Remote remedy: At New York's Beth Israel Medical Center, a surgeon performs a heart operation sitting at a computer console.

RoboSurgeons

Their bedside manner is a tad impersonal. But the computer-assisted robotic systems finding their way into today's operating room may someday save your life. BY STEVE DITLEA


Ultraderm

In the state-of-the-art hospital operating room, 67-year-old Eugene Bem lies anesthetized, pierced through the chest by three narrow, stainless-steel rods held by aluminum and plastic mechanical arms draped in translucent vinyl. Under way in the operating room is a critical portion of a heart bypass operation, but missing is the customary crowd of surgeons around the patient. Instead, in a corner across the room, a cardiac surgeon sits alone at a computer, his back to the operating table. Hunched over an enveloping, streamlined console, his feet tapping at pedal switches and fingers rapidly manipulating sensitive handheld controllers, the doctor in surgical scrubs could pass for some silent-movie mad scientist at his mighty Wurlitzer organ.

In fact, it's a day this past summer at New York's Beth Israel Medical Center, and cardiac surgeon Hani Shennib is offering a preview into the future of robotically assisted heart operations. Peering remotely into his patient's chest cavity via a tiny video camera mounted at the end of one of the three steel rods, the surgeon performs the delicate task of harvesting a chest artery to be used in a heart bypass graft. Still at the console, Shennib grasps, cuts and cauterizes using surgical instruments on the tips of the other two rods; the instruments, deep in the patient's chest, respond precisely to the physician's hand movements, which are relayed via a computer to the electromechanical arms.

Welcome to the future of the operating room. The computer-mediated part of this heart operation is still under clinical testing pending approval by the U.S. Food and Drug Administration. But just a few days prior to the Beth Israel procedure, the FDA approved the commercial sale of the computer-controlled robotics for abdominal laparoscopic surgery as well as minimally invasive gallbladder, prostate, colorectal and esophageal procedures—potentially 3.5 million operations a year in the United States.

With more than 50 advanced robotic systems already in hospitals around the world (the machines have previously been approved for sale in Europe and are in clinical trials in Japan), the robot-assisted operating room of tomorrow is just around the corner for many patients. Indeed, the cascade of robotic surgery "firsts" proclaimed by hospitals in the United States and abroad became a torrent after the FDA's initial commercial approval.

The day after the FDA announcement, for example, Henrico Doctors' Hospital in Richmond, Va., publicized the first non-clinical-trial use of robotic surgery for a gallbladder removal; the operation was performed by surgeon William E. Kelley with a da Vinci system on 35-year-old Kimberly Briggs. To demonstrate just how nontraumatic the procedure could be, less than four hours after her operation was over Briggs was wheeled into a press conference, where she told reporters, "I feel great."

The potential advantages of the robotic systems are dramatic. The robotic arm positions and holds the video camera with greater accuracy and steadiness than any human being could. Seated comfortably instead of standing over the patient, the surgeon is less subject to stress and fatigue—a critical factor during procedures that can last many hours. Should there be a tremor in the surgeon's hand, as there could be during a long operation, the computer filters it out. There's an expression for this robotic version of a steady hand: "virtual stillness."

The technology also holds the promise of making minimally invasive operations, in which surgery is performed through small incisions, available to a far larger group of patients. Minimally invasive techniques mean less trauma for the patient and have become common for such operations as gallbladder removal. In today's more conventional version of minimally invasive surgery, long-stemmed, narrow instruments are directly controlled by the surgeon; it's somewhat like using chopsticks to perform surgery. Because of the special training required and limits to its applicability, this form of surgery is practiced by fewer than one-third of U.S. surgeons. Thanks to computer-assisted procedures that are more exact and reproducible, a new generation of minimally invasive techniques could make less trauma for the patient the norm rather than the exception.

