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ORIGINAL ARTICLE

Open versus minimally invasive surgery for rectal cancer: a single-center cohort study on 237 consecutive patients

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Abstract
Minimally invasive surgery (MIS) is gaining popularity in rectal tumor treatment. However, contrasting data are available regarding its safety and efficacy. Our aim is to compare the open and MIS approaches for rectal cancer treatment. Two-hundred-thirty-seven patients were included: 113 open and 124 MIS rectal resections. After the propensity score matching analysis (PS), the cases were matched into 42 open and 42 MIS. Short- and long-term outcomes, and pathological findings were analyzed before and after PS. A further comparison of the same outcomes and costs was conducted between the laparoscopic and the robotic approaches. As a whole, a sphincter-preserving procedure was more frequently performed in the MIS group (110 vs 75 cases; $p < 0.0001$). The estimated blood loss during MIS was significantly lower than during open surgery [127 (±92) vs 242 (±122) mL; $p < 0.0001$], with clear advantages for the robotic approach over laparoscopy [113 (±87) vs 147 (±93) mL; p 0.01]. Complication rate was comparable between the two groups. A higher rate of CRM positivity was evidenced after open surgery (12.4% vs 1.7%; p 0.004). A higher number of lymph nodes was harvested in the MIS group [12.5 (±6.4) vs 11 (±5.6); p 0.04]. After PS, no difference in terms of perioperative outcomes was noted, with the only exception of a higher blood loss in the open approach [242 (±122) vs 127 (±92) mL; $p < 0.0001$]. For the matched cases, no difference in 5-year overall and disease-free survival was evidenced (p 0.50 and 0.88, respectively). Mean costs were higher for robotics as compared to laparoscopy [9812 (±1974)€ vs 9045 (±1893)€; p 0.02]. MIS could be considered as a treatment option for rectal cancer. The PS study evidenced clear advantages in terms of estimated blood loss over the open surgery. Costs still remain the main limit for robotics.

Keywords Rectal cancer · Minimally invasive · Robotic proctectomy · Laparoscopy

Introduction

Minimally invasive surgery (MIS) is being increasingly used for the treatment of rectal cancer. However, the feasibility and potential advantages of both laparoscopic and robotic rectal resections are still a matter of debate.

As compared to the open proctectomy, laparoscopy has demonstrated better perioperative outcomes and comparable oncological safety [1–4]. However, two recent trials [5, 6] have failed in showing the non-inferiority of the laparoscopic technique, leading the authors to conclude that laparoscopy should not be routinely recommended for rectal cancer treatment. These contrasting results could be justified with a more demanding learning curve for laparoscopic proctectomy, the technical difficulty of the laparoscopic pelvic dissection (partially related to the use of non-articulating instruments), the 2D-vision, and the fulcrum effect.

The more recent introduction of the robotic platform was thought to potentially overcome these limitations, thanks to the high-definition, 3D-imaging vision, the favorable ergonomics and the seven-degree of movement. The initial experiences evidenced benefits in terms of conversion rate, estimated blood loss, sphincter-preserving procedures, length of hospital stay and pathological outcomes [7–11]. In contrast with these promising data, the recent ROLARR trial [12]

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has brought unexpected results, not showing any superiority of the robot-assisted proctectomy over the laparoscopic approach. Despite the strength of the study design, the different experiences of the authors in robotic surgery and the no blinding to treatment allocation make these results highly questionable.

With the aim of giving our contribution in defining the safety and feasibility of MIS in rectal cancer resection, we present our results from a single tertiary referral center. A comparison in terms of short-term, pathological and long-term outcomes has been performed between the open and the MIS approaches. A propensity score analysis has been additionally conducted to reduce potential biases.

Methods

The study involved all patients with a histologically proven diagnosis of rectal adenocarcinomas who underwent open or laparoscopic or robotic surgery at the Digestive Surgical Unit of the "A.Gemelli" Hospital of Rome from January 2013 to January 2017. After the institution review board (IRB) approval, a retrospective review was performed from a prospectively maintained database. Data reporting conforms to the Enhancing the QUAlity and Transparency of health Research (EQUATOR) network guidelines. All operations were performed by the same two surgeons (GBD and SA). Patients operated by GBD underwent an open rectal resection (ORR) while the MIS approach was reserved to all patients operated by SA. At the time of the study, SA had already performed at least 60 laparoscopic rectal resections (LRR) and 25 robotic rectal resections (RRR), which are required to complete the learning curve for the appropriate minimally invasive treatment of rectal diseases [13, 14].

The choice between the laparoscopic approach and the robotic one was dependent on the robotic platform availability (twice a month in the first 2 years and once a month in the last 2 years). All robot-assisted procedures were single-docking and totally robotic.

All cases were discussed in a multidisciplinary rectal tumor board meeting, and neoadjuvant therapy (namely, preoperative radiochemotherapy) was offered in case of radiological extramural or node-positive diseases.

Inclusion criteria were: (1) patients aged 18 or older with a histologically proven diagnosis of rectal adenocarcinoma; (2) tumor location within 15 cm from the anal verge.

Tumor location was defined as: high rectum (10–15 cm from the anal verge), middle rectum (5–10 cm from the anal verge) and low rectum ($\leq$5 cm from the anal verge).

The exclusion criteria were: (1) multiple primary cancers; (2) emergent cases.

All patients received the same protocol of perioperative care that included antibiotic prophylaxis, thrombotic prophylaxis, analgesic care and diet resumption. Prophylaxis for deep-vein thrombosis was achieved applying antiembolic stockings and routine pre- and postoperative administration of heparin according to the body weight.

To avoid injuries of the inferior epigastric artery, ancillary trocars in the MIS group were placed prior visualization by transperitoneal direct visualization.

The analyzed demographic and clinical data included: age, gender, the American Society of Anesthesiologists (ASA) score, preoperative clinical stage, tumor location and neoadjuvant therapy.

Collected perioperative data were: operative time, sphincter-preserving procedures, diverting ostomy, estimated blood loss (EBL), conversion rate, postoperative morbidity, length of hospital stay and reoperation and mortality rates within 30 days after surgery.

An additional analysis of the histopathological findings in terms of TNM stage (AJCC Cancer Staging System, 7th edition), tumor dimension, number of lymph nodes harvested, circumferential radial margin (CRM) and distal margin negativity was also conducted.

The distal margin was considered positive when $\leq$1 mm was detected between the closest tumor and the cut edge [5, 6]. Similarly, the circumferential radial margin (CRM) was considered positive when $\leq$1 mm.

Long-term outcomes included disease-free survival (DFS) and overall survival (OS) at 5 years.

The primary endpoint of the study was to compare the open and MIS approaches (including both LRR and RRR) for each of the above-mentioned variables. To reduce the bias from confounding variables, a propensity score (PS) analysis was additionally performed. OS and DFS were evaluated only for the matched cases.

