Robotic Colorectal Surgery for Neoplasia

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KEYWORDS

- Robotic • Colorectal • Colon • Rectal • Cancer • Neoplasia
- Total mesorectal excision

KEY POINTS

- Robotic colorectal surgery has several advantages to surgeons, including improved visualization, enhanced control, and improved ergonomics.
- Robotic total mesorectal excision (RTME) is currently the main application for colorectal surgeons, and it is associated with a lower rate of conversion to open surgery than its laparoscopic counterpart.
- Outcomes after robotic colorectal surgery are similar to conventional laparoscopy.
- The learning curve for robotic colorectal surgery is short, but surgeons are often already experts in laparoscopy, which makes the number difficult to interpret.

INTRODUCTION

Minimally invasive surgery (MIS) for colon and rectal cancer is now universally accepted as providing equivalent oncologic outcomes to open surgery and offers added benefits, including earlier return of bowel function, shortened length of stay, and better cosmesis. The evidence for laparoscopy comes from multiple well-designed randomized controlled studies, meta-analyses, and case-matched and prospective cohort studies.[1–8] Laparoscopy, however, has several well-known limitations, including limited range of movement, 2-D vision, requirement of a highly trained assistant, and a long learning curve.[9]

Robotic surgery is in essence laparoscopy with sophisticated equipment designed to overcome these limitations. The key elements of the robotic platform include high-definition 3-D vision, EndoWrist (Intuitive Surgical, Sunnyvale, CA, USA) instruments

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with greater degrees of freedom, and absence of tremors of the human hand to the instrument tips.[10]

Colon and rectal surgery was one of the earliest specialties to adopt robotic surgery, with Weber[11] and Hashizume[12] reporting the first operations for benign and malignant colorectal disease, respectively in 2002. D'Annibale[13] and Giulianotti[14] from Europe and Delaney and colleagues[15] from the United States were the early pioneers of this technology, publishing some of the seminal papers in this field.[11–17]

For the purpose of this article, the term *robot* refers to the da Vinci Si 4-arm system (Intuitive Surgical, Sunnyvale, California). The latest system is known as the Xi and is discussed in detail later. With the dual console system, it is possible to walk a trainee through the operation, with graded responsibility to complete more complex tasks as training progresses. The system also allows a more objective validation of surgical skill and competence using the skill simulator and external animate and inanimate models.

BENEFITS OF ROBOTIC SURGERY

Benefits to the Surgeon

The major advantage of robotic surgery for the surgeon is improved visualization, because robotic imaging includes depth perception akin to open surgery due to the stereoscopic 3-D image, a consequence of a dual telescope system. This allows a more precise dissection and preservation of critical structures, for example, the pelvic autonomic nerves during mesorectal excision.[18] Additionally, the heat generated at the tip of the dual lens system makes fogging and loss of clarity infrequent.

The second benefit is the instrumentation. The double-jointed EndoWrist has improved versatility compared with conventional nonarticulating laparoscopic instruments, and it maneuvers well in tight spaces, such as the pelvis. There is less dependence on a skilled assistant, because the surgeon controls the camera as well as a third operating arm, which can be used for retraction. Robot instruments also eliminate surgeon tremor, allowing for a more controlled dissection. When working in the deep pelvis, especially in obese men, the advantages of robotic instrumentation become the most apparent.

Another important advantage to robotics is improved ergonomics for the operating surgeon. The surgery is performed while sitting down, and the controls can be adjusted to reduce the pain and fatigue of a long, complex operation.[19] Conventional laparoscopy, on the other hand, is known to be associated with a high incidence of neck, back, and shoulder pain, muscle stiffness, headache, visual discomfort, and fatigue.[20,21]

Limitations

The major issue in robotic surgery is the significant increase in cost compared with laparoscopic and open surgery. The cost increase has 3 components[10]: (1) fixed costs of purchase and subsequent machine maintenance, (2) consumables (drapes and instruments with limited lifespan), and (3) increased operative time. Another limitation to robotics is the absence of haptics or tactile feedback. The surgeon understands tissue grip by visual cues, such as tissue blanching or shearing. Therefore, there is potential for suture fray and tissue injury if the surgeon is inexperienced. This is a component of the robotic learning curve, and practice in the dry, porcine, or cadaveric laboratory significantly improves understanding of tissue and suture tensile strength.

