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LARGE INTESTINE (B CASH AND R CHOKSHI, SECTION EDITORS)

The Current Role of Robotics in Colorectal Surgery

Harith H. Mushtaq[1] · Shinil K. Shah[2] · Amit K. Agarwal[3]

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Abstract

Purpose of Review Despite the growth in laparoscopic surgery, comparable oncological outcomes, and reduced complication rates, the majority of colorectal surgery is still performed via an open approach. Reasons for this may include technical difficulties associated with operating in narrow spaces such as in the pelvis and inadequate experience. Robotic surgery provides potential solutions to some of these challenges. This review will summarize the state of the literature regarding robotic colorectal surgery.

Recent Findings The most consistent benefit of robotic surgery is decreasing operative conversions, specifically in rectal cancer. In partial colectomies, there is evidence to support quicker return to bowel function. Oncologic outcomes compared to the laparoscopic approach are equivalent.

Summary Robotic surgery provides solutions to the challenges posed by laparoscopy, including wristed instruments, ease of intracorporeal suturing, and ergonomic advantages. Randomized trials to evaluate peri-operative outcomes will be important. If robotics is able to facilitate conversion of open colectomies to their minimally invasive equivalent, robotics may end up proving to be advantageous in the peri-operative and post-operative period. Continued studies are warranted.

Keywords Robotic colorectal surgery · Total mesorectal excision · Low anterior resection · Abdominoperineal resection · Colectomy · Colon cancer · Rectal cancer

Introduction

In 2000, the da Vinci Surgical System (Intuitive Surgical Inc., Sunnyvale, CA) gained initial approval by the US Food and Drug Administration (FDA). It was designed to facilitate minimally invasive surgery by placing technology (patient side cart and surgeon console) between the patient and surgeon. There has been dramatic growth of this technology since that time. Currently, robotic surgery is used in multiple surgical subspecialties including urology, gynecology, surgical oncology, bariatric and foregut surgery, colorectal surgery, and cardiac and thoracic surgery. As of September 2017, there were 4271 robotic docking units worldwide, including 2770 in the USA, 719 in Europe, and 561 in Asia [1]. With the recent advances in robotic technology, including new platforms designed for multiple quadrant surgery, there is increased interest in robotics in colorectal surgery. Our review will evaluate the recent colorectal surgery specific literature. We will focus on the advantages, criticism, cost, operative times, and outcomes of robotics in colorectal surgery as compared to traditional surgical approaches.

Methods

PubMed was utilized to identify database studies, systematic reviews, single and multicenter experiences, meta-analyses, and randomized studies, with priority given to articles published within the last 5 years. Search terms utilized included robotic, robot, surgery, colon, colorectal, total mesorectal excision, colectomy, colon cancer, rectal cancer, low anterior resection, and abdominoperineal resection. We excluded case reports and small case series. In general, there are few randomized multicenter prospective studies evaluating robotics in colorectal surgery. The literature regarding this topic should be interpreted in the context of the quality of the evidence.

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✉ Amit K. Agarwal
Amit.k.agarwal@uth.tmc.edu

1 General Surgery, McGovern Medical School at UT Health, 6431 Fannin Street, MSB 4.331, Houston, TX 77030, USA

2 Minimally Invasive and Elective General Surgery, McGovern Medical School at UT Health, 6431 Fannin Street, MSB 4.156, Houston, TX 77030, USA

3 Colon and Rectal Surgery, McGovern Medical School at UT Health, 6431 Fannin Street, MSB 4.158, Houston, TX 77030, USA

History of Laparoscopy and Emerging Robotics in Colorectal Surgery

The use of minimal invasive surgery began in the early 1980s. Since that time, laparoscopy has become increasingly used in different surgical subspecialties. The first laparoscopic colorectal surgery documented in the literature was in 1990 (laparoscopic assisted sigmoid resection) [2]. Since that time, the evidence has supported the notion that minimally invasive colorectal surgery results in improved outcomes including decreased morbidity and mortality rates, costs, and hospital length of stay [3]. In parallel, however, the challenges with laparoscopy have also become clear. These challenges include limited movement with rigid laparoscopic instruments, two-dimensional visualization of the operative field, and technical and anatomic challenges posed by small/narrow fields, such as in the pelvis.

