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EVIDENCE-BASED CURRENT SURGICAL PRACTICE

Robotic Colorectal Surgery

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Abstract
Introduction Minimally invasive surgery has many potential benefits, and the application of recently developed robotic technology to patients with colorectal diseases is rapidly gaining popularity.
Quality and Outcomes However, the literature evaluating such techniques, including the outcomes, risks, and costs, is limited. In this review, we evaluate and summarize the existing information, calling attention to areas where future investigation should occur.

Keywords Robotics · Colorectal surgery · Minimally invasive surgery

Introduction

The use of minimally invasive technology has had a significant impact on colorectal surgery and every year brings new applications. The first laparoscopic colorectal surgery was performed in 1991. Since then, the laparoscopic approach in colon surgery, for cancer as well as benign disease, has been shown to confer significant short-term benefits: reduction of pain, shorter hospital stay, and earlier return to work, without increasing adverse outcomes.[1–3] Minimally invasive surgery for rectal cancer is technically much more challenging but seems to confer the same benefits. It was initially feared that laparoscopic rectal cancer surgery was an oncologically inferior operation compared to open proctectomy, with early reports raising concerns about a higher rate of positive circumferential resection margin (CRM).[4] However, the recent report of the colorectal cancer laparoscopic or open resection trial (COLOR) II, the largest randomized, multi-institutional clinical trial comparing laparoscopic to open proctectomy, demonstrated no difference in short-term oncologic outcomes, including rates of positive CRM.[5] Long-term follow-up in a smaller series showed no difference in survival or disease recurrence.[3]

Laparoscopic surgery does have limitations, however. The instruments are rigid, restricting the surgeon's movements, and this can be a significant disadvantage when operating in the narrow confines of the pelvis. Additionally, the surgical assistant must have considerable experience to provide a stable camera view and steady retraction. These issues result in a steep learning curve; one study estimated that true proficiency is achieved only after 50 cases.[6]

Since the early 2000s, the use of a robotic surgical platform has become increasingly popular. Robotic technology may help overcome some of the limitations of laparoscopic colorectal surgery.[7] Robotic surgical instruments are flexible and maneuverable, providing wristed movement. This allows the surgeon to reach around anatomic structures, to operate in small spaces, and to perform precise lateral dissection. The robotic camera provides a high-definition three-dimensional (3D) view; mounted on a robotic arm, it is stable and controlled by the operating surgeon. The newest robotic platform contains three operating arms, allowing the surgeon to self-assist with retraction and operate in a more ergonomically favorable position. Lastly, it has been estimated that the learning curve is reached after approximately 20 cases, even for surgeons who lack significant laparoscopic experience.[8] Because the robot affords improved visualization and manipulation, facilitating precise dissection within the confines of the bony pelvis, the use of robotic-assisted resection for patients with rectal cancer has been increasing. Many groups have described application of the technology to benign conditions as well, including complicated diverticulitis,[9] rectal

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prolapse,[10,11] and restorative proctectomy for inflammatory bowel disease.[12–14] The symptoms, evaluation, and treatment of benign colorectal diseases vary greatly and are beyond the scope of the current discussion. In this article, we focus on the use of minimally invasive robotic surgery in the treatment of colorectal cancer, including a review of the literature to date.

Symptoms

It is estimated+ that more than 140,000 people in the USA are diagnosed with colorectal cancer annually, and 50,000 die of disease each year.[15] The majority of cases are detected on routine screening studies, and many patients present without symptoms. The presence of symptoms generally indicates locally advanced disease. Right-sided colonic lesions are often associated with anemia and vague abdominal complaints, whereas left-sided and rectal tumors present with hematochezia or change in bowel habits.[16]

Diagnosis

Colorectal cancer diagnosis is made with endoscopic biopsy of malignant polyps or masses. Following complete colonoscopy, patients should be evaluated for evidence of distant metastases. This is usually done by computed tomography imaging (with oral and intravenous contrast) of the chest, abdomen, and pelvis. Carcinoembryonic antigen levels are generally evaluated preoperatively (and are routinely checked during long-term postoperative surveillance). Patients with locoregional colon cancer and no evidence of metastatic disease are candidates for colon resection.[17]

Diagnosis and surgical planning for rectal cancer require additional studies. Rectal cancer is generally defined as a lesion located less than 12–15 cm from the anal verge. Digital rectal exam plays an important role in defining the character and location of low rectal tumors in relation to the anal sphincter complex and in determining whether or not a sphincter-preserving operation is possible.[18] Endorectal ultrasound and magnetic resonance imaging of the rectum can help determine the depth of tumor invasion or involvement of the mesorectal lymph nodes. All of this information is important in planning treatment.[19]

