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REVIEW ARTICLE

Minimally Invasive Surgery for Rectal Cancer: Current Status and Future Perspectives

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Abstract Although laparoscopic resection for colon cancer has been proven safe and feasible when compared with open resection, currently no clear evidence is available regarding minimally invasive surgery for rectal cancer. This type of surgery may benefit patients by allowing fast recovery of normal dietary intake and bowel function, reduced postoperative pain, and shorter hospitalization. Therefore, minimally invasive surgeries such as laparoscopic or robot surgery have become the predominant treatment option for colon cancer. Specifically, the proportion of laparoscopic colorectal cancer surgery in Korea increased from 42.6 to 64.7% until 2013. However, laparoscopic surgery for rectal cancer is more difficult and technically demanding. In addition, the procedure requires a prolonged learning curve to achieve equivalent outcomes relative to open surgery. It is very challenging to approach the deep and narrow pelvis using laparoscopic instruments. However, robotic surgery provides better vision with a high definition three-dimensional view, exceptional ergonomics, Endowrist technology, enhanced dexterity of movement, and a lack of physiologic tremor, facilitated by the use of an assistant in the narrow and deep pelvis. Recently, an increasing number of reports have compared the outcomes of laparoscopic and open surgery for colon cancer. Such reports have prompted a discussion of the outcomes of minimally invasive surgery, including robotic surgery, for rectal cancer. The aim of this review is to summarize current data regarding the clinical outcomes, including oncologic outcomes, of minimally invasive surgery for rectal cancer.

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Introduction: History of Minimally Invasive Surgery for Rectal Cancer

The history of minimally invasive surgery (MIS) dates back to 1987, when the introduction of laparoscopic cholecystectomy marked an important shift from open surgery [1]. Since the first successful incorporation of laparoscopy in colorectal surgery in 1991, MIS has also yielded many tremendous developments in the field of colorectal cancer [2]. For example, this technique has facilitated benefits such as a rapid recovery and shorter hospitalization, in addition to reduced postoperative pain [3–5]. Despite the acceptance of laparoscopic surgery for colorectal cancer, in addition to various types of abdominal surgery, many clinicians continued to express concerns that this technique would compromise survival by failing to achieve a proper oncologic outcome [6]. However, the COST trial demonstrated similar recurrence rates between laparoscopic and open colectomy and suggested that laparoscopic surgery is an acceptable alternative approach to open surgery for colon cancer [3]. Since then, many researchers have attempted to demonstrate the benefits and safety of laparoscopic colorectal surgery through randomized controlled trials such as A La Cart and COLOR II, which compared laparoscopic and open colorectal surgery [5, 7–10]. These previous studies proved that laparoscopic colon surgery could be equivalent to or not inferior to open surgery. However, the benefits of laparoscopic surgery for rectal cancer have not been clearly demonstrated. Rectal cancer surgery is technically demanding, given the anatomical challenges in the deep and narrow pelvis, and many surgeons harbor concerns about oncologic outcomes, including functional outcomes. Laparoscopic surgery also requires a steep learning curve to ensure adequate outcomes, and is an assist-dependent procedure [11]. MIS has led to many technical advances involving less invasive approaches in an attempt to overcome these limitations by combining open and laparoscopic techniques. The hand-assisted technique was first introduced in the 1990s [11]. This technique, which provides excellent capabilities of exploration and safe specimen retraction, was useful because it allowed the use of laparoscopic instruments during colorectal surgery, splenectomy, and other procedures considered too complex for a laparoscopic approach [12]. Single-incision laparoscopic surgery (SILS) [13] and natural orifice transluminal endoscopic surgery (NOTES) [14–16] were introduced for the same reason. Beyond laparoscopic surgery, robotic surgery has recently been applied for rectal cancer. This technique has overcome the limitation of laparoscopic colorectal surgery under difficult conditions such as a deep and narrow pelvis. Robotic surgery yields benefits such as dexterity of movement, a three-dimensional camera view, and reduced assistant-based physiological tremor. Currently, many trials are attempting to prove the safety and feasibility of MIS for rectal cancer.

The aim of this review is to summarize the published literature regarding the development of MIS for rectal cancer, as well as the current status and future perspectives regarding innovations of this technique for safety and feasibility.

A Standing Rule of Total Mesorectal Excision in Rectal Cancer

Total mesorectal excision (TME) has been a standard principle of rectal cancer surgery since its introduction in 1982, and is considered very important for oncologic outcomes [17]. In a study of 113 cases, Heald et al. reported no recurrences in 50 cases subjected to curative resection. Those patients were followed-up for more than 2 years with no pelvic or anastomosis site recurrences, whereas in previous studies, the local recurrence rates within 2 years ranged from 80 to 90%. Kapiteijn et al. reported improvements in local control and survival of patients with rectal cancer after the introduction of TME, compared with the outcomes of conventional rectal cancer surgery [18]. Incomplete mesorectal dissection yielded a significantly higher local recurrence when compared with complete dissection (36 vs. 20%) [19]. Therefore, TME is considered an essential procedure with regard to oncologic outcomes, even in cases involving laparoscopic resection. However, laparoscopic TME is a difficult procedure and has a steep learning curve. Kayano et al. evaluated the median number of cases required to achieve consistent results, and determined numbers as high as 50–150 for laparoscopic TME [20]. Postoperative morbidity and oncologic outcomes are significant concerns regarding the application of MIS for rectal cancer. Because inadequate dissection may cause poor oncologic and survival outcomes, it is important to maintain the "holy plane" during TME involving laparoscopic dissection. In laparoscopic surgery, improved optic instruments provide a clear and magnified view of the parietal and visceral fascia of the mesorectum and facilitate meticulous dissection along the correct plane. In other words, sharp dissection for TME and identification of neurovascular structures in the pelvic cavity are better achieved with laparoscopy. Thus, laparoscopic surgery for rectal cancer is expected to be safe and feasible with regard to oncologic and postoperative outcomes.

Are the Oncologic Outcomes of Laparoscopic Surgery for Rectal Cancer Not Inferior to Those of Open Surgery?