The secondary endpoint was to further compare the same outcomes between the laparoscopic and the robotic approaches. Due to the small sample size of the laparoscopic and robotic groups a PS analysis was not performed.

A financial analysis of both the operative costs and the number of surgeons needed for the laparoscopic and robot-assisted approaches was additionally conducted. Economic data were collected from the economic office of our institution. The acquisition and maintenance of the robotic devices were excluded from analysis. The calculated costs data were: operating room costs (in terms of operating time per minute, surgeon and anesthetist per minute), surgical equipment such as robotic and laparoscopic instruments, energy devices and staplers and hospital stay costs (including intensive care unit, floor, pharmaceutical, laboratory, pathology and radiology costs). Costs were analyzed in Euros (€). Any 30-day hospital readmissions were not included.

Statistical analysis

For the comparison between open surgery group and the MIS one, a case-matching was performed using the propensity score of 3 factors: ASA score, cTNM stage and tumor distance from the anal verge. Using these PSs, a 1:1 nearest neighbor matching was performed, and matched pairs were validated using the Hosmer–Lemeshow test.

Patients' characteristics between the open and MIS groups were compared using the Student's *t* test, Fisher's exact test and Chi-square test. DFS and OS were calculated from the date of surgery until recurrence and the last follow-up date, respectively, using the Kaplan–Meier method. Both these last two outcomes were evaluated only for the matched cases.

For the second endpoint, ordinal qualitative variables and quantitative variables were compared using the Wilcoxon sum of ranks test. Paired comparison of qualitative variables was performed using Fisher's exact test or Chi-square tests.

In any case, continuous variables were reported as mean ± standard deviation (SD) and categorical variables as numbers and percentages unless otherwise specified.

Statistical significance was accepted at the $p < 0.05$ level.

The variables that were significant at univariate analysis were entered into a logistic regression model to identify independent predictors. Results were expressed as odds ratio (OR) with 95% confidence interval (CI). Logistic regression was only performed for the matched cases.

All statistical analyses were conducted using the SPSS software (version 21.0; IBM Corporation, NY, USA).

Results

Data from a total of 237 patients were collected. The data set included 113 (47.7%) ORR and 124 (52.3%) MIS proctectomies (MIS group), which comprised 61 LRR and 63 RRR.

Using the PS, the patients were matched into an open group of 42 and a MIS group of 42 (Fig. 1).

Table 1 reports the patients' demographic and clinical characteristics of the overall cohort and matched cases. Before matching, tumor location in the low rectum was more frequently encountered in the open group as compared to the MIS group (44 patients—38.9% vs 30 patients, respectively—24.2%; *p* 0.02), with a consequent higher proportion of patients receiving neoadjuvant radio-chemotherapy (71–62.8% vs 58–46.8%, respectively; *p* 0.01). After matching, demographic and clinical data were homogeneous between the two cohorts.

The intraoperative and postoperative outcomes are summarized in Table 2. No intraoperative complications, here including injuries of the inferior epigastric artery during ancillary trocars positioning, were registered.

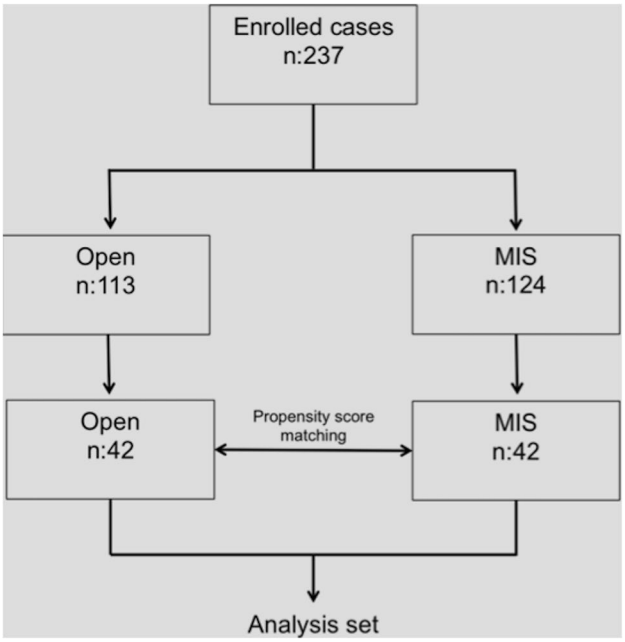

Fig. 1 Flow diagram of patients' selection. For propensity score: ASA score, cTNM and tumor distance from the anal verge

Before PS matching, the operative time was 46 min longer in the MIS group as compared to the open access ($p < 0.0001$). The robotic approach had a major influence on this outcome with a surgical time (including the docking time) of 283 (±68.8) vs 248 (±56) min for the LRR(*p* 0.003). A sphincter-preserving procedure was more frequently performed in the MIS group (110/124 vs 75/113 patients in the open group; $p < 0.0001$), while a higher rate of diverting ostomy was observed for the ORR (74.6% vs 53.6% in the MIS approach; *p* 0.004). Conversely, no difference was detected for these last two variables between the laparoscopic and the robotic approaches.

Intraoperative blood loss was significantly lower in the MIS group [127 (±92) mL] as compared to the open access [242 (±122) mL] ($p < 0.0001$). This superiority is mainly related to the better results obtained after RRR with an EBL of 113 mL as compared to 147 mL for the LRR group (*p* 0.01). A total of 16 patients in the MIS group required conversion to open surgery, with a higher proportion in the LRR group (13 vs 3 patients in the RRR group; *p* 0.04). There was no conversion from robotic to laparoscopic approach.

After PS matching, operative time and sphincter-preserving procedures were comparable between the two groups. A higher percentage of diverting ostomy was registered after ORR (78% vs 53.8% in the MIS approach; *p* 0.04). EBL was significantly lower in the MIS group as compared to the open access [127 (±92) mL vs 243 (±122) mL, respectively; $p < 0.0001$].

