Rectal cancer surgery: is robotic surgery supported by solid evidence?

Kelsey M. Evans, James M. Sahawneh, Marco Ferrara

Orlando Health Colon and Rectal Institute, Orlando, FL, USA

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Correspondence to: Marco Ferrara. Orlando Health Colon and Rectal Institute, Orlando, FL, USA. Email: Marco.Ferrara@orlandohealth.com.

Abstract: Robotic surgery for rectal cancer has gained increasing momentum over the last two decades. Minimally invasive surgery (MIS) has led to improved recovery time, shorter hospital length of stay (LOS), and decreased postoperative pain. Despite landmark studies comparing laparoscopic to open rectal cancer surgery failing to demonstrate noninferiority, several multicenter randomized clinical trials have shown similar oncological outcomes including local recurrence, disease-free survival (DFS), and overall survival (OS). Robotic-assisted laparoscopic surgery enhances elements to MIS including improved ergonomics causing less physical demand to the surgeon, better visualization with three-dimensional imaging, additional dexterity through flexible surgical instruments, and ability to navigate narrow spaces such as the pelvis. Robotic surgery has been shown to have similar oncological results when compared to open surgery. Although studies have not demonstrated superior oncologic outcomes with robotic surgery compared to laparoscopy, urogenital and sexual dysfunction may be improved with the robotic approach. Limitations to robotic surgery include increased cost, accessibility, and length of operation, although these factors may improve as surgeon experience grows. Recent trends have shown rapid expansion of the use of robotic surgery in the treatment of rectal cancer. The aim of this review article is to provide insight into the current evidence regarding robotic surgery for the treatment of rectal cancer.

Keywords: Rectal cancer; robotic; outcomes; total mesorectal excision (TME); cost

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Introduction

Background

According to the World Health Organization, colorectal cancer ranks third highest in incidence (6.1%) worldwide among men and women, and second in mortality (9.2%) (1). In the United States, colorectal cancer is the third most common cancer diagnosed and cause of cancer-related death. Alarmingly, the incidence of colorectal cancer has been increasing in adults younger than 50 years of age.

The treatment paradigms for rectal cancer have evolved over the past decades as advances in surgical treatment and additional therapies have developed. From the surgical perspective, the standardization of the total mesorectal excision (TME) has greatly improved oncologic outcomes. This involves the removal of the mesorectum, its associated lymph nodes, and the primary tumor itself with adherence to embryologic planes. This, in conjunction with the focus on obtaining a clear circumferential resection margin (CRM), has been monumental in decreasing recurrence and improving long-term survival in patients with rectal cancer (2,3).

The TME is considered the gold standard in rectal cancer surgery. Dissection of the visceral and parietal layers of the endopelvic fascia removes both the rectum and mesorectum. This aims to remove the rectum with surrounding mesentery, lymphatics, and blood vessels. The avascular plane reduces intraoperative blood loss, preserves autonomic nerves, and helps obtain a clear resection margin. TME has repeatedly been shown to improve recurrence and survival. During the widespread recognition of TME, a national cohort study in Norway showed that TME resulted in a 10–14% improved 4-year survival rate and reduction of 4-year local recurrence rates from 12% to 6% (4).

A negative distal margin is another component to performing oncologic resection of rectal tumors. Mesorectal nodal metastasis distal to the tumor is more common than intramural extension. A retrospective study of patients undergoing TME for rectal cancer found an average of 20.2% distal mesorectal spread: 0% of pT1 and pT2, 21.9% of pT3, and 50% of pT4. The longest distal spread was 2 cm for rectosigmoid tumors, 4 cm from the upper rectum, and 3 cm from the lower rectum (5). Thus, resection of the rectosigmoid and upper rectum is done 5 cm distal to the primary tumor. In most mid and low-rectal tumors, achieving a 2-cm negative distal margin can be adequate. Furthermore, a favorable lower rectal tumor with a 1cm distal margin has not been shown to affect oncologic resection (6). Cancers that involve the pelvic floor muscles and anal sphincter will typically require an abdominoperineal resection.

The CRM is the shortest distance between the tumor and mesorectal fascia. Studies have shown that a positive CRM leads to poor oncologic outcomes. The MERCURY Study evaluated the preoperative MRI of 374 patients with rectal cancer. The 5-year overall survival (OS) was 42.2% in patients with a positive CRM and 62.2% with a clear CRM (7).

