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Robotic Rectal Surgery

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Robotic technology is increasingly used in colorectal surgery during last decade. Whether this technology will translate into clinical efficiency and value of care remains to be determined. This review aims to discuss current data in robotic rectal surgery with emphasize on ergonomics, cost, and learning curve aspects. All relevant articles are reviewed in addition to published and unpublished work from the authors' own experience.
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KEY WORDS: robotic surgery; robotic rectal surgery; rectal cancer; robotic technology

INTRODUCTION

A paramount surgical innovation of the past three decades has been the introduction of minimally invasive surgery. Surgical practice has profoundly changed thorough numerous technological advantages provided by laparoscopic technique. The benefits associated with laparoscopic surgery were recognized in terms of shorter hospital stay, quicker recovery, and return to normal function.

Challenges during rectal surgery, however, are likely magnified when the additional difficulties of laparoscopic technique are added to the procedure because of the ergonomic limitations of the instruments. The laparoscopic surgeon is required to undertake the same multi-quadrant operations as open surgery but with limited tactile feedback and poorly designed instruments under the two-dimensional (2D) visualization, that reduces in-depth perception as well as hand-eye coordination. The robotic system offers several technological advantages that may overcome many of the difficulties associated with laparoscopic surgery. Three-dimensional immersive operating environment without a fulcrum effect, an ergonomic camera platform, and articulating instruments with seven-degrees freedom of motion are technological features that may help surgeons to perform procedures more skillfully. It is still unknown whether this technology will translate into clinical effectiveness and value of care. This review aims to clarify current developments in robotic rectal surgery.

METHOD

All relevant articles from PubMed using the search terms, Rectal Cancer, Total Mesorectal excision, proctectomy, robotic surgery, laparoscopic surgery, and open surgery published between 2000 and 2015 including randomized trials, meta-analyses, prospective and retrospective studies and reviews with substantial numbers were retrieved and used to produce this review in addition to published, and unpublished work from the authors' own experience.

Preoperative Planning

Proper patient selection is crucial to preoperative planning, and patients should be both medically fit and able to tolerate minimally invasive surgery. All patients should undergo a detailed history and physical examination. Preoperative colonoscopy and/or flexible sigmoidoscopy are recommended for all patients with rectal lesions especially for identification of tumor location and possible synchronous colorectal lesions. As part of the preoperative preparation for rectal surgery, patients should undergo a mechanical bowel preparation with oral antibiotics. In our practice, mechanical bowel preparation and oral antibiotics are compulsory to sustain low postoperative surgical site infection. Preoperative intravenous antibiotics are given within 30–60 min of the incision time, to ensure adequate concentration at the outset. Deep venous prophylaxis should include the use of sequential compression devices, as well as chemical prophylaxis (pre-operative heparin).

Procedure

Room setup and positioning. Preoperative antibiotics are administered based on Surgical Care of Improvement Project related measures [1]. Rectal irrigation with saline is performed in rectal cancer cases. A Foley catheter and orogastric tube is placed in all cases. The patient should be correctly positioned on the modified lithotomy position which allows access to the anus for the numerous purposes including intraoperative CO_2 colonoscopy and/or using stapling device. Intraoperative flexible sigmoidoscopy with CO_2 has been used in our practice for both tumor location and anastomotic evaluation. The lithotomy position provides additional space for the surgical team, especially when operating in the upper quadrants of the abdomen, by standing between the patient's legs (Fig. 1). Padded stirrups or yellow fins are used and attention is given to preventing peroneal nerve injury. Both arms are tucked at the patient's sides. A gel pad on the operating table can provide additional decubitus support and stability against extremes of table tilting. Changes in operation table position and subsequent patient sliding can lead to the stirrup applying pressure to the posterior aspect of the lower extremity, that constitutes risk for nerve injury. To avoid from nerve injury, we prefer to secure patients on the operating table with a strong tape anteriorly surrounding the chest to prevent patients from sliding during maneuvers. Two monitors on both sides of the table should be routine in laparoscopic surgery and robotic view should be added on these monitors via wire connection for the bed-

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Fig. 1. Modified lithotomy position in robotic surgery.

side assistant. This setup is also helpful in hybrid procedures where part of the operation is performed using laparoscopic approach (Fig. 2).