Table 1 Patients' demographic and clinical characteristics

Variable	Overall cohort			Matched cases		
	Open ($n=113$)	MIS ($n=124$)	p	Open ($n=42$)	MIS ($n=42$)	p
Age, years (±SD)	65 (±12.8)	64.6 (±10.9)	0.53	65 (±11.1)	65.7 (±10.4)	0.92
Gender, *n* (%)						
Male	58 (51.3)	76 (61.3)	0.12	30 (71.4)	27 (64.3)	0.48
Female	55 (48.7)	48 (48.7)		12 (28.6)	15 (35.7)	
ASA, *n* (%)						
1	13 (11.5)	13 (10.5)		1 (2.4)	3 (7.2)	
2	54 (47.8)	63 (50.8)	0.97	24 (57.1)	20 (47.6)	0.57
3	42 (37.2)	44 (35.5)		15 (35.7)	18 (42.8)	
4	4 (3.5)	4 (3.2)		2 (4.8)	1 (2.4)	
Preoperative clinical stage						
cT						
cT1/2	36 (31.8)	36 (29)		12 (28.6)	11 (26.2)	
cT3	52 (46)	73 (58.9)	0.40	21 (50)	25 (59.5)	0.60
cT4	25 (22.2)	15 (12.1)		9 (21.4)	6 (14.3)	
cN						
cN+	62 (54.9)	50 (40.3)		16 (38.1)	17 (40.5)	
Tumor location in the rectum, *n* (%)						
High	24 (21.3)	44 (35.5)		16 (38)	19 (45.2)	
Middle	45 (39.8)	50 (40.3)	0.02	15 (35.8)	18 (42.9)	0.24
Low	44 (38.9)	30 (24.2)		11 (26.2)	5 (11.9)	
Tumor distance from anal verge, cm (±SD)	7.5 (±4.5)	9.7 (±4.2)	0.001	8.1 (±4.9)	9.6 (±3.6)	0.11
Neoadjuvant therapy	71 (62.8)	58 (46.8)	0.01	18 (42.8)	17 (40.5)	0.82

Although only approaching the statistical significance (p 0.08), postoperative complications of the overall cohort of study were more common after open surgery (45 patients—40%) than the MIS approach (36 patients—29%). Conversely, a similar morbidity rate was noted between the matched groups (p 0.24). When considering the minimally invasive approach used, RRR related with a lower postoperative incidence of complications (26 patients—42.6%) as compared to the LRR (10 patients—15.9%) (p 0.02). Details of postoperative complications are reported in Table 3, with the only evidence of a higher incidence of wound infection in the open group as compared to the MIS approach(6 patients—5.3% vs 1–1%, respectively; p 0.04).

No difference was noted in terms of reoperation rate, length of hospital stay, and postoperative mortality between the open and MIS techniques. In the open surgery group, reoperation was needed in 7 patients, due to anastomotic leakage in 3 cases, pelvic abscesses in 2 cases and bowel occlusion in 2 patients. Three patients died postoperatively: two patients of sepsis due to anastomotic leakage, while the remaining case died of myocardial infarction.

A laparotomy with a diverting ileostomy and peritoneal toilette was required due to anastomotic leakage after 6 and 5 days from surgery in two patients after LRR and RRR, respectively. Both these patients lately died of myocardial infarction on postoperative day 13 in the RRR group and of multiple organ failure on postoperative day 22 in the LRR group.

In terms of pathological outcomes (Table 4), a homogeneous distribution of tumor staging was observed in both the overall cohort and the matched cases. Despite a bigger tumor dimension in the open group [4.5 (±4.1) vs 3.1 (±1.5) cm in the MIS group, p 0.04], the number of harvested lymph nodes, CRM and distal margin negativity rates were similar between the two groups after PS matching.

However, considering the whole population, the MIS procedures led to a higher number of harvested lymph nodes [12.5 (±6.4) vs 11 (±5.6) in the open group; p 0.04] and CRM negativity rate(98.3% vs 87.6% after ORR; p 0.004).

The follow-up was completed in 98 patients after ORR and 111 after MIS, with a mean time of 39.1 (±14.5) and 37.81 (±13.9) months (p 0.21), respectively (Table 5). In the whole population, a higher recurrence rate was observed after the open approach with an incidence of 16% as compared to 6.3% in the MIS group (p 0.008). Although only approaching the statistical significance (p 0.06), long-term mortality rate was higher in the open surgery group (8.8%) than in the MIS approach (3.6%).

Table 2 Intraoperative and postoperative outcomes

Variable	Overall cohort			Matched cases		
	Open ($n=113$)	MIS ($n=124$)	p	Open ($n=42$)	MIS ($n=42$)	p
Operative time (min), mean (±SD)	219 (±59.6)	265 (±64.3)	< 0.0001	236.3 (±53)	243.5 (±56)	0.54
LRR		248 (±56)	0.003			
RRR		283 (±68.6)				
ARR, *n* %	75 (66.3)	110 (88.7)	< 0.0001	41 (97.6)	39 (92.9)	0.36
LRR		55 (90)	0.21			
RRR		52 (86.7)				
APR *n* (%)	38 (33.7)	14 (11.3)	< 0.0001	1 (2.4)	3 (2.1)	0.36
LRR		6 (10)	0.44			
RRR		8 (13.3)				
Temporary ostomy, *n* (%)	56 (74.6)	59 (53.6)	0.004	32 (78)	21 (53.8)	0.04
LRR		30 (27.3)	0.39			
RRR		29 (26.4)				
EBL, mL, mean (±SD)	242 (±122)	127 (±92)	< 0.0001	242 (±122)	127 (±92)	< 0.0001
LRR		147 (±93)	0.01			
RRR		113 (±87)				
Conversion, *n* (%)	–	16 (12.9)		–	7 (16.7)	
LRR		13 (21.3)	0.04			
RRR		3 (4.8)				
Morbidity, *n* (%)	45 (40)	36 (29)	0.08	5 (11.9)	9 (21.4)	0.24
LRR		26 (42.6)	0.02			
RRR		10 (15.9)				
Reoperation, *n* (%)	7 (6.2)	4 (3.2)	0.27	0	0	
LRR		3 (4.9)	0.29			
RRR		1 (1.6)				
Length of hospital stay (days), mean (±SD)	11 (±7.7)	11 (±8.2)	0.78	10.6 (±6.1)	10.1 (±5.6)	0.71
LRR		12 (±10.2)	0.06			
RRR		9 (±6.6)				
Mortality, *n* (%)	3 (2.6)	2 (1.6)	0.72	0	1 (2.4)	0.31
LRR		1	0.98			
RRR		1				

ARR anterior rectal resection, *APR* abdominoperineal resection, *EBL* estimated blood loss

Table 3 Postoperative surgical and medical complications

	Open ($n=113$)	MIS ($n=124$)	p
Anastomotic leakage, *n* (%)	5 (4.4)	6 (4.8)	0.88
Abscess, *n* (%)	5 (4.4)	4 (3.2)	0.63
Bowel occlusion, *n* (%)	1 (1)	2 (1.6)	0.61
Surgical site infection, *n* (%)	6 (5.3)	1 (1)	0.04
Pneumonia, *n* (%)	10 (8.8)	9 (7.2)	0.65
Urinary tract infection, *n* (%)	11 (9.7)	9 (7.2)	0.35
Urinary retention, *n* (%)	4 (3.5)	3 (2.4)	0.61
Progressive renal insufficiency, *n* (%)	2 (1.8)	1 (1)	0.50
Myocardial infarction, *n* (%)	1 (1)	1 (1)	0.94

None of these outcomes resulted statistically different when considering only the matched cases.