The resection of rectal cancer involves the division of the vascular supply with the associated lymphatics. Blood supply to the rectum is supplied by the inferior mesenteric artery (IMA) via the superior hemorrhoidal artery and internal iliac artery via the middle and inferior hemorrhoidal arteries. Ligation of the IMA just distal to its origin at the aorta is commonly termed "high tie" and division of the vessel distal to the takeoff of the left colic artery is termed "low tie". The HIGHLOW trial randomized 214 patients undergoing laparoscopic LAR and TME for rectal cancer. There was no significant difference in the number of lymph nodes collected, anastomotic leak (AL), and oncologic outcomes between the two groups. Both groups did have overall worsened urinary function, but the low-tie group had less urinary incontinence and obstructive urinary symptoms. The low-tie group also reported better male sexual function and was found to have improved uroflowmetric test results (8). A 5-year follow-up of 196 of the original 214 patients found a recurrence in 21.4% of patients. There was no significant difference in the number of distal or pelvic recurrence rates, 5-year OS, or 5-year disease-free survival (DFS) in high versus low tie (9).

Rationale and knowledge gap

Although a complete overview of the status of multimodal treatment for rectal adenocarcinoma is beyond the scope of this paper, the involvement of neoadjuvant therapy for locally advanced tumors is standard in many centers. The total neoadjuvant therapy (TNT) approach has led to paradigm-shifting rates of complete clinical and pathologic responses and has led to increasing feasibility of organ-sparing approaches for appropriately selected patients. Particularly for mid and distal rectal cancers, upfront surgical resection has become increasingly rare. However, in these scenarios, surgeons are operating in radiated fields with locally aggressive and incompletely responsive tumors. This can increase the challenges of surgical resection, especially when added to the anatomic challenges of operating in a narrow space in an increasingly obese population. As such, the development of appropriate techniques to optimize both oncologic and functional outcomes given these challenges has become paramount.

Objective

The majority of this review will discuss the surgical approach to rectal cancer and evaluate the current literature in relation to open *vs.* minimally invasive techniques with an emphasis on robotic-assisted minimally invasive surgery (MIS).

Assimilating laparoscopic techniques in rectal cancer surgery

Minimally invasive techniques have demonstrated superiority in factors related to recovery and pain for patients requiring abdominal surgery. However, there have previously been mixed results related to oncologic outcomes in MIS specific to rectal cancer. Despite the evidence to support the benefits of laparoscopic surgery, its assimilation into rectal cancer surgery has been challenging. In addition to the technical difficulties of operating in the narrow pelvis, this also stemmed from the concern about oncologic outcomes compared to open surgery. The CLASICC trial

(Conventional Versus Laparoscopic-Assisted Surgery in Colorectal Cancer), which evaluated 242 patients with rectal cancer, did demonstrate a high conversion rate of 34% as well as a trend towards higher CRM positivity in laparoscopic (12%) *vs.* open (6%), although not statistically significant (10). However, in long-term follow-up data published in 2013, this did not have a significant impact on local recurrence or survival (11).

The European Colorectal Cancer Laparoscopic or Open Resection (COLOR) II trial demonstrated a lower conversion rate compared to the CLASICC trial of 17%. Macroscopically they found no significant difference between the two groups for positive CRM, distal resection margin, morbidity, mortality, or 3-year DFS. However, they did find a quicker return of bowel function and shorter hospital stay in the laparoscopic group (12). The Comparison of Open Versus Laparoscopic Surgery for mid or low Rectal Cancer After Neoadjuvant Chemoradiotherapy (COREAN) trial had an even lower conversion rate of 1.2% and a low rate of CRM positivity (3%) (13). The 3-year DFS was significantly non-inferior—79.2% for laparoscopic surgery and 72.5% for open (P<0.001) (14).

The ACOSOG Z6051 was designed as a randomized controlled trial (RCT) to compare the laparoscopic and open treatment of rectal cancer in the United States in patients with stage II/III rectal cancer within 12 cm of the anal verge in those who received neoadjuvant chemoradiotherapy. In the variables of completeness of TME specimen, negative CRM, and negative distal margins, the laparoscopic technique did not meet the criteria for non-inferiority because the combined score of these variables was greater than 6% lower than the score for open resection (15). This composite score was utilized in another study—the ALaCaRT study based in Australia. This study corroborated the ACOSOG Z6051 results by performing a randomized, non-inferiority phase III trial including 26 surgeons and 475 patients with T1-3 rectal adenocarcinoma less than 15 cm from the anal verge. The authors compared open *vs.* laparoscopic resection and found that similarly, they could not provide non-inferiority based on completeness of TME, negative CRM, and negative distal margins. In this cohort, successful resection was achieved in 82% of the laparoscopic patients and 89% of the open group. TME completeness was achieved in 97% *vs.* 99% and CRM positivity was 7% *vs.* 3% in the laparoscopic and open groups, respectively. Distal margin involvement was <1% in both groups (16).