These challenges may help explain, in part, the reasons why the majority of colorectal surgery performed in the USA are still traditional open approaches. An analysis of the US National Cancer Database demonstrated that 44% of patients undergoing colectomy for malignancy underwent a minimally invasive approach [4]. Yeo et al. examined the National Inpatient Sample (NIS) database, evaluating patients undergoing elective colectomy from 2009 to 2012. Out of 509,029 patients who underwent elective colectomies, 266,263 (52.3%) were open, 235,080 (46.2%) were laparoscopic, and 7686 (1.5%) were robotic [5•]. Another review by Moghadamyeghaneh et al. during the same time period showed comparable results when evaluating patients undergoing elective total abdominal colectomy. Out of 26,721 patients, 16,780 (62.8%) had an open operation, while 9934 (37.2%) had a minimally invasive approach (9614 laparoscopic and 326 robotic). Patients who underwent open surgery had significantly higher mortality and morbidity as compared to laparoscopic resection, and there was no significant difference in mortality and morbidity between the laparoscopic and robotic approaches [6]. Although the majority of colectomies in the USA are still performed open, rates of minimally invasive approaches (laparoscopy and robotics) continue to increase [4]. Specifically, there appears to be more rapid increase in the use of robotics for treatment of rectal cancer [7, 8].

The initial robotic-assisted colectomy procedures were reported in 2001 by Weber et al. (sigmoid and right colectomy) [9]. The growth in robotics was largely fueled by small studies that demonstrated comparable outcomes to laparoscopy. In the late 2000s, the use of robotics was noted to have increased uniformly, with the largest growth seen in medium-sized and non-teaching hospitals [8]. Two studies evaluating the NIS comparing laparoscopic to robotic colectomy (2008 to 2010) showed overall comparable results between the two approaches. The studies echoed common criticisms of robotic surgery. There were differences in the methodology as well as the included patient populations in the two studies, which help explain the slightly differing results. Both studies demonstrated significantly decreased conversion rates to open as well as significantly increased costs associated with robotic surgery [8, 10]. Overall, complication rates were similar; however, Halabi et al. showed that post-operative bleeding was increased in robotic colonic (not rectal) procedures (3.4% vs. 2.14%, $p = 0.005$) [8]. Tyler et al. also reported that although overall complication rates were similar, the pattern of complications was different with higher post-operative infection, fistula, and venous thromboembolic events and lower ileus, anastomotic complication, and pneumonia rates seen with robotics as opposed to conventional laparoscopy. Some of these results are seemingly contradictory (fistula vs. anastomotic complication rates) [10].

Despite common criticisms, specifically increased costs and operative times, the use of robotics in colorectal surgery has continued to increase. Patients that are appropriate candidates for robotic surgery are similar to those for conventional laparoscopy. Contraindications include patients who present with hemodynamic instability, are unable to tolerate CO_2 insufflation, and/or are unable to tolerate general anesthesia. Relative contraindications may include extensive adhesions from prior surgeries, history of an open abdomen/loss of domain, emergency operations, coagulopathy, and/or lack of adequate training/experience.

In the following sections, we will summarize the advantages and disadvantages of robotic colorectal surgery in the different colorectal procedures (Table 1).

The Advantages and Disadvantages of Robotic Colorectal Surgery in Different Colorectal Procedures

Robotics has been often purported as a solution for the multiple challenges that often are cited as reasons for lack of more widespread adoption of laparoscopy. It has also been suggested as a way to encourage adoption of minimally invasive techniques in surgeons without significant laparoscopic experience [11].