Benefits to the Patient

The MIS approach to colorectal surgery has several well-known benefits compared with open colectomy, including smaller incisions, less pain, and a quicker overall recovery. Additionally, some smaller studies report less pain with robotics compared with laparoscopy, presumably due to reduced movement at trocar sites and less torque on the abdominal wall. These same studies show a slightly quicker return of bowel function.[22]

Another benefit to the patient is a lower rate of conversion to open surgery for robotics (0%–4.9%) compared with laparoscopy (7.3%–34%), although these data are from heterogeneous studies.[2,23–30] Additionally, patient subgroups previously categorized as unsuitable for a minimally invasive approach, including the morbidly obese and those with locally advanced rectal cancers requiring exenteration have been operated successfully with the robotic platform, thereby extending the spectrum of MIS.[27,31]

TECHNIQUE

Robotic Total Mesorectal Excision

RTME is widely believed to be the area of greatest benefit compared with laparoscopic total mesorectal excision (TME). TME is a technically demanding operation whether performed open or by minimally invasive methods. It involves identification and separation of the rectum in the embryologic interface between the visceral and parietal fascia—along the holy plane, as described by Heald.[32] This plane can and often is obfuscated by edema after pelvic radiation, and the penalty for violating the mesorectal fascia is grave—a positive circumferential margin (CRM), tumor perforation, or an incomplete mesorectum are strongly associated with increased local recurrence, distant metastases, and decreased survival.[33,34] In the deep pelvis, especially in men, there is a paucity of space, and the need to preserve an intact mesorectal envelope often leads to damage to the autonomic nerves, which leads to inadequate bladder emptying, retention, and impotence in men.[18]

Technical Aspects

There are 2 main approaches to RTME (**Table 1**): a fully robotic dissection and a hybrid approach. In the latter, conventional laparoscopy is used to mobilize the left colon and control the major vessels, with the robot docked solely for the pelvic portion of the operation.[35]

The fully robotic approach is typically more challenging because the robotic system has limited range of external instrument arm movement and changes in cart position (redocking) are often required to accomplish mobilization of the splenic flexure, left colon, and rectum. Single docking has been described for select patients,[36,37] but a dual-docking approach allows for adequate mobilization of the splenic flexure.[26,38,39] Regardless of docking, the fully robotic approach is difficult in larger patients, and it is associated with more minor complications compared to a hybrid approach,[40] so it should be used selectively. The Xi system (discussed later) is better suited to the fully robotic approach with minimized arm collision.

The hybrid approach uses 2 minimally invasive techniques. Standard laparoscopy is used to mobilize the left colon and splenic flexure, and the robot is then docked for the

Table 1
Main approaches to robotic total mesorectal excision

Approach	Colon Mobilization	Rectal Dissection
Fully robotic	Robot	Robot
Hybrid	Laparoscopy	Robot

TME.[41] The inherent benefits of the robotic system, including the camera and 3 working arms that are controlled by a single surgeon, the stability of the platform, and the precision of movement due to motion scaling and wrist articulation, all make it well suited for the difficult work required in the pelvis. A reverse hybrid technique has also been described and involves completion of the RTME first robotically, followed by rectal transection and completion of the left colon mobilization, lymphadenectomy, and anastomosis laparoscopically.[42]

Principles of robotic cart positioning

For RTME, the robot is either placed between a patient's legs or at a patient's left hip. Positioning the cart between the legs allows for an ergonomic, fast, and forgiving setup, with the lowest risk for robotic arm collision, both inside and outside. It does, however, make it difficult to access the perineum for intraoperative finger examination, flexible sigmoidoscopy, or transanal stapler application.

Conversely, positioning the cart at the left hip allows for easy access to the perineum, but it requires a clear understanding of spatial arm distribution and careful port placement. Even a small misplacement of the ports can lead to arm collisions. Positioning the cart at the left hip also gives the bedside assistant more room. The anatomic structures that can be accessed using the robotic device in either of these setup approaches are detailed in Table 2.

Robotic instruments: macroretraction and microretraction

Macroretraction refers to retraction of the necessary macrostructures during TME, for example, the rectosigmoid during the initial phase of dissection (opening of posterior plane) or the anterior pelvic structures during dissection along the Denonvilliers fascia. Microretraction refers to the application of tissue tension needed to perform cautery dissection in a desired tissue plane (Table 3).

