Robotic Surgical Systems

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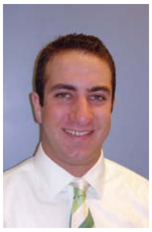
Over the next decade, the number of minimally invasive surgical (MIS) procedures performed will continue to rise while the number of invasive procedures that have a noninvasive option will decline. This trend will have a major impact on the number of robotic surgical systems in use. The increase is largely spurred by the known benefits of MIS procedures, such as decreased recovery time, blood loss, and the length of a patient's stay. However, it is important to note that to date, many complex procedures are not performed using MIS because of the difficulties experienced during manipulation and dissection with a laparoscope or endoscope.

Robotic surgical systems have the potential to improve upon many laparoscopic and endoscopic procedures currently performed manually, including those too complex or difficult to be performed using MIS. These systems do not typically replace the surgeon (only one instance of a completely autonomous robotic surgical procedure has been reported; see sidebar, p. 463). Rather, they create a more precise instrument for patient interface. While the advantages of such systems are still a point of some debate—especially in light of their approximately $1.5 million (not including consumables or service) price tag—support of their use slowly grows. For instance, the number and breadth of procedures that can be performed via robotic surgery has continued to grow—in 2004 more then 16,000 robotic surgical procedures were performed. Currently procedures include cardio, thoracic, gastric, urological, and gynecologic procedures such as hysterectomy or myomectomy.



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The da Vinci Surgical System instrument arm (© 2006 Intuitive Surgical, Inc.).

Robotic Surgical Systems Today

Currently a small number of different surgical robots are in use. According to Intuitive Surgical of California, the only commercial manufacturer of robotic surgical systems, more then 400 da Vinci surgical robots are in use worldwide; a number of other surgical systems are in use as well. AESOP (Automated Endoscope System for Optimal Positioning, also by Intuitive Surgical) is used in a far greater number of facilities, but its primary function is video positioning rather then surgical control. Robotic surgical systems in general comprise a number of components: the surgeon interface (console), the bedside robotic system, and the imaging processor. The surgical console usually resides between five and ten feet from the surgical field, depending on the facility's setup. The bedside robotic system, as the name implies, resides directly next to the patient; its robotic arms house the surgical instruments. The final component, the imaging processor, typically sits somewhere between the bedside surgical system and the surgeon's console, as it feeds the video to the console for the surgeon to view.

The surgical system itself has a number of technological advantages when compared to standard laparoscopic and endoscopic procedures. Among them are:

- 3-D visualization
- Increased tool mobility
- Hand micro-motion reduction

The 3-D visualization system is powered by the imaging processor and allows the surgeon sitting at the console to see the surgical field in 3-D. This more closely resembles an open (invasive) surgical environment. Under standard laparoscopic magnification, the surgical field is rendered in two dimensions, but by use of the specialized optics and scopes used during robotic surgery magnification is increased and rendered more fully in three dimensions, allowing the surgeon to closely view the small surgical field. This magnification advantage, along with the hand-tremor reduction, allows for surgery to be performed on considerably smaller regions of the body than in conventional procedures. Furthermore, through the use of special robotically controlled tools, the system is able to achieve seven degrees of freedom—each degree of freedom allows for an additional direction of articulation at the tool head (i.e., rotation, flexion, extension)—from the mechanical tool heads. This articulation, as with the visualization enhancements, more closely resembles an open surgical environment than standard laparoscopic procedures.

Impacts on the OR and Patient Care

Since the inception of minimally invasive surgical procedures in the 1970s and 1980s, there has been an ever-increasing number of procedures performed using significantly less-invasive means—to date there are more than 100 procedures that can be performed using minimally invasive surgical approaches. This is largely spurred by decreased recovery times and hospital stays associated with MIS procedures when compared to fully invasive practices—although this is a point of debate as some groups feel that although in the long term these reductions will be seen, in the short term inexperience will lead to complications.

This change will, over the next few years, begin to distort the transition from the traditional surgical suite and that of the interventional suite as equipment setups come to more resemble one another. Furthermore, there will be an increase in the numbers of procedures that are performed on an outpatient basis, either outside of the acute care facility in standalone surgical centers or in the physician's office. This will further drive a need for simplified technology setups requiring less day-to-day support while still necessitating regular calibration and monitoring.

Managing Robotic Surgical Systems

These robotic surgical systems, while requiring very little in the way of service management, do require some special handling and setup for clinical use. Since most surgical environments do not have space enough to allow for a separate surgical suite for robotic surgery, a number of issues often arise that are not typical of conventional surgery. These include system storage, maintenance of training, and preoperative setup. Furthermore, unlike many other medical technologies, because of the cost associated with the ownership of a single system, it is not typical for a single clinical/biomedical engineering department to have oversight of a fleet of robotic surgical systems.

Robotic surgical systems are not obtrusively large, but they do require storage space that is in relatively close proximity to the surgical suite; because of their value, it is important to keep them in a secure area as well. While the systems typically comprise a small number of modules, usually three, often a clinical engineer or biomedical technician is still required or sought during system/procedure preparation to provide technical support and setup assistance.

