

Robotic Surgery — Squeezing into Tight Places

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Back in the 1980s, the rationale for building a surgical robot was the stuff of science fiction. Intent on providing “a doctor in every foxhole,” military strategists envisioned a severely wounded soldier being loaded into a battlefield ambulance equipped with a robot so that a surgeon at a Mobile Army Surgical Hospital, or MASH unit, miles away could perform life-saving telesurgery to prevent exsanguination or some other physiological catastrophe. The National Aeronautics and Space Administration had a similar vision. A terrestrial physician would be able to remove an acutely inflamed appendix from a patient aboard a robot-equipped space station. In this high-tech future, surgery could be performed skillfully and promptly even in dangerous or inaccessible places.

By the 1990s, the rationale for such robots had become even more compelling. Minimally invasive laparoscopic surgery wasn't overcoming its severest limitations. Many kinds of anastomoses, especially of the microscopic variety, could not be performed well, if at all. Laparoscopic instruments were rigid tools that could move and rotate along only two axes (moving inward, outward, clockwise, and counterclockwise, with four “degrees of freedom”) and so could not duplicate surgeons' ability to apply pitch and yaw to their wrists — that is, to tilt manual instruments up and down or shift them from side to side. “The laparoscopic surgeon is forced to operate with chopsticks,” says Thomas M. Krummel, M.D., chair of the Department of Surgery at Stan-

ford University School of Medicine and a pioneer of robotic surgery. And whereas surgeons have binocular vision and rely heavily on their depth perception, the laparoscopic camera transmitted only a two-dimensional image. Alas, minimally invasive surgery proved to be good for extirpation but not for reconstruction.

Then, market forces dictated further innovations. Consumer-minded patients were demanding even more kinds of minimally invasive surgery. Insurers liked the shortened recovery periods associated with such operations, and medical-center accountants relished the increased flow of revenue. Hospitals began putting pictures of robots on the front of their advertising brochures.

So what, exactly, do the current incarnations of surgical robots consist of? Although many have fanciful anthropomorphic names such as da Vinci, ZEUS, AESOP, and Robodoc, they don't look at all like humans. Unlike industrial robots, they are not autonomous, and to be taxonomically correct, they ought not to be called machines. A surgical robot is actually a collection of wristed “servant” tools called manipulators, which receive digital instructions from an interfaced computer. The “master” surgeon, seated at an ergonomically designed video console with an “immersive” three-dimensional display, initiates the digital instructions by controlling sophisticated hand grips — essentially, joysticks with seven degrees of freedom¹ (adding the pitch, the yaw, and the “pincer-like” move-

ment to those that were already available). The manipulators inside the patient's body duplicate the surgeon's hand movements at the console, and software filters out even physiologic hand tremors. More than 10,000 operations have already been performed in this way.

Unaccommodating places are what robot-assisted surgery is all about. The human surgeon is not optimized for tiny spaces. An otolaryngologist by trade, I used to perform microscopic middle-ear surgery in a space the size of a pistachio shell. Too many of these operations were struggles. Because pediatric surgeons must frequently work in small spaces, they have applied minimally invasive techniques to a broader range of procedures — such as fundoplication and ligation of patent ductus arteriosus — than have other surgical specialists.

With the advent of robotics, pediatric surgeons began to dream about fixing fetal diaphragmatic hernias or myelomeningocele in utero²: a robot's computer can scale down a surgeon's hand movements into micromotions inside the fetal patient. And because no hysterotomy is required, such surgery is not subject to the disastrous complication of preterm labor.

Currently, pediatric laparoscopic surgery is limited by an inability to perform small anastomoses. Not so robotic surgery. Last year, Krummel teamed up with Craig Albanese, M.D., a pediatric surgeon at Stanford, to perform the first robot-assisted Kasai portoenterostomy, anastomosing a he-



patic-surface bile duct to a loop of small bowel, in a six-week-old infant born with biliary atresia.

Tight places, like minuscule ones, seem to cry out for robot-assisted surgery. Doing an open retropubic prostatectomy, for example, means that “you are operating in a deep, dark hole,” Krummel says. So it is not surprising that robot-assisted prostatectomy is taking off in the United States. Mani Menon, M.D., of Detroit’s Vattikuti Urology Institute, has performed more than 1000 such prostatectomies.³ The robot-assisted procedure is associated with lower rates of postoperative impotence and incontinence than the open procedure, says Menon, because the robot makes it considerably easier to spare nerves and to anastomose the urethra. Moreover, Menon believes that it permits more complete extirpation of malignant tissue.

The pericardial sac is an especially tight place, and it has long been believed that the rigid thoracic cavity, which doesn’t re-

quire external gas insufflation in order to maintain an adequate working space, was ripe for minimally invasive surgery. Such surgery has become available only recently, however, with new robots providing the impetus. Several surgeons have reported performing successful robot-assisted endoscopic anastomoses of the left internal thoracic artery to the left anterior descending coronary artery on the arrested or beating heart. Robotic techniques have not yet advanced far enough to make total endoscopic, closed-chest, beating-heart coronary-artery bypass grafting a feasible procedure, and “the back of the heart is a tough place to get to, no matter how you try it,” Krummel says. But cardiothoracic surgeons are persistent.

In addition to small or narrow places in the human body, remote places in the world are often mentioned by those invoking the promise of robotic surgery. Some observers have called “Operation Lindbergh,” the first

transatlantic cholecystectomy, nothing more than theater: a tele-surgeon in New York robotically removed a gallbladder from a patient in Strasbourg, France — without complications. But Krummel articulates the logical extension of this mode of operation: “Telesurgery might be a good way to distribute health care in the Third World.” And NASA hasn’t forgotten about its potential for the proposed manned missions to the Moon and to Mars.

Of course, important disadvantages of the robotic approach abound. A robot can cost \$1 million or more, not including the maintenance contract and the expensive disposable items required for each procedure. Each robot’s footprint is quite big, and its instruments don’t provide a sense of touch. Not unexpectedly, the learning curve for the effective use of these tools is long and steep. The robot’s toolbox isn’t very full, and the time required to switch from one instrument to another lengthens operating time. Most of all, the majority of published studies of robot-assisted surgery have really been technical notes describing feasibility. Prospective studies comparing robotic with conventional procedures will be needed in order to establish a clear benefit.

But even as the current robotic systems begin to be put to such tests, the true visionaries in this domain are focusing on the surgical robot less as a mechanical device than as an information system — one that should be fused with other information systems. One proposed example of this kind of fusion is image-guided surgery, also called surgical navigation.

Robot-assisted surgeons will be able to see real-time, three-dimensional scanner images electronically superimposed over the operative field that is displayed on the monitor. In other words, on the screen, human anatomy will be rendered translucent, and the surgeon will be able to determine the exact location of a tumor and more readily avoid damaging vital structures — such as the major intraparenchymal vessels and bile ducts that are sometimes inadvertently severed during division of the liver or the inferior vena cava that may be injured during right adrenalectomy. In fact, with preoperative scanner images, sur-

geons could robotically practice their patients' surgery the night before, and the robot's computer could be programmed not to allow its instruments to penetrate the vena cava, thereby eliminating bloody intraoperative mishaps.

"Surgery is going digital," Krummel says. "It's no longer about blood and guts but bits and bytes. I don't think [surgical robotics] is an end technology, but a step along the way to something bigger. What might be a bit troubling, though," concludes Krummel, "is that the [first part] of the progress curve seems long and flat. But, that's how it's been with so many other big advances."

An interview with Dr. Lawrence Cohn, a surgeon at Brigham and Women's Hospital, Boston, can be heard at www.nejm.org.

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