OS and DFS did not differ between the open and MIS groups (Fig. 2). The 5-year estimated OS was 74% for patients in the open surgery group and 80% for the MIS

Table 4 Pathological assessment

Variables	Overall cohort			Matched cases		
	Open ($n=113$)	MIS ($n=124$)	p	Open ($n=42$)	MIS ($n=42$)	p
TMN stage, n (%)						
0	6 (5.3)	13 (10.5)		1 (2.4)	4 (9.5)	
I	32 (28.3)	38 (30.6)		19 (45.2)	14 (33.3)	
II	25 (22.1)	30 (24.2)	0.20	13 (31)	13 (31.1)	0.23
III	27 (23.9)	30 (24.2)		9 (21.4)	8 (19)	
IV	23 (20.4)	13 (10.5)		0	3 (7.1)	
Tumor dimension (cm), mean (±SD)	3.8 (±3.1)	3.3 (±3.2)	0.80	4.5 (±4.1)	3.1 (±1.5)	0.04
Lymph nodes harvested, mean (±SD)	11 (±5.6)	12.5(±6.4)	0.04	12 (±5.1)	12.8 (±5.1)	0.48
CRM negative, n (%)	99 (87.6)	122 (98.3)	0.004	42 (100)	42 (100)	
Distal margin negative, n (%)	112 (99)	124 (100)	0.30	42 (100)	42 (100)	

Table 5 Long-term outcomes

	Overall cohort			Matched cases		
	Open ($n=98$)	MIS ($n=111$)	p	Open ($n=42$)	MIS ($n=39$)	p
Follow-up, months mean (±SD)	39.1 (±14.5)	37.81 (±13.9)	0.21	33.2 (±13.6)	29.4 (±15.4)	0.60
Metastastic recurrence, n (%)	18 (16)	7 (6.3)	0.008	6 (11.9)	4 (10.3)	0.58
Local	4	2		2	2	
Local + distant	3	1		1	1	
Distant	11	4		3	1	
Mortality at follow-up, n (%)	10 (8.8)	4 (3.6)	0.06	5 (11.9)	2 (5.1)	0.27

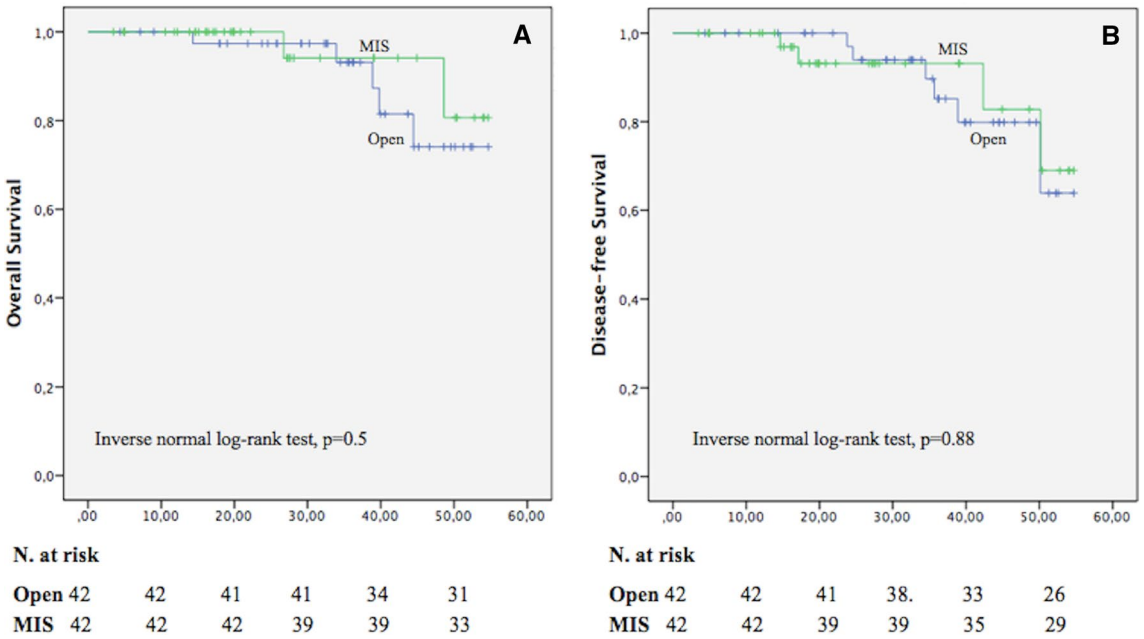

Fig. 2 Kaplan–Meier plots of overall survival (**a**) and disease-free survival (**b**)

cohort (p 0.50), while the 5-year estimated DFS was 63% and 69% (0.88), respectively.

A sub-analysis of OS and DFS was additionally performed for patients who underwent preoperative

radio-chemotherapy (35 patients). No difference was evidenced in terms of OS and DFS according to the type of approach used. More specifically, the 5-year estimated OS was 64.9% and 66.7% in the open and MIS groups, respectively (p 0.7). Similarly, comparable DFS rates were evidenced between the two techniques: 51% for the open surgery cohort and 54% for the MIS one (p 0.8).

Predictive factors analysis of clinical outcomes (Table 6)

At univariate analysis, higher EBL values were associated to patients older than 65 years [165.4 (±115.2) mL vs 206.8 (±106.4) mL in younger patients; $p < 0.0001$], to the open approach for rectal resection [242 (±122) mL vs 127 (±92) mL in the MIS group; $p < 0.0001$] and to the tumor location in the middle and low rectum [197.6 (±124.6) mL and 186.8 (±103) mL, respectively, as compared to 171.8 (±98.8) mL in the high rectum cohort of patients; p 0.001].

However, only the open approach resulted as an independent risk factor for higher EBL values (OR 6.66; 95% CI 2.4–18.4; $p < 0.0001$) at the logistic regression.

Regarding the temporary ostomy rate, the univariate analysis revealed a significant association to male patients (82.6% as compared to 59.6% for the female cohort; p 0.05), to the open approach (78% vs 53.8% in the MIS group; p:0.02), to a higher cTNM stage (78.7% in stage III–IV vs 48.5% in stage I–II; p 0.005) and to the neoadjuvant therapy (83.9% vs 55.1% of patients who did not undergo any preoperative treatment; p 0.008).

Even in this case, logistic regression confirmed the open approach as the only influencing factor on the higher rate of temporary ostomy (OR 3.77; 95% CI 1.27–11.23; p 0.01).

Economic and human resources outcomes of MIS

The overall mean total costs were higher in the robotic group [9812 (±1974) €] as compared to the laparoscopic group [9045 (±1893) €] (p 0.02). The mean operating room costs were lower for LRR [2325.4 (±908.8) € vs 3264.7 (±1597) € in the robotic cohort; p 0.03], as well as the mean costs of surgical equipment [1926.72 (±494) vs 2328.6 (±352) € in the robotic group; $p < 0.0001$]. Conversely, no difference was evidenced in terms of hospital stay costs between the two techniques [3616.5 (±1402.7) and 3889.4 (±1457) € in the RRR and LRR groups, respectively; p 0.38].