During RTME, the bedside assistant is actively working to allow tension and exposure. Additionally, each robotic arm has an assigned role as follows: right arm (#1) – cautery dissection; middle arm (#2) – microretraction and bipolar cautery; and left arm (#3) – macroretraction. The physical right hand of the operator controls the right arm (#1) of the robot, while the physical left hand of the operator controls the middle (#2) and the left (#3) robotic arms, switching in-between with the use of the clutch mechanism. The most common robotic instrument used by the right robotic arm (#1) is the cautery hook or monopolar scissors. The middle arm (#2) is often supplied with a bipolar fenestrated grasper and the left arm (#3) holds the Cadiere (Intuitive

Table 2
Anatomic structures that can be accessed using the robotic device

	Setup	
Anatomic Structure	**Between the Legs**	**Right Hip**
Splenic flexure	–	+ (Low splenic flexure/short patients)
Descending colon	–/+	+
Inferior mesenteric vein	–	+ (Potential reach/collision problem)
Inferior mesenteric artery	+	+
Rectosigmoid	+	+
Rectum		
Upper/mid	+	+
Low/levators	+	+ (Potential reach/collision problem in tall patients)

Table 3
Definitions of macroretraction and microretraction

Macroretraction	Retraction of necessary macrostructures by freezing a retracting arm (rectosigmoid during posterior dissection, anterior pelvic structures during anterior dissection)
Microretraction	Application of necessary tissue tension by an active arm to perform dissection in desired tissue plane

Surgical, Sunnyvale, CA, USA) forceps. The summary of each instrument function is presented in Table 4.

Robotic rectal dissection

Dissection commences posteriorly, entering the avascular holy plane and avoiding injury to the hypogastric nerves,[43] and working down to the pelvic floor and coccyx. Dissection then continues laterally, and then finally the rectovesical/rectovaginal fold of the peritoneum is incised to expose Denonvilliers fascia, and the rectum is mobilized from the prostate/vagina. Maintaining the plane of dissection posterior to Denonvilliers fascia avoids troublesome bleeding from the vascular plexus that surrounds the seminal vesicles and prevents sexual dysfunction from occurring. Dissection anterior to this fascia is required only in anteriorly placed tumors. The fixed third-arm retraction on the bladder/vagina, provided by the retracting robotic arm #3, significantly facilitates surgical access and visualization during the anterior rectal dissection.

Distal rectal transection can be accomplished through several techniques. The robot can be undocked, and either the left lower quadrant or suprapubic ports upsized to facilitate a laparoscopic stapler. There is also a robotic stapler available, which can be used for arm #1. The specimen can then be removed through a small extraction site (Pfannenstiel incision, reversed McBurney incision, or lower midline incision) through the ileostomy site or through the anus. In obese patients, the authors' preferred method is the Pfannenstiel incision because it has the lowest incidence of incisional hernia.[44]

In patients who undergo abdominoperineal resection, TME can be combined with robotic intra-abdominal transection of levators. This allows the surgeon to obtain the cylindrical-shaped specimen while minimizing the perineal wound.[45] It also allows for controlled division of the levators under direct visualization and a narrowing transection perimeter of the levators on the side not affected by tumor.

Retraction and handling of the mesorectal specimen is important, especially with large tumors. A break in the mesorectal and colonic envelope can increase the risk

Table 4
Robotic instrument functions

Arm	Instrument	Function
Robotic arm #1 (right)	Cautery hook/scissors	Dissection
Robotic arm #2 (middle)	Bipolar fenestrated grasper (ProGrasp)	Microretraction/dissection/ bipolar cautery
Robotic arm #3 (left)	Cadiere forceps, Graptor, double fenestrated grasper	Macroretraction/dissection
Assistant left arm (right upper quadrant)	Bowel grasper	Macroretraction and microretraction
Assistant right arm (suprapubic)	Suction-irrigator	Suction-irrigation, macroretraction, and microretraction

of tumor cell seeding. In the authors' experience, a majority of breaks in the mesorectal envelope happened during macroretraction that was applied during dissection in the presacral space. Rarely should the third robotic arm grasp the fascia propria of the rectum (mesorectal envelope).