Rectal Cancer

Presumably due to the challenges of operating in the pelvis, initial large database studies suggested that the highest

Table 1 Summary of the advantages and disadvantages of robotics in colorectal surgery

Advantages	Disadvantages
Decreased rates of conversion to open operations, particularly in rectal cancer	Increased costs
Equivalent oncological outcomes	Longer operative times
Facilitation of an intra-corporeal anastomosis, particularly with right colectomy which may help decrease rates of ileus and hospital length of stay	

percentage of robotic colorectal procedures were for the treatment of rectal cancer and diverticular disease [8]. Several key studies provide important insight including several randomized trials comparing robotics to laparoscopy for the treatment of rectal cancer.

Multiple analyses have demonstrated robotics to be associated with lower conversion rates and equivalent oncologic outcomes, including lymph node retrieval, proximal, distal, and circumferential resection margins, adequacy of total mesorectal excision, and overall and cancer-free survival. Robotics though has been associated with increased operative times and costs. The majority of the published meta-analyses, however, are based on non-randomized studies with potential selection bias.

Ohtani et al. examined 23 studies ($n = 4348$) comparing robotic to laparoscopic surgery for rectal cancer. In the robotic group, an increased number of patients underwent neoadjuvant chemoradiation (674 vs. 566, OR 1.90 [1.44, 2.51], $p < 0.00001$) and had tumors closer to the anal verge (lower rectal cancer) (531 vs. 313, OR 1.86 [1.20, 2.90], $p = 0.006$), suggesting different patient populations. Despite this, robotic was associated with decreased conversion rates (27 vs. 139, OR 0.30 [0.19, 0.46], $p < 0.00001$) [12]. Cui et al. evaluated nine studies ($n = 949$) comparing robotic to laparoscopy for sphincter preserving surgery for rectal cancer. Lower estimated blood loss, decreased conversion rates (3 vs. 29 patients, RD −0.05 [−0.09, −0.01], $p = 0.02$), decreased hospital length of stay, and decreased post-operative complications were observed in the robotic group. Operative times were longer with robotics [13]. The theme of lower conversion rates for robotics in the treatment of rectal cancer has been supported in multiple meta-analyses, including by Li et al. ($n = 3601$, 17 studies, OR 0.35 [0.19, 0.62], $p < 0.001$) [14], Wang et al. ($n = 1229$, 8 studies, OR 0.23 [0.10, 0.52], $p < 0.01$) [15], Sun et al. ($n = 592$, OR 0.08 [0.02, 0.31], $p = 0.0002$) [16], Lee et al. ($n = 2224$, 17 studies, RR 0.28 [0.15, 0.54], $p = 0.0001$) [17], Xiong et al. ($n = 1229$, 8 studies, OR 0.23 [0.10, 0.52], $p = 0.0004$) [18], and Yang et al. ($n = 726$, 7 studies, RD −0.07 [−0.13, 0.00], $p = 0.04$) [19]. Robotics was also associated with decreased conversion rates and increased operative times in a meta-analysis of randomized trials [20••]. Additionally, the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) database analysis demonstrated robotics to be associated with decreased operative conversion rates as well as decreased hospital length of stay for pelvic cases [21].