Both studies performed follow-up analyses that evaluated DFS and locoregional recurrence (LRR). In the ACOSOG Z6051 trial authors found 2-year DFS in the lap group to be 79.5% *vs.* open of 83.2% which was not statistically significant. LRR was 4.6% in lap and 4.5% in open while distant recurrence was 14.6% in laparoscopic and 16.7% in open. None of these were statistically significant differences and the authors conclude that laparoscopic-assisted techniques are not statistically different in this regard (17). In order to meet the criteria as a "successful surgery" patients had to have a complete or nearly complete TME specimen, CRM >1 mm, and DM >1 mm. An unsuccessful surgery was associated with reduced DFS (HR 1.87, 95% CI: 1.21–2.91). When evaluating these different aspects of the composite score, CRM was the only variable that significantly affected DFS (HR 2.31, 95% CI: 1.40–3.79). The laparoscopic technique did not increase the risk of recurrence compared to open, however, unsuccessful surgery did (P=0.006). In the ALaCaRT follow up LRR was 5.4% in the lap group and 3.1% in the open group, which was not statistically significant. CRM positivity was the only variable associated with a higher risk of LRR at 2 years (15.8% *vs.* 3.8%, P=0.04). DFS at 2 years was 80% in the lap and 82% in the open group (18).

The results from both these follow-up studies demonstrate no significant difference between laparoscopic and open techniques regarding 2-year DFS and LRR. Positive CRM appears to predict worse outcomes and surgeons should use their best judgment related to the skillset required to achieve a clear CRM. There are even some data to suggest laparoscopic surgery can achieve wider negative CRM in the pelvis (19).

Robotic-assisted surgery

Robotic devices

Robotic-assisted surgery evolved from the minimally invasive technique of laparoscopic surgery. One of the first robotic systems was known as the Zeus system (Computer Motion, Inc., Santa Barbara, CA, USA) followed by the da Vinci system (Intuitive Surgical, Inc., Mountain View, CA, USA). The Zeus ceased production in 2003 and now the da Vinci dominates the surgical arena and has done so for the last decades. For the purposes of this review, we focused on the da Vinci platform, which by far has the most robust body of literature.

Benefits

Ergonomics

Ergonomics are an important consideration for surgical efficiency and performance. Some studies demonstrate work-related musculoskeletal disorders which lead to poor performance, leave of absence, practice modification, or early retirement. Improving the ergonomic environment may lead to prolonged careers and improved performance in surgeons and medical proceduralists (20). The main components of robotic surgery that have been studied are visualization, posture, and manipulation (21). The robotic-assisted technique allows for three-dimensional vision and surgeon control of the camera. Surgeons remain in a seated position that is tailored to everyone. Articulated instruments allow for greater degrees of freedom in the manipulation of tissue in addition to a tremor filtration technology.

The increasing prevalence of obesity lends another potential advantage in robotic systems from an ergonomic standpoint. Obesity is a known risk factor for conversion to open surgery, which increases morbidity and hospital length of stay (LOS). The ROLARR study subgroup analysis demonstrated the benefit of robotic-assisted techniques in obese men. The BJS study in 2020 compared short-term perioperative and oncologic outcomes or robotic proctectomy in obese *vs.* non-obese patients. They found that obesity was not associated with serious adverse short-term perioperative or oncologic outcomes after robotic rectal cancer surgery. Regardless, the benefits of ergonomic optimization to the surgeon from a longevity standpoint cannot be overstated in this patient population.

Visualization

Visual input is a vital component of our sensory system and ultimately the ergonomics related to performing surgery. Laparoscopic surgery allows for a monocular view within a two-dimensional display. The addition of three-dimensional visualization allows improved depth perception on the robotic platform. In addition, the surgeon has full control of the camera themselves. In laparoscopic surgery, the loss of depth perception as well as the disparity of screen location compared to the operative field may result in mental fatigue. Falk *et al.* demonstrated that 3D visualization within the robotic console can reduce ocular strain, errors, and performance time (22). Some authors suggest that this may provide a visual perceptual mismatch that can contribute to mental fatigue (23).