In terms of human resources employed, clear advantages were evidenced in the robotic surgery cohort (with a mean number of 2.17 (±0.38) surgeons involved) as compared to a mean number of 2.67 (±0.47) surgeons in the LRR group ($p < 0.0001$).

Discussion

Despite the rapidly expanding MIS technology and the increased integration of both laparoscopic and robotic surgeries into rectal diseases treatment, clear evidences on the feasibility of both these approaches are still insufficient and confusing. The short-term surgical outcomes and the oncologic radicality of the laparoscopic approach have been recently called into question in the ACOSOG Z6051 and the ALaCART trials [5, 6]. Similarly, the initial promising results of robotic surgery in the treatment of rectal cancer [15–20] have been contradicted in the recent ROLLAR study [12].

Multiple factors could justify these diverging results, which are mainly related to the above-mentioned studies designs and to the high surgical skills required to adequately perform minimally invasive proctectomies.

As a matter of fact, both ACOSOG Z6051 and ALaCART trials [5, 6] are non-inferiority studies and consequently they are not designed to demonstrate whether one method of rectal resection is superior to the other. As a result, the inability to establish the non-inferiority is not to be considered as a contraindication to the laparoscopic approach.

Similarly, definitive conclusions on the safety and feasibility of robotic proctectomies cannot be drawn from the ROLARR trial [12], whose major limitations are related to the not homogeneous levels of experience in robotic surgery of the authors and to the absence of blinding to treatment allocation, which make the results highly questionable [21, 22].

At this regard we do believe that conclusive data on the efficacy of the MIS approach could only be defined when high-skilled surgeons in MIS will be involved and when a standardization of both operative technique and perioperative care will be held [22].

Based on these premises, we have reported our experience from a single tertiary referral center, involving only surgeons with high skills in both open and MIS approaches. Additionally, the propensity score matching was performed to make the background patient data uniform. At this regard both patients' clinical and tumor characteristics were taken into consideration, making the patients' background balanced and the comparison between the open and MIS approaches reliable.

The longer operative time is a well-known disadvantage of MIS [3, 23–25]. Considering our cohort of study, a longer operative time was observed in the MIS group [265 (±64.3) min] as compared to the open approach [219 (±59.6) min] ($p < 0.0001$). Even if we firstly thought that technical difficulty in operating in narrow pelvises with rigid instruments for laparoscopy and the docking time for the robotic approach could have been the main causes of a prolonged

Table 6 Univariate and multivariate logistic regression for influencing factors on EBL and temporary ostomy rate

Variable	Univariate analysis		Multivariate analysis		
	EBL, mL (±SD)	*p*	OR	95% CI	*P*
Age					
≥65	165.4 (±115.2)	< 0.0001	0.96	0.919–1.002	0.07
<65	206.8 (±106.4)				
Gender					
Male	186.1 (±114.28)	1	–	–	–
Female	181.6 (±110.8)				
Type of surgery					
Open	242 (±122)	< 0.0001	6.66	2.4–18.4	< 0.0001
MIS	127 (±92)				
ASA score					
1	175 (±184.8)	0.7	–	–	–
2	186 (±110.8)				
3	178 (±112)				
4	233 (±57)				
Tumor location in the rectum					
High	171.8 (±98.8)	0.001	1.58	0.8–2.9	0.13
Middle	197.6 (±124.6)				
Low	186.8 (±118.4)				
cTNM, stage					
I–II	176.8 (±127)	0.09	–	–	–
III–IV	189.7 (±103)				
Neoadjuvant therapy					
Yes	192.2 (±103.4)	0.45	–	–	–
No	179.26 (±119.3)				
Type of resection					
ARR	185 (±113.2)	0.75	–	–	–
APR	160 (±108.8)				
Variable	Temporary ostomy, *n* (%)	*p*	OR	95% CI	*p*
Age					
≥65	27 (64.3)	0.7	–	–	–
<65	26 (68.4)				
Gender					
Male	47 (82.6)	0.05	1.01	0.089–11.65	0.98
Female	14 (59.6)				
Type of surgery					
Open	32 (78)	0.02	3.77	1.27–11.23	0.01
MIS	21 (53.8)				
ASA score					
1	1 (25)	0.1	–	–	–
2	31 (75.6)				
3	20 (62.5)				
4	1 (33.3)				
Tumor location in the rectum					
High	22 (66.7)	0.64	–	–	–
Middle	19 (61.3)				
Low	12 (75)				

Table 6 (continued)

Variable	Temporary ostomy, *n* (%)	*p*	OR	95% CI	*p*
cTNM, stage					
I–II	16 (48.5)	0.005	3.22	0.83–12.53	0.09
III–IV	37 (78.7)				
Neoadjuvant therapy					
Yes	26 (83.9)	0.008	0.49	0.043–5.62	0.56
No	27 (55.1)				

operative time, no difference was found between the two techniques after the PS matching. This led to consider the type of surgery that was performed (ARR or APR) as the main factor influencing the overall operative time.

As a matter of fact, a higher number of APRs were registered in the ORR group (38–33.7% vs 14–11.3% in the MIS group—$p < 0.0001$). The absence of splenic flexure mobilization and reconstructive phase likely enables time-sparing procedures as compared to the need for ARR of splenic flexure mobilization and performing colo-rectal or colo-anal anastomoses.

To have reached comparable operative time after PS matching confirms what was already reported by Ahmed et al. [10], according to whom an extensive experience in minimal access surgery and a high-volume referral center bring acceptable operative time for both laparoscopic and robotic surgeries.

Of note, no intraoperative complications were encountered in all our cohorts of study. Regarding the MIS group, no injury of the inferior epigastric artery during ancillary trocars positioning has been registered. Despite this being an uncommon complication, it may occur in up to 2% of laparoscopic procedures [26]. In this regard, multiple techniques for a safe trocars introduction have been proposed. Direct transperitoneal visualization, as performed in our MIS group, is the ideal approach to use [27]. When it is not possible (i.e., obese patients), transillumination and surface landmarks are considered a reliable technique [27]. In addition, recent data have reported a significant reduction of vessel injuries when lateral trocars are placed superiorly to the anterior superior iliac spines and at least 6 cm distance from the midline [28].

Interestingly, a higher rate of temporary ostomies was evidenced in the open group of both the whole cohort of study (56 patients—74.6% vs 59 patients—53.6% in the MIS cohort; *p* 0.004) and after PS matching (32 patients—78% vs 21 patients—53.8% in the MIS population; *p* 0.04). As a further confirmation, the open approach resulted in the only influencing factor for a higher rate of temporary ostomies at the multivariate analysis (OR 3.77; 95% CI 1.27–11.23; *p* 0.01). This finding may be justified by the increased ease of dissection in confined spaces that is particularly guaranteed by the robotic approach [29], leading to perform the anastomosis in a safer manner as compared to the open technique.