Because of the nature of the primary procedures in which surgical robots are currently used, there already exists a heightened level of necessary risk management. One key issue is the necessary training to perform robotic surgical procedures. While the procedures are in some cases the same as might be performed without robotic aid, performing a surgical procedure using surgical robotics is vastly different on many levels. According to some sources, a surgeon must typically perform 20 to 30 procedures before he or she can be considered a proficient user of a surgical robot system. Thus, it is vital that all necessary training is considered by the purchasing facility prior to, and during, negotiation of the device. Other members of the surgical team, such as the nurse coordinator (see below) must also have adequate training to maximize surgical outcomes and safety.

Interestingly, technical management of many robotic surgical systems is nearly a "hands-off" approach for the in-house biomedical department. The reasoning for this is primarily focused on the complexity of the system as a whole. Typically the systems are designed to monitor

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their own functionality. Through self-diagnostics, they provide feedback necessary to acquire service when needed, while not providing enough information to allow an in-house technician to attempt a quick fix. This is at least in part to prevent the system from being opened to resolve issues through board-by-board checks, as may sometimes be done in a radiology suite.

Yet, even though the service is basically hands-off, it is still vital to monitor the system's service and ensure regular inspection. The maintenance of a close relationship with the service technicians is also vital, as any catastrophic failure of the system would still, most likely, be cause for biomedical engineering's involvement.

Service Training and Troubleshooting

Currently, there is no service training available for in-house biomedical technicians or clinical engineers on most robotic surgical systems. As such, it is necessary to have service technicians from the original equipment manufacturer come onsite for all repairs requiring physical fixes or upgrades to the system, including preventative and scheduled maintenance. This fact alone makes it vital to negotiate a service contract that will cover the surgical robot and all of its components during the purchase process. Typically, the manufacturers will have dedicated service staff for specific facilities, which allows a service engineer to be familiar with each system and any corrective or preventive actions that have been taken on that system.

In the event of a robotic system malfunction, a standardized process has been developed to resolve the situation as rapidly as possible. Typically, when a system malfunction takes place a nurse coordinator—one of the members of the surgical team who has received formalized training on the robot as well as limited troubleshooting training—will immediately contact a 24-hour service line and discuss the problem with a senior on-call engineer. Upon explanation of the problem, a system reset can be performed. If the system reset does not resolve the issues then the process continues, typically with one of two outcomes: an acceptable solution is determined and taken or parts are ordered/shipped and a technician is dispatched to the location—usually within 24 hours. If the second of these two outcomes is determined, it becomes the decision of the surgeon, if the problem cannot be sufficiently resolved, as to whether standard endoscopy procedures or invasive (open) procedures will be used to complete the procedure.

Looking to the Future

Currently, the safety (or foreseen safety) impact has been a primary impetus behind the evolution of robotic surgical systems. It is with these goals in mind that research into new areas of laparoscopy and endoscopy procedures with robotic surgical systems will continue—seeking to use the robotic system capabilities to perform MIS pro-

A Brief History

The term robot was first coined by Karel Capek in the 1920s in a Czechoslovakian theater production called *Rossum's Universal Robots* (R.U.R.). From this first mention of the concept of the robot, their capabilities have continuously advanced from the world's first working robot used in a General Motors car plant in 1961 to expedite production of door handles to the robots of today capable of performing surgical procedures unaided.

The first surgical robots came about in 1985 with the introduction of PUMA-560, a surgical robot used to perform a brain biopsy under CT guidance. This was followed up by the PROBOT in England, used to aid in prostatic surgery, and later by the ROBODOC at the University of California at Davis, which was capable of precision placement during orthopedic hip procedures. It would, however, take a number of years before surgical robots as we envision them today would be a reality.

A leap forward in surgical robot technology came in 1999 with the introduction of the original da Vinci robotic surgical system produced by Intuitive Surgical and Computer Motion's ZEUS robotic surgical system, which both allowed the surgeon to sit at a console while the robotics of the system are staged over the patient. The market however, would not remain a two-company field for long; in 2003 Intuitive Surgical sought to solidify its control over the market by acquiring Computer Motion, its primary competitor, thereby increasing its patent and knowledge holdings.

Some argue, however, that perhaps the greatest leap took place in Rome in 2006, when a team of physicians in Boston, MA, monitored a robotic surgical system performing an undisclosed heart procedure unaided. The procedure took approximately 50 minutes and was performed solely by the robot.

cedures with better outcomes across a larger breadth of case types and patients.

The ability to minimize a surgeon's hand tremors and fatigue while providing 3-D imaging of a region *in vivo* have allowed procedures that could not previously have been performed via scope. But, as these advantages become more accepted, continued steps need to be taken. One such step may be the addition of tactile feedback to the surgeon. This will be crucial in the continuing progress of such technologies, as it will give the surgeons "feel" of what they are performing. While some surgeons believe this is not necessary, as they are able to visualize tensions on the surrounding tissue, the addition would be a welcome one nonetheless.

Interestingly, while telesurgery has been performed using the ZEUS system, it is no longer considered to be a top-tier goal within robotic surgical systems, as having the surgeon patient-side is vital in an emergency situation. This concept, however, may still become a reality as groups such as DARPA (Defense Advanced Research Projects Agency) may still feel a vested interest in the ability to perform surgical procedures on soldiers with the surgeon a great distance away. ■

For More Information

- Intuitive Surgical
  www.intuitivesurgical.com
- "Robotics in General Surgery"
  Journal of the American Medical Association (JAMA)
  www.archsurg.com
- "Robotics and Allied Technologies in Endoscopic Surgery"
  Journal of the American Medical Association (JAMA)
  www.archsurg.com

For additional resources on robotic surgical systems,
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