Posture

Surgeons often suffer from musculoskeletal pain and discomfort due to prolonged periods of standing and poor posture during operations including extended periods of neck and back flexion, which may lead to long-term musculoskeletal and neurologic problems. Laparoscopic surgery may be less physically demanding than open surgery but can lead to static strain and muscle tension. Studies have shown that the greatest strain occurs in the shoulders and neck for laparoscopic surgery and forearms, lower back, and neck for robotic surgery (24-26). One study demonstrated less neck, shoulder, and back pain in robotic surgery compared to laparoscopic (27). Some studies even demonstrate more activation of the non-dominant hand in robotic surgery when compared to laparoscopic and improved fine motor skills of the non-dominant hand (25,28). Lastly, the surgeon can take short breaks during an operation to mitigate fatigue or stress.

Manipulation

The robotic system allows for ease of manipulation by eliminating the fulcrum of laparoscopy instruments. This leads to an increase in the degrees of freedom of movement, helps to eliminate tremors, and increases magnification to appropriately scale movement. The degree of freedom offered in a robotic system is six compared to four in laparoscopy which has been shown to reduce the time for task completion (23,29). The long laparoscopic instruments can increase tremor due to length and can create a perceived visual disconnect based on the direction a surgeon must move the instrument to obtain desired effect.

Limitations

Cost

Cost has been a longstanding criticism of robotic surgery. The robotic system is more expensive than laparoscopic equipment and even more so than an open approach. There are limited data as to the cost-benefit of robotic surgery as it relates to rectal cancer. A decision-analytic model evaluating one-year costs and outcomes by Simianu *et al.* factored in surgical outcomes, costs, and patient-report outcomes. Both laparoscopic and robotic were considered more cost-effective than open surgery, with laparoscopy being more cost-effective than the robotic approach by $983/case (30). A single institution study of 68 patients looked more specifically at robotic abdominoperineal resection (APR), as the majority do not require a splenic flexure mobilization or anastomosis. Compared to laparoscopy, there was an increase in the mean cost by 26% and median cost by 43%, but this was not statically significant. Operative time, LOS, complications, conversion to open, and oncologic complete resection were found to be similar. The study was not powered to detect a significant increase in cost due to the small sample but does suggest robotics has a cost-effective role in rectal cancer, particularly with APR (31).

Haptic feedback

A drawback to robotic surgery is the loss of haptic feedback in the most used models. This sensory loss may reduce the assessment of tension, causing excessive force on tissues and potential injury. Typically, surgeons overcome the lack of tactile feedback with visual cues in identifying tissue deformation (32). This is a learned skill and can take time to develop and master. Locally advanced rectal cancers may alter and obscure surrounding tissue, with manual palpation helping to guide dissection. Thus, during the early emergence of robotic surgery, its use was not suggested for locally advanced rectal tumors. In the world of TNT, the presence of fibrosis within the pelvis is often encountered and can be difficult to interpret at times using just visual cues.

Accessibility

Robotic platforms have become increasingly popular within essentially all fields of surgery. Trends using the American College of Surgeons National Quality Improvement Program Database from 2013 to 2018 revealed a four-fold increase in the number of robotic cases performed for non-urgent colectomies from 3.9% to 16%. There were decreased rates for both open cases, 19.5% to 12.9%, and laparoscopy, 76.6% to 71.2% (33). The price of the Da Vinci Robot system is approximately $2 million. They are increasingly being found in academic centers, and larger hospital systems in higher-income locations (34). The National Cancer Database was used to evaluate possible disparities as it relates to robotic utilization for rectal cancer from 2010 to 2014. Patient populations including females, black, the elderly, the non-privately insured, those with limited access to higher level institutions, or residing in less educated areas were less likely to undergo a robotic surgical approach for rectal cancer (35).

Robotic surgery outcomes

Oncologic outcomes [TME, CRM, distal margin (DM), proximal margin (PM)]

As discussed earlier in this paper, TME has become the gold standard for oncologic resection and a tenet of the paradigm of care for rectal cancer patients. There have been numerous studies demonstrating that poor TME quality is significantly related to worse recurrence rates, both locally and distally (36,37). Interestingly, a study looking at 700 patients that have open, laparoscopic, and robotic operative approaches failed to demonstrate a difference amongst these modalities for a non-complete mesorectal grade. However, distal tumors (<5 cm from the anal verge), APRs, and positive CRM were associated with an incomplete mesorectum. This further supports that the confines of a narrow pelvis may make a complete dissection more difficult (38).