The oncologic adequacy of robotic resection for rectal cancer has been evaluated by multiple studies. Lee et al. evaluated five studies ($n = 510$) comparing robotic to laparoscopic intersphincteric resection. Similar to others, robotics was associated with decreased conversion rates to open (1.31% vs. 5.59%, RR 0.22 [0.05, 0.97], $p = 0.04$) and decreased blood loss (137.2 ± 79.2 ml vs. 173.6 ± 95.6 ml, MD 41.89 [15.15, 68.27], $p = 0.002$). Oncologic outcomes were not statistically different, although there were fewer lymph nodes in the pathologic specimen (12.9 ± 1.4 vs. 15.6 ± 3.3) and lower positive circumferential resection margins 6.59% vs 8.44%) in the robotic as compared to the laparoscopic group [22]. A meta-analysis of studies evaluating short- and long-term oncologic outcomes with robotic as compared to laparoscopy also showed decreased lymph node yield for robotic cases (five studies, $n = 685$). They reported a mean yield of 13.4 ± 7.5 versus 15.4 ± 9.5 for robotic as compared to laparoscopy, $p = 0.001$). These studies included patients with both colon and rectal cancer. It is important to understand that for both studies, lymph node yield met or exceeded current recommendations [23]. Lower rates of positive circumferential resection margins has also been reported by Wang et al. (OR 0.44 [0.20–0.96], $p < 0.05$), Sun et al. (OR 0.5 [0.25, 1.01], $p = 0.05$), and Xiong et al. (OR 0.44 [0.20, 0.96], $p = 0.04$) [15, 16, 18]. However, the majority of reported studies demonstrate equivalent oncologic outcomes for robotic as compared to conventional laparoscopy in the treatment of rectal cancer [24]. One of the largest studies evaluating short-term oncologic outcomes ($n = 6403$) in minimally invasive surgery for rectal cancer demonstrated no significant differences in oncologic parameters. Similar to other studies, robotics as compared to conventional laparoscopy was associated with lower operative conversion rates (9.5% vs. 16.4%, $p < 0.001$) [25]. Additionally, the most recent propensity-based analysis of the ACS NSQIP database evaluating patients undergoing robotic, laparoscopic, and open resections from rectal cancer demonstrated no differences in positive circumferential resection margin or mean lymph node harvest between the three approaches [26].

Some of the above-mentioned studies have demonstrated robotic surgery to be associated with better post-operative recovery of urological and sexual function. In a retrospective review by Park et al., robotic-assisted resection was associated with greater improvement of sexual function (International Index of Erectile Function score) at 3 and 6 months after surgery as compared with laparoscopic resection ($p = 0.006$ and $p = 0.016$, respectively) [27]. Decreased erectile dysfunction rates have been described with robotic total mesorectal excision [15, 18]. Other studies have shown similar findings [17, 28]. However, when specifically evaluating randomized trials, International Index of Erective Function scores were lower in robotic as compared to laparoscopic surgery, indicating worst erectile function [20••]. Few studies have evaluated the effects of robotic as compared to laparoscopic rectal cancer surgery on female sexual dysfunction [28].

A cohort study by Kim et al. evaluating postoperative urinary function compared a prospective robotic group ($n = 39$) with a retrospective laparoscopic cohort ($n = 30$). Robotics was associated with earlier return of urinary function at 3 months after surgery as compared to traditional laparoscopy ($p = 0.036$). However, at 1 year, there were no differences in function between the two groups [29]. Lee et al. described lower International Prostate Symptom Scores with robotic surgery at 3 months, but no difference at 6 or 12 months [17]. Improved early function has been noted in other studies [28]. Li et al. examined 17 studies ($n = 3601$) and reported that urinary retention was lower with robotic-assisted techniques (OR 0.41 [0.18, 0.89], $p = 0.025$) [14]. When evaluating randomized trials, patients undergoing laparoscopic surgery had increased International Prostate Symptom Scores at 12 months, which indicated more urinary dysfunction [20••].

It is important to evaluate the results from above-mentioned studies compared to largest randomized control trial evaluating robotic surgery for rectal cancer (robotic versus laparoscopic resection for rectal cancer (ROLARR)) [30]. The study randomized 471 patients from 29 centers in 10 countries to robotic versus laparoscopic resections for rectal cancer. Forty surgeons with varying prior laparoscopic and robotic experience participated in this study. The study found no significant difference in conversion rate (8.1% vs. 12.2%, robotic vs. laparoscopic, $p = 0.16$) between the groups. Subgroup analysis showed an improvement in conversion rates in robotic group versus conventional laparoscopy in men ($p = 0.04$). This suggested that robotic surgery may be of more benefit than laparoscopy in men, presumably due to anatomic reasons (narrow pelvis). The study also showed that intra-operative complications, post-operative complications, 30-day mortality, bladder dysfunction, and sexual dysfunction were not statistically significantly different between the groups (Fig. 1).

