Robotic Total Mesorectal Excision for Rectal Cancer: Current Evidences and Future Perspectives

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Despite the technical limitations of minimally invasive surgery, laparoscopic total mesorectal excision (LTME) for rectal cancer has short-term advantages over open surgery, but the pathological outcomes reported in randomized clinical trials are still in controversy. Minimally invasive robotic total mesorectal excision (RTME) has recently been gaining popularity as robotic surgical systems potentially provide greater benefits than LTME. Compared to LTME, RTME is associated with lower conversion rates and similar or better genitourinary functions, but its long-term oncological outcomes have not been established. Although the operating time of RTME is longer than that of LTME, RTME has a shorter learning curve, is more convenient for surgeons, and is better for sphincter-preserving operations than LTME. The robotic surgical system is a good technical tool for minimally invasive surgery for rectal cancer, especially in male patients with narrow deep pelvises. Robotic systems and robotic surgical techniques are still improving, and the contribution of RTME to the treatment of rectal cancer will continue to increase in the future.

Keywords: Rectal neoplasms; Total mesorectal excision; Robotic surgical procedures

INTRODUCTION

Treatment of rectal cancer has improved with multimodal treatments such as preoperative neoadjuvant chemoradiotherapy, radical surgery using total mesorectal excision (TME), and adjuvant chemotherapy. Radical resection is a key step in the standard treatment of rectal cancer and is considered important for favorable oncological outcomes. Therefore, the development of surgical methods that enhance the accuracy of TME by means of innovative instruments and technologies is closely related to the results of rectal cancer treatment.

In the past, abdominoperineal resection was mostly performed for rectal cancer due to a lack of understanding of the pelvic anatomy and the technical difficulties of colorectal or coloanal anastomosis. However, nowadays, sphincter-preserving surgery has become more frequent due to the introduction of TME by Heald et al. [1], the double stapling anastomosis technique, and neoadjuvant chemoradiotherapy for locoregional disease control [2, 3].

TME is a gold-standard technique and an essential oncological principle for mid or low rectal tumors which involves dissection along a surgical plane ("holy plane") between the mesorectum and presacral fascia and preservation of the sacral vessels and hypogastric nerves. TME concept can promote structure preservation and allow for en bloc resection of tumor and lymphatic tissue, and better functional and oncological outcomes. For the upper rectal tumors, tumor-specific mesorectal excision which spares the distal rectum by dividing the mesorectum and rectum at least 4 to 5 cm below the lower margin of the tumor has been shown to be oncologically acceptable [4-6].

However, TME procedure for middle or low rectal tumors is not always successful due to significant problems such as narrow pelvis, bulky tumors, and surgeon's lack of understanding of TME anatomy. Therefore, high-quality TME is not often achieved, and this can jeopardize oncological results. Sound knowledge of the complex pelvic anatomy is needed to obtain a complete and high-quality TME specimen, and well-designed instruments suitable for working in confined spaces with secure vision are required.

Since the Lacy trial [7] in 2002 reported safety and feasibility is
issue in the use of laparoscopy for colon cancer, the MRC-CLASSIC trial [8] in 2005, the COREAN trial [9] in 2010, and the COLOR II trial [10] in 2013, the representative multicenter randomized clinical trials for laparoscopic rectal cancer surgery have been conducted showing no differences in local recurrence or disease-free survival outcomes between laparoscopic surgery and open surgery. In contrast, the ACOSOG Z6051 [11] and ALaC-aRT [12] trials used a composite assessment index (circumferential resection margin [CRM], distal resection margin [DRM], and completeness of TME) of successful rectal cancer resections but did not verify the noninferiority of laparoscopic surgery to open surgery. In the comparison of the ACOSOG and COREAN trials in which most patients received neoadjuvant chemoradiotherapy, short-term recovery and pathologic outcomes were better in the COREAN trial. This was considered due to differences in the body mass index (BMI) distribution of the patients and the experience of the surgeons. Currently, the safety of laparoscopic surgery for the treatment of rectal cancer is still controversial, and the National Comprehensive Cancer Network guidelines recommend that laparoscopic experts perform laparoscopic TME (LTME) limited to nonadvanced diseases.