The ROLARR trial, which was the first and largest RCT on robotic *vs.* laparoscopic approaches for curative rectal cancer surgery, was published in 2017 and demonstrated similar TME completeness amongst robotic and laparoscopic resection (76.4% and 77.6%, respectively; P=0.33) (39). A criticism of the ROLARR trial was the potential inexperience of robotic surgeons and the concern that some of these surgeons were still in the learning phase and had not yet achieved mastery. The laparoscopic group of surgeons had performed on average 152.5 cases, yet the robotic surgeons only 67.9. Similarly, in 2018 Kim *et al.* found an 80.3% and 78.1% completeness rate in robotic and laparoscopic approaches, respectively (P=0.599) (40). Lim *et al.* in a prospective study performed in 2017 found the rates to be similar (95.9% *vs.* 100% P=0.384), as did Valverde *et al.* in 2017 (88% *vs.* 82% P=0.28) (41,42). None of the above-mentioned studies demonstrated any statistically significant difference. One study performed by Baik *et al.* did however demonstrate better rates of complete resection of 92.9% in the robotic group compared to 75.4% in the lap group (43). In the meta-analysis and systematic review published by Prete *et al.*, they evaluated the completeness of TME in two trials and did not find a significant difference in the rate of incomplete resection (44).

Although TME is an integral part of oncologic outcomes, CRM plays a large role as well. A positive CRM is associated with lower tumors and those with greater depth of invasion (45). A recently published comprehensive review of the literature comparing robotic and laparoscopic techniques did not demonstrate a statistically significant difference between these modalities, with a greater than 90% CRM negative rate for both groups (46). In addition, the Prete *et al.* meta-analysis did not find a significant difference between the robotic and laparoscopic groups (44). A study by D'Annibale *et al.* in 2013 demonstrated an improved negative CRM rate in robotic patients compared to lap (100% *vs.* 88%, P=0.022) (47). However, this was one of the only studies to do so until a recently published RCT was published by Feng *et al.* in China. This was a multicenter superiority trial in a modified intention-to-treat analysis of 1,171 patients with rectal cancer performed in 11 Chinese hospitals. Patients with low/middle rectal cancer, cT1-3N0-1 or ycT1-3Nx, no cT4, and no evidence of distant metastasis were randomized to either robotic or laparoscopic resection in a 1:1 ratio. The robotic group did have improved oncological outcomes compared to the laparoscopic group, with CRM ≤1 mm of 4.0% *vs.* 7.2% (P=0.023) and macroscopic complete resection 95.4% and 91.8% (P=0.042). The statistical significance was less apparent in the subgroup analysis of the type of surgery performed, LAR, and APR. The robotic group experienced fewer 30-day complications (Clavien-Dindo Grade II or higher) 16.2% and 23.1% (P=0.003), fewer APR 16.9% and 22.7%, shorter postoperative hospital stays 7.0 and 8.0 days (P=0.0001), fewer conversion to open 1.7% and 3.9% (P=0.021), and fewer intraoperative complications 5.5% and 8.7% (P=0.030) (48). This REAL Study Group does suggest better oncological resection and 30 days postoperative recovery. Limitations of this study include no standardized perioperative protocol, performed in Chinese centers that in general approach neoadjuvant and adjuvant therapy differently than in the United States, and an average body mass index (BMI) of 23.5 kg/m^2.

The distal margin, which also plays a role in local recurrence, is recommended by the National Comprehensive Cancer Network guidelines to be 4 to 5 cm below the distal edge of the tumor when possible. Although the robotic ability to navigate a narrow pelvis would theoretically allow for better margins, studies have failed to demonstrate a statistically significant difference between robotic and laparoscopic techniques. The same applies to the proximal margin, with the failure of current literature to support a statistical difference.