Treatment

Colon resection remains the mainstay of treatment for locoregional colon cancer, with 5-year relative survival rates ranging from 65 to 95 %, depending on stage.[15] For stage II or III rectal cancer that invades beyond the muscularis propria into the perirectal fat (T3) or involves regional lymph nodes (N1–2), neoadjuvant chemoradiation therapy followed by surgical resection is the accepted standard of care.[20] Over the past few decades, the widespread adoption of total mesorectal excision (TME) and advances in neoadjuvant chemoradiotherapy have been shown to reduce rates of local recurrence.[21–23]

In general, patients without significant previous abdominal surgery are candidates for a minimally invasive surgical approach. For some patients, robotic surgery may have advantages over laparoscopy. Laparoscopic rectal resection is associated with relatively high rates of intraoperative conversion, which has limited its popularity in rectal cancer surgery.[24] Obese patients with low-lying tumors or patients with a narrow pelvis are especially at risk.[25,26] There are now several nonrandomized comparison trials reporting lower conversion rates in robotic than laparoscopic surgery, even in patients with tumors less than 5 cm from the anal verge.[27–29] This is likely due to the improved retraction, visualization, and precision of dissection afforded by the robot.

However, the robotic/minimally invasive approach may not be practical in all cases. Patients with previous abdominal surgery may benefit from an initial diagnostic laparoscopy to determine if there are extensive adhesions, the presence of which might greatly prolong and possibly reduce the benefits of a minimally invasive curative-intent procedure. Similarly, in patients with large tumors involving adjacent organs, the method of surgical approach must be considered from the oncologic perspective first, and the treatment plan must be individualized accordingly.

Many groups describe a hybrid laparoscopic/robotic approach, wherein pedicle ligation and splenic flexure mobilization are performed laparoscopically and the pelvic portion is done robotically.[27,30,31] This may be helpful for laparoscopic surgeons beginning robotic surgery, as they approach the mid-abdomen and left upper quadrant using familiar laparoscopic instrumentation and techniques, reserving robotic technology for the pelvis. We prefer the totally robotic approach, in which the robot's arms are repositioned between the splenic flexure mobilization and the pelvic portion of the operation. This streamlines the procedure and may reduce costs by entirely eliminating the need for laparoscopic equipment.[32,33]

If assessment of bowel perfusion is necessary, indocyanine green fluorescence and visualization are available on the robotic platform to help guide location of the bowel transection.[34] Using vessel sealing technology for the vascular pedicle, as well as dissection and ligation can also reduce the number of instrument changes and resulting costs; compared to clips and vascular staplers, bipolar vessel sealers have been shown to lessen the time needed to achieve vascular control.[35] The anticipated launch of a robot-deployed stapling device later this year will further improve efficiency.

Risks

Robotic surgery comes with a unique set of risks and potential complications, and most of them are technical in nature and not necessarily unique to the robotic platform. Lack of tactile feedback has been hypothesized to lead to traction and crush injuries. The surgeon must learn to rely on optical cues while pushing tissue, instead of grasping it for prolonged periods of time. The platform's high-resolution 3D optical system facilitates this adjustment. However, the surgeon must also become accustomed to a perceived reduction in the field of view while in the robotic console and must keep instruments in the line of sight at all times.[36] Risk of iatrogenic bowel injury, which has been best addressed in the urologic literature, occurs at a frequency of <1 %, as the colorectal surgeon quickly learns to rely on visual cues and feedback to adjust the visual field and tension.[37–39] Reporting on their early experience with robotic colorectal surgery, Patel et al.[40] describe two incidents of iatrogenic injury in 30 patients: one a thermal and one a traction injury. Both were repaired with colorrhaphy, without further consequence.[40] The frequency of this particular event is difficult to measure, because it is not often counted as an intraoperative complication but rather as an additional procedure and is therefore likely underreported. Other aspects of robotic surgery that may lead to difficulties are arm placement and the risk of external collisions. Port placement and positioning of the robotic arms are critical to a smooth operation—even more so than in laparoscopic surgery. Learning to place the arms and joints in the "sweet spot" takes practice but becomes easier with experience.[36] As in all surgical procedures, vigilance and meticulous attention to detail help prevent complications.