Regardless of the surgical approach whether conventional open surgery or minimally invasive surgery, the principles of the TME are to keep accuracy, obtain completeness, and preserve autonomic nerves. In this respect, robotic surgical systems are expected to improve patient’s functional and oncologic outcomes than open or laparoscopic surgery using revolutionized technology to overcome many of the limits in laparoscopic surgical systems. In this paper, we reviewed current evidences and future perspectives on robotic TME (RTME) for rectal cancer.

da Vinci SURGICAL SYSTEM FOR RECTAL CANCER SURGERY

The da Vinci surgical system (Intuitive Surgical, Sunnyvale, CA, USA) was born out of the need to overcome the limitations of laparoscopic surgery compared to open surgery. Despite confirmation of its safety and noninferiority to open surgery and the benefits of early recovery and good cosmetic outcome, laparoscopic surgery is still more technically challenging than open surgery due to many drawbacks. The advantages of the robotic surgical systems include advanced stereoscopic 3-dimensional (3D) vision and absence of tremors and rotating and articulating movements, which allow for precise dissection with preservation of neurological and vascular structures in narrow confined spaces. The robotic systems also improve the placement and safety of intracorporeal sutures [13].

Robotic surgical systems were initially frequently used in the treatment of pelvic organ diseases such as gynecological tumors, urological tumors, and rectal cancer, which are located in narrow confined spaces and require technical skills [14]. In the study by Weber et al. [15] in 2002, early robotic surgery in the form of robotic-assisted laparoscopic colectomy was performed for intestinal mobilization, and laparoscopic surgery was performed for mesenteric division, intestinal transection, and anastomosis. The da Vinci S and da Vinci Si, which are early versions of the da Vinci surgical system, had relatively long docking times, were bulky, and had limited application in multi-quadrant surgery. The da Vinci Xi, which is the latest version released in 2014, overcame the limitations of the S and Si versions with an easier docking process, wider range of motion, smaller robot arms, and a dynamic camera system that can be attached to any robotic arm. Thus, the new Xi version allows for easier multi-quadrant access to different anatomical areas and for totally robotic surgery with single docking [16]. Recently the newly developed da Vinci SP system, robotic single-port platforms represent a viable option for advanced surgical procedure including urological and oropharyngeal procedures and begin to show its feasibility in the use for transanal approach rectal cancer surgery [17]. The da Vinci SP version has advantages with the 3 fully-wristed and elbowed instruments, and the fully-wristed endoscope through a single 2.5-cm cannula which can reach anywhere within 360° from the 1 port placement.

ROBOTIC TME

The initial use of RTME on 6 patients was reported in 2006, its operative outcomes were similar to those of open TME (OTME) and LTME, and it had the benefit of reducing the fatigue and stress of the surgeon during the procedures [18]. Kim et al. [19] also reported on the level of surgeon physical discomfort after robotic intersphincteric resection for rectal cancer (robotic surgery, n = 108; open surgery, n = 114). The score of Lawson et al. [20] for surgeon physical discomfort (none, 0 to severe, 5) was significantly lower in the robotic surgery group than in the open surgery group (robotic surgery, 1.4; open surgery, 3; P < 0.001).

Unlike colon cancer, rectal cancer occurs deep in the narrow pelvis. As surgical dissection is continued downward, a more secure field of vision is required and tissue manipulation in the pelvic space using laparoscopic instruments becomes more difficult, and this can lead to tissue damage or tumor spread. Therefore, robotic systems with the advantages of 3D magnification and reduction of surgical stress and fatigue are very important and can impact surgical outcome. During the RTME procedure, the rectum and mesorectum are removed as a unit by meticulous sharp pelvic dissection between the visceral and parietal pelvic fascia under excellent vision and good illumination. The dissection plane can be easily set in the narrow pelvic space by continuous traction and countertraction using robotic instruments with the endo-wrist function, and the use of the third robotic arm for steady countertraction is essential for sharp and precise pelvic dissection. During anterior dissection between the seminal vesicle, prostate, or vagina and the Denonvilliers’ fascia, the robotic system can set an accurate anatomical plane due to the stability of the camera plat-
form and consistent steady countertraction using the third robotic arm. With regard to autonomic nerve preservation, the 3D magnified view of the robotic system can discriminate nerve structures better than in laparoscopic or open surgery. Compared to the laparoscopic approach, the above-mentioned advantages of the robotic approach are immense, especially when operating on low rectal cancers with unfavorable size and progression.