Survival

Oncologic outcomes including CRM, DM, and completeness of TME play important roles in OS. It appears that in large-scale RCT's, the most important component for DFS is negative CRM. The ACOSOG and ALaCaRT trials observed an increase in local recurrence two years after surgery with an involved CRM. In a review performed by Lam *et al.* published in 2021, the authors identified that few studies have reported on overall or DFS (46). Patriti *et al.* demonstrated no difference in overall and DFS in robotic and laparoscopic groups, however only followed patients for 3 years (49). Studies to date have failed to demonstrate a statistically significant difference in DFS at 5 years. Cho *et al.* performed a case-matched retrospective study that demonstrated 81.8% and 79.6% survival in robotic and laparoscopic techniques (P=0.538), respectively (50). Similarly, in a prospective case-matched cohort study, Park *et al.* found DFS to be 80.6% and 82.8% in robotic and laparoscopic techniques, respectively (P=0.298) (51). In 2017, Kim *et al.* also performed a retrospective cased matched study that found OS to be 90.5% in the robotic group and 78% in the laparoscopic group, however, this was not statistically significant (P=0.3231). The overall DFS was also not significant and was 72.6% and 68%, respectively. The authors did perform a multivariate analysis and found that the use of the robot was a positive prognostic factor for OS and cancer-specific survival, which was to our knowledge the first study to do so (P=0.0040, HR =0.333, P=0.0161, HR 0.367) (52). The limitations of this study include selection bias with the demographic difference between the two groups, including a younger robotic group. Lim *et al.* performed a prospective case-matched study in patients who had mid to low rectal cancer who received neoadjuvant CRT that demonstrated OSl of 90% and 93.3% in the robotic and laparoscopic groups, respectively (P=0.424) and DFS at 5 years of 76.8% and 76%, respectively (P=0.834). The local recurrence rate was 2.7% robotic and 6.3% laparoscopic (4 *vs.* 2 patients, P=0.308) and the systemic recurrence rate was 18.9% robotic *vs.* 15.6% laparoscopic (14 *vs.* 10 patients, P=0.644) (41). No studies have demonstrated a significant difference in OS, DFS, or cancer-specific survival.

When considering short-term survival, a recent meta-analysis published in 2022 by Safiejko *et al.* evaluated 42 studies and found that survival to hospital discharge or

30-day OS rate was significantly better in the robotic group (99.6%) compared to the laparoscopic (98.8%) (P=0.05) (53).

Non-oncologic outcomes

With comparable oncologic and long-term (5-year DFS) outcomes amongst laparoscopic and robotic surgery, it is worth noting the non-oncologic outcomes amongst these two modalities. This includes considerations such as LOS, conversion to open, operating time, and cost. A study performed by Hu *et al.* evaluated NSQIP data from 2016–2017 in patients undergoing robotic and laparoscopic proctectomy to compare these non-oncologic variables (54). The authors found that amongst 3,845 patients (70% of which underwent laparoscopic approach) and after a propensity adjustment, the robotic approach was associated with a decrease in conversion to open (−6.7%, P<0.01), decreased LOS (−0.6 days, P=0.01), and less postoperative ileus (−3.7%, P=0.01). However, it had an increase in operative time of 20.3 minutes (P<0.01). Prior studies have mimicked these results and demonstrated lower conversion rates and significantly longer operating times without differences in post-operative complications (44,55-57). The retrospective review performed by Crippa *et al.*, evaluated 600 patients and found that those undergoing robotic surgery had an overall lower complication rate (37.2% *vs.* 51.2%, P<0.001). Additionally, robotic surgery was found to be the most protective factor for the odds of complication (OR 0.485, P=0.006). Conversion to open surgery and a complication were risk factors for a prolonged LOS and robotic surgery was the only independent protective factor (OR 0.62, P=0.027) (58).

Conversion to open is a widely accepted outcome measure when comparing robotic and laparoscopic surgery in rectal cancer. Conversion to open can have a significant impact on overall patient outcomes and has been associated with the risk of AL, overall morbidity, wound infection, and worse overall long-term outcomes (59-61). Robotic surgery may have an advantage in this regard and be able to overcome some of the technical difficulties related to laparoscopic surgery that can lead to conversion to open. A recent retrospective cohort study in Japan utilized over 20,000 patients and propensity-matched two groups of 2,843 that had both robotic and laparoscopic LAR. They found that the robotic group had a significantly lower conversion to open rate (0.7% *vs.* 2%, P<0.001). The robotic group did have a longer operating time (352 *vs.* 382 minutes, P<0.001), lower in-hospital mortality (0.1% *vs.* 0.5%, P=0.007), and shorter LOS (13 *vs.* 14 days, P<0.001). The overall conversion to open rate was not found to be significantly different between robotic and laparoscopic surgery in the ROLARR trial. However, when subsequent analysis of this data was performed, it did demonstrate that robotic surgery had a lower conversion rate when performed by more experienced robotic surgeons and in more demanding scenarios such as in obese patients.

A similar study performed in 2013 using ACS-NSQIP data demonstrated lower rates of conversion to open (10% *vs.* 13.7%) in the robotic group and decreased LOS (4.5 *vs.* 5.3), which were both statistically significant. The Prete *et al.* meta-analysis found an overall rate of perioperative complications amongst 5 trials to be similar (27.3 in robotic and 26.7 in laparoscopic) with similar rates of wound infections, urinary dysfunction, and respiratory complications (44). Additionally, this meta-analysis demonstrated a significantly longer operative time in the robotic group (5 trials, 681 patients) that was 38 minutes longer than laparoscopic (P<0.00001). A meta-analysis published in 2022 assessed the safety and efficacy of the robotic *vs.* laparoscopic approach and found that patients who underwent robotic surgery had earlier time to first flatus (2.4 *vs.* 2.9 d, P=0.03), significantly lower conversion to open rates (2.6% *vs.* 7.3%, P<0.001), decreased length of hospital stay (8.0 *vs.* 10 days, P<0.001), decreased operative time (297.4 *vs.* 339.5 minutes, P<0.001), and overall no differences amongst 30-day complications (27.2 *vs.* 19.0 in robotic and laparoscopic, respectively, P=0.53) (53).

A recent meta-analysis and systematic review performed by Wang *et al.*, found that in over 5,400 patients and 20 studies reviewed the robot was associated with longer operative time, lower conversion to open, shorter LOS, and faster bowel recovery with fewer overall complications. However, they did not demonstrate a significant difference between estimated blood loss (EBL) or AL rate (62). Regarding bleeding requiring transfusion, Hu *et al.* found that the laparoscopic group had greater rates of this compared to robotic (7% *vs.* 6%), however did not reach statistical significance (54). Similarly, Baik *et al.* did not find a statistically significant difference between groups for change in preoperative (1–2 weeks before surgery) and post-operative hemoglobin concentrations (P=0.905) (43). Patriti *et al.* reported similar EBL between groups and none required transfusions (49). The systematic review and meta-analysis performed by Safiejko, which included 24 studies found EBL to be 224±327.6 for the robotic group and 210.8±305.2 mL which was not statistically significant

(P=0.95). Blood transfusions were required in 3.7% and 2.1% of cases, respectively (P=0.32) (53). Shiomi *et al.* did demonstrate an advantage in robotic TME, specifically in patients with visceral obesity. Blood loss and LOS were significantly less in the robotic group compared to the laparoscopic (63).

AL is a feared complication that can lead to longer hospitalization, further surgery, and oncologic consequences. Kulu *et al.* evaluated patients with AL after undergoing surgery for rectal cancer and found that it was associated with an increased risk of mortality (HR 2.30, P=0.003) and significantly worse DFS (HR 1.88, P=0.011) (64). Similarly, a meta-analysis performed by Ha *et al.*, including 34 studies found that AL was associated with increased local recurrence [relative risk (RR) 1.90, 95% confidence interval (CI): 1.48–2.44, I^2=78%] and reduced OS (RR 1.36, 95% CI: 1.24–1.50, I^2=74%), cancer-specific survival (RR 1.41, 95% CI: 1.19–1.68, I^2=56%), and DFS (RR 1.40, 95% CI: 1.20–1.63, I^2=86%), but had no significant effect on distant recurrence (RR 1.20, 95% CI: 0.94–1.53, I^2=61%) (65). D'Annibale *et al.* found the incidence of AL and overall complications to be statistically similar in robotic and laparoscopic approaches. They did however see a significantly longer hospital LOS in the laparoscopic group, which likely contributed to the slightly higher complication rate (47). In a study by Crolla *et al.*, they found the AL rate to be higher in laparoscopic *vs.* robotic, however, this did not reach statistical significance (8.2% *vs.* 4.5%, P=0.29). Overall complication rates were higher in laparoscopic as well, but not significantly (39.7% *vs.* 30.4%, P=0.074) (66). Panteleimonitis *et al.* looked at obese patients (BMI >30), 63 of which underwent robotic surgery for rectal cancer, and did not find any significant difference in AL. The LOS was significantly shorter in the robotic group (6 *vs.* 8 days, P=0.014) (67).

Urinary dysfunction and sexual dysfunction

Preservation of pelvic autonomic nerves is tied to the TME with dissection of the mesorectum and pre-sacral fascia. Urogenital dysfunction caused by injury to the pelvic autonomic nerves can worsen the quality of life (QoL). QoL including social and physical functioning related to urogenital dysfunction is an important decision factor as survival from rectal cancer improves (68). A robotic approach offers high-resolution three-dimensional visualization and articulating instruments available within narrow a pelvis, which may aid in the protection of the pelvic autonomic nerves. A systematic review and meta-analysis by Flynn *et al.* in 2022 compared urogenital dysfunction between robotic and laparoscopic TME. Male sexual dysfunction was favored in robotic over laparoscopic in 7 of 11 studies, with no difference shown in the remaining 4. Pooled data from 5 studies showed improved male sexual dysfunction at 1 year with robotic surgery (OR, 0.51, P=0.043). Urinary dysfunction was favored in 6 of 12 studies, with pooled data from 4 studies favoring better urinary function at 1 year after robotic surgery (OR 0.26, P=0.016). Despite the limitations of the review, they posited that robotic surgery may improve urinary and male sexual dysfunction compared to laparoscopy (69). Similarly, in the meta-analysis performed by Safiejko *et al.*, the robotic group had significantly fewer patients with urinary retention after surgery compared to the laparoscopic group (3.5% *vs.* 6.1%, P=0.02) (53).