In the case of cardiac operations, these advances mean the surgeon is able to spare the patient the trauma and pain involved in cracking open the breastbone and using a heart-lung pump while the heart is stopped. In fact, Beth Israel heart patient Bem was released the next day instead of after the weeklong hospital stay (at $1,400 per day) that is routine following open-heart surgery.

Hearts of Gold

Medical regulators in the federal government share the increasing enthusiasm for robotically assisted surgery. In approving the million-dollar da Vinci system made by Intuitive Surgical of Mountain View, Calif., the FDA gave the technology a verbal pat on the chassis. "This system is the first step in the development of new robotic technology that eventually could change the practice of surgery," said FDA Commissioner Jane E. Henney. At the same time, the FDA notified Intuitive Surgical's chief rival, Computer Motion in Goleta, Calif., that robotic surgery devices will be cleared for market release on an accelerated basis. This makes it likely that Computer Motion's $750,000 ZEUS Robotic Surgical System will also be approved by the FDA for sale for some procedures by sometime next year. (Like all medical devices, robotic surgery equipment must be approved by the FDA separately for each type of procedure.)

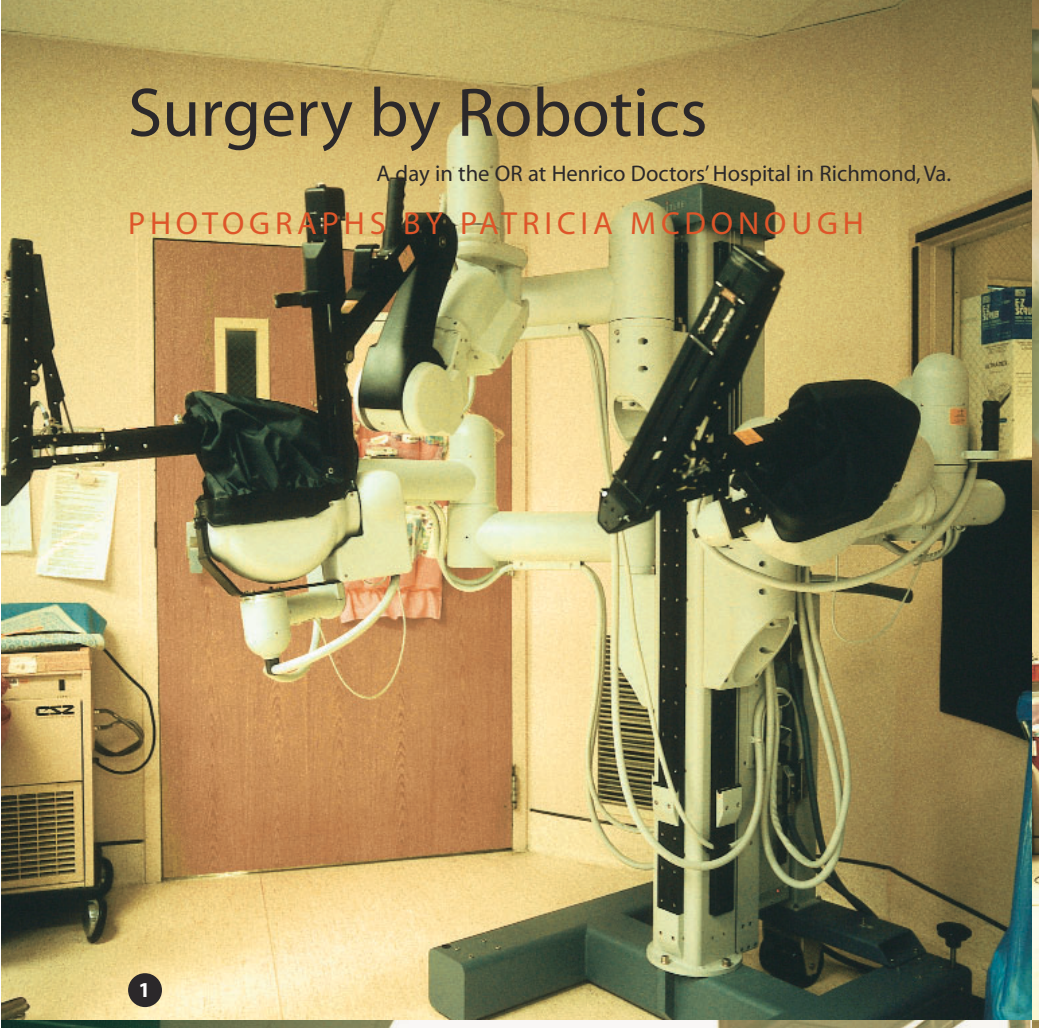
Given recent regulatory **approval, robotically assisted surgery** is just around the **corner** for many patients.

PHOTOGRAPH (PREVIOUS SPREAD): THE NEW YORK DAILY NEWS

Surgery by Robotics

A day in the OR at Henrico Doctors' Hospital in Richmond, Va.

PHOTOGRAPHS BY PATRICIA MCDONOUGH



1 The da Vinci robotic apparatus waits in the operating room prior to a minimally invasive procedure for a patient with gastroesophageal reflux disease.
2 Surgical nurses hook up the endoscope, which uses twin cameras, to the video monitoring system.
3 One of the robotic arms, equipped with the narrow surgical instrument.
4 A nurse drapes the robotic platform with sterile covering.
5 Finally ready for surgery, the robotic apparatus patiently awaits the patient.

When it comes to robot-assisted surgery, however, the performance of cardiac procedures is the Holy Grail. More than 400,000 open-heart surgeries are performed each year in the United States, at a cost of nearly $20 billion. Both lifesaving and expensive (typically $25,000 per operation), open-heart coronary bypass surgery is often referred to as the "gold standard" by practitioners and hospital administrators.

Cardiac surgeons say the looming presence of robotics in the operating room could revolutionize the operations. "The integration of computers and robotics will have as great an impact as the introduction of anesthesiology into the operating room," said heart surgeon Ralph Damiano Jr., speaking at the recent Fourth International Congress on Computers and Robotics in the Operating Room, in Santa Barbara, Calif. At the same time, Damiano, who in 1998 was the first physician in the United States to perform robotically assisted heart bypass surgery, cautioned that the technology alone is not enough to guarantee wide-scale adoption of the techniques; operating-room economics apply too.

The challenge is to demonstrate that, in addition to reducing operating overhead with fewer personnel in the operating room and shorter patient hospital stays, robotic surgery will also result in improved outcomes over current methods, attracting even more patients. By focusing on heart operations, the manufacturers of the new surgical equipment are banking on this becoming the earliest area of wide adoption—and for good reason. According to Jan Wald, senior vice president for equity research at George K. Baum & Co., "the profit margin for hospitals is very low, only about 2.5 percent—no more than what supermarkets make. But cardiac surgery is very profitable; it's a big moneymaker in any hospital." Hence the anticipated market for high-priced, high-tech computer-assisted cardiac surgery systems, which are second in cost only to magnetic resonance imaging and other sophisticated medical imaging systems in today's big-ticket capital equipment for hospitals.

Robo Duels

GIVEN THE HIGH STAKES, IT'S HARDLY A coincidence that Beth Israel's and New York University's medical centers are among the facilities most aggressively pursuing the technology in cardiac surgery. "New York is one of the most competitive markets for heart care in the hospital business," says Richard Gemming, executive director of the Heart Institute for Continuum Health Partners Inc., which runs Beth Israel and a half-dozen other formerly independent hospitals in the vicinity. Due to consolidation and a New York State medical regulatory system that limits the number of cardiac centers, a few operating rooms must vie for the area's large and sophisticated patient population; if a healthcare facility falls below a mandated number of operations necessary to maintain surgical expertise, the hospital can lose its cardiac approval.

In this atmosphere of intense competition, it's also not surprising that Beth Israel and NYU are adopting rival equipment—da Vinci and ZEUS systems. In principle, the hardware is similar, consisting of a computer-mediated surgical workstation with a high-quality video display and hand-input devices, a wired network to communicate surgeons' gestures, and a cart bearing the system's robotic arms. In practice, however, da Vinci and ZEUS differ in crucial ways.

By design, da Vinci's console is meant to be immersive: The surgeon looks down at a three-dimensional view of the patient's innards, as picked up by a two-chip charge-coupled device (the same type of chip used in digital cameras) video element in the scope at the end of one of the stainless-steel rods. To assure a top-notch, stereoscopic, nonfatiguing view, mirrors reflect images from two full-sized monitors, hidden within the bulky console, into the left and right eyepieces of the visor port.

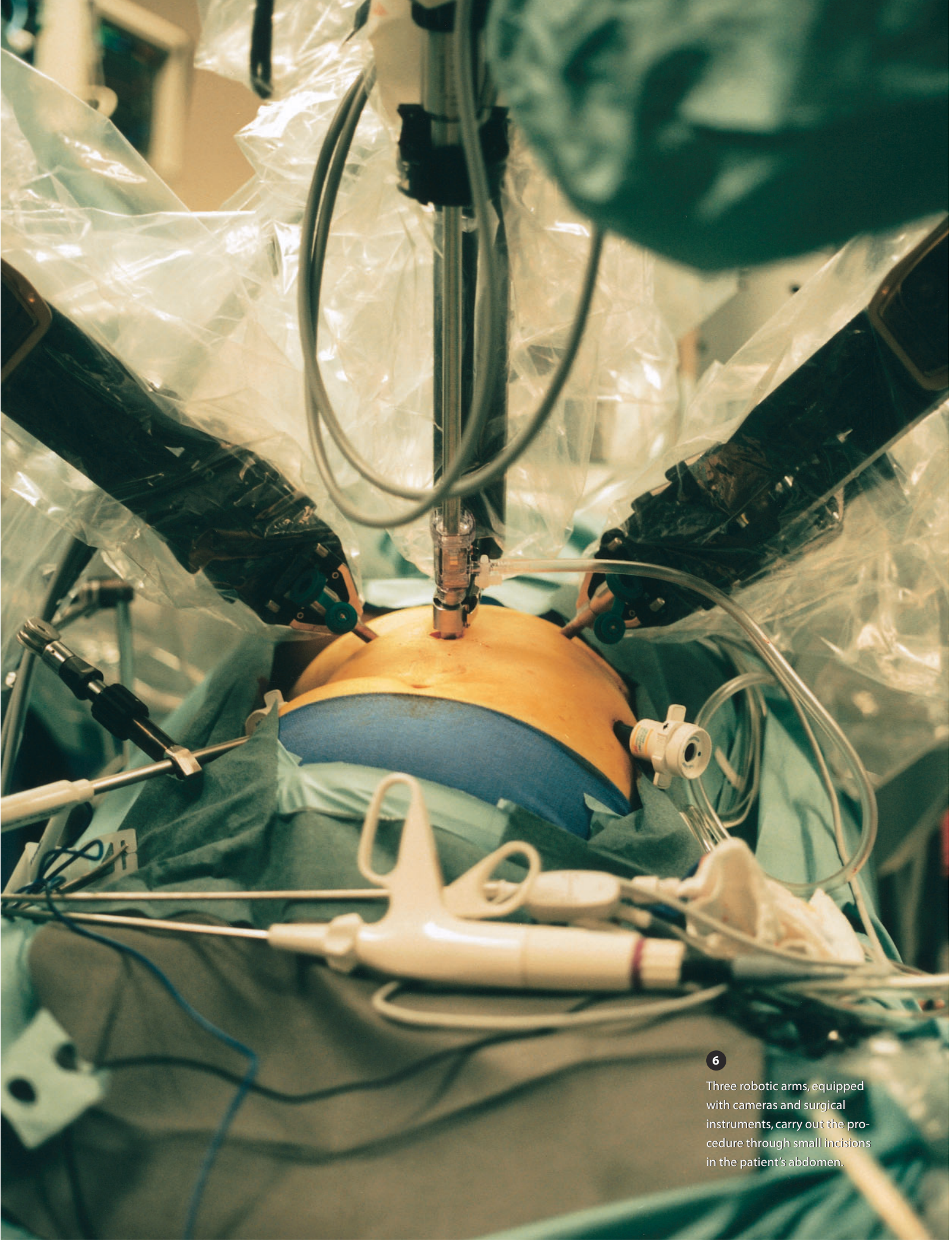
By contrast, the ZEUS console is more like a computer workstation: The surgeon sits opposite a vertical screen—available with 3-D stereo imaging using lightweight polarizing glasses. An in-depth display, it turns out, may not be as crucial as the subtle color cues available from monocular high-definition video, especially at 10 times magnification, which is beyond the augmentation afforded by simple optics worn by a nonrobotically assisted surgeon.

For the heart surgeons, both types of high-quality displays make it possible to see anatomical features in precise detail. "You can see anatomical structures you've never seen before," says NYU's Eugene Grossi; as director of the hospital's cardiovascular research laboratory he was responsible for adding a Sony high-definition TV system to the ZEUS equipment. Says Beth Israel's Shennib of his da Vinci console: "It's the best medical visualization I've ever seen."

Beyond the displays, other key differences can be found in the systems' hand controllers and coupled robotic arms and instruments. ZEUS replicates the endoscopic instrumentation used in conventional minimally invasive surgery. (An endoscope is a slender optical tube passed into the body to allow the surgeon to view an operation.) The surgeon activates the long-stemmed chopstick-like instruments by compressing V-shaped handles. This control device, though perhaps not as intuitive as other types, involves a set of manipulations to which practitioners of minimally invasive surgery are already accustomed.

The da Vinci system adds another wristlike articulation to the instrument tips and an extra degree of freedom to its hand controllers. "It provides better dexterity. The motion is close to having your hand inside the patient," says Shennib. But not exactly. The da Vinci's force feedback, a computer-synthesized tactile resistance felt by the surgeon when making an incision or sewing a suture, provides a cue to instruments' actions but doesn't accurately replicate what is sensed in hands-on work. According to Shennib, "You feel resistance from the [robotic] arms when you're pushing on the controls, but not the delicate feedback of pulling or pushing on tissue."

High-quality **displays** used with the **robotic systems** make it possible to see anatomical features in **precise** detail.



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Three robotic arms, equipped with cameras and surgical instruments, carry out the procedure through small incisions in the patient's abdomen.

Grinding to a Start

WHILE CARDIAC SURGERY AT TWO OF Manhattan's leading medical centers may be the high-profile payoff of robotic surgery today, the technology's roots are less glamorous. Incorporating robotics into surgical procedures began at academic institutions including MIT, the Carnegie-Mellon Institute and several campuses of the University of California. In 1986, the University of California at Davis and IBM's Thomas J. Watson Research Center joined forces to begin development of computer-assisted hip replacement surgery; by 1992, a spinoff of that effort, Integrated Surgical Systems, introduced the Robodoc Surgical Assistant System.

The job of this robotic system is to grind away bone. At best, conventional surgical techniques leave gaps of 1 millimeter or more between bone and implant, but no more than 0.5 millimeters of bone will grow out from a cut bone. The insurmountable space eventually leads to implant failure. Milling bone with greater precision than an experienced surgeon could, Robodoc assures that a cementless prosthesis can achieve long-term fixation by allowing bone to grow into the porous coating of the implant. In fact, this March, Integrated Surgical reported that Robodoc had been used for the first total knee replacement performed using robotic surgery.

But grinding down hips and knees doesn't fire the public imagination like mending an ailing heart. With the goal of aiding in complex procedures such as heart operations, companies developing robotics have come up with increasingly sophisticated systems. In 1994, Computer Motion produced the first FDA-cleared robot for assisting surgery in the operating room—the Automated Endoscopic System for Optimal Positioning, or AESOP. AESOP is essentially an electromechanical arm for positioning an endoscope. Two years later, voice control by the surgeon was added, allowing for exact, hands-free control during an operation.

In 1998, Computer Motion introduced ZEUS, its robotic surgery system capable of operating on everything from an ailing heart to an inflamed gallbladder.

Rival technology underlying Intuitive Surgical's da Vinci system grew up around the same time, financed by government funding for research in "tele-surgery"—computer-assisted medical procedures delivered at a distance. In the early 1990s, SRI International in Menlo Park, Calif., was one of several institutions receiving grants from the Department of Defense's Advanced Research Projects Agency to develop tele-surgery. A prototype system was built and proved an inspiration to Frederic Moll, who cofounded Intuitive Surgical in 1995 and is now the company's medical director. "What got me excited wasn't the remote-surgery aspect," Moll recalls, "but the way the system eliminated the need for a hand to be directly connected to a surgeon's instruments. It offered new ways of solving the challenges in minimally invasive techniques."

Tele-surgery could give an accident victim on a desolate highway **remote access** to **world-class** surgeons at major medical facilities.

Doctors on Call

WHILE RESEARCH INTO TELE-SURGERY helped to jump-start robotics in the operating room, distant operations have remained an elusive application. However, it may eventually prove to be one of the most significant uses of robotic surgery.

With either da Vinci or ZEUS, a surgeon seated across the room from the patient could as readily be operating from another room down the hall or from an office across town. Without having to spend hours traveling and prepping for each surgery, a specialist could perform procedures in several different operating rooms scattered throughout a region on the same day. At least that's the theory. In practice, there are limits, including ones caused by what can be a disorienting lag time between a surgeon's hand motions and the robotic arms' actions. Due to transmission delays over longer distances, the maximum effective range seems to be about 30 miles by wireless communication and 200 miles via a cable connection. The unreliability of network communication infrastructures presents even more of an obstacle—at least for now.

At NYU Medical Center one morning this August, surgeon Stephen Colvin is operating on the heart of a 56-year-old woman to repair a damaged mitral valve. The physician is working by hand with endoscopic instruments, while invoking robotic help to position the scope that is relaying the close-up view to a video monitor hanging above the patient. "AESOP!" he says. There's a trill of acknowledgment from the machine. "Move back. Up. Up." The scope moves to the proper orientation.

In the hallway outside the operating room, Grossi leads an audiovisual team televising the operation via satellite uplink to a medical conference in Montana. Eventually, interns and doctors at remote teaching venues could experience the actual surgical motions of their world-class colleagues on force-feedback-equipped simulators. At the moment, however, maintaining video communications is a difficult enough challenge. At the operation's most critical phase, the TV signal is lost on the downlink in Montana. (A burst of radiation from a microwave oven on the conference's premises apparently knocked out today's lesson.)

While tele-surgery may not yet be ready for prime time, it's only a temporary setback. Next time, the physicians will use broadband telephone lines to secure a steady transmission link. And soon they expect to televise a complete robotically assisted surgery. In such increments, tele-mentoring and tele-surgery will advance—further accelerating development of computer-enhanced procedures. It will take significant improvements in communications networks, but in perhaps the not too distant future, an accident victim on a rural highway in Nebraska, or a heart patient in an isolated village in France, could have remote access to care by the finest world-class surgeons at major medical facilities.

With the enabling technology for robotic surgery already making an impact in the operating room, it's just a matter of time before a surgical star "phoning in" a complicated procedure is a routine event in the operating room. TR

7 The "real" surgeon, William Kelley, manipulates the surgical instruments from a console in the corner of the OR.
8 Nurses follow the procedure on a video monitor.
9 Nurses are ready to make any needed adjustments.
10 The surgeon guides the robotic instruments from the console.
11 The surgical instruments used by the da Vinci robotic system alleviate hand tremors.