

Robotics Are Coming to Colorectal Surgery Despite Slow Adaptation, Steady Innovation Points to Future With NOTES

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Some surgeons have touted robotic-assisted laparoscopic colon and rectal surgery as the next great breakthrough in minimally invasive surgery. In contrast to the relatively slow adaptation of laparoscopic colon resections, once of interest only to experts in the field, robotic-assisted procedures are being embraced by many colon and rectal surgeons today who are eager to explore them first-hand—despite the paucity of literature on the subject.

The Literature

In 1995, a team of Johns Hopkins University researchers developed a prototype robotic-assisted laparoscopic system and performed the first robotic cholecystectomy a few years later (*Am J Surg* 2004;188:19S-26S). In 2001, Philip A. Weber, MD, et al performed the first robotic-assisted laparoscopic colectomy for benign disease (*Dis Colon Rectum* 2002;45:1689-1694). Soon afterward, Makoto Hashizume, MD, and colleagues reported three resections for malignant disease using a robotic system (*Surg Endosc* 2002;16:1187-1191).

Recent innovations have included a stable three-dimensional (3D) camera platform; optimal ergonomics and instrumentation with wide-range degrees of freedom; and modulation of motion. Today, the only FDA-approved robotic system is the da Vinci Surgical System (Intuitive Surgical).

Conventional Limits

The benefits of laparoscopic colorectal surgery compared with traditional open techniques have been established: less surgical trauma, diminished intraoperative blood loss and reduced wound infection and pulmonary complication rates. Additionally, smaller incisions with less scarring, reduced need for narcotics, earlier return of bowel function and shorter hospital stays also have been well documented.

Multiple reports have shown no detrimental effects of laparoscopic surgery in patients with curable colorectal cancer. The laparoscopic approach maintains the basic principles of open oncologic surgery, including adequate resection margins, en bloc mesenteric and vascular resection and minimal intraoperative manipulation of the tumor mass and complete lymphadenectomy.

Yet, some limitations of laparoscopic surgery for colon and rectal cancers may account for its slow acceptance by the field. In laparoscopic surgery, the video camera is assistant-dependent and can be unstable; the view is two-dimensional (2D); and the range of motion is limited. The fixed instrument restricts wrist movements.

Surgery of the rectum poses the additional challenges of operating in a deep space where the sacrum restricts downward range of motion and the reach of laparoscopic instruments. Division of the rectum and mesorectum requires awkward angles and position changes with frequent inadvertent camera smudging and fogging. Suturing and knot tying are more restricted. The exceptionally skilled laparoscopist can overcome these challenges, but for most general and colorectal-trained surgeons, these deterrents are significant.

What Is Robotic-Assisted Laparoscopy?

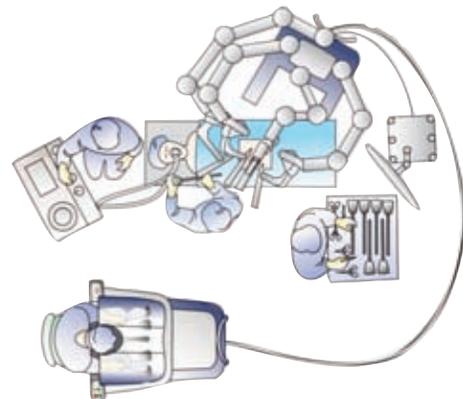
Robotic surgery recaptures many of the features of open surgery while preserving the minimally invasive platform. The surgical robotic system comprises a work unit and console linked via a computer-based interface. The work unit has one camera arm and three surgical arms that dock to the patient. The surgeon sits and operates at the console adjacent to the operative field.

Each surgical arm is fitted with specialized articulated instruments and, along with the camera arm, docks into the operative field through trocars. A complex cable-driven joint at the distal end of the instruments gives the surgeon two additional degrees of freedom compared with conventional laparoscopic instruments. This results in movements that mimic the wrist during open surgery.

The camera arm supports a 12-mm, high-resolution, 0- and 30-degree endoscope. Two three-chip, charge-coupled devices within the camera head transfer the image to the surgeon's console. This creates an integrated 3D representation of the operative field that far exceeds the 2D view.

At the console, the surgeon's elbows rest on a smooth support in front of the robotic handles. The thumb and index finger of each hand pass through two rings on respective master manipulators, which are mobile in all directions. Surgical movements correspond to the tips of the articulated instruments in the operative field. Tip articulations mimic the upward, downward and side-to-side wrist flexibility. Intracorporeal and deep manipulation, anastomosis and knot tying are feasible and natural.

The computer filters out unintended movements and tremors. Throughout the procedure, the surgeon repositions the hands on the console to the optimal ergonomic location by pressing on the master foot pedal, which temporarily disconnects and keeps the intracorporeal instruments locked until the repositioning is complete. An adjacent foot switch manipulates the camera.



Studies have suggested that the robotic camera lens smudges and fogs less than the assistant-controlled camera and causes fewer inadvertent laparoscope movements (*Surg Laparosc Endosc Percutan Tech* 2002;12:46-51). With the operating surgeon controlling the camera in robotic-assisted surgery, the view tends to focus on the pertinent anatomy more rapidly than with an assistant. The robotic arm keeps the camera still and steady.

Why Robotic-Assisted Surgery?

The most convincing indications for robotic surgery are for procedures in small, deep and narrow operating fields, and for when minimally invasive surgery requires extreme accuracy (Arch Surg 2003;138:777-784). For this reason, as well as for its nerve-sparing effects, robotic-assisted laparoscopic surgery (RALP) has gained widespread use relatively quickly. In 2000, there were 1,500 robotic prostatectomy procedures reported; in 2008, more than 80,000 cases were reported (Curr Opin Urol 2008;18:173-179).