Port placement. Further attention is necessary in the positioning of ports, with consideration given to the range of dissection required within the abdomen as well as the potential for external collisions of the robotic arms. Decision making for port locations are gradually and accurately perfected based on individual experience. Port replacement for rectal surgery is shown in Figure 3. Whether totally robotic [2,3] or hybrid technique [4] will be employed depends on surgeon discretion. While totally robotic rectal procedures have been reported with acceptable and safety results, various hybrid procedures likewise offers benefits associated with robotic approach. For the hybrid technique, variations depend on onset of robotic surgery where can be either ligating the vessels or splenic flexure mobilization followed by laparoscopic surgery. In all conditions, a minimum distance of "one-hand's breadth" is required to avoid external collisions of the robotic arms.

Operative steps. In our practice, the operation routinely begins with video-endoscopic assessment of the abdomen and the tumor site when applicable (Fig. 4). In order to perform a robotic rectal surgery, five to six ports are required including camera and assistant ports. Insufflation through umbilical port is achieved and pneumoperitoneum is obtained. Following pneumoperitoneum, the camera is inserted and additional trocars are placed under direct vision. Robot is docked using the two right-sided robotic trocars (8 mm and 8 mm) and two left-sided robotic trocars. The patient then is positioned in the right side down and slight Trendelenburg to facilitate displacement of the small bowel and the cecum out of the pelvis. At first using the robot, a medial-to-lateral mobilization of the left colon is accomplished and this is our preferred approach. Monopolar cautery with scissors is usually employed, and access to an avascular plane is accessed during the dissection. Vascular identification may begin either at the level of the inferior mesenteric artery (IMA), which constitutes our classic approach, or at the level of the inferior mesenteric vein (IMV). Once the inferior mesenteric artery is identified, high ligation is achieved using Hem-o-Lok clips or vessel sealer. Subsequently, the IMV is ligated as well as lesser sac is entered by division of the gastrocolic and splenocolic ligaments. Once the medial-to-lateral dissection is completed, mobilization of the left colon is performed. After completing this step by obtaining adequate colonic mobilization, the robotic arm is flipped from right side to the left side and the pelvic dissection is started. At this point, mesorectal excision begins at the sacral promontory below the plane of the superior hemorrhoidal artery, in the avascular plane that exists between mesorectal envelope and endopelvic parietal fascia. Dissection is carried out all the way down to the levator muscle with careful preservation of both the hypogastric nerve plexuses including the erigent pillar and entirety of mesorectal envelope. Classically, we divide the rectum using reticulating endoscopic stapling devices, often with one, or two fires of endoscopic staplers. At this point, there is also an unconventional technique described, that includes transecting the rectum under direct vision using a cautery hook and then purse-string suture of the rectal cuff followed by EEA stapling [5]. The specimen is then exteriorized from the right lower quadrant incision where the potential ileostomy is going to take place by using a wound protector (Fig. 5). As defined in laparoscopic surgical approach [6,7], natural orifice specimen extraction (NOSE) through the anus has also been reported in patients undergoing total mesorectal excision (TME) [8].

From Laparoscopic to Robotic TME Rectal Cancer: Current Status

The evidence provided by randomized controlled MRC CLASICC (Conventional vs. Laparoscopic-Assisted Surgery for Colorectal

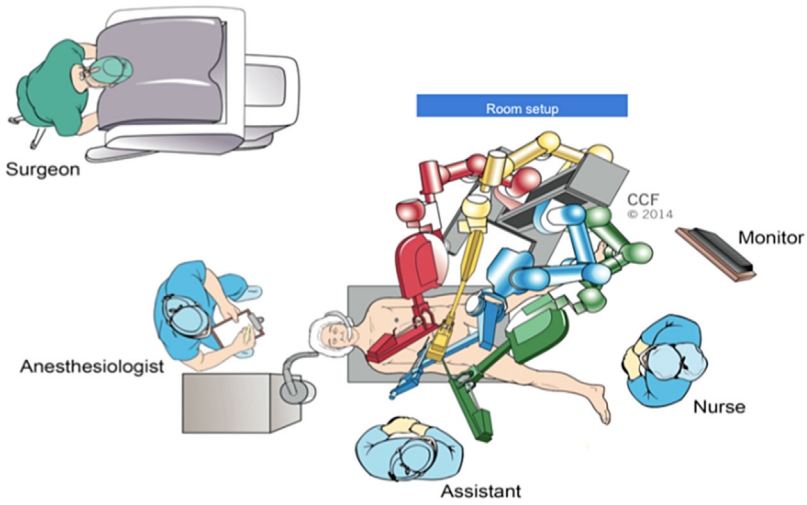


Fig. 2. Room setup in minimally invasive rectal surgery (Reprinted with permission of the Cleveland Clinic Center for Medical Art & Photograph © 2014. All Rights Reserved.)