As reported in previous case series [1–3, 5, 6, 9–11, 25, 30], clear advantages in terms of EBL in the MIS group have been documented [127 (± 92) mL vs 242 (± 122) mL in the open group; $p < 0.0001$]. Moreover, the multivariate analysis we performed confirmed the open approach as the only influencing factor on a higher EBL value (OR 6.66; 95% CI 2.4–18.4; $p < 0.0001$).

Robot-assisted procedures have particularly influenced this outcome. This is mainly related to the better visualization guaranteed by the MIS, where image magnification allows to selectively recognize and isolate blood vessels [31].

In addition to this advantage, the capability of the robotic platform to work in constrained spaces has been reflected by a significant reduction of conversion rate as compared to laparoscopy [32]. In our case series only 4.8% of RRR were converted to open as compared to 21.3% in the laparoscopic group (*p* 0.04).

Because converted patients have higher complication rates, the low conversion rate for robotic proctectomy may support better postoperative courses [33]. Although no difference in postoperative morbidity was observed between open and MIS approaches, laparoscopic rectal resection related with a higher incidence of postoperative morbidity (42.6%) as compared to the robotic approach (15.9%) (*p* 0.02). These results are in line with most of the robotic and laparoscopic series [34–36].

Pathological radicality of MIS is another major matter of debate. Adequate TME, CRM status and number of retrieved lymph nodes are known to strongly impact patients' prognosis [37, 38]. Since TME completeness is assessed subjectively by means of a macroscopic evaluation, we decided to define pathological outcomes based only on the CRM status and the number of harvested lymph nodes. In some previous studies CRM negativity did not differ between laparoscopic and open surgery groups, while in other studies a higher positivity rate was observed after the laparoscopic approach [3, 5, 6, 33, 39]. Most of the authors justify these disappointing data with the difficulty in achieving an appropriate dissection plane when working with rigid instruments in the pelvis,

especially for low rectal tumors. Even if the robotic platform was initially supposed to overcome this limitation, no advantages have been observed in most of large case series and in two recent meta-analyses [3, 10, 40]. In line with such data, no statistical difference was noted after PS in our case series between the open surgery and MIS approaches. The initial disparity observed in the whole cohort of study could be mainly due to the more common tumor location in the low rectum in the open group. This would have led to a major technical difficulty and consequently to a higher incidence of positive CRM in the open proctectomy.

Similarly, a significant difference in the number of retrieved lymph nodes was only observed in the whole population [11 vs 12.5 in the open and MIS approaches, respectively; p 0.004]. These data are mainly related to the neoadjuvant treatment, which was more frequently required in the open group. As a matter of fact, in line with previous studies [3], after PS, an equal distribution of neoadjuvant radio-chemotherapy between the two groups was registered and no difference in the number of retrieved lymph nodes was noted (p 0.48).

With regards to OS and DFS, there are no large studies showing a significant difference between MIS and open surgery for rectal cancer. In the COLOR II study [1], similar locoregional recurrence was demonstrated between the laparoscopy and the open surgery. Similarly, the COREAN study [41] showed the non-inferiority of DFS after laparoscopic surgery. Additionally, a recent meta-analysis on 14 studies comparing the open and laparoscopic approaches [3] documented no differences in terms of OS and DFS between the two techniques. The long-term results of the other 2 studies, the ALaCaRT trial and the ACOSOG Z6051 trials [5, 6], are still awaited.

Even less studies have investigated the long-term outcomes after robotic proctectomy. So far, the estimated DFS and OS at 3 years range between 73.7 and 79.2% [16, 42] and 90.1% and 97% [43, 44], respectively. There was no difference between the open and MIS approaches deriving from the long-term analysis of our data, with an OS rate at 5 years of 74% and 80% (p 0.50), respectively, and a 5-year estimated DFS of 63% and 69% (0.88) respectively.

After PS, no difference was evidenced in terms of local and distant recurrence between the two techniques. However, a higher incidence can be noted in the open access of the whole cohort of study (18 patients—16% vs 7 patients—6.3%; p 0.008). This can be justified by a higher rate of postoperative stage IV and a more frequent CRM positivity after open proctectomy.

In terms of economic evaluation, few studies are present in the literature comparing RRR and LRR [45–47]. We evidenced higher mean total cost for the robotic approach [9812 (± 1974) vs 9045 (± 1893) € in the LRR group; p 0.02] here including both the operating room and hospitalization costs. However, from the subanalysis we conducted, no difference was evidenced regarding the mean hospital stay costs [3616.5 (± 1402.7) in the RRR cohort as compared to 3889.4 (± 1457) € in the LRR group; p 0.38]. This in line with Baek et al. experience [45] and Morelli et al. study [47], although hospitalization costs were superior for the laparoscopic approach in this last report.

Based on these results, costs still remain the main limitation of the robotic approach. However, we do believe that the introduction in the near future of new robotic/digital platforms with reduced related costs will hopefully pave the way for the routine use of robotic systems for rectal resection.

The main limitations of our study are its retrospective design and the small sample size reached after PS. However, the PS analysis brought to a uniform background of the two groups, which made comparison reliable. Perioperative and pathological outcomes resulted similar between the two techniques, with a clear advantage for the MIS approach in terms of EBL. Even better outcomes in terms of postoperative morbidity and conversion rate have been observed in the robotic group as compared to the laparoscopic approach.

Despite the single-center design of the study guaranteeing uniformity for the surgical techniques used, it represents, on one hand, one of its main limitation. For instance, the involvement of multiple centers would have given a more representative state-of-art description of the role of MIS in the treatment for rectal cancer.

Regarding the long-term outcomes, we acknowledge that OS and DFS results should be interpreted with caution, particularly given that we only had 2.8 and 2.4 years of follow-up data for the open and MIS approaches, respectively.

The results we presented support the safety and feasibility of the MIS approach when performed by high-skilled surgeons in high-volume centers. The need for larger and randomized studies to give definitive conclusions is undeniable. In this regard, the involvement of authors with a completed learning curve for MIS and the use of a standardized operative technique and postoperative care should be considered as essential steps of future studies design.

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Compliance with ethical standards

Conflict of interest Giuseppe Quero, Fausto Rosa, Riccardo Ricci, Claudio Fiorillo, Maria Cristina Giustiniani, Caterina Cina, Roberta Menghi, Giovanni Battista Doglietto, Sergio Alfieri declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent For this type of study formal consent is not required.