Early reports described significantly high surgical complication rates associated with MIS. Reissman et al. reported a postoperative complication rate of 18% with laparoscopic surgery [21] and wound or trocar site recurrence rates of 21% for colorectal surgery [22]. The development of instruments and surgical techniques have led to significant decreases in surgical complications, with a port site recurrence rate of <1% in a review that covered the period from 1993 to 2000 [23]. However, oncologic concerns regarding laparoscopic rectal surgery remain, and several retrospective trials have attempted to demonstrate the safety and feasibility of this procedure when compared with open surgery. For example, Ströhlein et al. described comparable local recurrence (6.9%) and long-term survival rates (overall survival: stage I, 75.2%; stage II, 73.4%; stage III, 51.3%) in a comparison of laparoscopic and open surgery ($p = 0.42$), and observed rapid recovery and short hospitalization in the former ($p = 0.037$) [24]. Kim et al. also investigated the benefits and oncologic outcomes of laparoscopic rectal cancer surgery [25]. These authors reported safe and adequate mid-term oncologic outcomes, with a postoperative complication rate of 20.5% and local recurrence rate of 2.9% in the laparoscopic group. Laurent et al. demonstrated similar long-term local control and cancer-free survival rates with laparoscopic and open surgery for rectal cancer [26]. Recent randomized controlled trials (RCTs) also did not observe differences in the resection margin, lymph node harvest, tumor recurrence, and mid- to long-term survival between laparoscopic and open surgery. However, most RCTs have focused on colon cancer when comparing the outcomes of open and laparoscopic surgery for colorectal cancer [3, 4, 27, 28]. In large-scale and randomized trials such as the MRC-CLASSIC trial, the 3-year overall survival rate with laparoscopic surgery for rectal cancer was not inferior to that of open surgery (68.4 vs. 66.7%; $p = 0.55$) [5]. Two surgical methods also did not differ with respect to 3-year disease-free survival (DFS; open, 67.7% vs. laparoscopic, 66.3%; $p = 0.70$). However, 29% of all patients with rectal cancer were converted from laparoscopic to open surgery, and the most common causes for conversion were excessive tumor fixation (41%), obesity (26%), anatomical uncertainty (21%), and inaccessibility of tumors (20%). In that study, the CRM involvement rates were higher with laparoscopic than with open surgery (7 vs. 5%), although this difference was not significant. Bonjer et al. demonstrated similar locoregional recurrence and DFS rates between laparoscopic surgery and open surgery for rectal cancer (locoregional recurrence rate: 5.0% in both groups) in the COLOR II trial [9]. In that trial, the DFS rates were 74.8 and 70.8% with laparoscopic and open surgery, respectively. The overall survival rates also did not differ significantly (open, 83.6% vs. laparoscopic, 86.7%). However, the ACOSOG trial failed to demonstrate the noninferiority of laparoscopic surgery for rectal cancer [29]. In that RCT, successful resection was achieved in 81.7% of patients in the laparoscopic group and 86.9% in the open group. Conversion to open surgery occurred in 11.3% of patients, and CRM involvement was observed in 12.1% of laparoscopic and 7.7% of open cases ($p = 0.11$) Although the authors failed to demonstrate the noninferiority of laparoscopic surgery, the number of harvested lymph nodes and rate of severe complication did not differ significantly between the groups (laparoscopic, 22.5% vs. open, 22.1%). The time to recovery of bowel movement was more rapid ($p = 0.03$) and intraoperative blood loss was significantly reduced ($p = 0.004$). Another RCT, the ALaCaRT trial, also failed to establish the noninferiority of laparoscopic surgery for rectal cancer relative to open surgery [10]. The successful resection rates were 82 and 89% for laparoscopic and open surgery, respectively ($p = 0.38$). A higher CRM involvement rate was observed with laparoscopic surgery (7% vs. open, 3%; $p = 0.06$), and the conversion rate from laparoscopic to open surgery was 9% (Tables 1 and 2).

Transition from Laparoscopic to Robotic Surgery for Rectal Cancer and Development of the Robotic System: From Si to Xi

The CLASSIC trial observed a higher conversion rate (34%) and higher rates of CRM involvement with laparoscopic rectal resection [5]. Recently, robotic surgery has revolutionized and expanded the field of MIS beyond laparoscopic surgery. This system can provide three-dimensional views and improved ergonomics, while eliminating assistant-based physiologic tremor [30]. Robotic surgery does not require a long learning curve if the clinician possesses laparoscopic experience. This technique also yields tremendous outcomes for low rectal cancer in the deep and narrow pelvis, in contrast to laparoscopic surgery, which is difficult, time-consuming, and associated with higher conversion rates. In a review, Trastulli et al. compared the outcomes of robotic and laparoscopic resection of rectal cancer in eight studies and obtained mean conversion rates of 2% in the robot group and 7.5% in the laparoscopic group [31]. Two studies described the reasons for conversion, which included a severely narrow pelvis that precluded rectal dissection, bleeding of the pelvic wall, insufficiently long dissection instrument, and obesity with a narrow pelvis.

The da Vinci robotic system was approved by the United States Food and Drug Administration (FDA) in 2000 [32]. This system provides enhanced, operator-controlled, three-dimensional high definition vision, EndoWrist technology with seven degrees of freedom, and tremor elimination with improved dexterity. Weber et al. and Hashizume et al. first performed robotic colorectal surgery in 2002 [33, 34]. D'Annibale et al. reported several cases treated via robotic colorectal surgery and concluded that a robotic system might be useful for procedures such as takedown of the splenic flexure, dissection of the inferior mesenteric artery, identification of the nerve plexus, and dissection of a narrow pelvis [35]. Baik et al. confirmed the findings of D'Annibale et al. and demonstrated that TME for rectal cancer was more easily and effectively achieved with a robotic system [36]. Robotic rectal resection is performed in two steps because the da Vinci system cannot self-adjust to allow access to more than one quadrant of the abdomen. These steps, the colonic phase and pelvic phase, occur when the robot system is adjusted. The time-consuming and difficult nature of these steps led to the introduction of a hybrid technique involving a conventional laparoscopic approach for the colonic phase and robotic approach for the pelvic phase. This method advantageously reduces the operative time in cases of rectal cancer in which the left colon and splenic flexure are mobilized by a conventional laparoscopic technique, followed by a robotic technique for pelvic dissection (e.g., TME) [37, 38]. Total robotic techniques involve performance of an entire robotic operation involving a single-docking or dual-docking technique, which requires the operating table to be repositioned between the colonic and pelvic phases. Although several studies have reported improved outcomes with robotic surgery for rectal cancer, this technique still has many limitations. The costs of the robotic system and instruments and the prolonged operation time are nonnegligible drawbacks. The strong, bulky robotic arms lack haptic feedback during dissection. Inexperienced surgeons can easily avulse tissues if they fail to perceive a subtle view.