Quality and Outcomes

The research on robotic colorectal surgery is just beginning to mature and is limited by a lack of randomized controlled trials. The robotic versus laparoscopic resection for rectal cancer (ROLARR) trial addresses this issue.[41,42] The rest of the literature to date consists of nonrandomized comparison trials, cohort studies, and observational outcome data. These studies are limited by small sample size, selection bias, heterogeneous patient cohorts, and short follow-up. Yet, they offer a great deal of information about the quality of robotic surgery for colorectal disease. Several well-designed reviews and meta-analyses have summarized the findings, and we will discuss their conclusions below.

A significant amount of data exists on short-term outcomes in robotic colorectal surgery. Multiple meta-analyses conclude that robotic surgery does not appear to be associated with significantly longer operative times than laparoscopy.[43–46] Only one review addresses estimated blood loss, reporting that it is less in robotic colorectal surgery, possibly because of improved visualization and control of bleeding.[46] However, these conclusions are unclear because of heterogeneity and bias in the datasets (i.e., robotic or laparoscopic splenic flexure mobilization and diverting ileostomy rates), tumor location (colon or rectum), and experience of the operating surgeon. As expected, they show no clinically significant difference in the length of stay.[43–47]

Most studies report no difference in overall complication rates (including the rate of anastomotic leak)[43–49] between robotic and laparoscopic colorectal surgeries, although there may be differences in the types of complications. A recent review of the Nationwide Inpatient Sample found that patients undergoing robotic colon resection had higher rates of postoperative infection, fistulae, and thromboembolic complications, but lower rates of ileus, anastomotic complications, and pneumonia than patients treated laparoscopically.[47]

Most significantly, the robotic platform is associated with a reduced risk of conversion to open surgery.[25,29,43,44,47] Yang et al.[46] reported a 40 % reduction in the rate of conversion compared to laparoscopic surgery. This is consistent with the gynecological literature, which reported that the use of the robotic platform is associated with >50 % reduced risk.[50] This was found to be true even in patients with lower tumors who had undergone previous surgery and required neoadjuvant therapy.[25,27,45]

With regard to oncologic outcomes, multiple analyses have reported no difference in the number of lymph nodes obtained, and no clinically meaningful difference in proximal or distal margins, between robotic and laparoscopic resections.[25,43–46] However, in two recent analyses of prospectively collected robotic rectal surgery experiences published in early 2013, Kang et al.[48] and D'Annibale et al.[29] both reported lower rates of positive CRM in robotic cases, suggesting that this may play a role in future outcomes. Baik et al.[30] scored the quality of the mesorectal excision—now an important standard in determining overall surgical quality, and known to affect long-term survival—and noted that robotic excision was associated with improved quality. The only long-term outcome data available, from Kang et al.,[48] reported no difference in 2-year survival in patients following robotic, laparoscopic, or open TME for rectal cancer.

Preservation of the autonomic nerves controlling bladder and sexual function is crucial in rectal cancer surgery. Early data from the conventional versus laparoscopic-assisted surgery in colorectal cancer (CLASSIC) trial indicated that patients undergoing laparoscopic rectal surgery had worse sexual function postoperatively, probably as a result of imprecise mesorectal planes of dissection.[4] Kim et al.,[51] reporting on a prospective cohort study of robotic and laparoscopic TME, concluded that the urinary function scores of patients undergoing robotic resection returned to baseline at 3 months, compared to 6 months for patients undergoing laparoscopy. They also reported that sexual

Table 1 Studies evaluating the number of cases needed to achieve proficiency in robotic colorectal surgery, as measured by operative time

Authors	Location	Measure	Number of cases
Sng et al.[53]	Rectal	Docking and console time	35
D'Annibale et al.[29]	Rectal	Operative time	22
Jiménez-Rodríguez et al.[8]	Rectal	Operative time	22
Bokhari et al.[61]	Rectosigmoid	Console time	15

function returned to baseline sooner with robotic TME, at 6 months, compared to 12 months with laparoscopic TME.[51] These results were corroborated by D'Annibale et al.,[29] who found that 100 % of patients undergoing robotic TME reported preservation of sexual function at 1-year follow-up, compared to 43 % of patients who developed moderate to severe sexual dysfunction after laparoscopy. The authors hypothesized that precise dissection of Denonvilliers' fascia and avoidance of the lateral neurovascular bundles was the basis for these excellent results.[29] Data from the urologic literature indicates that surgical technique is paramount in reducing neurapraxia following pelvic surgery. Alemozaffar et al.[52] reported using a technique to minimize lateral blunt dissection and countertraction in favor of sharp dissection, facilitating dissection of the neurovascular bundle; the result was a significant reduction in rates of postoperative sexual and urinary dysfunction.