Right and Abdominal Colectomy

The role of robotic surgery in other locations other than pelvis has also been studied. In general, there have been comparable outcomes with a suggestion of decreased conversion rates when compared to laparoscopy. Similar to other colorectal operations, there are a paucity of randomized trials.

Xu et al. published a meta-analysis of robotic as compared to laparoscopic right hemicolectomy. Robotics was associated with longer operative times, but with lower overall complications, quicker return of normal bowel function, and lower blood loss. There are several confounders in this data set, including a mix of extra and intra-corporeal anastomotic techniques as well as differences in baseline patient characteristics (younger patients in the robotic group) [31]. The finding of quicker return to bowel function with robotic as compared to laparoscopic right colectomy has been demonstrated by other studies, including by Zarak et al. [32, 33]. Other analyses have demonstrated similar results, i.e., longer operative times with robotic-assisted approaches without any significant differences in clinical outcomes [34, 35]. This includes one of the randomized trials comparing robotic to laparoscopic right colectomy [36]. In a recent meta-analysis comparing robotic to laparoscopic right colectomy (11 studies, $n = 8257$), robotics was associated with longer operative time and increased total costs, but decreased conversion rates (RR 1.7 [1.1, 2.6], $p = 0.02$) and quicker return to bowel function (2.3 days vs. 3.3 days, $p = 0.016$). Of importance, when studies evaluating robotic versus laparoscopic right colectomy with extracorporeal anastomosis were compared, no significant differences were noted with regard to peri-operative complications [37].

Multiple studies have demonstrated decreased length of stay with robotic as compared to laparoscopic colorectal surgery [38–40]. Analysis of the ACS NSQIP database similarly demonstrated decreased length of stay with robotic as compared to laparoscopic abdominal colectomy (4.3 days vs. 5.3 days, $p < 0.001$) [21]. Of note, this study evaluated all abdominal colectomy procedures, not limited only to right colectomy. Similar findings were observed by Kulayat et al. in a propensity-matched analysis of patients undergoing minimally invasive colectomy (2013–2015) that robotic-assisted laparoscopic colectomy was associated with decreased hospital length of stay (4.6 days vs. 5.2 days, robotic vs. laparoscopic, $p < 0.001$) [41]. Almost uniformly, robotics is associated with increased operative times.

When evaluating the data specifically on robotic right hemicolectomy, some of the differences particularly increased operative time and quicker return of bowel function may be secondary to an intra-corporeal anastomosis facilitated by the robotic technique. The majority of studies evaluating

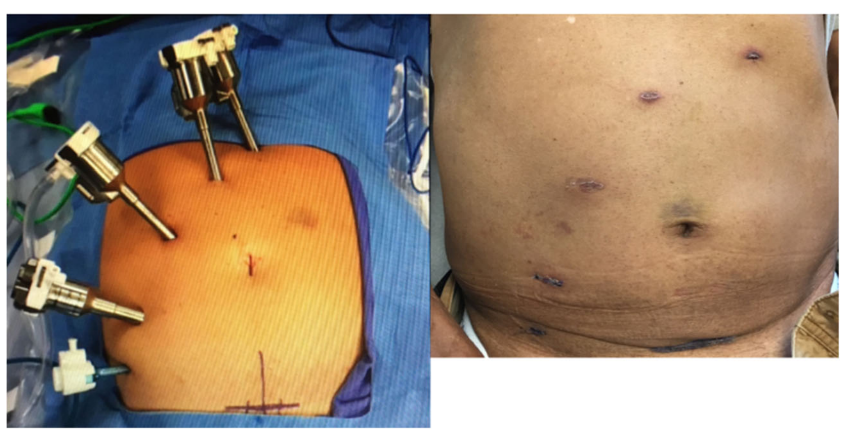

Fig. 1 Port Placement and final appearance after robotic-assisted low anterior resection with low transverse extraction site