OUTCOMES

Perioperative Outcomes

Robotic surgery is associated with comparable perioperative outcomes, such as length of stay and return of bowel function, as with laparoscopic surgery. Operative time and blood loss are similar to laparoscopy, whereas conversion rates are lower than with laparoscopy, varying from 0% to 4.9%, respectively, compared with 7.3% to 34%, respectively, in large laparoscopic series.[2,23–26,28–30,40,46] A 2012 meta-analysis also reported lower rates of conversion to open surgery (2% vs 7.5%, $P = .0007$).[47] Short-term complication rates are similar to laparoscopy, with an anastomotic leak rate of 1.8% to 12.1%.[24–26,28,35,40,46]

Oncologic Outcomes

Rates of CRM positivity are 0% to 7.1% for RTME, with a distal margin positivity of 0% to 1.9% and a lymph node yield of 13 to 20 nodes.[24–26,28,35,40,46] The number of studies with long-term outcomes data is limited, but emerging data indicate disease-free survival (DFS) and overall survival (OS) rates comparable to open and laparoscopic TME. Reported 3-year DFS rates are between 73.7% and 79.2% and OS rates between 90.1% and 97.0%.[24,35,40,46] There are only a few studies reporting 5-year survival data. Park and colleagues,[48] with a median follow-up of 58 months, found no significant differences in 5-year OS, DFS, or local recurrence rates between patients treated with robotic and laparoscopic surgery for rectal cancer. The 5-year OS rate was 92.8% in robotic and 93.5% in laparoscopic surgical procedures ($P = .829$). The 5-year DFS rates were 81.9% and 78.7%, respectively ($P = .547$). Local recurrence was similar: 2.3% and 1.2% ($P = .649$). In one of the largest series of 200 consecutive resections for rectal cancer, Hara and colleagues[49] reported local pelvic control and OS and DFS rates of stage III patients at 5 years as 93.0%, 88.6%, and 76.6%, respectively.

Functional Outcomes

Genitourinary function can be disturbed after TME due to injury to the superior hypogastric plexus around the root of the inferior mesenteric vein, hypogastric nerves, pelvic plexus, or splanchnic nerves (sacral and pelvic). Damage to the superior hypogastric plexus can lead to disturbances in ejaculation in men and to decreased lubrication in women, whereas a lesion in the pelvic splanchnic nerves or the pelvic plexus causes erectile dysfunction in men and cause diminished labial engorgement response in women. Both laparoscopy and robotic surgery lead to diminished libido and sexual dysfunction, but there is earlier recovery in the robotic arm (6 months) compared with laparoscopy (1 year). Bladder parameters, including filling and voiding function, deteriorate when measured at 1 month but recover within 3 months in robotic versus 6 months in laparoscopy.[50] Luca and colleagues[18] found no change in bladder function in the robotic arm and postulate that this is due to better visualization of the nerves and early catheter removal.

Robotic Versus Laparoscopic Resection for Rectal Cancer Trial

The Robotic versus Laaroscopic Resection for Rectal Cancer (ROLARR) trial is an ongoing international, multicenter, prospective randomized controlled trial of robotic-assisted versus laparoscopic surgery for the curative treatment of rectal cancer. The preliminary results were presented at the American Society of Colon and Rectal Surgeons 2015 meeting in Boston. The short-term postoperative and pathologic outcomes analysis showed that robotic systems had a nonsignificant reduction in conversion rates (8.1% vs 12.2%, $P = .158$).

No differences were observed in the short-term postoperative complication rate (33.1% in the robotic group vs 31.7% in the laparoscopic group) and oncological outcomes (CRM positivity 5.1% in the robotic group vs 6.3% in the laparoscopic group). The lack of a statistically significant difference could be explained by the limited number of patients enrolled in the study and by the bias related to differences in the surgeons' expertise in the robotic and laparoscopic approach.

Cost Data

Cost data were not evaluated in the ROLARR trial. A Korean study, however, reported total charges of $14,647 for RTME versus $9978 for laparoscopic TME.[51] Similarly, in the United States, the mean cost of robotic surgery was $22,640 versus $18,330 for the hand-assisted laparoscopic approach ($P = .005$).[35]

Robotic Colon Resections: Is There a Role?

Since the first reported robotic colon resections in 2002, robotic assistance has been used to perform all manner of colon resections: right, left, transverse, sigmoid, and total colectomy. The sigmoid robotic colectomy essentially represents the colonic mobilization and lymphadenectomy as for rectal cancer resections and is an important learning tool, although there was no oncologic superiority or clinical benefit found compared with laparoscopy.

Robotic right colectomy has been extensively studied in comparison to laparoscopy and provides no measurable benefit, either in terms of perioperative outcomes, including blood loss and conversion rates, or complications, including anastomotic leaks.[52] There is a significant increase in operative time and an increased cost of approximately $3000. An interest in robotic assistance in right colectomy has resurfaced due to its ability to facilitate complete mesocolic excision.[53] Complete mesocolic excision with central vascular ligation, as proposed by Hohenberger and colleagues,[54] is a technique to remove the right colon along its defined embryologic planes with dissection of all vessels up to the superior mesenteric axis with a complete lymphadenectomy.