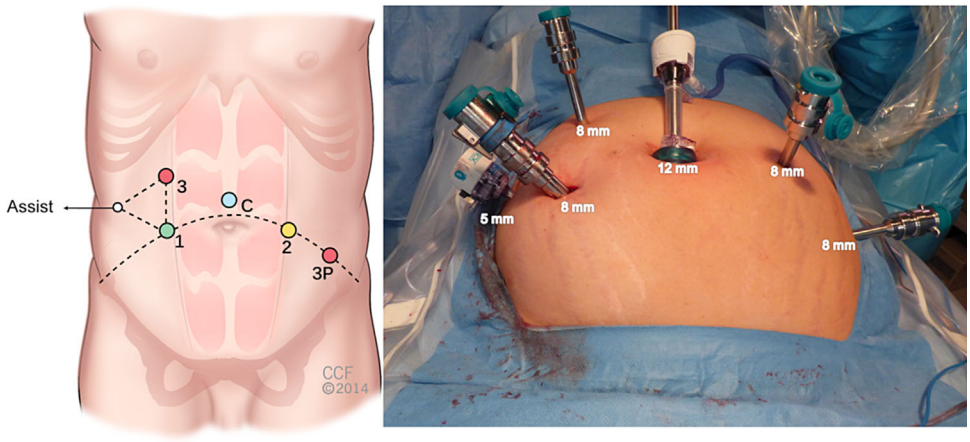


Fig. 3. Port placement for a four arm robotic-assisted proctectomy. A supra-umbilical 12 mm balloon port is inserted for the pneumoperitoneum. Eight millimeter robotic ports for the right and left upper quadrant and 8 mm robotic port is placed in right lower quadrant. A 5 mm assistant port is placed in the right lateral aspect of the abdomen positioned in an equal distant site from the right lower and right upper ports.



Fig. 4. Video-endoscopic assessment of the abdomen before robotic surgery.

Cancer) trial raised oncological concerns regarding laparoscopic surgery due to a high conversion and increased radial margin positivity rate (12% vs. 4%) [9]. Although radial margin positivity did not translate into an increase in local recurrence, the high-conversion rate (34%) and the inferior survival outcome associated with converted cases at the 5 year follow-up still remain areas of debate. Revised practice parameters published by the American Society of Colon and Rectal Surgeons has innovated the practice guideline indicating that laparoscopic rectal resection can be performed "with equivalent oncological outcomes" in comparison with open TME when performed by experienced laparoscopic surgeons.

Robotic technology is predominantly suited for operations that require a relatively small anatomical field in which great precision is essential. The unique randomized controlled trial has been conducted by Baik et al. compared the robotic tumor-specific mesorectal excision and conventional laparoscopic surgery in rectal cancer patients and reported a significantly shorter length of hospital stay in the robotic tumor-specific mesorectal excision group [10]. The meta-analysis by Memon et al., which focused on clinical and oncological outcomes, revealed a lower conversion rate and similar circumferential margin involvement, distal resection margin and harvested lymph node rates [11]. Recently released meta-analysis showed that robotic TME (RTME) is associated with lower rate of conversion and circumferential resection margins positivity and reduced incidence of erectile dysfunction but similar peri/postoperative and oncological outcomes including distal resection margin, proximal resection margin and local recurrence rates (12). Numerous studies have analyzed the feasibility and oncological safety of robotic rectal surgery. The short-term clinical and available oncological outcomes of selected studies for robotic rectal cancer surgery are shown in Tables I and II, respectively. Studies addressing oncological outcomes of robotic TME indicated 3 years DFS rates ranging between 73.7% and 79.2% [13–15].