References

1. van der Pas MH, Haglind E, Cuesta MA, Fürst A, Lacy AM, Hop WC, Bonjer HJ, Group CcLoORIS (2013) Laparoscopic versus open surgery for rectal cancer (COLOR II): short-term outcomes of a randomised, phase 3 trial. Lancet Oncol 14(3):210–218
2. Kang SB, Park JW, Jeong SY, Nam BH, Choi HS, Kim DW, Lim SB, Lee TG, Kim DY, Kim JS, Chang HJ, Lee HS, Kim SY, Jung KH, Hong YS, Kim JH, Sohn DK, Kim DH, Oh JH (2010) Open versus laparoscopic surgery for mid or low rectal cancer after neoadjuvant chemoradiotherapy (COREAN trial): short-term outcomes of an open-label randomised controlled trial. Lancet Oncol 11(7):637–645. https://doi.org/10.1016/S1470-2045(10)70131-5
3. Chen K, Cao G, Chen B, Wang M, Xu X, Cai W, Xu Y, Xiong M (2017) Laparoscopic versus open surgery for rectal cancer: a meta-analysis of classic randomized controlled trials and high-quality nonrandomized studies in the last 5 years. Int J Surg 39:1–10
4. Greenblatt DY, Rajamanickam V, Pugely AJ, Heise CP, Foley EF, Kennedy GD (2011) Short-term outcomes after laparoscopic-assisted proctectomy for rectal cancer: results from the ACS NSQIP. J Am Coll Surg 212(5):844–854
5. Fleshman J, Branda M, Sargent DJ, Boller AM, George V, Abbas M, Peters WR Jr, Maun D, Chang G, Herline A, Fichera A, Mutch M, Wexner S, Whiteford M, Marks J, Birnbaum E, Margolin D, Larson D, Marcello P, Posner M, Read T, Monson J, Wren SM, Pisters PW, Nelson H (2015) Effect of laparoscopic-assisted resection vs open resection of stage II or III rectal cancer on pathologic outcomes: the ACOSOG Z6051 randomized clinical trial. JAMA 314(13):1346–1355. https://doi.org/10.1001/jama.2015.10529
6. Stevenson AR, Solomon MJ, Lumley JW, Hewett P, Clouston AD, Gebski VJ, Davies L, Wilson K, Hague W, Simes J, Investigators AL (2015) Effect of laparoscopic-assisted resection vs open resection on pathological outcomes in rectal cancer: the ALaCaRT randomized clinical trial. JAMA 314(13):1356–1363. https://doi.org/10.1001/jama.2015.12009
7. Ng KH, Lim YK, Ho KS, Ooi BS, Eu KW (2009) Robotic-assisted surgery for low rectal dissection: from better views to better outcome. Singap Med J 50(8):763–767
8. Wexner SD, Bergamaschi R, Lacy A, Udo J, Brolmann H, Kennedy RH, John H (2009) The current status of robotic pelvic surgery: results of a multinational interdisciplinary consensus conference. Surg Endosc 23(2):438–443. https://doi.org/10.1007/s00464-008-0202-8
9. Trastulli S, Farinella E, Cirocchi R, Cavaliere D, Avenia N, Sciannameo F, Gulla N, Noya G, Boselli C (2012) Robotic resection compared with laparoscopic rectal resection for cancer: systematic review and meta-analysis of short-term outcome. Colorectal Dis 14(4):e134–e156. https://doi.org/10.1111/j.1463-1318.2011.02907.x
10. Ahmed J, Cao H, Panteleimonitis S, Khan J, Parvaiz A (2017) Robotic versus laparoscopic rectal surgery in high-risk patients. Colorectal Dis. https://doi.org/10.1111/codi.13783
11. Xiong B, Ma L, Huang W, Zhao Q, Cheng Y, Liu J (2015) Robotic versus laparoscopic total mesorectal excision for rectal cancer: a meta-analysis of eight studies. J Gastrointest Surg 19(3):516–526. https://doi.org/10.1007/s11605-014-2697-8
12. Jayne D, Pigazzi A, Marshall H, Croft J, Corrigan N, Copeland J, Quirke P, West N, Rautio T, Thomassen N, Tilney H, Gudgeon M, Bianchi PP, Edlin R, Hulme C, Brown J (2017) Effect of robotic-assisted vs conventional laparoscopic surgery on risk of conversion to open laparotomy among patients undergoing resection for rectal cancer: the ROLARR randomized clinical trial. JAMA 318(16):1569–1580. https://doi.org/10.1001/jama.2017.7219
13. Foo CC, Law WL (2016) The learning curve of robotic-assisted low rectal resection of a novice rectal surgeon. World J Surg 40(2):456–462. https://doi.org/10.1007/s00268-015-3251-x
14. Son GM, Kim JG, Lee JC, Suh YJ, Cho HM, Lee YS, Lee IK, Chun CS (2010) Multidimensional analysis of the learning curve for laparoscopic rectal cancer surgery. J Laparoendosc Adv Surg Tech A 20(7):609–617. https://doi.org/10.1089/lap.2010.0007
15. deSouza AL, Prasad LM, Ricci J, Park JJ, Marecik SJ, Zimmern A, Blumetti J, Abcarian H (2011) A comparison of open and robotic total mesorectal excision for rectal adenocarcinoma. Dis Colon Rectum 54(3):275–282. https://doi.org/10.1007/DCR.0b013e3182060152
16. Baek JH, McKenzie S, Garcia-Aguilar J, Pigazzi A (2010) Oncologic outcomes of robotic-assisted total mesorectal excision for the treatment of rectal cancer. Ann Surg 251(5):882–886. https://doi.org/10.1097/SLA.0b013e3181c79114
17. Baik SH, Gincherman M, Mutch MG, Birnbaum EH, Fleshman JW (2011) Laparoscopic vs open resection for patients with rectal cancer: comparison of perioperative outcomes and long-term survival. Dis Colon Rectum 54(1):6–14. https://doi.org/10.1007/DCR.0b013e3181fd19d0
18. Choi DJ, Kim SH, Lee PJ, Kim J, Woo SU (2009) Single-stage totally robotic dissection for rectal cancer surgery: technique and short-term outcome in 50 consecutive patients. Dis Colon Rectum 52(11):1824–1830. https://doi.org/10.1007/DCR.0b013e3181b13536
19. Hellan M, Anderson C, Ellenhorn JD, Paz B, Pigazzi A (2007) Short-term outcomes after robotic-assisted total mesorectal excision for rectal cancer. Ann Surg Oncol 14(11):3168–3173. https://doi.org/10.1245/s10434-007-9544-z
20. Nagtegaal ID, VandeVelde CJ, VanderWorp E, Kapiteijn E, Quirke P, VanKrieken JH, Cooperative Clinical Investigators of the Dutch Colorectal Cancer G (2002) Macroscopic evaluation of rectal cancer resection specimen: clinical significance of the pathologist in quality control. J Clin Oncol 20(7):1729–1734. https://doi.org/10.1200/jco.2002.07.010
21. Alfieri S, Di Miceli D, Menghi R, Cina C, Fiorillo C, Prioli F, Rosa F, Doglietto GB, Quero G (2018) Single-docking full robotic surgery for rectal cancer: a single-center experience. Surg Innov 1:5. https://doi.org/10.1177/1553350618765868
22. Alfieri S, Quero G, Parvaiz A (2018) Robotic-assisted vs conventional laparoscopic surgery for rectal cancer. JAMA 319(11):1163–1164. https://doi.org/10.1001/jama.2017.21692
23. Toda S, Kuroyanagi H (2014) Laparoscopic surgery for rectal cancer: current status and future perspective. Asian J Endosc Surg 7(1):2–10. https://doi.org/10.1111/ases.12074
24. Fung AK, Aly EH (2013) Robotic colonic surgery: is it advisable to commence a new learning curve? Dis Colon Rectum 56(6):786–796. https://doi.org/10.1097/DCR.0b013e318285b810
25. Martínez-Pérez A, Carra MC, Brunetti F, de'Angelis N (2017) Short-term clinical outcomes of laparoscopic vs open rectal excision for rectal cancer: a systematic review and meta-analysis. World J Gastroenterol 23(44):7906
26. Saber AA, Meslemani AM, Davis R, Pimentel R (2004) Safety zones for anterior abdominal wall entry during laparoscopy: a CT scan mapping of epigastric vessels. Ann Surg 239(2):182