**PERIOPERATIVE OUTCOMES**

**Operating time and learning curve**
Since the introduction of the da Vinci system for rectal cancer, issues of safety and feasibility of the robotic system have been dealt with, but the problems of long operating time and high cost have not been solved yet. The reported mean operating time for RTME is 3 to 5 hours, and this shows that RTME tends to take longer than LTME. The perioperative outcomes including operating time are presented in Table 1 [21-30]. In general, most robotic colorectal surgeons are experts in LTME, but surgeons need additional time to overcome the learning curve of RTME. Beginners in robotic surgery undergo trial and error to create visual fields, experience movement limitation of robotic instruments and external collisions of robotic arms, and are unfamiliar with the surgical console.

Surgical outcomes are closely related to the experience of the surgeon. Therefore, since the introduction of the laparoscopic surgery, surgeons are using RTME for rectal cancer.

**Table 1. Perioperative outcomes after total mesorectal excision for patient with rectal cancer**

| Study                | Country     | Design   | Year | Operation | Sample size (n) | Tumor location (%) | Operating time (min) | Estimated blood loss (mL) | Hospital stay (day) | Conversion rate (%) | Overall complication (%) | Anastomotic complication (%) |
|----------------------|-------------|----------|------|-----------|-----------------|---------------------|----------------------|-------------------------|----------------------|-----------------------|--------------------------|----------------------------|
| Pigazzi et al. [21]  | Multination | Retrospective 2010 | RTME | 143 | 9.8/29.4/58.7 | 297 (90–660)± | 283 (0–6,000)± | 8.3 (2–33)± | 4.9 | 41.3 | 10.5 |
| Baek et al. [22]     | USA         | Retrospective 2011 | RTME | 41 | 12.2/51.2/36.6 | 296 (150–520) | 200 (20–2,000) | 6.5 (2–33) | 7.3 | 22.0 | 8.6 |
|                      |             |          |      |           |                 |                     |                      |                         |                      |                       |                          |
| Kwak et al. [23]     | Korea       | Retrospective 2011 | RTME | 59 | 10.2/49.9/40.7 | 270 (241–325)± | NA | NA | 0 | 32.2 | 13.5 |
|                      |             |          |      |           |                 |                     |                      |                         |                      |                       |                          |
| Kim et al. [24]      | Korea       | Retrospective 2012 | RTME | 100 | 15/41/44 | 188 ± 45 | NA | 7.1 ± 2.1 | 0 | 26.0 | 2.0 |
|                      |             |          |      |           |                 |                     |                      |                         |                      |                       |                          |
| D’Annibale et al. [25]| Italy      | Retrospective 2013 | RTME | 50 | 16/18/66 | 270 (240–315) | NA | 8 (7–11) | 0 | 10.0 | 10.0 |
|                      |             |          |      |           |                 |                     |                      |                         |                      |                       |                          |
| Kang et al. [26]     | Korea       | Retrospective 2013 | RTME | 165 | 34.5/65.5 | 309.7 ± 115.2 | 133.0 ± 192.3 | 10.8 ± 5.5 | 0.6 | 20.6 | 7.3 |
|                      |             |          |      |           |                 |                     |                      |                         |                      |                       |                          |
| Park et al. [27]     | Korea       | Retrospective 2013 | RTME | 40 | NA | 233.5 ± 57.5 | 45.7 ± 40.0 | 10.6 ± 4.2 | 0 | 15.0 | 7.5 |
|                      |             |          |      |           |                 |                     |                      |                         |                      |                       |                          |
| Kim et al. [28]      | Korea       | Retrospective 2016 | LTME | 60 | 20.0/28.3/51.7 | 466.8 ± 115.6 | 74.2 ± 50.0 | 8.6 ± 2.4 | 0 | 15.0 | 6.7 |
|                      |             |          |      |           |                 |                     |                      |                         |                      |                       |                          |
| Jayne et al. [29]    | Multination | RCT      | 2017 | RTME | 237 | 30.1/45.3/24.2 | 298.5 ± 88.7 | NA | 8.0 ± 5.8 | 8.1 | 33.1 | 14.8 |
|                      |             |          |      |           |                 |                     |                      |                         |                      |                       |                          |
| Fransgaard et al. [30]| Denmark    | Retrospective 2018 | RTME | 706 | NA | NA | NA | NA | 6.7 | 21.0 | NA |
|                      |             |          |      |           |                 |                     |                      |                         |                      |                       |                          |
|                      |             |          |      |           |                 |                     |                      |                         |                      |                       |                          |

Values are presented as number only, mean ± standard deviation, *mean (range), *median (range), or ‘median (interquartile range). RTME, robotic total mesorectal excision; LTME, laparoscopic total mesorectal excision; OTME, open total mesorectal excision; NA, not applicable; RCT, randomized controlled trial.