Case series, comparative, and multicenter studies have revealed that implementation of robotic technology is feasible, effective, and safe for

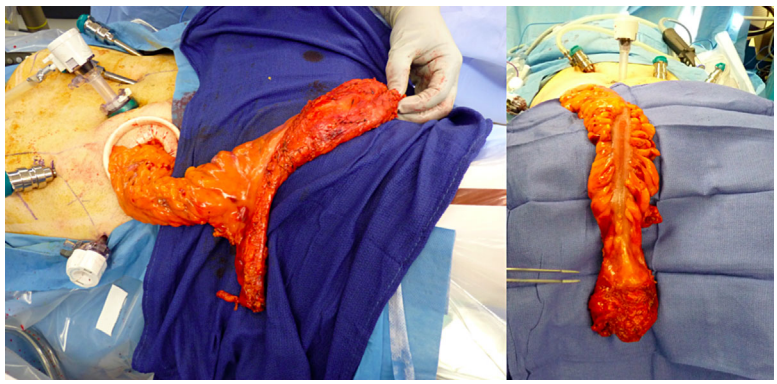


Fig. 5. Specimen extraction from ileostomy site.

TABLE I. Use of Robotics in Rectal Cancer Surgery—Clinical Outcomes

Author, year	Number of patients	Surgical technique	Type of procedure	Mean operating time (min)	Estimated blood loss (mL)	Length of Stay, day	Conversion rate (%)	Overall complication rate (%)	Anastomotic complications (%)
Choi et al. 2009 [3][a]	50	Totally robotic	RTME	304 (190–405)	NA	9.2 (5–24)	0	18	8.3
deSouza et al. 2010 [30][a]	44	Hybrid	RTME	347 (155–510)	250 (50–1000)	5 (3–36)	4.5	4.5	4.5
Pigazzi et al. 2010 [31][a]	143	Hybrid	RTME	297 (90–660)	283 (0–6000)	8.3 (2–33)	4.9	41.3	10.5
Kim et al. 2010 [32][b]	100 per group	Totally robotic	RTME	385.3 ± 102.6	NA	11.7 ± 6.7	2	20	8.2
			LTME	297.3 ± 83.74	NA	14.4 ± 10	3	27	11.1
Park et al. 2011 [33][b]	52 vs. 143	Hybrid	RTME	233 ± 52.4	NA	10 ± 19.2	0	10	9.6
			LTME	158 ± 49.2	NA	15 ± 12.2	0	15	5.6
Baek et al. 2011 [34][b]	41 vs. 41	Hybrid	RTME	296 (150–520)	200 (20–2000)	6.5 (2–33)	7.3	22	8.6
			LTME	315 (174–584)	300 (17–1000)	6.6 (3–20)	22	26.8	2.9
Kang et al.2013 [19][b]	165 per group	Totally robotic	RTME	309.7 ± 115.2	133 ± 192.3	10.8 ± 5.5	0.6	20.6	7.3
			LTME	277.8 ± 81.9	140.1 ± 216.44	13.5 ± 9.2	1.8	27.9	10.8
			OPEN	252.6 ± 88.1	275.4 ± 368.8	16 ± 8.64	NA	24.8	3.4
D'Annibale et al. 2013 [35][b]	50 per group	Totally robotic	RTME	270 (240–315)	NA	8 (7–11)	0	10	10
			LTME	280 (240–350)	NA	10 (8–14)	12	22	14

RTME, robotic total mesorectal excision; LTME, laparoscopic total mesorectal excision; NA, not available.
[a]Case series.
[b]Comparative studies.

rectal cancer. However, high-level evidences of clinical superiority with respect to the short-term outcomes over conventional rectal surgery are still lacking. Further studies are essential to evaluate the long-term results and potential benefits of robotic rectal surgery over laparoscopic rectal surgery. Due to absence of satisfactory evidence to support robotic-assisted rectal cancer surgery encouraged the design and employment of prospective randomized trial. Currently, ACOSOG-Z6051 and ROLARR studies, which are pending, aim to provide concrete evidences related to robotic approach with respect to operative morbidity and mortality, oncological endpoints, quality of life, and cost-effectiveness [11,16].

Open Versus Robotic TME for Rectal Cancer

RTME technique was compared to open surgical approach in relatively low-number studies [17–9]. Patients with extraperitoneal [18] and those with mid- and low-rectal cancer [19] who underwent RTME were compared with rectal cancer patients treated with OTME. In these studies [17–19], RTME provided the advantages of minimal access with shorter hospitalization, similar postoperative complication, and oncological outcomes.

Robotic Rectal Surgery in Obese Patients

With considering the nature of US population, with more than one-third of which is obese, laparoscopic surgery is challenging as for any intra-abdominal procedure, due to the lack of adequate exposure or excessive fat [20]. Robotic surgery (RS) has the potential technological advantages to overcome this challenges associated with obesity. There is no data specifically addressing the outcomes of robotic assistance on overweight rectal cancer population. Our institutional data (Table III) comparing robotic and laparoscopic rectal patients, whose BMI values are nearly 35 kg/m^2, showed similar intraoperative (operative blood loss, blood transfusion, complication, conversion rates, and operative time) and oncologic outcomes. Compared to LS, RS was found to be associated with two important benefits; quicker return of bowel function (median, 3 vs. 4 days) and shorter hospital stay (median, 6 vs. 7 days, respectively).

Learning Curve

It is still challenging to select optimal outcome measure as a proxy for clinical effectiveness of minimally invasive colorectal surgery.

TABLE II. Use of Robotics in Rectal Cancer Surgery—Oncological Outcomes

	Type of procedure	CRM positivity (%)	DRM, cm	Mean/median number of lymph nodes harvested	DFS	OS
Choi et al. 2009 [3][a]	RTME	2	1.9 ± 1.1	20.6 ± 10	NA	NA
deSouza et al. 2010 [15][a]	RTME	0	NA	14 (5–45)	NA	NA
Pigazzi et al. 2010 [31][a]	RTME	0.7	2.9 ± 1.8	14.1 (1–39)	77.6	97
Kim et al.2010 [32][b]	RTME	3	2.7 ± 1.9	14.7 ± 9.7	NA	NA
	LTME	2	2.6 ± 1.8	16.6 ± 9.1		
Park et al. 2011 [33][b]	RTME	1.9	2.8 ± 1.9	19.4 ± 10.2	NA	NA
	LTME	2.4	3.2 ± 2.1	15.9 ± 10.1		
Baek et al. 2011 [34][b]	RTME	4.9	3.6 (0.4–10)	13.1 (3–33)	NA	NA
	LTME	2.4	3.8 (0.4–11)	16.2 (3–33)		
Kang et al.2013 [19][b]	RTME	4.2	1.9 ± 1.4	15.0 ± 9.4	83.5	NA
	LTME	6.7	2.0 ± 1.4	15.6 ± 9.1	81.9	
	OTME	10.32	2.2 ± 1.7	17.4 ± 10.9	79.7	
D'Annibale et al. 2013 [35][b]	RTME	0	3 (2–7)	16.5 (11–44)	NA	NA
	LTME	12	3 (1–6)	13.8 (4–29)		

RTME, robotic total mesorectal excision; LTME, laparoscopic total mesorectal excision; NA, not available; OTME, open total mesorectal excision; CRM: circumferential resection margin; DRM, distal resection margin; DFS, disease free survial; OS, overall survival.
[a]Case series.
[b]Comparative studies.

TABLE III. Institutional Data Comparing Robotic and Laparoscopic Proctectomies in Obese Patients

Intraoperative outcome	RP group (n = 29)	LP group (n = 27)	*P*-value
Operative blood loss, ml, mean (sd)	434.0 (612.4)	339.4 (271.9)	0.68
Intraoperative transfusion, n (%)	6 (20.7)	5 (18.5)	0.84
Intraoperative complication, n (%)	2 (6.9)	0 (0.0)	0.49
Ureter injury	0	0	
Conversion to open surgery, n (%)	1 (3.4)	5 (18.5)	0.09
Operative time, min, mean (sd)	329.0 (102.2)	294.6 (81.1)	0.13
Oncologic outcome			
Proximal margin, cm, mean (sd)	17.4 (6.2)	21.6 (9.3)	0.09
Distal margin, cm, mean (sd)	3.9 (2.1)	3.2 (2.0)	0.17
LN positive, mean (sd)	1.6 (4.0)	1.4 (2.6)	0.54
LN total, mean (sd)	25.5 (14.0)	21.8 (9.6)	0.52
Radial margin involved ($\leq$1 mm), n (%)	2 (6.9)	2 (7.4)	0.99
Postoperative outcome			
Bowel movement, days, mean (sd)	3.2 (1.9)	4.3 (2.3)	0.01
Oral regimen, days, mean (sd)	3.7 (2.4)	4.6 (3.4)	0.59
Hospital stay, days, mean (sd)	6.4 (4.2)	8.4 (4.4)	0.02
Anastomotic leak, n (%)	0	0	
Overall SSI, n (%)	4 (13.8)	4 (14.8)	0.99
Wound distruption, n (%)	2 (6.9)	2 (7.4)	0.99
Sepsis, n (%)	1 (3.4)	1 (3.7)	0.99
Ileus, n (%)	4 (13.8)	8 (29.6)	0.15
Urinary tract infection, n (%)	1 (3.4)	1 (3.7)	0.99
Urinary retention, n (%)	7 (24.1)	5 (18.5)	0.61
Atelectasis, n (%)	2 (6.9)	0 (0.0)	0.49
Re-operation, n (%)	2 (6.9)	2 (7.4)	0.99
Re-admission, n (%)	4 (13.8)	6 (22.2)	0.41
Mortality, n (%)	0	0	

RP, robotic proctectomy; LP, laparoscopic procteectomy; LN, lymph node; SSI, surgical site infetion.

Operating time is commonly used [21–23], but the learning curve is not just limited to the speed of operation, it also involves other aspects of achieving proficiency such as gaining the confidence and capability of handling a whole spectrum of surgical situations [24]. Studies evaluating learning of adoption to robotic technology suggested three phases, which is defined from initial learning to higher expertise or mastery. Reports indicated that first phase of learning is achieved after a range of 9–41 cases. Future studies with optimal outcome measures are needed to better appreciation by surgeons.

Cost of Robotic Rectal Surgery

The cost of a robotic system counting its yearly maintenance fees and disposables can represent a significant cost to hospitals and health systems. This is compounded by the lack of reimbursements by payers. Available reports showed high-cost rates associated with robotic colorectal surgery when compared to conventional approaches [25,26].

However, cost-conscious strategy (using only cautery and scissors rather than vessel sealing device etc) and increased operative experience may be cost-effective. Data are limited about impact of operative experience on short-term outcomes including cost as well as postoperative complications following robotic rectal surgery. Our institutional and unpublished data analyzed the cost-conscious strategy with increasing experience on costs associated with rectal cancer patients who underwent robotic proctectomy between 2011 and 2014. Patients were classified based on operating surgeons' experience (n = 12 patients, Table IV). This is the outcome of one robotic surgeon's experience compared to four surgeons with high volume for open proctectomy. With increasing experience, robotic proctectomy for rectal cancer may improve value of care with reduced hospital stay, less postoperative morbidity and similar hospital costs compared to open surgery. Expected improvements in technology and potential competitions may reduce the cost of robotic surgery in the future.

TABLE IV. Cost Analysis of Robotic Surgery Compared to Open Approach

	Open (n = 68)	Robotic (n = 32)	*P*-value
Length of stay, d	9 ± 7	5 ± 3	<0.0001
Overall complication, n (%)	34 (50)	8 (25)	8 (25)
2011–2012	1 ± 0.4	1.5 ± 0.5	0.02
	n = 26	n = 12	
2013	1 ± 0.8	0.96 ± 0.3	0.14
	n = 20	n = 15	
2014	1 ± 0.6	1.2 ± 0.6	0.10

We did not present the actual cost values due to our institution's cost privacy policy. Each parameter of the cost analysis was presented as a ratio between the actual value of presented value and actual mean value of the open surgery in the same time period.

Future Directions

In the last two decades, surgical techniques have moved toward a less invasive approach from open to laparoscopic surgery. In order to minimize port-related complications and pain, laparo-endoscopic Single Site Surgery (LESS) was established as an alternative to conventional laparoscopic surgery over time. However, the development of LESS in more complex procedures was troubled with technical challenges due to decreased instrument maneuverability and frequent instrument collision [27]. In addition to aforementioned technological advantages of robotic surgery, introducing the robotic platform into LESS through the finer instrument articulation may overcome the these LESS-associated technical difficulties.

Another technological advancement in the robotic colorectal surgery is the addition of image guidance and tissue perfusion analysis. The anastomotic leakage is one of the most dreaded complications in colorectal surgery. One of the main causes of anastomotic leakages is considered to be the perfusion of the intestinal stump. The evaluation of the perfusion of the stumps is usually subjective based on the active bleeding edge of the section, the pulsatility of the mesentery vessels, and the lack of discoloration of bowel segments. In minimally invasive surgery, the loss of tactile feedback can make this assessment even more challenging. Near-infrared camera of the robotic platform allows visualizing the vascular structure of the colon after indocyanine green injection. It was reported that fluorescence imaging reduced

anastomotic leak rate after low-anterior resection and may also help to identify sentinel lymph node [28].

New technology offers numerous advantages including simpler docking, end-mounted camera aiming better-qualified vision, autofocus, and well-designed arms [29]. In our view, whether ergonomic benefits of novel robotic technology will translate into superior clinical outcome should be criticized from many aspects.

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