The da Vinci Xi system was recently introduced and is expected to overcome the limitations of the previous platform. The da Vinci Xi system combines the functionality of a boom-mounted system with the flexibility of a mobile platform [39]. With this simpler docking system, the scope can be placed on any of the robotic arms and autofocused. The oblique disposition of the trocar would enable the completion of splenic flexure mobilization and the pelvic phase with a single-docking technique. The instruments have a very wide range

Table 1 Postoperative outcomes of laparoscopic and open surgery for rectal cancer

Study	Operation method	Complication	CRM involvement	No. of LN harvested	Incomplete TME
Laurent et al. [27]	Laparoscopic	77 (32.0%)	16 (7.0%)		19 (8.0%)
	Open	88 (37.7%)	11 (6.0%)		12 (5.2%)
COLOR II [10]	Laparoscopic	81 (12%)	56 (10%)	13 (10.0–18.0)	19 (<3%)
	Open	49 (14%)	30 (10%)	14 (10.0–19.0)	9 (<3%)
ALaCaRT [11]	Laparoscopic	44 (<21%)	16 (7%)		8 (3%)
	Open	62 (<25%)	7 (3%)		2 (1%)
ACOSOG [30]	Laparoscopic[a]	26 (10.8%)	29 (12.1%)	17.9 ± 10.1	19 (7.9%)
	Open	17 (7.7%)	17 (7.7%)	16.5 ± 8.4	11 (5.0%)

CRM circumferential resection margin, *LNs* lymph node, *TME* total mesorectal excision

[a] ACOSOG, laparoscopic surgery consisted of laparoscopic, 68.8% and robotic, 14.2%

of movement from the transverse colon to the levator ani. Improved arms allow the ports to be placed in closer proximity, thus avoiding collision. Morelli et al. compared the use of da Vinci Xi and Si system for rectal cancer and observed significantly reduced operating time and hospitalization with the former [39]. In this study, only 40% of cases using the Si system were fully robotic, compared with 100% of cases using the Xi system.

Clinical Outcomes of Robotic Surgery for Rectal Cancer

Despite the lack of definitive oncologic outcomes, robotic surgery allows better access to the deep and narrow pelvis. The mean operation time was significantly longer with robotic surgery than with laparoscopic surgery. In a systemic review by Mak et al., most studies observed a longer operation time with robotic surgery, which was attributed to robotic instrument docking and switching (robotic, 281.8 min vs. laparoscopic, 242.6 min) [32]. The conversion rates for robotic surgery ranged from 0 to 8.0%, whereas those for laparoscopic surgery ranged from 1.8 to 22%. The reasons for conversion included obesity, anatomical difficulty, bulky tumor, narrow and deep pelvis, adhesion from previous surgery, equipment malfunction, and intraoperative complications such as massive bleeding and rectal perforation. These authors also found that in five of 11, greater blood loss was reported in the laparoscopic group than robotic group. Pigazzi et al. reported the outcomes of a multicenter study of robotic surgery for rectal cancer, wherein the conversion rate was 4.9% and lymph node harvesting was more efficient in the robotic group vs. the open group [40]. Baik et al. also reported a local recurrence rate of 3.6% and favorable survival with robotic surgery (3-year DFS, 79.2%; OS, 93.1%) [41]. D'Annibale et al. compared the postoperative and oncologic outcomes between robot and laparoscopic surgery for rectal cancer [35]. In that study, the techniques did not differ in terms of the number of harvested lymph nodes and complications, although the conversion rate to open surgery was higher in the laparoscopic group ($p = 0.011$). In another retrospective study, Cho et al. compared the outcomes of open surgery and MIS for rectal cancer in Korea [42]. These authors found no differences in the rates of CRM involvement, 5-year OS (laparoscopic, 88.5% vs. robotic, 88.3% vs. open, 85.3%; $p = 0.49$), and 5-year DFS (laparoscopic, 83.5% vs. robotic, 74.4% vs. open, 78.4%).

Table 2 Oncologic outcomes of laparoscopic and open surgery for rectal cancer

Study	Operation method	Local recurrence	Disease-free survival	Overall survival
Ströhlein et al. [25]	Laparoscopic	5-year: 6.9%		5-year, open vs. laparoscopic
	Open	5-year: 9.5%		Stage I: 75.2 vs. 85.4%
				Stage II: 73.4 vs. 66.7%
				Stage III: 51.3 vs. 60.1%
Kim et al. [26]	Laparoscopic	2.9%		
Laurent et al. [27]	Laparoscopic	5-year: 3.9%	5-year: 82%	5-year: 83%
	Open	5-year: 5.1%	5-year: 79%	5-year: 72%
COLOR II [10]	Laparoscopic	3-year: 5%	3-year: 74.8%	3-year: 86.7%
	Open	3-year: 5%	3-year: 70.8%	3-year: 83.6%

The results demonstrate that robotic and laparoscopic surgery yielded comparable oncologic outcomes. The ROLARR trial has not yet reported the results of an ongoing RCT to compare laparoscopic and robotic surgery for rectal cancer [43]. This trial has investigated differences in the rates of conversion and oncologic efficacy between laparoscopic and robot surgery for rectal cancer. The authors reported a nonsignificantly lower conversion rate (laparoscopic, 12.2% vs. robotic, 8.1%) and CRM involvement rate after robotic surgery (laparoscopic, 6.3% vs. robotic, 5.1%). The 30-day morbidity and mortality rates were similar in both groups. However, a subgroup analysis indicated significant differences in the conversion rates among male patients (laparoscopic, 16.0% vs. robotic, 8.7%), patients with low rectal cancer (laparoscopic, 13.3% vs. robotic, 7.2%), and obese patients (laparoscopic, 27.8% vs. robotic, 18.9%). Morelli et al. compared the postoperative and pathologic outcomes of the da Vinci Xi and Si systems and found better results with the former in terms of the operative time (Xi, 257.8 min vs. Si, 353.5 min; $p < 0.01$), complete robotic dissection rate (Xi, 100% vs. Si, 20%; $p < 0.005$), hospitalization ($p = 0.01$), and time to catheter removal ($p = 0.03$) [39]. Moreover, the authors observed no differences between the systems in terms of lymph node harvesting, CRM involvement, and TME quality. Although that study achieved comparable outcomes, the size of the enrolled patient cohort was small. However, we hope that these findings and those of further studies will increase the acceptance of robotic surgery as a minimally invasive technique for rectal cancer (Tables 3 and 4).

Sexual and Urinary Dysfunction Associated with Minimally Invasive Surgery for Rectal Cancer

Sexual and urinary dysfunction are well-known complications of rectal cancer surgery; these occur because of the close proximity of the pelvic nerves to the mesorectum and the difficulty in identifying anatomical structures such as the inferior hypogastric plexus in the narrow and deep pelvis. Laparoscopic surgery for rectal cancer has yielded similar or higher rates of sexual dysfunction when compared with open surgery [27, 44, 45]. However, robotic surgery for rectal cancer provides surgeons with a better view and improved ergonomics when dissecting pelvic anatomical structures [46]. Conventional open TME has been associated with urinary dysfunction rates of 0–12% and sexual dysfunction rates of 10–35% [47, 48]. Jayne et al. compared the rates of bladder and sexual dysfunction between laparoscopic and open surgery for rectal cancer and achieved similar bladder function outcomes in both groups ($p = 0.129$) [49]. However, erectile function tended to be worse after laparoscopic surgery, compared with open surgery ($p = 0.063$). Kim et al. evaluated voiding and sexual function after laparoscopic and robotic TME for rectal cancer [48]. These authors reported that robotic TME was associated with an earlier recovery of normal voiding and sexual function, compared to laparoscopic TME. In that study, the recovery periods of reduced urinary function were 6 months in the laparoscopic group and 3 months in the robotic group. Regarding sexual function, the recovery period was reduced with 6 months in robotic surgery than laparoscopic surgery. Although several studies reported worse outcomes with laparoscopic surgery, the technical and instrumental improvements of robot surgery can provide better outcomes regarding bladder and sexual dysfunction.

Sphincter-Preserving Surgeries Such as Intersphincteric Resection and Hemilevator Ani Excision

Abdominoperineal resection (APR) is planned for low rectal cancers occurring close to or invading the anal sphincter. However, APR was associated with a higher CRM involvement rate (10%) and local recurrence rate (20%) when compared with lower anterior resection (LAR) [50]. The 5-year survival of patients who underwent APR was poor as 59%, whereas that of LAR was 70%. Anatomical difficulties concerning the surgical approach in the deep and narrow pelvis led to poor outcomes after APR. Recently, sphincter-preserving surgery has become popular because of the advantageous oncologic outcome, as well as anal sphincter preservation. Several studies have shown the safety and feasibility of laparoscopic sphincter-preserving surgery for low rectal cancer [51–54]. Portier et al. reported the apparent oncologic safety of sphincter-preserving surgery for very low rectal cancer. In that study, local recurrence and 5-year overall survival rates ranged from 6.7 to 10.6% and from 80.0 to 86.1%, respectively [55]. Denost et al. reported a CRM involvement rate of 9%, local recurrence rate of 4%, 5-year DFS rate of 83%, and OS of 70% for laparoscopic TME with coloanal anastomosis (CAA) for rectal cancer [54]. In addition to LAR with CAA, intersphincteric resection (ISR) was applied to preserve the anal sphincter in cases of low rectal cancer with invasion to the anal sphincter. Schiessel et al. introduced ISR in 1994, in which proctectomy and TME are combined with bilateral or ipsilateral resection of the internal sphincter [56]. Park et al. reported a shorter hospitalization (laparoscopic, 12.9 days vs. open, 18.1 days; $p < 0.001$) and time to bowel movement (laparoscopic, 2.6 ± 0.9 vs. open, 3.2 ± 1.6; $p = 0.017$) in the ISR group when compared with the open group [57]. In that study, the groups had similar local recurrence rates (2.6 vs. 7.7%; $p = 0.184$), and the improved 3-year DFS of the laparoscopic group was not significant (82.1% vs. open, 77.0%; $p = 0.523$). In another study, Park et al. compared the short-term outcomes of robotic ISR with

Table 3 Postoperative outcomes of robotic and laparoscopic surgery for rectal cancer

Study	Operation method	Complication	CRM involvement	No. of LNs harvested
Pigazzi et al. [41]	Robotic	59 (41.3%)	0.7%	14.1
Baik et al. [42]	Robotic	47 (12.7%)	21 (5.7%)	15.6 ± 9.0
D'Annibale et al. [36]	Robotic	5 (10%)	0	16.5 ± 7.1
	Laparoscopic	11 (22%)	6	13.8 ± 6.7
Cho et al. [43]	Laparoscopic	25 (20%)	4 (3%)	18.2 ± 6.7
	Robotic	8 (9%)	5 (6%)	18.0 ± 7.6
	Open	70 (17%)	20 (5%)	18.9 ± 7.8

CRM circumferential resection margin, *LNs* lymph nodes, *TME* total mesorectal excision

laparoscopy for low rectal cancer [58]. The procedures yielded similar postoperative morbidity rates (laparoscopic, 12.5% vs. robotic, 15.0%; $p = 0.745$) and CRM involvement rates (5.0 vs. 7.5%; $p = 1.000$). However, the robotic group had a longer operation time (235.5 min vs. laparoscopic, 185.4 min; $p = 0.001$). As an alternative sphincter-preserving surgical method, AlAsari et al. reported the use of robotic hemilevator excision for low rectal cancer [59]. This procedure includes a standard TME to the levator ani level via the abdominal approach and wide excision of the levator muscles via the perineal approach. The authors observed no postoperative complications and comparable pathologic outcomes. However, few studies have presented the outcomes of sphincter-preserving surgery involving hemilevator excision, rather than ISR alone, and these previous studies have been small. In the future, a randomized trial is needed to demonstrate the safety and feasibility of MIS as a sphincter-preserving surgical technique. In addition, a demonstration of long-term functional outcomes after ileostomy repair is needed.

Expansion to Transanal TME and Development of Instruments for Better Outcomes

Various attempts have been made to overcome laparoscopic limitations such as a two-dimensional view, unstable assistant-controlled camera, poor ergonomics, straight tip instruments, fulcrum effect, and enhanced tremor effect. Single-incision laparoscopic surgery has reduced the numbers of required incisions and ports, thus yielding better cosmetic results and reduced wound pain. NOTES aimed to eliminate external incisions by gaining access via transvaginal, transgastric, transvesical, and transrectal approaches. However, NOTES has previously been associated with many hurdles. Similarly, transanal TME was recently introduced to overcome the technical difficulties associated with laparoscopic rectal dissection in the deep and narrow pelvis. This technique has the advantages of facilitating anorectal dissection, clear distal margins, and transanal specimen extraction. Sylla et al. first reported transanal mesorectal dissection using laparoscopy-assisted transanal endoscopic microsurgery (TEM) instruments [60]. Further investigations are needed to clarify the long-term oncological and functional outcomes. Atallah et al. also reported a hybrid approach combining TEM and single-port surgery for the local excision of a rectal tumor, transanal MIS (TAMIS) [61]. In 2011, transanal TME with a single-port device and laparoscopic instruments was introduced [62]. Several studies have reported the feasibility and efficiency of transanal TME [63–66]. Hasegawa reviewed 13 articles concerning transanal TME for rectal cancer [67]. These authors demonstrated comparable outcomes of transanal and conventional TME and noted that the former approach facilitates perianal dissection in patients with a deep and narrow pelvis. Transanal access can yield improved specimen quality and an adequate distal margin under direct vision. Moreover, transanal TME eliminates the need for abdominal wound elongation, which can cause postoperative complications. With a laparoscopic approach, it is difficult to reach to the pelvic floor with the tips of instruments, and small hand motions are amplified in the deep pelvis. Verheijen et al. performed robotic transanal TME for rectal cancer and demonstrated complete excision with clear margins and no postoperative complications [68]. The development of surgical instruments such as access ports, anastomotic circular staplers, and energy devices have facilitated this approach. Transanal TME should be applied to suitable patients with proper

Table 4 Oncologic outcomes of robotic and laparoscopic surgery for rectal cancer

Study	Operation method	Local recurrence	Disease-free survival	Overall survival
Pigazzi et al. [41]	Robotic	3-year: 1.5%	3-year: 77.6%	3-year: 97%
Baik et al. [42]	Robotic	3-year: 3.6%	3-year: 79.2%	3-year: 93.1%
Cho et al. [43]	Laparoscopic	5-year: 3.5%	5-year: 83.5%	5-year: 88.5%
	Robotic	5-year: 7.5%	5-year: 74.4%	5-year: 88.3%
	Open	5-year: 5.1%	5-year: 78.4%	5-year: 85.3%

indications, and increased surgical experience is needed to ensure long-term outcomes in the future. In fact, the ongoing multicenter COLOR III trial has demonstrated the efficacy and safety of transanal TME vs. conventional TME for rectal cancer in a randomized setting [69].

Conclusions

MIS can provide favorable outcomes for patients with rectal cancer. A considerable body of data supports the feasibility, safety, and oncologic outcomes of MIS, compared with open surgery. However, multicenter randomized trials are needed to confirm and clarify those benefits. Innovative approaches to technical instrument and surgical method design have been undertaken to promote patient benefits and user-friendliness. These improvements and developments will facilitate the widespread application of MIS for rectal cancer.

In the future, randomized controlled trials of MIS for rectal cancer are needed to further analyze and compare the outcomes of laparoscopic and robotic resection or robotic and open resection. We expect that the results of these trials will help to establish MIS as a safe and feasible procedure for rectal cancer surgery.