27. de Rosnay P, Chandiramani M, Usman S, Owen E (2011) Injury of epigastric vessels at laparoscopy: diagnosis and management. Gynecol Surg 8(3):353–356
28. Rahn DD, Phelan JN, Roshanravan SM, White AB, Corton MM (2010) Anterior abdominal wall nerve and vessel anatomy: clinical implications for gynecologic surgery. Am J Obstet Gynecol 202(3):234.e231–234.e235
29. Zimmern A, Prasad L, Marecik S, Park J, Abcarian H (2010) Robotic colon and rectal surgery: a series of 131 cases. World J Surg 34(8):1954–1958
30. Ursi P, Santoro A, Gemini A, Arezzo A, Pironi D, Renzi C, Cirocchi R, Di Matteo F, Maturo A, D'Andrea V (2018) Comparison of outcomes following intersphincteric resection vs low anterior resection for low rectal cancer: a systematic review. G Chir 39(3):123
31. Popescu I, Vasilescu C, Tomulescu V, Vasile S, Sgarbura O (2010) The minimally invasive approach, laparoscopic and robotic, in rectal resection for cancer. A single center experience. Acta Chir Iugosl 57(3):29–35
32. Allemann P, Duvoisin C, Di Mare L, Hubner M, Demartines N, Hahnloser D (2016) Robotic-assisted surgery improves the quality of total mesorectal excision for rectal cancer compared to laparoscopy: results of a case-controlled analysis. World J Surg 40(4):1010–1016. https://doi.org/10.1007/s00268-015-3303-2
33. Guillou PJ, Quirke P, Thorpe H, Walker J, Jayne DG, Smith AM, Heath RM, Brown JM, group MCt (2005) Short-term endpoints of conventional versus laparoscopic-assisted surgery in patients with colorectal cancer (MRC CLASICC trial): multicentre, randomised controlled trial. Lancet 365(9472):1718–1726. https://doi.org/10.1016/S0140-6736(05)66545-2
34. Laurent C, Leblanc F, Wutrich P, Scheffler M, Rullier E (2009) Laparoscopic versus open surgery for rectal cancer: long-term oncologic results. Ann Surg 250(1):54–61. https://doi.org/10.1097/SLA.0b013e3181ad6511
35. Strohlein MA, Grutzner KU, Jauch KW, Heiss MM (2008) Comparison of laparoscopic vs. open access surgery in patients with rectal cancer: a prospective analysis. Dis Colon Rectum 51(4):385–391. https://doi.org/10.1007/s10350-007-9178-z
36. Tsang WW, Chung CC, Kwok SY, Li MK (2006) Laparoscopic sphincter-preserving total mesorectal excision with colonic J-pouch reconstruction: five-year results. Ann Surg 243(3):353–358. https://doi.org/10.1097/01.sla.0000202180.16723.03
37. Awwad GE, Tou SI, Rieger NA (2013) Prognostic significance of lymph node yield after long-course preoperative radiotherapy in patients with rectal cancer: a systematic review. Colorectal Dis 15(4):394–403. https://doi.org/10.1111/codi.12011
38. Baik SH, Kwon HY, Kim JS, Hur H, Sohn SK, Cho CH, Kim H (2009) Robotic versus laparoscopic low anterior resection of rectal cancer: short-term outcome of a prospective comparative study. Ann Surg Oncol 16(6):1480–1487. https://doi.org/10.1245/s10434-009-0435-3
39. Hida K, Okamura R, Sakai Y, Konishi T, Akagi T, Yamaguchi T, Akiyoshi T, Fukuda M, Yamamoto S, Yamamoto M, Nishigori T, Kawada K, Hasegawa S, Morita S, Watanabe M, Japan Society of Laparoscopic Colorectal S (2017) Open versus laparoscopic surgery for advanced low rectal cancer: a large, multicenter, propensity score matched cohort study in Japan. Ann Surg. https://doi.org/10.1097/sla.0000000000002329
40. Prete FP, Pezzolla A, Prete F, Testini M, Marzaioli R, Patriti A, Jimenez-Rodriguez RM, Gurrado A, Strippoli GFM (2017) Robotic versus laparoscopic minimally invasive surgery for rectal cancer: a systematic review and meta-analysis of randomized controlled trials. Ann Surg. https://doi.org/10.1097/sla.0000000000002523
41. Jeong SY, Park JW, Nam BH, Kim S, Kang SB, Lim SB, Choi HS, Kim DW, Chang HJ, Kim DY, Jung KH, Kim TY, Kang GH, Chie EK, Kim SY, Sohn DK, Kim DH, Kim JS, Lee HS, Kim JH, Oh JH (2014) Open versus laparoscopic surgery for mid-rectal or low-rectal cancer after neoadjuvant chemoradiotherapy (COREAN trial): survival outcomes of an open-label, non-inferiority, randomised controlled trial. Lancet Oncol 15(7):767–774. https://doi.org/10.1016/S1470-2045(14)70205-0
42. Baik SH, Kim NK, Lim DR, Hur H, Min BS, Lee KY (2013) Oncologic outcomes and perioperative clinicopathologic results after robot-assisted tumor-specific mesorectal excision for rectal cancer. Ann Surg Oncol 20(8):2625–2632. https://doi.org/10.1245/s10434-013-2895-8
43. