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Review Article

Robotic Surgery for Rectal Cancer: Operative Technique and Review of the Literature

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Abstract
The number of patients undergoing robotic surgery for rectal cancer has rapidly increased in Japan, since the government approved the procedure for national insurance coverage in April 2018. Robotic surgery has the potential to overcome some limitations of laparoscopic surgery, especially in the narrow pelvis, providing a three-dimensional view, articulated instruments, and a stable camera platform. Although meta-analyses and randomized controlled trials have failed to demonstrate the superiority of robotic surgery over laparoscopic surgery with respect to the short-term clinical outcomes, the published findings suggest that robotic surgery may be potentially beneficial for patients who are obese, male, or patients undergoing sphincter-preserving surgery for rectal cancer. The safety and feasibility of robotic surgery for lateral lymph node dissection, the standard procedure for locally advanced lower rectal cancer in Japan, have been demonstrated in some retrospective studies. However, additional prospective, randomized trials are required to determine the actual benefits of robotic surgery to ameliorate the urogenital and oncological outcomes. The cost of this approach is a long-standing principal concern. A literature search showed that the cost of robotic surgery for rectal cancer was 1.3-2.5 times higher per patient than that for the laparoscopic approach. We herein describe our surgical technique using a da Vinci Surgical System (S/Si/Xi) with 10 years of experience in performing robotic surgery. We also review current evidence regarding short-term clinical and long-term oncological outcomes, lateral lymph node dissection, and the cost of the procedure.

Keywords
Robotic surgery, Laparoscopic surgery, Minimally invasive surgery, Rectal cancer, Mesorectal excision, Lateral lymph node dissection

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Introduction

Minimally invasive approaches such as laparoscopic surgery have widely been employed to reduce the burden on patients worldwide in the last three decades. However, whether laparoscopic rectal surgery (LRS) is non-inferior to open rectal surgery (ORS) for rectal cancer remains somewhat controversial. Although two large randomized controlled trials (RCTs)[1-4] have previously revealed comparable surgical outcomes between LRS and ORS, recent large RCTs have yet demonstrated[5,6] the non-inferiority of pathological outcomes for LRS compared to with those for ORS. In the ALaCaRT study, complete total mesorectal excision (TME) and circumferential resection margin (CRM) negativity were achieved in 86.6% and 93.3% of patients with LRS and in 91.9% and 97.0% of patients with ORS,

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respectively. In addition, in the ACOSOG Z6051 study, successful resection occurred in 81.7% of patients in the LRS group and in 86.9% in the ORS group. These results did not support the non-inferiority of LRS compared with ORS for patients with rectal cancer. The primary concerns regarding LRS are the technical and anatomical complexity in the pelvis of male and obese patients. The limited dexterity of non-articulating instruments with an unstable camera platform due to assistant-based physiologic tremors leads to difficulties in manipulation while performing TME.

RRS has overcome these ergonomic and optical limitations of LRS, and enormously improves surgical precision when using wristed instruments with seven degrees of freedom and stable three-dimensional (3D) visualization, thus reducing the reliance on an assistant surgeon for procedures in the abdomen and pelvis. Just before the first domestic RRS was performed at Fujita Health University in 2009[7], two surgeons were certified to manipulate the da Vinci Surgical System (dVSS) after completing a case observation in Korea and hands-on training in Houston, USA. The port placement for TME and the theater configuration mostly originate from high-volume centers in Korea. Thus, the TME procedure has gradually been improved and has become standardized at some leading hospitals in Japan over the last decade. Although the largest RCT[8] failed to demonstrate superiority in the conversion rate for RRS compared with that of LRS, several favorable outcomes have been reported in terms of the clinical benefits[9-11]. In addition, the aforementioned advantages of robotic surgery can contribute to a steep learning curve, according to the results of cumulative sum (CUSUM) analysis in some studies[12,13]. To date, there have been a few retrospective studies[14,15] reporting the short-term outcomes of robotic lateral lymph node dissection (LLND) for lower rectal cancer, but this extended surgery remains a long-standing controversial issue in Western countries. Although RRS is currently more costly than LRS for both hospitals and governments, inter-enterprise competition and the foundation of high-volume centers for novel approaches in patients with rectal cancer are expected to lead to additional achievements with respect to the clinical outcomes[16], and might eventually contribute to a reduction in the cost of the procedure in the future.

This review article aims to (i) comprehensively appraise recent literature on robotic surgery for rectal cancer and (ii) summarize current evidence regarding the clinical and oncological outcomes as well as the extended operation and the cost of the procedure.

Methods

A systematic search of the PubMed and Cochrane databases was conducted to investigate the tools recently published in the objective perioperative assessments and long-term oncological outcomes of robotic surgery for rectal cancer. We hereby provide a little background on the dVSS (Intuitive Surgical, Inc., Sunnyvale, CA, USA), which is currently accepted as the standard procedure throughout the country. We will also address the following 10 endpoints: operative duration, learning curve, estimated blood loss (EBL), conversion to open laparotomy, anastomotic leakage, urinary and sexual function, pathological outcomes, long-term oncological outcomes, LLND, and cost.

da Vinci Surgical System and Surgical Technique

da Vinci Surgical System

In the United States, the Food and Drug Administration approved the dVSS for intra-abdominal surgery in 2000, and robotic-assisted low anterior resection for rectal cancer was first reported in 2006[17]. The Pharmaceutical Affair Law approved the introduction of the dVSS in Japan in 2010; currently, Japan is the second largest dVSS-possessing country in the world following the United States. However, most procedures have yet to be covered by the Japanese health insurance system, with the exception of prostatectomy and partial nephrectomy in the urology. Nonetheless, 12 new procedures were included in the list of Japanese insurance coverage in April 2018. Chronologically, the da Vinci Surgical S, Si, and Xi Systems were released in Japan in 2009, 2012, and 2015, respectively. At present, approximately 150 Si and Xi systems are in operation throughout the country. The dVSS consists of three separate parts: the surgeon console is for manipulation, the patient cart is the robot itself with four arms to attach the instruments, and the vision cart is a tower containing a monitor, an energy source, and inflation equipment. Important technological improvements from the S to the Si system included dual-console capability to support education for young trainees and collaboration with assistant surgeons during surgery. The most recent Xi system includes the option to use more flexible robotic arms, and a scope can be placed on any of the robotic arms and can be autofocused, enabling surgeons to complete TME for rectal cancer with a single-port setting. Port placements for the Si and Xi systems are shown in Figure 1.

Surgical technique

The patient was placed in the right-side-down Trendelenburg position. After the conventional laparoscopic preparations to retract the small bowel cephalad, the patient cart is docked on the left caudal side and remains in this position throughout the robotic procedure with both the Si and Xi systems. An assistant surgeon uses a 12 mm port on the right side of the patient for the S/Si system (Figure 1a), and on the cranial side for the Xi system (Figure 1b). Pelvic dissection is performed along the proper plane depending on

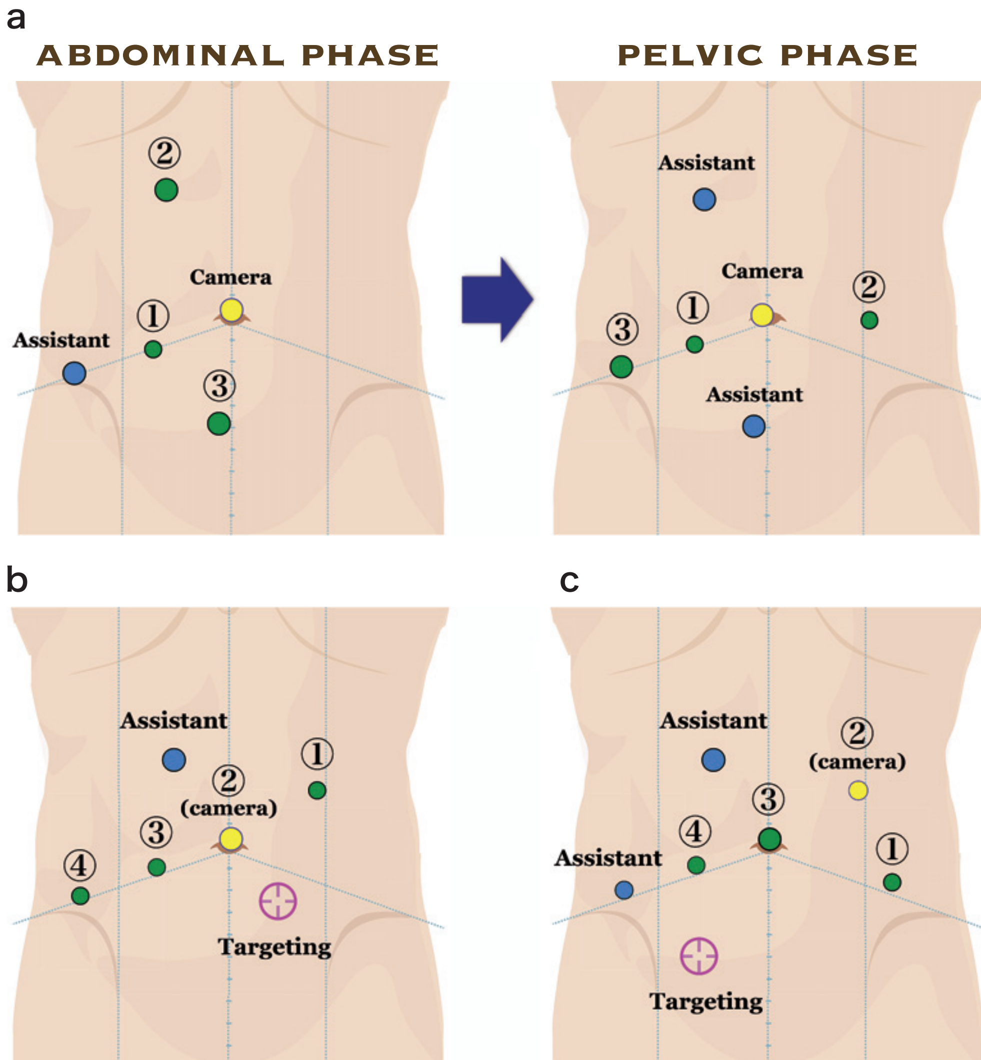

Figure 1.
a: Port placement for total mesorectal excision (TME) with the S/Si system.
Changing a setting from abdominal phase to pelvic phase during surgery.
b: Port placement for TME with the Xi system.
To complete TME and lateral lymph node dissection (LLND) on the left side, if necessary.
c: Port placement for LLND on the right side with the Xi system, if necessary.

the depth of the tumor or lymph node involvement. After bowel transection following tumor-specific mesorectal excision or TME, the patient cart is rolled out. Subsequently, LLND can be performed from the left side to the right side in the pelvic space. When performing LLND on the right side, an additional port is placed (Figure 1c) on the left lower quadrant to avoid limiting the range of motion of the instrument. In the event of intersphincteric resection (ISR), a Loan Star retractor system is used to dissect the rectum transanally, and hand-sewn interrupted anastomosis is performed. For APR, the specimen is extracted from the peritoneal wound. Finally, a defunctioning stoma is created for LAR or ISR, if necessary, and a permanent stoma is created via the retroperitoneal space for APR.

Short-term Outcomes

Operative duration and learning curve

A longer operative duration was the most consistent short-term outcome in the series of meta-analysis and RCTs published on RRS for rectal cancer[8,9,18-24], (Table 1). Jayne et al. reported[8] that the mean operative duration was 37.5 min longer with RRS than with LRS performed by a surgeon experienced with a median of 91 LRS and 50 RRS cases. Mak et al.[25] reported in a systematic review that the mean operative duration was 281.8 min for RRS compared with 242.6 min for LRS. Consequently, they attributed this difference to the docking and changing of the robotic

Table 1. Short-term Outcomes of Robotic Surgery Compared with Laparoscopic Surgery in Recent Reports of Meta-analysis or RCTs.

Author	Year	Study design	Number of RRSs	Number of LRSs	Operative duration	EBL	Conversion	Morbidity	Length of stay	LN harvest	CRM positivity
Liao et al. [52]	2019	Meta-analysis	470	480	(–)	(–)	(–)	(–)	(–)	N/S	N/S
Simillis et al. [9]	2019	Meta-analysis	561	3276	Longer	Less	N/S	N/S	Shorter	N/S	N/S
Phan et al. [11]	2019	Meta-analysis	512	519	(–)	(–)	Lower	(–)	(–)	(–)	(–)
Huang et al. [37]	2019	Meta-analysis	647	658	Longer	(–)	Lower	(–)	N/S	N/S	N/S
Li et al. [19]	2019	Meta-analysis	505	517	Longer	Less	Lower	N/S	Shorter	N/S	N/S
Lee et al. [20]	2018	Meta-analysis	273	237	Longer	Less	Lower	N/S	N/S	N/S	N/S
Ohtani et al. [21]	2018	Meta-analysis	2068	2280	Longer	N/S	Lower	N/S	(–)	N/S	N/S
Prete et al. [22]	2018	Meta-analysis	334	337	Longer	N/S	Lower	N/S	N/S	N/S	N/S
Cui et al. [23]	2017	Meta-analysis	473	476	Longer	Less	Lower	Lower	Shorter	(–)	N/S
Kim et al. [24]	2018	RCT	81	82	Longer	Larger	N/S	N/S	(–)	Higher	N/S
Jayne et al. [8]	2017	RCT	237	234	Longer	(–)	N/S	N/S	N/S	N/S	N/S

RRS: robotic rectal surgery
LRS: laparoscopic rectal surgery
RCT: randomized controlled trial
EBL: estimated blood loss
LN: lymph node
CRM: circumferential resection margin
N/S: not significant
(-): not available

arms and instruments during surgery. Morelli et al.[26] compared the use of the da Vinci Xi and Si systems for rectal cancer and reported significantly reduced operative duration when the Xi system was utilized. In this study, a fully robotic surgery was possible in 100% of cases using the Xi system compared with only 40% of cases using the Si system. As such, it can be estimated that the previous reports are not reflective with respect to the optimal operative duration in view of the surgeon's proficiency with RRS.

When assessing the learning curve in the clinical setting, CUSUM analysis is widely employed[12,13,27-29] due to several advantages, including independence from sample size, efficacy in detecting small shifts in the system, and ability to allow continuous analysis over time and rapid evaluation of data[30]. Barrie et al.[31] reported that the learning curve for LRS ranged between 60 and 80 based on CUSUM analysis and the operative time. In contrast, the learning curve for RRS ranged from 15 to 30 cases. Moreover, Huang et al.[18] indicated that the learning curve for robotic surgery was shorter for patients with rectal cancer, and even for patients who principally exhibited more advanced disease after undergoing neoadjuvant chemoradiation therapy. Another significant aspect of the learning curve is related to whether it has an impact on the pathological outcomes for RRS. Corrigan et al.[32] indicated that the CRM-positive rate was 2.9% for the learning curve versus 4.6% for surgeon competence without a significant difference. They concluded that the learning curve for the surgeon had no impact on the CRM-positive rate in comparison to the surgeon's competence with RRS.

Estimated blood loss

A reduction in the EBL was reported in a series of meta-analyses published on RRS in comparison to LRS and ORS. This reduction was observed in studies that evaluated RRS versus LRS[9,19,20,23] and those that assessed RRS versus ORS[9]. Shiomi et al.[33] reported that in RRS, the EBL was 10.5 mL in obese patients and 10.0 mL in non-obese patients without a significant difference (P=0.83), whereas in LRS, the EBL was 34.0 mL in obese patients and 13.0 mL in non-obese patients with a significant difference (P=0.02). This finding might suggest the value of robotic technology for laborious operations in obese patients. It is worth noting that perioperative blood loss and blood transfusion[34,35] in patients with colorectal cancer are associated with the incidence of surgical site infection and the survival rates[36], even though the reports were not for RRS procedures.

Conversion rate

The ROLARR trial[8] investigated the conversion rate to open laparotomy as the primary endpoint in RRS (8.1%) versus that in LRS (12.2%), and demonstrated a non-significantly lower conversion rate for the former (OR=0.61 [95% CI: 0.31-1.21], P=0.16). However, a subgroup analysis showed significant differences in the conversion rates among male patients (RRS 8.7% versus LRS 16.0%) (OR=0.46 [95% CI: 0.21-0.99], P=0.04). In this trial, multivariate logistic regression analyses revealed significantly higher odds of conversion to open laparotomy for obese patients, male patients, and patients who underwent low anterior resection compared with those who underwent abdominoperineal resection. Furthermore, most systematic reviews[11,19-23,37] reported a lower conversion rate with RRS than with LRS. However, a quality assessment study by Hoshino et al. using the AMSTAR-2 tool[38] indicated that the consequences had critically low-quality evidence. The authors concluded that high-quality systematic reviews involving a selection of high-quality studies with adequate methodology are required to clarify the efficacy of RRS.

Anastomotic leakage (AL)

AL is one of the major complications in colorectal surgery, especially for patients with mid-to-lower rectal cancer. The incidence of AL varies widely from 3% to 30% and increases the mortality[39-43]. Recent meta-analyses have revealed similar morbidity rates for patients undergoing RRS in comparison to LRS[21,22], LRS and ORS[9] for rectal cancer. Although such data wield a powerful influence in the clinical setting, these quantitative outcomes should be interpreted cautiously, given the variability in patient selection. A recent large-scale RCT demonstrated that the occurrence of AL after surgery in RRS (12.2%) was comparable to that in LRS (8.9%). Another relatively small-scale RCT has also shown that there was no statistically significant difference in AL between RRS (12.1%) and LRS (6.8%) (P=0.286). RCTs have a clear methodological advantage for balancing confounding variables to clarify the real effects of a treatment modality.

Urinary and sexual function

As a whole, the urogenital function is one of the most important issues affecting the postoperative quality of life for patients with rectal cancer. While postoperative urogenital impairment is considered to be multifactorial, surgical damage to the pelvic autonomic nerve is regarded as the primary cause[44]. Urogenital functions are controlled predominantly through the sympathetic nerves originating from the superior hypogastric plexus and the parasympathetic nerves originating from the pelvic plexus and its branches. Surgical damage to the sympathetic nerves leads to unstable and ejaculation disorders, whereas damage to the parasympathetic nerves causes a lack of detrusor bladder contraction and erectile problems in male patients[45]. TME has been the optimal surgical procedure for rectal cancer since Heald et al.[46] first reported the procedure in 1982. However, urogenital dysfunction still has well-recognized postoperative complications due to the anatomical proximity between the mesorectum and the pelvic nerves and the difficulty of identifying tiny anatomical structures such as the nerves of the inferior hypogastric plexus in the narrow pelvis. On the theoretical side, better 3D visualization of the anatomical structures in the pelvis and the use of a robotic arm with seven degrees of freedom in RRS enable the surgeon to carefully preserve the autonomic nerves. In evaluating postoperative urinary function through the administration of a questionnaire, most studies have used the International Prostatic Symptom Score, containing questions on the following seven factors: frequency, nocturia, weak urinary stream, hesitancy, intermittence, incomplete emptying, and urgency. On the other hand, previous studies assessed male sexual function with the International Index of Erectile Function (IIEF), a self-administered questionnaire that analyzes five factors: erectile function, orgasmic function, sexual desire, intercourse satisfaction, and overall satisfaction. Nevertheless, there seems to be a hypothesis that RRS can improve the urogenital functional outcomes compared with LRS. Some studies[24,47] have demonstrated favorable urogenital outcomes in RCTs and in propensity score matching (PSM) analysis, while other advocates were unable to show the advantages[8,48,49]. Comparison studies on the urogenital function between RRS and LRS are shown in Table 2. Although some studies[50,51] reported that RRS was associated with an earlier recovery of normal urinary and sexual function compared with that in LRS, it is still controversial and challenging to clarify the superiority of RRS due to limitations such as selection bias and measurement bias with a small sample size. Therefore, to date, there has been no concrete evidence demonstrating a significant advantage of RRS against LRS in terms of urogenital function.

Pathological outcomes

(1) *CRM and distal margin (DM)*

CRM positivity is defined as the presence of tumor cells within 1 mm of the CRM in pathological analysis. It was observed in 5.1% of patients with RRS and in 6.3% with LRS in the ROLARR trial[8]. There was no statistically significant difference in the odds of CRM positivity between the groups. Another RCT in Korea also reported[24] that CRM positivity and DM were identified 6.1% and 1.5 cm with RRS and 5.5% and 0.7 cm with LRS, respectively, without a significant difference between the groups. However, Liao et al.[52] reported that RRS contributed to better outcomes than LRS with respect to the distance between the tumor edge and DM in a meta-analysis (95% CI, 0.29-1.37, P=0.003).

Shirouzu et al.[53] investigated the optimal DM in sphincter-preserving surgery with 610 consecutive specimens, and the results indicated that a distal resection margin of 1 cm might be an appropriate clearance for most tumors in patients with rectal cancer. The real reason why LRS failed to achieve a sufficient DM in RCTs is difficult to explain, but it may be attributed to the aforementioned advantages of RRS.

Table 2. Outcomes of Urinary and Sexual Function in Robotic Rectal Surgery (RRS) Compared with Laparoscopic Rectal Surgery (LRS) in Recent Reports.

Author	Year	Study design	Number of RRSs	Number of LRSs	IPSS (baseline)	IPSS (POM 3)	IPSS (POM 6)	IPSS (POM 12)	IIEF (baseline)	IIEF (POM 3)	IIEF (POM 6)	IIEF (POM 12)
Kim HJ et al. [47]	2018	PSM analysis	130	130	4.4 vs 4.4	8.1 vs 9.0	※ **6.3 vs 7.9**	5.0 vs 5.7	18.4 vs 17.2	13.4 vs 12.6	15.7 vs 14.1	16.3 vs 15.6
Jayne D et al. [8]	2017	RCT	175	176	N/S	(–)	N/S	(–)	N/S	(–)	N/S	(–)
Wang G et al. [48]	2017	Prospective	71	66	4.0 vs 4.1	(–)	(–)	6.8 vs 9.7	56.4 vs 57.9	(–)	(–)	46.2 vs 40.1
Park SY et al. [51]	2014	Retrospective	32	32	8.5 vs 8.2	10.7 vs 11.4	9.8 vs 10.5	9.5 vs 10.4	18.9 vs 18.6	11.5 vs 9.1	※**14.1 vs 9.4**	15.1 vs 13.7
D'Annibale et al. [13]	2013	Retrospective	30	30	3.2 vs 3.5	(–)	(–)	3.5 vs 4.2	(–)	(–)	(–)	(–)
Kim NK et al. [49]	2010	Prospective	100	100	7.4 vs 8.5	9.5 vs 11.7	8.1 vs 8.2	(–)	22.5 vs 16.3	18.2 vs 8.0	15.4 vs 12.6	19.2 vs 12.2

IPSS: International Prostate Symptom Score
IIEF: International Index of Erectile Function
PSM: propensity score matching
RCT: randomized controlled trial
※$P<0.05$ for difference in mean scores between groups
N/S: not significant
(–): not available

(2) *Mesorectal grade*

Garcia-Granero et al.[54] classified the mesorectal grade into three types to improve the quality control: complete, nearly complete, and incomplete. (A) Complete: intact mesorectum with minor irregularities in a smooth mesorectal surface. No defect is deeper than 5 mm. (B) Nearly complete: irregularity of the mesorectal surface. At no site is the muscularis propria visible. (C) Incomplete: little bulk to the mesorectum with defects down to the muscularis propria and/or very irregular CRM. Milone et al.[55] conducted a meta-analysis using 12 articles in which complete TME was reported by all authors. The studies consist of 1510 procedures (687 RRS and 823 LRS) and showed a significant difference in favor of RRS (OR=1.83, 95% CI 1.08-3.10, P= 0.03). Although the author concluded that RRS is a better option in obtaining complete TME in comparison to LRS, the following factors should be noted: (1) There was a significant heterogeneity among the included studies. (2) There was a lack of high-quality studies in the literature. (3) A large number of upper rectal cancers treated with TME were included in the analysis. On the other hand, Jayne et al.[8] and Kim et al.[24] indicated in their RCTs that complete TME was achieved in 75.4% and 80.3% of patients with RRS and in 75.2% and 78.1% of patients with LRS, respectively. There was no significant difference between the groups in both studies. Based on the quality of the evidence, it cannot reasonably be concluded that either modality is superior for complete TME in rectal cancer.

Long-term Outcomes

Robotic surgery has a relatively short history. Therefore, there are few comparative studies between RRS and LRS reporting the long-term oncological outcomes in the literature at present. Cho et al.[56] conducted a PSM analysis with 278 patients in both the RRS and LRS groups. In this study at Yonsei University in Korea, the overall 5-year local recurrence rate and systemic recurrence rate were 5.9% and 16.3% for RRS and 3.9% and 18.0% for LRS, respectively, without significant differences between the groups. In a multivariate analysis of risk factors for local recurrence, postoperative complications (>Grade III) and CRM involvement were identified as independent prognostic factors, whereas tumor size (>3.0 cm), Stage III, and CRM involvement were identified as independent prognostic factors for systemic recurrence. The 5-year overall survival (OS) and the 5-year disease-free survival (DFS) were confirmed to be similar between the groups. Moreover, multivariate analysis showed that the prognostic factors affecting the 5-year OS were Stage III and tumor differentiation.

Similarly, previous comparative studies reported 3-year oncological outcomes[57-60]. Park et al.[61] also performed a comparison of 5-year LRR, OS, and DFS rates (2.3% versus 1.2%, 92.8% versus 93.5%, and 81.9% versus 78.7%, respectively) in RRS and LRS, with no significant difference observed between the groups. In an RCT with a small sample size, Patriti et al.[62] reported the OS, DFS, and recurrence rate between the RRS and LRS, and no differences were observed in all categories. Furthermore, several meta-analysis studies[20,21,63] investigated the long-term oncological outcomes. In summary, RRS did not show any superiority over LRS in terms of oncological advantages, and both RRS and LRS provided favorable outcomes for patients with rectal cancer. On the other hand, Kim et al.[64] reported in a PSM study that the robotic approach was a significant prognostic factor for OS and cancer-specific survival as well as operative duration in the multivariate analysis.

In Japan, Yamaguchi et al.[65] and our group[66] recently reported favorable long-term survival rates with RRS for rectal cancer. Although these results were from single-center, single-arm, retrospective studies, the number of patients was adequate and the patients achieved better longevity at each stage compared with the national registry of patients with cancer of the rectum[67]. Thus, further prospective multicenter RCTs are essential to investigate the long-term outcomes between RRS and LRS in the near future, and the long-term outcomes of the ROLARR trial and the COLRAR trial in Korea are eagerly awaited.

Lateral Lymph Node Dissection

Although lateral lymph node (LLN) metastasis is generally considered to be a systemic disease and preoperative chemoradiation therapy followed by TME is the standard treatment in Western countries, surgical treatment of LLN metastasis in Japan is based on the concept that it is a regional rather than distant metastasis. In Japanese guidelines[67], LLND is indicated when the lower edge of the tumor is located distal to the peritoneal reflection and when the depth of the tumor is T3 or deeper. According to the retrospective studies[68-72] in Japan, the frequency of lateral spread for lower rectal cancer is 16%-25% in patients with T2 or deeper rectal cancer. An RCT (JCOG0212)[73] failed to demonstrate the non-inferiority of TME alone compared with TME+LLND in clinical Stage II/III patients with lower rectal cancer. In this study, the local recurrence rates were 12.6% and 7.4% for TME alone and TME with LLND, respectively. Kanemitsu et al.[74] reported the efficacy of open LLND in 1191 consecutive patients for lower rectal cancer with respect to the long-term oncological outcomes. They also showed that the relative risk of local recurrence was 2.0 in patients with unilateral LLND compared with those with bilateral LLND. As a result of these findings, LLND remains the standard surgical treatment in Japan. With regard to robotic LLND, Park et al. first reported[75] their initial experience and the safety and feasibility of the minimally invasive approach in 2012. Since then, several studies[15,76,77] have demonstrated the favorable short-term outcomes of LLND in RRS. Although LLND remains technically challenging, several advantages, which include increased freedom in the movement of instruments and enhanced dexterity, seem to be particularly useful in RRS, especially in the narrow pelvis for LLND. Yamaguchi et al.[78] investigated the long-term oncological outcomes in a case-matched study and reported that the 5-year overall and relapse-free survival rates with RRS tended to be better than those with ORS. Furthermore, the 5-year local relapse-free survival rate was significantly higher with RRS than with ORS. Thus, further prospective studies with long-term outcomes, especially in RRS versus LRS for lower rectal cancer, are required in order to justify the benefits of the robotic approach when performing LLND. Recently, Kim et al.[79] demonstrated the impact of transanal fluorescence injection around tumors and 3D lymphovascular reconstruction by volume rendering to avoid an incomplete LLND. In this study, all index LLNs, including clinically positive nodes among indocyanine green bearing lymph nodes, were clearly identified intraoperatively by matching them with the corresponding 3D images. The recent progress of technological innovation for RRS is quite promising. However, the development of a novel technique appears to be essential for further amelioration in terms of the clinical outcomes for patients with rectal cancer.

Cost

The cost versus benefits for healthcare is a critical issue whenever and wherever a new technology is introduced to an institute. In addition to the initial investment, the running cost for maintenance and consumable instruments must also be budgeted. RRS was previously considered to have a higher cost than LRS. Given this background, several studies[80-82] have investigated the cost of the procedure with RRS and LRS. In the cost analysis performed by Ramji et al.[80], although there was no statistically significant difference between LRS and ORS with respect to the median operating room costs and the total cost of care for patients with rectal cancer, RRS required approximately $6000 Canadian dollars added to the median cost of each operation. However, no significant difference was observed in any other component of the patients' hospital stay or episode of care. Moreover, Baek et al.[82] reported that the total hospital charges (14,647 USD versus 9978 USD; P=0.001) were significantly and approximately 1.5 times higher in the RRS group than in the LRS group. Payments made by patients (11,540 USD versus 3956 USD; P<0.001) also showed the same difference. On the other hand, a PSM analysis in Korea revealed that patients in the RRS group had to pay about 2.5 times more than those in the LRS group under the national health insurance system (12,613 USD versus 5104 USD; P<0.001). The inclusion of other similar studies[21,83,84] showed that the cost of RRS was relatively higher by 1.3–2.5 times per patient in comparison to the cost for LRS. The longer operative duration in RRS is another important factor that may explain the higher charges as reported in several studies[85-87]. By contrast, experience acquisition and modification of the procedure will lead to a reduction in the operative duration, and hence the cost, as reported in other studies[88,89]. As described in the previous section, a significant reduction was observed in the rate of conversion to open laparotomy following RRS compared with LLS. Cleary et al.[90] demonstrated that the adjusted episode payments for minimally invasive surgery (MIS) when converted to open surgery were significantly higher than for the procedure completed with MIS. Although payments for RRS were higher than those for LRS, the difference was substantially decreased when conversion to open cases was included. Based on the recent literature reports, Hottenrott et al.[16] highlighted two important issues. Firstly, the foundation of highly specialized institutions with high-volume robot-assisted procedures can reduce the costs as well as the operative duration, morbidity rate, and length of hospital stay. Secondly, inter-enterprise competition is required to reduce the price of robots and related instruments in the near future.

Conclusion

Robotic surgery has been proven to be safe and feasible as a novel and alternative surgical treatment modality compared with conventional laparoscopic surgery in patients with rectal cancer. With technological advancements, the robotic approach can be extended to include more advanced cases, such as LLND or concomitant multiple organ resection, to improve surgical outcomes. However, more robust evidence is required to determine the actual benefits and cost effectiveness of RRS. In addition, further development of robotic technology is necessary to achieve a better environment for highly reliable and mature treatment options for rectal cancer.

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Conflicts of Interest

There are no conflicts of interest.

Author Contributions

HK: Substantial contributions to the conception or design of the work, and the acquisition and interpretation of data for the work.

TH: Revising the manuscript critically for important intellectual content.

KM: Having a discussion about the work.

YK: Having a discussion about the work.

KA: Having a discussion about the work.

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Disclaimer

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