References

1. Reynolds W Jr (2001) The first laparoscopic cholecystectomy. Journal of the Society of Laparoendoscopic Surgeons 5(1):89–94
2. Jacobs M, Verdeja JC, Coldstein HS (1991) Minimally invasive colon resection (laparoscopic colectomy). Surgical Laparoscopy & Endoscopy 1(3):144–150
3. Group TCOoSTS (2004) A comparison of laparoscopically assisted and open colectomy for colon cancer. N Engl J Med 350(20):2050–2059. doi:10.1056/NEJMoa032651
4. Veldkamp R, Kuhry E, Hop WC, Jeekel J, Kazemier G, Bonjer HJ, Haglind E, Pahlman L, Cuesta MA, Msika S, Morino M, Lacy AM (2005) Laparoscopic surgery versus open surgery for colon cancer: short-term outcomes of a randomised trial. The Lancet Oncology 6(7):477–484. doi:10.1016/s1470-2045(05)70221-7
5. Guillou PJ, Quirke P, Thorpe H, Walker J, Jayne DG, Smith AMH, Heath RM, Brown JM (2005) Short-term endpoints of conventional versus laparoscopic-assisted surgery in patients with colorectal cancer (MRC CLASICC trial): multicentre, randomised controlled trial. Lancet 365(9472):1718–1726. doi:10.1016/s0140-6736(05)66545-2
6. Berends FJ, Kazemier G, Bonjer HJ, Lange JF (1994) Subcutaneous metastases after laparoscopic colectomy. Lancet (London, England) 344(8914):58
7. Fleshman J, Sargent DJ, Green E, Anvari M, Stryker SJ, Beart RW, Jr HM, Flanagan R, Jr PW, Nelson H, Clinical Outcomes of Surgical Therapy Study G (2007) Laparoscopic colectomy for cancer is not inferior to open surgery based on 5-year data from the COST Study Group trial. Ann Surg 246(4):655–662 . doi:10.1097/SLA.0b013e318155a762discussion 662-654
8. Lacy AM, Delgado S, Castells A, Prins HA, Arroyo V, Ibarzabal A, Pique JM (2008) The long-term results of a randomized clinical trial of laparoscopy-assisted versus open surgery for colon cancer. Ann Surg 248(1):1–7. doi:10.1097/SLA.0b013e31816a9d65
9. Bonjer HJ, Deijen CL, Abis GA, Cuesta MA, van der Pas MH, de Lange-de Klerk ES, Lacy AM, Bemelman WA, Andersson J, Angenete E, Rosenberg J, Fuerst A, Haglind E, Group CIS (2015) A randomized trial of laparoscopic versus open surgery for rectal cancer. N Engl J Med 372(14):1324–1332. doi:10.1056/NEJMoa1414882
10. Stevenson AR, Solomon MJ, Lumley JW, Hewett P, Clouston AD, Gebski VJ, Davies L, Wilson K, Hague W, Simes J, Investigators AL (2015) Effect of laparoscopic-assisted resection vs open resection on pathological outcomes in rectal cancer: the ALaCaRT randomized clinical trial. JAMA 314(13):1356–1363. doi:10.1001/jama.2015.12009
11. Cima RR, Pattana-arun J, Larson DW, Dozois EJ, Wolff BG, Pemberton JH (2008) Experience with 969 minimal access colectomies: the role of hand-assisted laparoscopy in expanding minimally invasive surgery for complex colectomies. J Am Coll Surg 206(5):946–950 . doi:10.1016/j.jamcollsurg.2007.12.021discussion 950-942
12. The HALS Study Group, Demetrius EM, Litwin M, Darzi A, Jakimowicz J, Kelly JJ et al (2000) Hand-Asisted laparoscopic surgery (HALS) with the HandPort system initial experience with 68 patients. Ann Surg 231:715–723
13. Froghi F, Sodergren MH, Darzi A, Paraskeva P (2010) Single-incision laparoscopic surgery (SILS) in general surgery: a review of current practice. Surgical laparoscopy, endoscopy & percutaneous techniques 20(4):191–204. doi:10.1097/SLE.0b013e3181ed86c6
14. Knol J, D'Hondt M, Dozois EJ, Vanden Boer J, Malisse P (2009) Laparoscopic-assisted sigmoidectomy with transanal specimen extraction: a bridge to NOTES? Techniques in coloproctology 13(1):65–68. doi:10.1007/s10151-009-0461-y
15. Park JS, Choi GS, Lim KH, Jang YS, Kim HJ, Park SY, Jun SH (2010) Clinical outcome of laparoscopic right hemicolectomy with transvaginal resection, anastomosis, and retrieval of specimen. Dis *Colon rectum* 53(11):1473–1479. doi:10.1007/DCR.0b013e3181f1cc17
16. Wolthuis AM, Penninckx F, D'Hoore A (2011) Laparoscopic sigmoid resection with transrectal specimen extraction has a good short-term outcome. Surg Endosc 25(6):2034–2038. doi:10.1007/s00464-010-1472-5
17. Heald RJ, Husband EM, Ryall RD (1982) The mesorectum in rectal cancer surgery-the clue to pelvic recurrence? Br J Surg 1982(69):613–616
18. Kapiteijn E, Putter H, van de Velde CJ (2002) Impact of the introduction and training of total mesorectal excision on recurrence and survival in rectal cancer in The Netherlands. Br J Surg 89(9):1142–1149. doi:10.1046/j.1365-2168.2002.02196.x
19. Nagtegaal ID, van Krieken JH (2002) The role of pathologists in the quality control of diagnosis and treatment of rectal cancer-an overview. European journal of cancer (Oxford, England: 1990) 38(7):964–972
20. Kayano H, Okuda J, Tanaka K, Kondo K, Tanigawa N (2011) Evaluation of the learning curve in laparoscopic low anterior resection for rectal cancer. Surg Endosc 25(9):2972–2979. doi:10.1007/s00464-011-1655-8
21. Reissman P, Salky BA, Pfeifer J, Edye M, Jagelman DG, Wexner SD (1996) Laparoscopic surgery in the management of inflammatory bowel disease. Am J Surg 171(1):47–50 discussion 50-41
22. Wexner SD, Cohen SM (1995) Port site metastases after laparoscopic colorectal surgery for cure of malignancy. Br J Surg 82(3):295–298