Multiple accounts have revealed lower rates of postoperative impotence and incontinence with robotic versus open prostatectomy. Authors have suggested that this technique permits more complete extirpation of malignant tissue (J Urol 2008;180:1018-1023). Because rectal procedures also involve a narrow, deep and confined operative field with nearby critical structures, it logically follows that they would actualize the advantages of RALP.

Oncologic rectal resection with mesorectal excision, whether open or laparoscopic, requires precise technique, a challenge even for the most experienced surgeon. Technical expertise may result not only in better oncologic resection but also in improved quality of life if nerve-sparing surgery is accomplished. The robotic system provides excellent access and visualization in this restricted space. Robotic resection greatly enhances mesorectal excision with identification and preservation of autonomic nerves as well as suturing and knot tying in the deep pelvis to oversew a stapled anastomosis.

Another important advantage is the surgeon's location—at an ergonomically ideal position with midline visualization of the operative field and ambidextrous utility of the instruments. In open surgery, the surgeon may struggle to visualize critical structures in the deep pelvis and compromise his or her posture to gain access and retraction.

One must weigh the advantages of the robotic approach against its limitations (Table 1). The robotic system is bulky. It requires a large operating suite, and the surgeon must operate at a console at a distance from the operating table, a position many find awkward and intimidating.

Like all new technologies, the robotic system has a learning curve. Authors have suggested that surgeons complete 20 cases to learn advanced skills with a robotic system, including intracorporeal anastomosis, suturing and knot tying (Arch Surg 2003;138:777-784). For hospital privileges, the surgeon is typically required to have a proctor for the first five cases and to maintain a database of the first 20 cases (Table 2). The manufacturer offers a three-phase training program.

Additional limitations include the longer setup time the system requires in comparison with laparoscopy. Along with unit and instrument costs, this can increase the overall operative cost by an average of \$350 per case (Dis Colon Rectum 2003;46:1633-1639). A four-armed da Vinci Surgical System sells for \$1.25 million, with annual maintenance of about 10% of the total price. Semireusable instruments (10 uses) cost \$2,000.



Single-Port Surgery, NOTES

The current system facilitates natural orifice extraction of the surgical specimen (natural orifice transluminal endoscopic surgery [NOTES]). For rectal resections, we have begun to use robotic-assisted surgery for transvaginal and transanal extractions. The precision of intracorporeal suturing has allowed us to perform modified hand-sewn colo-anal anastomosis from an abdominal approach for bowel continuity. Robotic-assisted surgery will allow us to offer patients the best chance for a sphincter-sparing procedure.

Single-port robotic access devices will involve the independent movement of multiple instruments with deep and articulated motions in two or more quadrants that could overcome the limitations of current laparoscopy. Existing laparoscopic single-port techniques do not facilitate independent instrumentation and full range of motion without significantly compromising the working operative field and intracorporeal techniques. Thus, these single-port technologies are limited to basic procedures confined to a single organ in a single operative field.

Robotic-assisted technology may facilitate use of the single-port surgery in more complex colorectal procedures. Future prototypes will include single-port access and endoluminal capabilities, resulting in integrated approaches to natural orifice and transendoluminal techniques.

Future Directions

Within the next two years, Intuitive Surgical plans to introduce laser capability as well as articulated sealing energy instruments to its da Vinci system. This new robotic architecture will be smaller, with expanded range of motion and smaller and more diverse tools. The systems will be in fully integrated operating room suites and have the ability to move the table intraoperatively without undocking the system. Future generations may include haptics to provide force feedback and incorporate tensile sensors to provide the sense of "touch" to the robot.

Soon, da Vinci platforms will enable advanced data and image fusion, including import of 3D reconstructed computed tomographic images and real-time ultrasound with wristed instruments to enhance the 3D visual field. High-resolution preoperative images preloaded into the computer will allow the surgeon to view the virtual surgical field in various magnifications and angles during the procedure. Image overlay will enable one to detect and identify hidden anatomic structures and perhaps even operate where the view is otherwise obstructed. The technology can also help ensure negative radial and distal margins during oncologic resections.

Studies will evolve to evaluate the oncologic and quality-of-life outcomes of robotic-assisted rectal procedures. Until then, we can only theorize that the benefits of this technological approach will translate into improved patient outcomes, as they have for prostate cancer.

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Table 1. Advantages and Limitations of Using a Robotic Surgical System

Advantages	Limitations
Wristed movements with seven degrees of freedom	Expert laparoscopic experience prerequisite for learning curve
Exposure and maneuverability in deep and narrow region	Loss of tactile sensation and tensile feedback
Ease of intracorporeal suturing and knot tying	Prolonged setup and overall OR time
Steady camera platform with 3D view of operative field	Bulky equipment with surgeon at console away from OR table
Optimal surgeon position and ergonomics	Additional costs of prolonged OR time and equipment
Computerized scaling of motion and elimination of physiologic tremor	Usually requires additional ports (five or six)

3D, three-dimensional; OR, operating room.

Table 2. Requirements for Hospital Privileges To Perform Robotic-Assisted Rectal Procedures

- Privileges in advanced laparoscopic colon and rectal procedures is prerequisite
- Completion of Intuitive Surgical's da Vinci training course
- Observation of cases involving robotic surgery in the pelvis (colorectal, urologic or gynecologic)
- Successfully complete five cases with accredited proctor approval
- Maintain database of initial 20 cases with acceptable 30-day outcomes review