Another proposed benefit associated with robotic colorectal surgery is a lower learning curve. As noted, recent reports have estimated that the learning curve is achieved after approximately 20 cases, less than half of the cases needed to reach proficiency in laparoscopic colorectal surgery[6] (see Table 1). However, in their analyses of longitudinal robotic colorectal experience, Jimenez-Rodriguez et al.[8] and Sng et al.[53] found that the learning curve is more complex than a simple linear equation. Both authors reported a three-phase learning curve: (1) acquisition of basic robotic skills, (2) increasing competence and the addition of more complicated cases, and (3) achievement of robotic mastery, including the ability to tackle the most complicated cases.[8,53] Jimenez-Rodriguez et al.[8] found that the rate of complications did not decrease significantly with experience; however, they suggested that this was because more difficult cases were undertaken in phases 2 and 3. Sng et al.[53] reported a slightly higher rate of complications in the last two phases. In a study on the learning curve for robotic hysterectomy, Woelk et al.[54] suggested that the rate of intraoperative complications, rather than length of operative time, was a more meaningful measure of competence and reflected improvements in patient safety and outcomes. They found that the rate of intraoperative complications decreased steadily up to approximately 90 cases, at which point it became lower than the complication rate for open hysterectomy.

If stabilization of operative time is used as the primary measure, it indicates that proficiency requires twice the number of cases than previously thought.[54] However, learning curves are a dynamic endpoint and differ for each surgeon. Residents are now gaining more experience in minimally invasive surgery. Previous training in laparoscopic techniques may facilitate the learning of robotic skills.[55] Robotic simulator skill sets may shorten the learning curve.[56]

Data on robotics in right colectomy is limited. deSouza et al.[57] compared their robotic and laparoscopic experiences with right colectomy and found no increase in complications or length of stay. However, they noted that patients undergoing robotic surgery had longer operations and were more often readmitted, contributing to a significant increase in cost (see Table 2). In a randomized controlled trial on robotic colorectal surgery, Park et al.[58] found no differences in complications, length of stay, or oncologic outcomes for robotic versus laparoscopic right colectomy. They did report a significant increase in the operative time for robotic cases, more than 1 hr longer. The authors noted subjectively that the robot's precision and visualization made vascular and lymph node dissection easier and that they were able to perform more intracorporeal anastomoses using the robotic platform—a finding corroborated by Trastulli et al.[59] This may ultimately lead to decreased wound complication rates in longer-term follow-up, but the data is not currently available. Some argue that robotic right colectomy may be a path to a step-wise increase in the robotic experience and attainment of skill sets. Huettner et al.[60] reported greater resident involvement in right colectomies compared to sigmoidectomies, without a significant increase in adverse outcomes.

The role of robotics in colorectal cancer surgery is still being defined. Robotic technology shows great promise, and

Table 2 Outcomes reported for robotic right segmental colon resections

	N			Mean operative time, min			Complication rate, %			Mean LOS, days		
Authors	Rob	Lap	Open	Rob	Lap	Open	Rob	Lap	Open	Rob	Lap	Open
Park et al.[58]	35	35	–	195*	130*	–	17	20	–	8	8	–
Luca et al.[62]	33	–	102	192*	–	136*	24	–	33	5* **	–	8* **
deSouza et al.[57]	40	135	–	159*	118*	–	20	21	–	5**	5**	–
Rawlings et al.[63]	17	15	–	219*	169*	–	6	13	–	5	6	–

*$p<0.05$; **Value is reported as median

studies to date have demonstrated its safety. Some studies have shown that robotic colorectal cancer surgery is clearly superior to laparoscopy in reducing rates of intraoperative conversion, a finding that is most likely the result of better optics, instrumentation, and retraction. Whether robotic surgery for colorectal cancer will improve long-term outcomes, such as sexual and urinary function, remains unclear. As the use of robotic surgery grows, critical evaluation of results and outcomes is vitally important—not only to prevent undue harm to patients but also to control the considerable financial challenges posed by this expensive new technology in our era of rising health-care costs. Additional high-quality, randomized studies are needed to determine the real advantages and shortcomings of minimally invasive robotic surgery for colorectal cancer.

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