23. Clinical Outcomes of Surgical Therapy Study G (2004) A comparison of laparoscopically assisted and open colectomy for colon cancer. N Engl J Med 350(20):2050–2059. doi:10.1056/NEJMoa032651
24. Strohlein MA, Grutzner K-U, Jauch K-W, Heiss MM (2008) Comparison of laparoscopic vs. open access surgery in patients with rectal cancer: a prospective analysis. Dis *Colon rectum* 51: 385–391
25. Kim SH, Park IJ, Joh YG, Hahn KY (2006) Laparoscopic resection for rectal cancer: a prospective analysis of thirty-month follow-up outcomes in 312 patients. Surg Endosc 20(8):1197–1202. doi:10.1007/s00464-005-0599-2
26. Laurent C, Leblanc F, Wutrich P, Scheffler M, Rullier E (2009) Laparoscopic versus open surgery for rectal cancer: long-term oncologic results. Ann Surg 250(1):54–61. doi:10.1097/SLA.0b013e3181ad6511
27. Jayne DG, Guillou PJ, Thorpe H, Quirke P, Copeland J, Smith AM, Heath RM, Brown JM, Group UMCT (2007) Randomized trial of laparoscopic-assisted resection of colorectal carcinoma: 3-year results of the UK MRC CLASICC Trial Group. J Clin Oncol 25(21): 3061–3068. doi:10.1200/JCO.2006.09.7758
28. Law WL, Lee YM, Choi HK, Seto CL, Ho JW (2007) Impact of laparoscopic resection for colorectal cancer on operative outcomes and survival. Ann Surg 245(1):1–7. doi:10.1097/01.sla.0000218170.41992.23
29. Fleshman J, Branda M, Sargent DJ, Boller AM, George V, Abbas M, Peters WR Jr, Maun D, Chang G, Herline A, Fichera A, Mutch M, Wexner S, Whiteford M, Marks J, Birnbaum E, Margolin D, Larson D, Marcello P, Posner M, Read T, Monson J, Wren SM, Pisters PW, Nelson H (2015) Effect of laparoscopic-assisted resection vs open resection of stage II or III rectal cancer on pathologic outcomes: the ACOSOG Z6051 randomized clinical trial. JAMA 314(13):1346–1355. doi:10.1001/jama.2015.10529
30. Corcione F, Esposito C, Cuccurullo D, Settembre A, Miranda N, Amato F, Pirozzi F, Caiazzo P (2005) Advantages and limits of robot-assisted laparoscopic surgery: preliminary experience. Surg Endosc 19(1):117–119. doi:10.1007/s00464-004-9004-9
31. Trastulli S, Farinella E, Cirocchi R, Cavaliere D, Avenia N, Sciannameo F, Gulla N, Noya G, Boselli C (2012) Robotic resection compared with laparoscopic rectal resection for cancer: systematic review and meta-analysis of short-term outcome. Colorectal disease: the official journal of the Association of Coloproctology of Great Britain and Ireland 14(4):e134–e156. doi:10.1111/j.1463-1318.2011.02907.x
32. Mak TW, Lee JF, Futaba K, Hon SS, Ngo DK, Ng SS (2014) Robotic surgery for rectal cancer: a systematic review of current practice. World J Gastrointest Oncol 6(6):184–193. doi:10.4251/wjgo.v6.i6.184
33. Weber PA, Merola S, Wasielewski A, Ballantyne GH (2002) Telerobotic-assisted laparoscopic right and sigmoid colectomies for benign disease. Dis *Colon rectum* 45(12):1689–1694 . doi:10.1097/01.dcr.0000037657.78153.a8discussion 1695-1686
34. Hashizume M, Shimada M, Tomikawa M, Ikeda Y, Takahashi I, Abe R, Koga F, Gotoh N, Konishi K, Maehara S, Sugimachi K (2002) Early experiences of endoscopic procedures in general surgery assisted by a computer-enhanced surgical system. Surg Endosc 16(8):1187–1191. doi:10.1007/s004640080154
35. D'Annibale A, Pernazza G, Monsellato I, Pende V, Lucandri G, Mazzocchi P, Alfano G (2013) Total mesorectal excision: a comparison of oncological and functional outcomes between robotic and laparoscopic surgery for rectal cancer. Surg Endosc 27(6): 1887–1895. doi:10.1007/s00464-012-2731-4
36. Baik SH, Kang CM, Lee WJ, Kim NK, Sohn SK, Chi HS, Cho CH (2007) Robotic total mesorectal excision for the treatment of rectal cancer. J Robot Surg 1(1):99–102. doi:10.1007/s11701-007-0015-0
37. Baik SH, Kwon HY, Kim JS, Hur H, Sohn SK, Cho CH, Kim H (2009) Robotic versus laparoscopic low anterior resection of rectal cancer: short-term outcome of a prospective comparative study. Ann Surg Oncol 16(6):1480–1487. doi:10.1245/s10434-009-0435-3
38. Park JS, Choi GS, Lim KH, Jang YS, Jun SH (2011) S052: a comparison of robot-assisted, laparoscopic, and open surgery in the treatment of rectal cancer. Surg Endosc 25(1):240–248. doi:10.1007/s00464-010-1166-z
39. Morelli L, Guadagni S, Di Franco G, Palmeri M, Caprili G, D'Isidoro C, Cobuccio L, Marciano E, Di Candio G, Mosca F (2016) Use of the new da Vinci Xi (R) during robotic rectal resection for cancer: a pilot matched-case comparison with the da Vinci Si (R). Int J Med Robot. doi:10.1002/rcs.1728
40. Pigazzi A, Luca F, Patriti A, Valvo M, Ceccarelli G, Casciola L, Biffi R, Garcia-Aguilar J, Baek JH (2010) Multicentric study on robotic tumor-specific mesorectal excision for the treatment of rectal cancer. Ann Surg Oncol 17(6):1614–1620. doi:10.1245/s10434-010-0909-3
41. Baik SH, Kim NK, Lim DR, Hur H, Min BS, Lee KY (2013) Oncologic outcomes and perioperative clinicopathologic results after robot-assisted tumor-specific mesorectal excision for rectal cancer. Ann Surg Oncol 20(8):2625–2632. doi:10.1245/s10434-013-2895-8
42. Cho MS, Kim CW, Baek SJ, Hur H, Min BS, Baik SH, Lee KY, Kim NK (2015) Minimally invasive versus open total mesorectal excision for rectal cancer: long-term results from a case-matched study of 633 patients. Surgery 157(6):1121–1129. doi:10.1016/j.surg.2015.01.010
43. Jayne D, Pigazzi A, Tsang C (2016) Robotic vs. laparoscopic resection for rectal cancer: the ROLARR Trial. https://www.fascrs.org/video/robotic-vs-laparoscopic-resection-rectal-cancer-rolarr-trial.
44. Stamopoulos P, Theodoropoulos GE, Papailiou J, Savidis D, Golemati C, Bramis K, Panoussopoulos SG, Leandros E (2009) Prospective evaluation of sexual function after open and laparoscopic surgery for rectal cancer. Surg Endosc 23(12):2665–2674. doi:10.1007/s00464-009-0507-2
45. Jones OM, Stevenson AR, Stitz RW, Lumley JW (2009) Preservation of sexual and bladder function after laparoscopic rectal surgery. Colorectal disease: the official journal of the Association of Coloproctology of Great Britain and Ireland 11(5): 489–495. doi:10.1111/j.1463-1318.2008.01642.x
46. Luca F, Valvo M, Ghezzi TL, Zuccaro M, Cenciarelli S, Trovato C, Sonzogni A, Biffi R (2013) Impact of robotic surgery on sexual and urinary functions after fully robotic nerve-sparing total mesorectal excision for rectal cancer. Ann Surg 257(4):672–678. doi:10.1097/SLA.0b013e318269d03b
47. Kim NK, Aahn TW, Park JK, Lee KY, Lee WH, Sohn SK, Min JS (2002) Assessment of sexual and voiding function after total mesorectal excision with pelvic autonomic nerve preservation in males with rectal cancer. Dis *Colon rectum* 45(9):1178–1185. doi:10.1097/01.dcr.0000027125.03278.26
48. Kim JY, Kim NK, Lee KY, Hur H, Min BS, Kim JH (2012) A comparative study of voiding and sexual function after total mesorectal excision with autonomic nerve preservation for rectal cancer: laparoscopic versus robotic surgery. Ann Surg Oncol 19(8): 2485–2493. doi:10.1245/s10434-012-2262-1
49. Jayne DG, Brown JM, Thorpe H, Walker J, Quirke P, Guillou PJ (2005) Bladder and sexual function following resection for rectal cancer in a randomized clinical trial of laparoscopic versus open technique. Br J Surg 92(9):1124–1132. doi:10.1002/bjs.4989
50. den Dulk M, Putter H, Collette L, Marijnen CA, Folkesson J, Bosset JF, Rodel C, Bujko K, Pahlman L, van de Velde CJ (2009) The abdominoperineal resection itself is associated with an adverse outcome: the European experience based on a pooled analysis of