Upper/lower. *Gastrointestinal complications including anastomotic leak within 30 days postoperatively.
surgery, shortening the learning curve period and operating time of minimally invasive surgery have been great concerns. According to reports, the learning curve of laparoscopic colorectal surgery is 30 to 70 cases [31-34]. Technical proficiency in robotic surgery is achieved after 20 cases because of the technical advantages of robotic surgery over laparoscopy, and it shortens the learning curve of TME [35]. Before the release of da Vinci Xi, the docking process was regarded as a pitfall and robotic rectal surgeons tried to improve it. Therefore, various methods of approach were developed for RTME using the different trocar positions and docking processes of the da Vinci S and Si versions. The hybrid method of RTME entails using laparoscopy for the step of inferior mesenteric artery (IMA) ligation with or without splenic flexure mobilization, which can help shorten the docking process, while fully robotic surgery with single docking was developed and implemented by surgeons. Trocar placement can vary depending on surgeon preference, patient anatomical characteristics, and intraoperative conditions such as difficulty of exposure of the inferior mesenteric vein or splenic flexure, unfavorable localization of the small bowel, visceral obesity, and need for multiple positional changes [16]. Therefore, optimal trocar placement and docking procedures are of prime concern for beginners in robotic surgery. Since the introduction of the da Vinci Xi version, the operating time and learning curve of RTME have decreased to an acceptable range compared to LTME due to improvements in the docking process and the excellent implementation of fully robotic procedures [16]. Basic robotic surgical skill set can be acquired in the simulation laboratory, and commercially available simulators have been shown to be capable of assessing robotic surgical skills [36]. Currently, the learning curve and operating time of RTME are no longer problems for laparoscopic experts, and totally robotic procedures using the Xi version have become easier than before for beginners. Interestingly, a study reported that no difference in adaptation to robotic procedures was observed between beginners in robotic surgery with experience in laparoscopic surgery and those without such experience [37].

Conversion rate
The conversion rate of LTME has been investigated and the distribution has been shown to vary even in randomized clinical trials. The COREAN trial [9] reported a conversion rate lower than that reported in Western studies, and this may be due to the relatively lower BMI and fewer patients with obesity in the trial. Clinically, conversion rates are important with regard to oncological outcomes because, in general, the abilities of the surgeon and the assistant, patient characteristics, and tumor characteristics can affect the radicality of the surgical procedure and the conversion rate [38]. In the initial periods of RTME, its conversion rate received attention for having a range of 0% to 7.3%, which was considered lower compared to the conversion rate of LTME that ranged from 0% to 22% [39]. Trastulli et al. [40] reviewed 8 studies for the conversion rates of laparoscopic and robotic rectal cancer surgeries and reported mean conversion rates of 2% for RTME and 7.5% for LTME. It was considered that the technological advantages of the robotic surgical system can make RTME easier and prevent conversion to open surgery. Conversion rate was recently assessed in the ROLARR trial [29] and conversion rates of 8.1% for robotic surgery and 12.2% for laparoscopic surgery were reported, but there was no significant difference between the groups of patients that underwent robotic surgery or laparoscopic surgery (P = 0.16). Interestingly, although the ROLARR trial statistically failed to show a lower conversion rate in the robotic group, subgroup analysis confined to male patients revealed a significantly lower conversion rate in the robotic group (robotic surgery group, 8.7%; laparoscopic surgery group, 16%; P = 0.0429). This result was probably because the pelvises of the male patients are narrower than those of the female patients. This relates to the technical difficulty of laparoscopic surgery, and the limitations of laparoscopic surgery are overcome by robotic surgery. Although not statistically significant, conversion rates in patients with obesity (robotic surgery, 18.9%; laparoscopic surgery, 27.8%; P = 0.2944) and patients who underwent low anterior resection (robotic surgery, 7.2%; laparoscopic surgery, 13.3%; P = 0.0909) tended to be lower in the robotic group than in the laparoscopic group. Although further studies with larger study populations seem to be necessary, robotic surgery may help overcome the technical difficulties of laparoscopic surgery in men, patients with obesity, and patients scheduled to undergo low anterior resection. The conversion rates of RTME are presented in Table 1.

Voiding and sexual functions
Urinary and sexual dysfunctions are major concerns after rectal cancer surgery, and they are caused by direct or indirect injury to the pelvic autonomic nerves during rectal dissection. These functional sequelae greatly impact the quality of life of patients. Meticulous dissection along the surgical plane of TME between the mesorectum and pelvic fascia can be performed to completely resect the tumor, but nerve tissue around the surgical plane of the TME can easily be affected or damaged during the procedure. Therefore, nerve preservation during TME is vital for the quality of life of patients with rectal cancer, especially for the preservation of voiding and sexual functions. In the COREAN trial [9], LTME was shown to be associated with more acute voiding difficulties requiring catheter insertion than OTME (open surgery, 4.1%; laparoscopic surgery, 10%; P = 0.034). The researchers explained that these results may be related to the broader retractor used in open surgery that results in less severe neuropaxia than in laparoscopic surgery where smaller instruments are used for retraction. However, these functional disturbances were observed in the short-term period and were transient.

Robotic surgery involves use of instruments with different action mechanisms and offers good visual assessment to discriminate nerve tissues. In a phase II randomized trial that compared RTME and LTME, it was found that sexual function at 12 postoperative
months was significantly better in the RTME group than in the LTME group (mean scores of the colorectal cancer-specific quality of life questionnaire module [QLQ-CR38]: RTME, 35.2 and LTME, 23; \( P = 0.032 \)) [41]. In a comparative study, the RTME group showed early recovery with normal voiding and sexual function within 6 postoperative months, whereas the LTME group showed functional recovery after 12 postoperative months [42]. In a case-matching comparison of male patients, bladder dysfunction was similar in the RTME and LTME groups for 12 months, but recovery from erectile dysfunction occurred earlier in the RTME group than in the LTME group [43]. Although individual study showed slightly different outcome profiles, the results were favorable in the RTME group in terms of preservation of voiding and sexual functions. However, in the ROLARR trial [29], no significant difference in bladder dysfunction and sexual dysfunction was observed 30 days and 6 months after surgery between the RTME and LTME groups.

In general, there are several determining factors of genitourinary dysfunction after rectal cancer surgery, and they include tumor location, neoadjuvant chemoradiotherapy, preoperative baseline function, and extent of nerve preservation during surgery [44-47]. In rectal cancer surgery, genitourinary dysfunction is often caused by nerve damage in the following surgical procedures: IMA ligation around the root of IMA and mesorectal mobilization which cause sympathetic nerve injury and result in retrograde ejaculation and urinary incontinence; low rectum and lateral wall dissection which causes hypogastric plexus and nervi erigentes injury and results in impaired ejaculation and detrusor contractility; erectile dysfunction, and dyspareunia; and dissection around the anterior side of the Denonvilliers’ fascia which may cause neurovascular bundle damage and result in male erectile dysfunction [48-52].

The visual capacity to distinguish nerves from other structures is better in robotic surgery than in laparoscopic surgery. The 3D magnified visualization through the surgeon-controlled camera system can provide a stable surgeon-oriented view and improved anatomical discrimination for nerve preservation such that precise dissection is possible. The endo-wristed instruments with hand tremor filtering on each of the 3 arms can provide a stable surgical approach with excellent traction-countertraction. The articulating movement from the surgical console is ergonomic and can reduce unfavorable manipulation, injury, and surgeon fatigue, thereby improving functional outcome.

**Anastomotic leakage**

One of the major complications of rectal cancer surgery is anastomotic leakage. The incidence of anastomotic leakage as reported in literature is 3.9% to 19.2% [53-59]. It has been reported that the multivariable factors associated with anastomotic leakage after rectal cancer surgery include patients with diabetes mellitus, American Society of Anesthesiologists physical status classification, intake of steroid medication, previous radiation therapy, surgical approach (minimally invasive or open), insufficient blood supply or tension at the site of anastomosis, and technical error during stapling [60-66]. A comparative study of RTME (n = 56) and LTME (n = 57) reported that the outcomes of serious complications were better in RTME than in LTME (robotic surgery, 5.4%; laparoscopic surgery, 19.3%; \( P = 0.025 \)) and include anastomotic leakage (robotic surgery, 1/56 [1.8%]; laparoscopic surgery, 4/57 [7.0%]) [39].

Suggested advantages of robotic TME regarding anastomotic leakage may be due to the technological advantages of RTME described below, which prevent anastomotic leakage. First, due to the superior visualization of blood and lymphatic flow in the robotic indocyanine green fluorescent view, robotic systems have an improved ability to preserve blood flow; therefore, surgeons can determine the perfusion status at the site of anastomosis and the range of distal or proximal transection level [67]. Second, intracorporeal reinforcement sutures can be more easily placed with the articulating endo-wrist of robotic systems. Third, IMA low ligation for better blood supply can be easily performed with the robotic system. Lastly, by reducing the number of firing staplers, the endo-wrist stapler of the robotic system can reduce transection error [68]. The anastomotic complication rates of RTME are presented in Table 1.

**PATHOLOGIC RESULTS**

Besides the TNM staging and tumor biology, the surgical outcomes of DRM, CRM, and completeness of the TME have been considered as a major prognostic factor. The optimal length of DRM for oncologic safety in sphincter-preserving low rectal cancer surgery is still controversial. The 2-cm length is clinically acceptable because the intramural tumor spread rarely exceed 1 to 2 cm in distance [69, 70]. The oncologic significance of the DRM, CRM, or TME completeness is that these factors are closely related to the local tumor recurrence and can influence the oncologic outcomes. Various factors influence these pathologic results including the neoadjuvant chemoradiation therapy, narrow pelvis, bulky tumor size, existence of perirectal lymph node metastasis, measurement methods, and surgical approach methods of minimally invasive or open surgery [69]. Between conventional open surgery and minimally invasive laparoscopic or robotic surgery for rectal cancer, these pathologic outcomes play a role as the indicator of the noninferior measurement of each operation method.

The TME completeness was better observed in open surgery in ALaCaRT trial (TME completeness, 92% vs. 87%) [12] and ACOSOG trial (complete TME, 95% vs. 92%) [11]. In robotic surgery, although the DRM and CRM data were slightly different in each independent study (Table 2 [21, 28, 41, 71-82]), many studies of the RTME have been reported as showing better results than LTME in TME completeness. Allemann et al. [83] reported better results of RTME compared with LTME in TME completeness (95% vs. 55%) and Kim et al. [84] also reported significantly
better TME specimen quality in RTME group than LTME (97% vs. 91%). Barnajian et al. [85] reported a matched comparison of the first 20 cases of RTME. Although the quality of TME was not significantly different in the OTME, LTME, and RTME groups during the learning curve of RTME (P = 0.153), the depth of CRM was significantly greater in the RTME group (OTME, 8 mm; LTME, 4 mm; RTME, 10.5 mm; P = 0.026). The researchers reckoned that the greater depth of CRM in the RTME group during the learning curve of RTME may be related to the ability of the robotic instruments to overcome the fulcrum effect produced by trocars during LTME, and not the ability and skills of the surgeon. So, to prove the superiority of RTME in these pathologic results and short-term oncologic outcome compared to LTME, more clinical trials are currently required. **ONCOLOGICAL OUTCOMES**

Since the introduction of the da Vinci system for rectal cancer surgery, many studies have confirmed the safety and feasibility of the robotic surgical system and reported the advantage of early functional recovery. However, evidence that robotic surgery has improved oncological outcomes more than laparoscopic or open surgery is still insufficient. Oncological outcomes are dependent on a variety of factors during treatment. Of the several multimodal

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**Table 2. Short- and long-term oncological outcomes after total mesorectal excision for patient with rectal cancer**

| Study               | Year | Operation | Sample size (n) | Tumor location from AV (cm) | Follow-up (mo) | PCRT (%) | CRM positivity (%) | Length of DRM (cm) | LR (%) | DR (%) | OS (%) | DFS (%) |
|---------------------|------|-----------|----------------|-----------------------------|----------------|----------|-------------------|-------------------|--------|--------|--------|---------|
| Short-term oncological outcomes |       |           |                |                             |                |          |                   |                   |        |        |        |         |
| Pigazzi et al. [21] | 2010 | RTME      | 143            | NA                          | 17.4           | 65.1     | 0.7                | 2.9               | 1.5    | NA     | 97.0   | 77.6    |
| Baek et al. [71]   | 2010 | RTME      | 64             | NA                          | 20.2           | 85.9     | 0                  | 3.4               | 3.1    | NA     | 96.2   | 73.7    |
| Baik et al. [72]   | 2013 | RTME      | 370            | NA                          | 26.5           | 21.1     | 5.7                | 2.5±1.4           | 3.6    | NA     | 93.1   | 79.2    |
| Kim et al. [28]    | 2016 | RTME      | 60             | NA                          | 48.5           | 36.7     | 11.7               | 3.1±1.7           | 1.9    | 26.4   | 87.7   | 72.8    |
| Kim et al. [73]    | 2017 | RTME      | 310            | 3.3±1.7                     | 36.0           | 48.4     | 1.0                | 1.4               | 3.6    | 17.0   | 91.1   | 79.5    |
| Kim et al. [41]    | 2018 | RTME      | 66             | NA                          | 12.0           | 77.3     | 6.1                | 1.5               | NA     | NA     | NA     | NA      |
| Lee et al. [74]    | 2018 | RTME      | 24             | 5.2±1.9                     | 22.0           | 50.0     | 8.3                | 1.9               | 0      | 4.2    | NA     | NA      |
| L-TaTME            |      |           | L-TaTME        | 21                          | 6.1±1.6        | 66.7     | 4.8                | 2.2               | 4.8    | 9.5    | NA     | NA      |
| Sannour et al. [75] | 2018 | RTME      | 267            | NA                          | 23.8           | 75.0     | 2.5                | >1.0              | 2.4    | 16.9   | 87.0   | 82.0    |
| Long-term oncological outcomes |      |           |                |                             |                |          |                   |                   |        |        |        |         |
| Pai et al. [76]    | 2015 | RTME      | 101            | NA                          | 34.9           | 74.3     | 5.0                | 3.5±2.7           | 4.0    | NA     | 90.1   | 79.2    |
| Yoo et al. [77]    | 2015 | RTME      | 44             | NA                          | 3.2±0.7        | 36.5     | 54.5               | 9.1               | 1.3    | NA     | 95.2   | 76.7    |
| Law et al. [80]    | 2017 | RTME      | 220            | 7 (0–12)                    | 31.4           | 41.4     | 4.1                | 3                 | 5.2    | NA     | 71.8   | 81.9    |
| Kim et al. [81]    | 2020 | RTME      | 488            | 3.3±1.7                     | 60.0           | 50.0     | 1.4                | 1.7±1.1           | 2.5    | NA     | 86.7   | 80.7    |
| Asoglu et al. [82] | 2018 | RTME      | 14             | <10                         | 87.0           | 100      | 0.5                | 2.7               | 3.8    | 2.5    | 83.3   | 81.8    |
| L-TaTME            |      |           | L-TaTME        | 65                          | <10            | 87.0     | 100                | 1.8               | 6.3    | 20.1   | 75.0   | 74.4    |

Values are presented as number only, mean ± standard deviation, or median (range) unless otherwise denoted.

AV, anal verge; PCRT, preoperative chemoradiotherapy; CRM, circumferential resection margin; DRM, distal resection margin; LR, local recurrence; DR, distant recurrence; OR, overall survival; DFS, disease-free survival; RTME, robotic total mesorectal excision; LTME, laparoscopic total mesorectal excision; L-TaTME, laparoscopic transanal total mesorectal excision; NA, not applicable.

aThree years for short-term oncological outcomes and 5 years for long-term oncological outcomes. bFour-year data. cintersphincter resection (ISR). dNon-ISR. ePartial ISR; subtotal ISR, 1.2±0.9; total ISR, 1.2±1.0.
treatments for rectal cancer, preoperative disease control with neoadjuvant chemoradiotherapy and postoperative control with adjuvant chemotherapy have regimens that are standardized according to guidelines. These perioperative management protocols have little impact on oncological outcomes, but there are no guarantees of complete locoregional control without tumor splitting or spread during TME with the operative procedures. Therefore, the surgical procedure of TME can be considered as having a significant impact on oncological outcomes. Since the introduction of the da Vinci system, the technological advantages of RTME over LTME have been considered to have a positive impact on oncological outcomes. Robotic surgery promotes better tumor control with a better visual approach during IMA ligation, splenic flexure mobilization, and TME. Despite these potential benefits of RTME, the superiority of oncological outcomes after RTME has not yet been proven. Studies including randomized clinical trials [29, 41] and case-matched analyses have only reported noninferior short-term operative or pathologic outcomes of RTME compared to those of LTME or OTME [22, 23, 26]. Kim et al. [86] compared the survival outcomes of the following 3 groups: OTME (n = 1,095), LTME (n = 486), and RTME (n = 533). They reported that no significant differences were observed in the rates of 3-year local recurrence (2.5% to 3.4%; P = 0.85), overall survival (91.9% to 94.6%; P = 0.352), and disease-free survival (82.2% to 83.1%; P = 0.944) between the 3 groups. Interestingly, multivariable analysis revealed that RTME is a significant determinant of sphincter-preserving operations (OTME + LTME, 91.8%; RTME, 95.1%; P < 0.001) regardless of tumor stage and location. In a phase II randomized clinical trial, the outcomes of resection margins, number of harvested lymph nodes, and TME quality were found to be similar between RTME and LTME (RTME: complete, 80.3% and nearly complete, 18.2%; LTME: complete, 78.1% and nearly complete, 21.9%) [41]. The short-term and long-term oncological outcomes of RTME are presented in Table 2.

ROBOTIC TRANSANAL TOTAL MESORECTAL EXCISION

Robotic transanal TME (TaTME) was developed for more secure distal transection margins and to allow for distal dissection through the anal canal. TaTME also follows the principle of TME described by Heald [1], but the direction of dissection is countercurrent. Before the current concept of TaTME, the transanal approach to rectal cancer surgery was based on the transanal abdominal transanal (TATA) resection performed by Marks et al. [87]. The next development was the introduction of transanal endoscopic microsurgery (TEM) for early tumors. However, the application of TEM was temporary and limited due to the poor cost-benefit of TEM devices [88]. Transanal minimally invasive surgery (TAMIS), which uses the minimally invasive single-port laparoscopic platform, was developed recently and has gained popularity [89]. TaTME is an approach that combines the transabdominal and TAMIS approaches of TME. It has the advantages of easy access to the low rectum, improved TME quality, and adequate DRM [90]. In TaTME procedures, minimally invasive single-port laparoscopic platforms have technical limitations similar to those of single-port laparoscopic surgery; therefore, beginners have to overcome the learning curve of single-port surgery and understand the new countercurrent anatomy of the pelvis. Owing to its technological advantages, robotic TaTME may be more beneficial than laparoscopic TaTME. The Xi version of the da Vinci system, which has the capability for reduced-port or single-incision plus one-port surgery, is most beneficial for TaTME. The newly developed da Vinci SP system provides more revolutionized options for TaTME and endoluminal transanal surgery. Marks et al. [17] performed transanal rectal resections on cadaveric models using the da Vinci SP surgical system, and the surgical system performed well for all types of surgery. The researchers reported that the SP system has the potential to expand transanal surgery to the next step beyond TaTME, which is natural orifice transluminal endoscopic surgery (NOTES). Evidences for TaTME and robotic TaTME using da Vinci SP surgical system are currently lacking. However, given the potentials of the da Vinci SP surgical system, it is expected to be the system of choice for rectal cancer surgery in the future.

THE FUTURE PERSPECTIVES OF ROBOTIC SURGERY FOR RECTAL CANCER

Several new robotic system technologies have recently been developed and tried in TME. Continuous neuromonitoring during TME has been tried by many surgeons with different platforms to preserve nerve tissue during rectal cancer surgery and improve functional outcomes [91]. RTME has been successfully performed with a neuromapping device on a da Vinci Xi system as intraoperative pelvic neuromapping with real-time electromyography and cystomanometry signals transmitted to a surgical console in multi-image views [92]. Although the methods for preserving pelvic neuromuscular functions are limited and still in the early stages, they are expected to gain popularity among colorectal surgeons in the future. Imaging-guided surgery using navigation systems has also been tried and is under development. Robotic-assisted stereotactic real-time navigation surgery using the da Vinci Xi platform and navigating interface has been attempted [93]. Although it is generally not a usable platform due to many limitations, navigating with the surgical system will further enhance the surgeon’s perception in future surgeries.

For over 20 years, da Vinci surgical systems had a monopoly in the field of minimally invasive robotic surgery. Many competitors of Intuitive Surgical have been trying to develop various types of minimally invasive robotic surgical platforms in the hope of sharing the robotic surgical market or replacing da Vinci surgical systems. They include Telelap ALF-X/Senhance surgical system...
CONCLUSION

To improve the outcome of rectal cancer surgery, complete TME should be safely and accurately performed. However, the laparoscopic approach is still challenging because of technical limitations in the narrow deep pelvis. Although 3D camera systems and articulating instruments are used in laparoscopic surgery, robotic surgical systems are better at maintaining TME principles, especially considering the technical aspects of rectal cancer surgery. The application of various robotic surgical systems in TME using the transabdominal or transanal approach will greatly contribute to favorable outcomes of minimally invasive surgery including TME for rectal cancer.

One last revolutionary idea is the use of artificial intelligence in surgical robotic systems. Deep learning (also known as machine learning) of the artificial intelligence is expressed using mathematical algorithms that enhance learning through experience and has the following 3 categories: unsupervised, supervised, and reinforcement learning [95]. It will be an epoch in history if surgical robots with machine-learning functions are created.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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