Transanal minimally invasive surgery (TAMIS)

TAMIS is a technique to remove rectal polyps and early rectal cancers through the anus. First introduced in 2009, laparoscopic TAMIS (L-TAMIS) has grown in popularity by providing organ preservation and improved visualization compared to traditional transanal excision. Difficulties with L-TAMIS include rigid, non-articulating instruments within a constrained operative field (70). The first robotic TAMIS (R-TAMIS), described in 2012, offered advantages compared to laparoscopy with 3D visualization, articulating movements, and improved ergonomics (71). In a systematic literature review by Jakobsen *et al.*, R-TAMIS outcomes were evaluated from 25 studies with 322 patients, mostly from case-reports or small series (72). Compared with recently reported L-TAMIS outcomes, R-TAMIS was found to have lower positive resection margins (3.7% *vs.* 8.6%) and less overall complication rates (10.5% *vs.* 18.4%) (73). Tumor recurrences were similar for R-TAMIS (4.1%) and L-TAMIS (6%). The da Vinci single-port robot (SP) offers improved access to narrow locations. SP is FDA approved for Head and Neck and Urology cases, but not for rectal surgery. An ongoing clinical trial looking at SP for TAMIS is underway, with early promising reports (71).

Conclusions

Robotic-assisted surgery for rectal cancer can be advantageous compared to other techniques due to its ability to provide three-dimensional vision, navigate narrow spaces within the pelvis, and improve overall dexterity for the surgeon. These qualities should ideally create an environment that allows for better oncologic resection and subsequently improved OS and QoL for the patient. Regarding data-driven outcomes, the current literature cannot demonstrate improved OS in robotic techniques. It appears it is not inferior to laparoscopic, but data does not yet suggest superiority.

In large-scale RCT, the most important component for DFS is negative CRM. The quality of dissection measured by positive CRM is comparable amongst laparoscopic, robotic, and open surgery suggesting that utilizing a minimally invasive technique does not have negative oncological consequences, despite some of the earlier landmark studies. Minimally invasive techniques have benefits including faster recovery, shorter LOS, and less pain when compared to open. The robotic technique specifically may provide better sexual and urinary outcomes as well as less conversion to open, shorter LOS, and even overall lower complication rates. However, this comes at the cost of longer operating times. This could be mediated with time as surgeons become more comfortable and facile at both docking and operating on the robot.

The original question and aim of this study were to determine if robotic surgery is appropriate for rectal cancer. The literature suggests that robotic surgery is appropriate for this type of surgery given the surgeon possesses the technical abilities, with the most important goal being good oncologic resection. The robot has unique abilities to navigate the necessary space for rectal cancer surgery and is not inferior to traditional laparoscopic techniques.

The main limitation to robotic surgery and implementing more widespread use is likely the cost and longer operating time. We may see both improve as surgeons become more efficient, and a broader analysis of overall cost can be performed. After all, the "cost" of surgery extends beyond the operating room. Studies suggest a lower conversion rate, shorter LOS, and fewer complications may provide an overall reduced cost to the hospital system over time. This is an area of active and enthusiastic continued research. Ultimately, operative modality should be based on surgeon comfort in performing the best oncologic resection for the patient.

Technological advances in robotic surgery continue, and it remains an evolving field. There are multiple robotic platforms and advances in technology in development. These will hopefully drive down cost and also provide potential improvements in patient outcomes. As parallel technologies improve with time, they may act as further boons to the advancement of robotic platforms. The integration of augmented and virtual reality within surgical robots is in its infancy and could further potentiate the ability of the surgeon. Training programs and simulations of increasing fidelity have been used to help prepare surgeons prepare for upcoming procedures. Professional societies have established proctoring programs and requirements for training as robotic surgery becomes more widespread. Although these are all exciting developments, one must remember that the robot is but a tool and cannot replace the steadfast adherence to the tenets of rectal cancer surgery by the operating surgeon.

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