laparoscopic right hemicolectomy reported an extra-corporeal anastomotic technique. Factors that may facilitate an intra-corporeal anastomosis with robotics include wristed instruments and increased ease of intra corporeal suturing [42]. When comparing intra-corporeal to extra-corporeal anastomosis with laparoscopic right hemicolectomy, similar findings of lower blood loss and quicker return of bowel function are noted [43]. When comparing intra-corporeal to extra-corporeal anastomosis with robotic right hemicolectomy, similar findings are noted, suggesting that the technique of anastomosis creation may have more to do with outcome differences [44]. This notion is further supported by studies demonstrating similar peri-operative outcomes when comparing robotic versus laparoscopic right colectomy when both procedures are performed with intra-corporeal anastomosis [45]. Other advantages of intra-corporeal anastomosis include smaller extraction sites, as well as the ability to choose off midline and low transverse extraction sites which may result in better cosmetic outcome as well as lower incisional hernia rates. Technical challenges, including laparoscopic intra-corporeal suturing, are among the reasons that laparoscopic right colectomy with intra-corporeal anastomosis is not more widely performed.

There are few studies that evaluate specifically long-term oncologic parameters in robotic right colectomy. The majority of the data on oncologic outcomes compares all abdominal colectomies. Spinoglio et al. compared patients undergoing robotic versus laparoscopic right colectomy with complete mesocolic excision (101 patients in each group) and noted that 5-year overall and disease-free survival was not significantly different. As echoed by other studies, robotics was associated with decreased conversion rates (0% vs. 6.9%, $p = 0.01$) and longer operative times [46]. A recent analysis of the US National Cancer Database demonstrated equivalent short-term outcomes when comparing robotic to laparoscopic colectomy with regard to lymph node retrieval and surgical margins. Interestingly, when a propensity-matched analysis of patients with stage 2 and 3 disease was performed, robotics was associated with significantly improved 5-year survival. It is unclear as to the reasons for this, but it may be related to selection bias with robotic cases and/or decreased operative conversion rates (15.1% vs. 10.6%, $p = 0.001$) [47]. Minimally invasive approaches (whether robotic or laparoscopic) may be advantageous in achieving recommended minimum lymph node harvest when compared to the open approach [48].

Robotic-assisted approaches may have utility in patients with obesity. A recent propensity matched analysis of the ACS NSQIP database (2012–2014) compared patients undergoing robotic versus laparoscopic colon and rectal surgery. When patients with a body mass index (BMI) of 30 kg/m^2 or higher were compared, the rate of prolonged ileus was decreased in patients undergoing robotic colectomy [49].

Patients that are appropriate candidates for robotic colectomy surgery are similar to those for conventional laparoscopy. There are no clear indications yet to clearly support robotic surgery. Potential advantages include decreased conversion rates, quicker return to bowel function, and decreased hospital length of stay. The literature suggests, aside from decreased conversion rates, that other outcome variables are likely secondary to facilitation of an intra-corporeal anastomosis (Fig. 2).

Rectopexy

Non-randomized studies have demonstrated that robotic-assisted rectopexy is a safe technique [50, 51]. Comparative studies have demonstrated the robotic technique to be associated with increased operative times and costs [52, 53]. A meta-analysis of robotic as compared to laparoscopic rectopexy for patients with rectal prolapse demonstrated that robotics was associated with increased operative times, decreased blood loss and post-operative complications (OR 0.42 [0.18, 0.97], $p = 0.04$), and decreased hospital length of stay (SMD −0.33 [−0.6, −0.05], $p = 0.02$) [54]. A recent prospective randomized study compared robot-assisted to laparoscopic ventral rectopexy procedures for posterior compartment procidentia. Peri-operative outcomes were evaluated using magnetic resonance (MR) defecography at 3 months post op. No significant differences were noted in perioperative outcomes, including operative time, length of stay, and 3 months MR defecography results [55].

Inflammatory Bowel Disease

There are a paucity of studies evaluating the role of robotics in the surgical management of patients with inflammatory bowel disease (proctectomy, ileal pouch anal anastomosis (IPAA)).

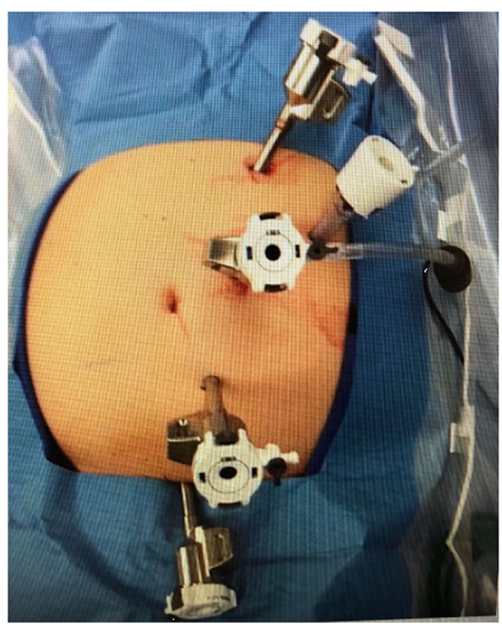

Fig. 2 Port replacement for robotic-assisted right hemicolectomy

The literature suggests similar outcomes, with longer operative times almost uniformly reported. This has been demonstrated when robotics was compared to laparoscopy [56, 57] as well as to open operations [58].

Robotics and Cost

Perceived increased peri-operative cost associated with robotic surgery has been a subject of discussion since its introduction. Cost can be divided to fixed costs (initial cost of the robot, non-disposable instruments, and maintenance of the robotic system) and non-fixed costs (disposable instruments). Learning curve and robotic experience are important factors that may influence operative costs. Morelli et al. evaluated surgical parameters and costs of a single surgeon's first 50 robotic versus laparoscopic rectal resections [64, 65]. The 50 cases were divided into three groups: the learning phase (cases 1–19), the competent phase (cases 20–40), and the experienced phase (cases 41–50). Operative times and overall costs were higher in the robotic group as compared to the laparoscopic group (270 vs. 312.5 min, $p = 0.006$). However, there was statistically significant reduction in overall cost between the different robotic learning curve phases ($p < 0.009$). Operative times and costs were significantly reduced in the experienced robotic phase compared with learning and competent phases. When fixed costs were excluded, no statistically significant difference was noted between the laparoscopic group and the experienced robotic phase group. These results suggest that as a surgeon proceeds through their learning curve, operative costs decrease. Additionally, it is important to note that the overall costs are also affected by length of hospital stay, readmission rates, and perioperative complications. In a value-based health care system, continued studies are warranted to demonstrate if robotic surgery is a cost-effective approach for colorectal surgery (Fig. 3a, b).

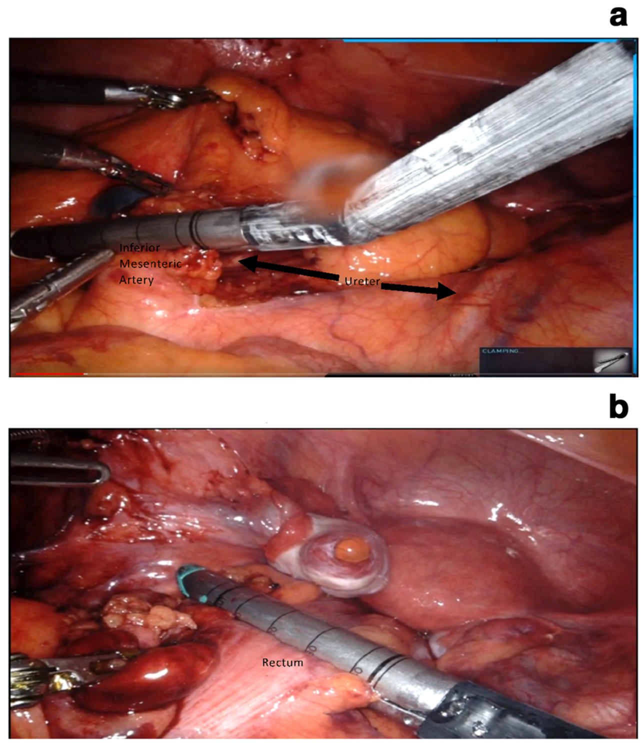

Fig. 3 **a** Operative view—securing IMA with robotic stapler. **b** Rectal transection—robotic sigmoid colectomy for complicated diverticulitis

Summary of Studies on Robotics and Colectomy

The most consistent benefit of robotics in colorectal surgery is with decreasing operative conversions, specifically in rectal cancer. It is important, however, to mention that this was not borne out in the largest randomized trial of laparoscopic as compared to robotic surgery for rectal cancer. When evaluating right and abdominal colectomy, there appears to be some evidence to support quicker return to bowel function, likely related to an intra-corporeal anastomosis facilitated by robotics. In general, oncologic outcomes with robotic as compared to laparoscopic colorectal surgery are equivalent. The main points of criticism of robotic surgery in colorectal surgery include increased costs and longer operative times without any consistent improvement in peri-operative variables. Longer operative times in colorectal surgery have been associated with worsened outcomes; however, when comparing longer minimally invasive cases (robotic and laparoscopic) to shorter equivalent open case, outcomes appear to be improved with a minimally invasive approach [59].

Conclusions

Minimally invasive approaches for the treatment of colorectal disease should be encouraged. In particular reference to patients with malignancy, the use of minimally invasive approaches may be associated with decreased time to initiation of adjuvant therapy [60].

The use of robotics in colorectal surgery is a relatively new, but increasingly utilized surgical approach [61]. Robotic surgery shares many of the advantages of laparoscopic surgery including less pain, faster recovery, shorter hospital length of stay, decreased postoperative wound complications, and better cosmetic outcomes. Although most colorectal operations are still performed via an open approach, various minimally invasive approaches continue to enjoy increased popularity in the field of colorectal surgery [62]. It is appropriate to conclude that robotic approaches for colorectal surgery are safe, may be associated with decreased conversion rates in rectal and colon cancer-related operations, and may result in quicker return to bowel function in right colectomy, likely related to facilitating intra-corporeal anastomoses.

The literature on robotics and colorectal surgery must be interpreted carefully, as the majority of data is based on non-randomized studies. There are a large number of single-center experiences published with potential for selection bias. Additionally, the increased adoption of robotics has paralleled the increased adoption of enhanced recovery after surgery (ERAS) and pre-habilitation protocols; some of the outcome advantages demonstrated in studies may, in part, be due to aggressive ERAS strategies. These protocols generally result in improved outcomes when applied to traditional laparoscopy, as well as to open cases [63].

Although the theoretical advantages of wristed instruments, enhanced visualization, ease of intra-corporeal suturing, and ergonomic advantages have been widely marketed as advantages of robotics, the preponderance of the data suggests no consistent improvement in peri-operative outcomes in colorectal surgery. This is not terribly unexpected. The majority of studies on robotics in colorectal surgery were based on platforms that were not designed for multi-quadrant surgery; newer platforms may offer some advantages, particularly when related to operative times [64–66]. A large amount of literature reflects results of surgeons in their learning curve with robotics. Additionally, as the majority of studies are retrospective in nature, there exists tremendous selection and other biases. Less (or more) complicated patients may have been chosen for robotic procedures based on surgeon judgment and experience.

With enhanced robotic technology, the introduction of new platforms, including those designed for trans-anal surgery [67] and platforms that are integrated with other operating room components, and continued evolution of surgeon experience, it remains to be seen if the promise of robotics will be borne out in future studies. Well-designed randomized trials to evaluate peri-operative outcomes (including quality of life measures) will be important. Surgeons should not expect different short- and long-term oncologic-related outcomes with robotic colorectal surgery. A properly done operation from an oncologic standpoint should result in similar outcomes, whether done open, laparoscopic, or robotic. However, if robotics is able to facilitate conversion of open colectomies to their minimally invasive equivalent, robotics may end up proving to be advantageous in the peri-operative and post-operative period. Continued studies are warranted.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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•• Of major importance

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