. He can step inside the heart and walk through its chambers.

Again, Chung moves about the room, this time stepping sideways and circling to his left. Inside the virtual world, Chung's movement in a semicircle allows him to walk around the tumor. If he were wearing the body suit and gloves, he could also rely on his tactile senses and touch the capillaries or a malignant tumor without cutting his patient open. It's the ultimate "laying-on" of hands without doing harm.

Finally, Chung takes a quick step to his right, seemingly glances over his shoulder, and then removes the helmet. Chung believes that his technique can improve radiotherapy treatment by allowing radiologists to step inside the patient's body and more accurately plan radiation treatments that destroy only the degenerate cells. Arrows on the patient's x-rays marked the beam's projected path for Chung. When he stepped to his right and glanced over his shoulder, Chung had realized that the radiation beam's path must move farther to the right, or it would damage healthy tissue on the way to the target. Chung determined the exact adjustment, lifted his helmet, and stepped back into reality. Though Chung strolled through a phantom picture of the body, the ridge between illusion and reality is narrow. The radiance is real, the patient is real—only the computer-driven trip into the chest cavity is not. It is virtual.



Jerry Prothero, a researcher at the Human Interface Technologies Lab at the University of Washington, demonstrates Virtual Reality technology for future training of eye surgeons. Using a VR hood, a surgeon will be able to practice techniques for eye surgery.

From Virtual Homes to Virtual Operating Rooms

The tools needed to build virtual bodies and operating rooms originated in other fields: architects, toy manufacturers, and military engineers first developed virtual worlds to build better houses, more realistic fantasy worlds, and deadlier weapons systems. Several software firms have developed computer generated representations of houses for construction firms. When architects don 3-D helmets and gloves, they do not stare at a flat computer screen. Instead, they enter the house, which moments before was *an idea*—a schematic on a piece of paper. The helmet and gloves mediate their senses—allow them to see, touch, smell, and hear inside the virtual home. Even though the building designers may work in three different locations across the United States, they can talk to each other and see each other's movements inside the virtual building through their fiber and silicon connection. Instead of joysticks, they use their bodies to control their motions and movements inside the virtual world, the same as in the real world.

The architects can *walk through* the virtual building, examine its layout, touch the walls, beams, and furniture. They can look beyond surface features and zoom in on every detail—down to the smallest bolt.