At present, robotic colectomy (with the Si system) can only be recommended as a learning tool to develop the skills necessary to eventually perform a high-quality TME.[52] The advent of the Xi, however, may change this practice.

LEARNING CURVE FOR ROBOTIC SURGERY

The learning curve for performing robotic colorectal operations is shorter than for laparoscopy and is achieved after 15 to 30 cases.[26,36] There are 3 phases identified in the learning curve for robotic colorectal operations[47–49]:

Phase 1 – initial learning (1–15 cases)
Phase 2 – increased competence (15–25 cases)
Phase 3 – period of highest skill (>25 cases)

Systematic reviews of learning curves in laparoscopic and robotic colorectal surgery show that defining proficiency is difficult and subjective, depending on the parameters studied.[55] Operative time is commonly used as a surrogate for efficiency but is imperfect, and shorter operative time and conversion rates do not always translate into better patient outcomes.[56] A 2016 systematic review determined that the mean number of cases was 29.7 for phase 1 and 37.4 for phase 2, with 39 cases necessary to be considered an expert.[57]

Melich and colleagues[58] looked at perioperative outcomes and learning curves for a single surgeon trained in open colorectal surgery who simultaneously adopted laparoscopic and robotic surgery at the beginning of his minimally invasive career. This series provided a unique insight on MIS learning curves and allowed for direct comparisons.[58] Although initially slower than laparoscopy, operative times for robotic surgery improved rapidly and after 41 cases became faster than laparoscopy.

EVOLUTION OF ROBOTIC TECHNIQUE

The da Vinci Xi System

The da Vinci Xi surgical robotic system represents a natural, evolutionary progress of the da Vinci technology. It is the fourth generation of the robotic line and currently the most sophisticated surgical robotic system available. Released in 2015, the Xi has a completely new system of robotic arm support involving an overhead boom from which 4 independent robotic arms are suspended. This simplified the docking process for the bedside assistant and allowed all arms to rotate as a group in a coordinated, computer-controlled fashion. This approach, combined with smaller ports for the robot arms, extended range of motion and increased the reach of the instruments. The optical system was also significantly enhanced and simplified while the scope can be positioned in any robotic arm. The Xi system allows for work in multiple quadrants without redocking and may extend the indications for robotic colectomy.

da Vinci Sp Single-Port Flexible System

Since the advent of natural orifice transluminal endoscopic surgery and more recently transanal TME, high hopes were placed on robotics to mitigate the challenging aspects of single-port surgery. A highly anticipated da Vinci SP flexible system device is currently awaiting Food and Drug Administration (FDA) clearance and is thought to be a new promising avenue for MIS. The computer-enhanced and coordinated control of the flexible robotic arms, including the optical system, is expected to improve precision and efficacy especially during the transanal approach.

Reduced Port and Single-Incision/Single-Port Robotic Colorectal Surgery

There is no FDA-approved single-port device for robotic colorectal surgery as yet. A modified port using an Alexis wound retractor placed through a transumbilical incision, with a surgical glove to form the cover of the port has been used by Lim and colleagues to perform single- port sigmoid colectomy successfully.[59] Trocars are placed through the cut fingers of the glove and a 3-arm robot configuration is used. Short-term oncologic outcomes and perioperative parameters are acceptable with this technique.

Reduced port surgery, using the FDA-approved single port through a transumbilical incision, with an additional robotic port in the right lower quadrant, has been reported by Bae and colleagues[60] for left colon, sigmoid, and rectosigmoid cancers with no conversions and adequate node yield and negative margins. The da Vinci single-port system has 4 ports, 1 for an 8.5-mm robotic camera, 1 for the assistant, and 2 curved trocars that allow instruments to cross each other. The major advantage over SILS is that the computer is able to allocate each instrument to the hand on the side of the ipsilateral visual field, meaning the left instrument is controlled seamlessly with the right hand and vice versa.

SUMMARY

Robotic surgery is a natural evolution of the minimally invasive technique and should be considered one of the tools currently available for practicing surgeons. It is not likely to replace the traditional laparoscopy; however, it should be treated as its complement in selected cases. Surgery in the deep pelvis is particularly amenable to a robotic approach. New robotic technology is emerging that addresses some of the weaknesses of the earlier systems, which may lead to increased utilization in the near future. In general, the surgeon benefits more than the patient from the use of robotic technology, because it allows for improved ergonomics, visualization, versatility, and control of the case.

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