Future of Medical Robot Technology

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In medicine, we are entering a new paradigm that is catapulted forward by advanced technology; and the most promising of these new technologies are robotics, telepresence, and virtual reality. These technologies are carried forth on the backs of computers and the telecommunications networks. The new standard bearers for medicine are not the professorial pedants, they are the "Nintendo surgeons."

Medical images, patient records, laboratory tests, vital signs, and physiologic data are all converted into digital format and displayed to physicians, nurses, and medical professionals on video monitors rather than on paper charts, x-ray film or pathology slides. In essence, more and more patient care is being performed through computer assisted (and digitally enhanced) methods. We now have a new physician emerging, a "digital physician," who is not only comfortable with the information technology, but is actually demanding it. Now physician can "dissolve time and space". The next generation of surgery will belong to robotics, telepresence, and virtual reality. The current state of the art in these fields is at the prototype and early clinical trial level.

Robots have always held the imagination to replaced human manual tasks by a machine that can more accurately, efficiently, and rapidly perform a task. The first of these robotic surgical machines to come on the clinical horizon is applied to artificial hip replacement. Dr. R.H.Tayler of the International Business Machine Corp. T.J. Watson Research Center and Dr. H.A. Paul of the University of California at Davis have developed a robotic device (Robodoc) that is capable of extreme accuracy in coring the femoral shaft to accept a femoral prosthesis precisely, thereby dramatically increasing the precision of the femur-prosthesis interface. The next-generation robots may come from the laboratory of Dr. Stephen Jacobsen of the University of Utah where the Utah/MIT dexterous hand brings dexterity, tactile sensation, and force feedback to the operator's hand. Delicate tasks, such as replacing a light bulb without breaking it, demonstrates the level of dexterity and sensory input that has been achieved. In a parallel project, the dexterous telerobotic arm has pioneered multisensory input remote robotic manipulation. By inserting your arm and hand into the Master Exoskeleton, manipulation of a distant robotic arm can permit precision performance of tasks (the Master/Slave teleoperator). These sophisticated machines point to a future where the ability of a surgeon performing a difficult surgical procedure may be enhanced by a robotic control, or where a surgical procedure can be remotely performed in a place too dangerous or distant for the surgeon to actually be present.

Another form of robots under intense investigation are miniature and microrobots. Pioneered at the Massachusetts Institute of Technology (MIT) Artificial Intelligence and Robotics Laboratory under the direction of Dr. Rodney Brooks and associate Anita Flynn, intelligent miniature robots have been developed. Two of the newer generation robots, Genghis Kahn and Atilla, have a limited artificial intelligence and autonomy. Rather than being programmed for a specific task, they have been programmed for a behavior, such as walking while avoiding or crawling over objects. They use sensory input "feelers" and microchip "vision" to navigate the world. Their size of 6 to 12 in. appear to be to large for specific surgical application ; however, Goliath is a robot about the size of a quarter with mobility and vision. Their latest generation "gnat" robot is a prototype that is approaching the size that could be applied to endoscopy. With further miniaturization and integration, it could be possible to develop a robot which is small enough to be placed in the gastrointestinal tract (through the rectum or swallowed) and navigated through tortuous curvatures much more effectively than current generation endoscope. Much research will be required to produce a truly working model.

Teleprersence is like teleoperation (which is used to robotically move dangerous nuclear materials); using a remote manipulator hand or arm and a video image, a surgeon can perform a procedure from a distance. One of the first of these new systems is the Green telepresence surgery system, developed by Dr. Philip Green of SRI International. This is a remote-controlled system developed to answer the three main deficiencies of laparoscopic surgery : (a) the absence of three-dimensional (3D) vision, (b) poor dexterity, and (c)

lack of sensory feedback. Telepresence surgery is accomplished by having a remote operative site with a dexterous manipulator and stereoscopic camera. This permits the surgeon to operated as if it were an open surgical case, regaining the sense of touch and dexterity while having the feeling of actually being at the operative site（telepresence） instead of in front of a video monitor. This system would not only allow the surgeon to operate with the patient adjacent, but even in a remote site such as space station or third world country.

Just as telepresence performs actual procedures, virtual reality will permit surgical procedure on imaginary bodies. There is currently a national research program, the "Visible Human Project," which is creating a virtual cadaver of 1-mm slices from CT, MRI, and photographs of a male and female human cadaver；this national resource provides the "standard" human anatomy that will recreate an ultrarealistic virtual human. It has taken over 40 years for flight simulators to become so realistic that commercial and fighter pilots perform hundreds of perfect takeoffs and landings before ever stepping into a cockpit; the rapid advancements indicated above predict that it will not take nearly as long for the surgical simulator to achieve equal validity.

This scenario for surgery can be translated into other disciplines. All this is possible because we have converted to the electronic image and remote manipulation, which dissolves space and time and permits medical diagnostics and therapeutics as never before. The framework is in place：telepresence surgery with the surgical workstation, satellite networking, robotics and miro-robotics, remote endoscopic and microscopic procedure, and virtual reality simulation. The advanced technology is here, and the future is now.

Laparoscopic surgery is a transition technology that marked the beginning of the information age revolution for surgery. Telepresence surgery, robotics, tele-education, and telementoring are the next step in the revolution. Using computer-aided systems such as robotics and image-guided surgery, the next generation of surgical systems will be more sophisticated and will permit surgeons to perform surgical procedures beyond the current limitations of human performance, especially at the microscale or on moving organs. More fundamentally, there will be an increased reliance on 3-dimensional images of the patient, gathered by computed tomography, magnetic resonance imaging, ultrasound, or other scanning techniques, to integrate the entire spectrum of surgical care from diagnosis to preoperative planning to intraoperative navigation to education through simulation. By working through the computer-generated image, first with preoperative planning and then during telepresence or image-guided procedures, new approaches to surgery will be discovered. These technologies are complemented by new educational opportunities, such as tele-education, surgical simulation, and a Web-based curriculum. Telementoring will permit further extension of the educational process directly into the operating room.

Robotics are now being used in all surgical fields. By increasing intra-abdominal articulation while operating through small incision, robotics are increasingly being used for a large number of visceral and solid organ operations, including surgery on the gallbladder, esophagus, stomach, intestines, colon, and rectum, as well as for the endocrine organs. As a specialty field, robotics should continue to grow. As the robotic era enters the world of general surgeon, more and more complex procedures will be able to be approached through small incision. As technology catches up with our imagination, robotic instruments and 3D monitoring will become routine and continue to improve patient care by providing surgeons with most precise, least traumatic ways of treating surgical disease.