Virtual Reality: A Window Into The Mind

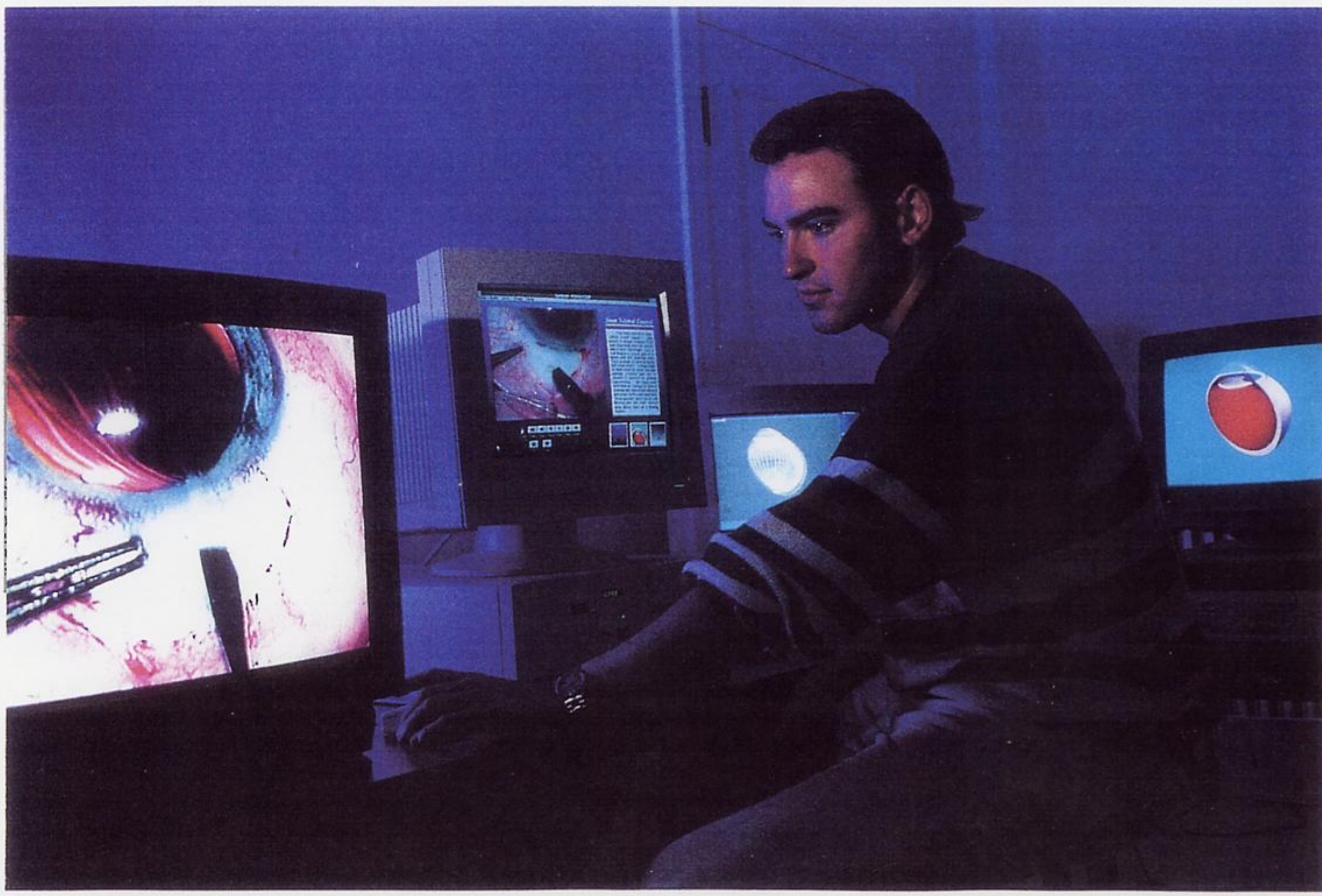
Similarly, a surgeon needs technologies which immerse him in his environment says Tom Furness, director of the Human Interface Technologies Laboratory (HITL) at the University of Washington. Furness believes that three changes are needed in the medical world:

* First, physicians need an electronic filing cabinet where they can immediately retrieve a patient's medical history, x-rays, CT-scans, and MRI's at the touch of a key or click of a mouse. They need information instantly, whether the patient is in the doctor's office, a nearby hospital, or fighting for his or her life on an emergency room table 3,000 miles away.

* Second, a virtual hospital has no walls. Just as the virtual house links ideas, information, and architects in different locations, doctors and medical engineers are betting that the virtual operating room or virtual examining room will link them across an international highway and help reintegrate a doctor-patient relationship fragmented by medical specialization.

* Third, physicians need "virtual interface technology," which will not only let them see the data but also "enter the data"—walk through an MRI or 3-D representation of a patient's beating heart and explore the information spatially. For Furness, the virtual interface serves as a "window into the mind." At this level, immersive virtual reality means that a group of specialists can explore and share concepts and ideas using all of their senses, including sight and touch.

The virtual patient offers surgeons, interns, and physicians such a window. Medical engineers around the world are not only building an accurate, computerized, three-dimensional surface view of a patient, they are also creating a virtual body—in most cases, an organ at a time—that includes anatomically correct muscular and skeletal systems, circulatory systems, and internal organs, a computer representation that functions like its cellular counterpart. Neurosurgeons can walk through thousands of pieces of data in preparation for a brain operation. Plastic surgeons can determine how well a wound will heal after a beauty operation by using time-lapse photography. Miniature probes and microcameras can help guide a surgeon through the uterine canal as he removes a hazardous cyst from an unborn child. "Virtual Reality" tools are no longer regarded as medical fantasy, but instead are viewed as a revolutionary method of the future—minimally invasive surgical techniques that do not employ saw, scalpel, or drill.