five European randomised clinical trials on rectal cancer. Eur J Cancer 45(7):1175–1183. doi:10.1016/j.ejca.2008.11.039
51. Dulucq JL, Wintringer P, Stabilini C, Mahajna A (2005) Laparoscopic rectal resection with anal sphincter preservation for rectal cancer: long-term outcome. Surg Endosc 19(11):1468–1474. doi:10.1007/s00464-005-0081-1
52. Selvindos PB, Ho YH (2008) Multimedia article. Laparoscopic ultralow anterior resection with colonic J-pouch-anal anastomosis. Dis *Colon rectum* 51(11):1710–1711. doi:10.1007/s10350-008-9322-4
53. Liang JT, Lai HS, Lee PH (2007) Laparoscopic pelvic autonomic nerve-preserving surgery for patients with lower rectal cancer after chemoradiation therapy. Ann Surg Oncol 14(4):1285–1287. doi:10.1245/s10434-006-9052-6
54. Denost Q, Adam JP, Pontallier A, Celerier B, Laurent C, Rullier E (2015) Laparoscopic total mesorectal excision with coloanal anastomosis for rectal cancer. Ann Surg 261(1):138–143. doi:10.1097/SLA.0000000000000855
55. Portier G, Ghouti L, Kirzin S, Guimbaud R, Rives M, Lazorthes F (2007) Oncological outcome of ultra-low coloanal anastomosis with and without intersphincteric resection for low rectal adenocarcinoma. Br J Surg 94(3):341–345. doi:10.1002/bjs.5621
56. Schiessel R, Karner-Hanusch J, Herbst F, Teleky B, Wunderlich M (1994) Intersphincteric resection for low rectal tumours. Br J Surg 81:1376–1378
57. Park JS, Choi GS, Jun SH, Hasegawa S, Sakai Y (2011) Laparoscopic versus open intersphincteric resection and coloanal anastomosis for low rectal cancer: intermediate-term oncologic outcomes. Ann Surg 254(6):941–946. doi:10.1097/SLA.0b013e318236c448
58. Park SY, Choi GS, Park JS, Kim HJ, Ryuk JP (2013) Short-term clinical outcome of robot-assisted intersphincteric resection for low rectal cancer: a retrospective comparison with conventional laparoscopy. Surg Endosc 27(1):48–55. doi:10.1007/s00464-012-2405-2
59. Kim NK, Lim D, AlAsari SF (2013) Robotic hemi-levator excision for low rectal cancer: a novel technique for sphincter preservation. OA Robotic Surgery 1(1):3. doi:10.13172/2053-3225-1-1-531
60. Sylla P, Rattner DW, Delgado S, Lacy AM (2010) NOTES transanal rectal cancer resection using transanal endoscopic microsurgery and laparoscopic assistance. Surg Endosc 24(5):1205–1210. doi:10.1007/s00464-010-0965-6
61. Atallah S, Albert M, Larach S (2010) Transanal minimally invasive surgery: a giant leap forward. Surg Endosc 24(9):2200–2205. doi:10.1007/s00464-010-0927-z
62. Tuech JJ, Bridoux V, Kianifard B, Schwarz L, Tsilividis B, Huet E, Michot F (2011) Natural orifice total mesorectal excision using transanal port and laparoscopic assistance. Eur J Surg Oncol 37(4):334–335. doi:10.1016/j.ejso.2010.12.016
63. Rouanet P, Mourregot A, Azar CC, Carrere S, Gutowski M, Quenet F, Saint-Aubert B, Colombo PE (2013) Transanal endoscopic proctectomy: an innovative procedure for difficult resection of rectal tumors in men with narrow pelvis. Dis *Colon rectum* 56(4):408–415. doi:10.1097/DCR.0b013e3182756fa0
64. Atallah S, Martin-Perez B, Albert M, deBeche-Adams T, Nassif G, Hunter L, Larach S (2014) Transanal minimally invasive surgery for total mesorectal excision (TAMIS-TME): results and experience with the first 20 patients undergoing curative-intent rectal cancer surgery at a single institution. Techniques in coloproctology 18(5):473–480. doi:10.1007/s10151-013-1095-7
65. Muratore A, Mellano A, Marsanic P, De Simone M (2015) Transanal total mesorectal excision (taTME) for cancer located in the lower rectum: short- and mid-term results. Eur J Surg Oncol 41(4):478–483. doi:10.1016/j.ejso.2015.01.009
66. de Lacy AM, Rattner DW, Adelsdorfer C, Tasende MM, Fernandez M, Delgado S, Sylla P, Martinez-Palli G (2013) Transanal natural orifice transluminal endoscopic surgery (NOTES) rectal resection: "down-to-up" total mesorectal excision (TME)—short-term outcomes in the first 20 cases. Surg Endosc 27(9):3165–3172. doi:10.1007/s00464-013-2872-0
67. Hasegawa S, Takahashi R, Hida K, Kawada K, Sakai Y (2016) Transanal total mesorectal excision for rectal cancer. Surg Today 46(6):641–653. doi:10.1007/s00595-015-1195-2
68. Verheijen PM, Consten EC, Broeders IA (2014) Robotic transanal total mesorectal excision for rectal cancer: experience with a first case. Int J Med Robot 10(4):423–426. doi:10.1002/rcs.1594
69. Deijen CL, Velthuis S, Tsai A, Mavroveli S, de Lange-de Klerk ES, Sietses C, Tuynman JB, Lacy AM, Hanna GB, Bonjer HJ (2016) COLOR III: a multicentre randomised clinical trial comparing transanal TME versus laparoscopic TME for mid and low rectal cancer. Surg Endosc 30(8):3210–3215. doi:10.1007/s00464-015-4615-x