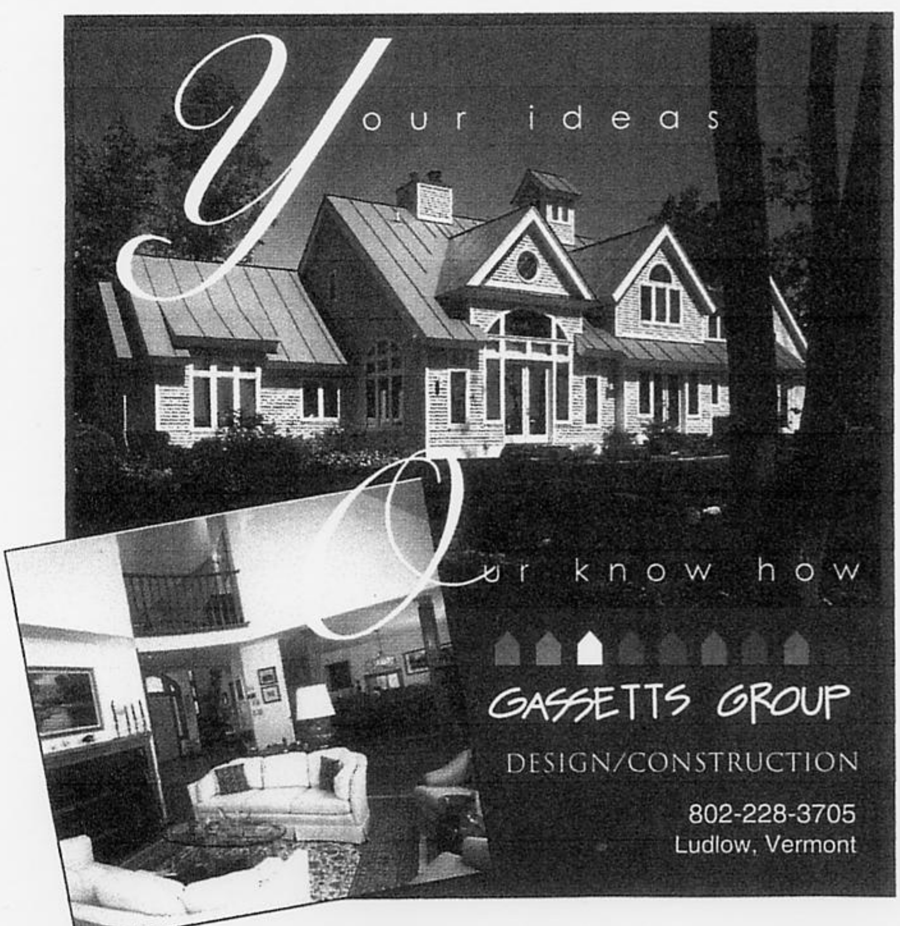


Ben Childers demonstrates the multimedia training system for the treatment of cataracts he is designing for ORBIS, a non-profit organization which brings modern medical technology to third-world physicians.

The Virtual Scalpel

At the Georgia Institute of Technology Bioengineering Lab in Atlanta, an ophthalmology student stares through the stereo eyepiece of the high-powered microscope. Directly beneath the microscope, a pen-shaped digitizer appears suspended in midair between three rods. The rods provide tension across three planes, simulating the tactile feedback that the student would experience during an operation. The digitizer maneuvers a virtual scalpel on the adjacent computer screen. As the young ophthalmologist moves or presses down on the digitizer, the virtual scalpel glides across the screen towards a 3-D photo-realistic image of the eye. As he begins his incision, the eye responds to his touch. It deforms, indents, and splits apart. The ophthalmologist feels the resistance in his instrument as he makes a three-millimeter incision into the sclera. With his first cut, this student begins a virtual cataract operation in which he can explore, experiment, and slip—but do no harm.

"The eye is an ideal organ for virtual reality research," says Michael Sinclair, co-director of the multimedia laboratory at the Georgia Institute of Technology. "The eye is a relatively simple structure and ophthalmologists use eyepieces in their work. We're creating a virtual environment by providing the ophthalmologist with both a microscope and a virtual scalpel during a simulated operation." The media lab has won many awards for its work. Sinclair and his staff designed a multimedia video, for instance, which helped Atlanta to secure the 1996 Olympics. Sinclair's lab has also developed a virtual glove, which allows physicians to examine patients remotely over a telecommunications hookup at the Georgia Medical College.



The Virtual Face

Like a skilled plastic surgeon, Steve Pieper marks several points around the lesion on the face where he plans to make an incision. He then draws a red line connecting the points, which represents the incision path. Pieper, however, is not a surgeon. He is an engineer at Dartmouth College who designed a computer-aided plastic surgery simulation with technical help from plastic surgeons. Instead of a scalpel, Pieper uses a mouse and special software to plot and test a surgical procedure on a 3-D scan of a patient's face. The 3-D surface image is a scanned image of one of Pieper's colleagues. The details are sharp, with excellent skin tone and image quality, and the face is life-like. When Pieper sets his program in motion, the marked skin surface becomes an elliptical incision with edges about an inch apart. A computer algorithm calculates where to cut so skin edges will align, reducing scarring. As time quickly lapses, the adjacent skin flaps mesh and the wound heals before the viewer's eyes.

Pieper's program can only approximate the healing process because it uses a generic thickness of the face and supplies no information about muscle location, range of motion, how specific muscle patterns pull on the skin, or the tensile strength of the skin.

"I can build a layered system with a thin epidermal layer, dermis layer, and biomechanical qualities but the program won't be interactive," says Pieper. "If we want to be accurate and place this model in a virtual world today, we must use a very fast supercomputer." Otherwise, the volume of data and subsequent calculations would require days or weeks of computing time. Right now, surgeons do not have a supercomputer on their desktop and they don't have the luxury of waiting weeks for a personal computer to churn out "what-if" scenarios when preparing for surgery, says Pieper.

Placing A Smile On The Virtual Face

While he can't speed up Pieper's computer model on a desktop today, Dr. Sunil Singh, Assistant Professor of Engineering at Dartmouth College, can place a smile (or a frown or any other emotional expression) on the virtual face. Through funding from the Office of Naval Research, Singh has collected data which accurately measures the kinematics—muscle relationships—of the head and the upper body. By using physics to study physiology, Singh can explain what opposing forces are at work when the head rotates or when someone clenches their fist or raises their arm over their head. From this data, Singh has built virtual faces and bodies on robots, which closely mimic human expressions and movements. His robots are not like Mickey or Minny, however.

> MANY TIMES YOU JUST CANNOT DESCRIBE A PATIENT'S SYMPTOMS OVER THE PHONE. IN THOSE CASES, A PICTURE IS WORTH TEN THOUSAND WORDS.

"Understanding these relationships so that you can obtain a smooth, natural motion is much different than Disney animation because animation works backward," says Singh. Animation starts with the arm raised and incrementally lowers the arm in a straight line to its specific starting position with no concern for the geometry that results when the muscles work together to complete a movement. A human, on the other hand, learns that a semicircular rotation expends the least amount of energy and conforms to the arm's natural geometry when it is raised above the head. The natural, recognizable motion, then, is strikingly different from the animated character because of the physics involved.

Once you understand the geometry and the opposing muscle forces that lead to the movement, you can accurately mimic an arm or head motion on a robot, says Singh. The Dartmouth engineer is currently building a database that reduces these complex movements to a series of numbers and equations. Once the movements are quantified, Singh will have a mathematical tool that provides the muscle tone missing in Peiper's model. At the same time, Singh is encoding (or again reducing to mathematical expressions) bone texture and cartilage and tissue density, critical information that will later provide the surgeon with tactile feedback—or the realistic feel of an incision—during a simulated operation. If Singh successfully creates such a program, the virtual face may become so realistic that a plastic surgeon could truly see, in advance, whether his surgical procedure would permanently eliminate his patient's smile.

Augmenting Patient Reality: Freeing The Handicapped Person

Thomas Reiss has Parkinson's disease. Like many Parkinson's patients, Reiss suffers from akinesia—or the inability to initiate and sustain walk-

TRAINING INTERNS

A young surgeon, dressed in gloves and body suit, flips down his glasses and enters the virtual operating room. He holds a catheter in his left hand, which he then begins threading into a virtual patient's leg shunt and up through the femoral artery. He controls the catheter's movements by pushing it forward or pulling it back and rotating the tip until it enters the appropriate vessel of the arterial tree. In his glasses, he sees a 3-D image of the arteries and heart. Another virtual image flashes vital signs on a virtual screen hovering near the table. Though the intern still seems confused by the 3-D geometry, the chief surgeon reassuringly coaches him through the procedure while watching the operation on a teleconferencing screen from his medical school office. At the right moment the professor advises his student which way to twist the catheter and how much pressure to exert.

Fantasy or interactive training model of the future? Data collection on the entire human anatomy proceeds at a rapid pace. For the past decade, researchers at the University of Washington have been mapping the anatomy through a variety of techniques including the digitizing of frozen cadaver cross-sections into a database. Johns Hopkins University, Engineering Animation, Inc., and the Biomechanics laboratory at the Mayo clinic are jointly developing a 3-D geometric database of the muscular-skeletal system and circulatory system, which they expect will be commercially available within 18 months. And while these scientists continue to map contours of the body, other researchers are painstakingly building computer programs—one body part at a time—that will eventually use this anatomical data in a virtual surgical ward.

ing. When Reiss enters a crowded room he freezes in place, unable to move. While scientists have known about the problem for a long time, they do not understand its cause. However, Reiss can trick his brain into issuing the walk command by placing an object on the floor just far enough away so that he must step forward to pick it up. By repeating the sequence, an akinesia sufferer can slowly walk forward. Reiss tosses dimes in his path to keep himself moving.

Last summer, Reiss contacted Susan Weghorst, director of medical application research at the Human Interface Technologies Laboratory, University of Washington. He had heard about virtual reality sunglasses called Virtual Vision Sports Eyewear—3-D glasses that float a large-screen television image in front of the viewer. Using microcameras and microcomputer chips, video images—television broadcast signals or special images stored on a computer chip—are projected onto each eyeglass. As the wearer looks toward a far wall, the stereo images merge into a single picture that seemingly floats in space. Reiss wondered whether he might use the glasses to place virtual dimes on the floor. Like the surgeon who will one day enhance the operating room by posting critical medical data about the patient onto a virtual screen, Reiss wanted to "augment" his own reality today by placing virtual dimes in his path. Thus far, the experiment has worked.

At the "Medicine Meets Virtual Reality II" conference in San Diego last January, Reiss, Weghorst, and her research team reported on their success with the glasses. At the drop of a virtual dime, Reiss now navigates tight rooms and corridors, barely breaking stride. "What is particularly promising," says Weghorst, "is that some patients like Reiss may be able to walk unassisted and without medication through at least some stages of the progressive disease." Normally, the symptoms are treated with L-dopa, a chemical precursor of the naturally occurring neural transmitter dopamine, which has many unwanted side effects.

Virtual reality tools are not limited to Parkinson's patients. "Virtual reality applications for prosthesis may help some handicapped people escape the limitations of their bodies," says Weghorst. In this case, the virtual environment translates limited movements into complex actions and serves as a link between the individual's action and the events taking place in the world.

"We can map any effector in the body," says Tom Furness. "The virtual body can do things the physical body cannot do." The slightest motion or energy change—an eye blink, a nod, a clenched jaw, the slightest synapse firing—could spark a computer mouse click, menu selection, or synthetic voice command that propels a quadriplegic through cyberspace where he communicates freely with the world.

Telemedicine And The Information Highway

"Virtual reality is not just a computer generated reality. Virtual reality also means using computers to facilitate remote surgery, remote diagnosis between doctors and patients at two different offices. It's telepresence, feeling like you are somewhere other than the physical location of your body." — Susan Weghorst

Two hours after Dr. James Leucke delivered a baby girl at the Big Bend Health Center in Alpine, Texas, the infant had difficulty breathing and became severely distressed. It was clear to Leucke that the little girl would not likely survive a 300-mile medivac flight to the Texas Tech Medical Center in Lubbock unless Leucke first stabilized her condition. Leucke, one other doctor, and two physician's assistants constitute the entire medical staff at Texas Tech., a health center serving a population spread across 18,000 square miles.

Earlier that day, Big Bend had just connected to an experimental telecommunications network called HealthNET, which connects the hospital to the Texas Tech Medical Center. Through HealthNET, Leucke asked for a consultation with Marion Meyers, a neonatal specialist at Texas Tech. Over an interactive video link, Meyers examined the little girl's x-rays and blood work, spoke with Leucke, and confirmed the diagnosis as acute acidosis, a pathologically high acid content in the blood. She instructed Leucke on the child's treatment, and by the next day the baby was stabilized and transported to the Lubbock Medical Center. Ten days later, the baby's parents took her home.

"Without the consultation," says Leucke during a videotape interview, "the baby would have died. Many times you just cannot describe the symptoms over the phone. In those cases, a picture is worth ten thousand words."

Over the past two years, Texas Tech Medical Center specialists have performed over 300 remote consultations. Their services include confirming Big Bend physicians' diagnoses; holding two-way video consultations with the rural practitioners, their patients, and the patients' families; and offering guidance over televideo links to surgeons at the rural hospital during difficult operations. Researchers at the Massachusetts General Hospital, Stanford University Medical Center, the Mayo Clinic in Chicago, and the Medical Project at the Medical College of Georgia are also using telemedicine to pass x-rays, CT-scans, and other information between the medical centers and hospitals in outlying regions.

Despite the advances taking place in virtual reality research at Dartmouth College, New Hampshire does not have a telemedicine program nor plans for a state-wide information network in place. Last December, however, the Koop Institute of Dartmouth College gathered together health care providers and planners from Maine, New Hampshire, and Vermont to discuss the possibilities of developing a regional health information network. C. Everett Koop called the conference "a preliminary meeting but an important first step" toward creating an information highway on-ramp for northern New Englanders.

The Well-Behaved Guest

"We are guests in the bodies of our patients," says Dr. Max Urban, a German surgeon. "As guests, we have to behave. We are not allowed to destroy anything." But before it is possible for U.S. physicians to become better guests, many technical obstacles, organizational problems and ethical questions loom on the horizon.

An Accessible High Speed Computer Network — Regular telephone lines cannot support virtual reality tools. Who will build the high speed network necessary for virtual medicine? If the federal government cannot or will not legislate the development of a national data highway, then who will build the network?

Access for All — Will rural doctors in the United States have the same access to high speed networks as their counterparts in the cities? While large distances may justify subsidizing telemedicine for rural doctors, will hospitals invest in remote technology for urban clinics serving minority populations and the urban poor?

Fragmented Data Trails — An Arthur D. Little report estimates that consumers could save $30 billion dollars if telemedicine and electroni medical records become the norm. But can hospitals and specialty departments agree enough so data can be transferred across departments, hospitals, and state borders?

Personal Privacy — Will computerized medical networks compromise the privacy of patients? Will restrictions be placed on individual files so that employers, life insurance companies, and the federal government can not have unlimited access to an individual's files?

The Perfect Virtual Body: Cost and Risk — How much data is enough? Will computers ever have enough data about an organ or system so that a robot can perform surgery without human aid? What levels of risk are doctors, patients, and society willing to accept?

Redefining Legal Definitions Of Physician Care — Can federal and state laws be amended so that remote diagnosis and surgery are covered? Presently, state Medicaid rules and federal Medicare regulations generally prohibit payment for a physician's services unless he lays his hands on the patient. Under current legal definitions, remote care does not meet this requirement.

Using silicon and fiber to link physicians, patients, and information may indeed allow future physicians to become better guests in their patients' bodies. A generation of physicians whose technical skills are honed on simulators and supported by other specialists on electronic links throughout the world may finally embody the seemingly antithetical traits we seek most in a physician: a highly skilled and compassionate "specialist" who gains his patient's trust because he possesses an intimate knowledge of the patient's personal life and general medical history—qualities which the modern day patient feels were lost with the passing of the general practitioner physician. ▲

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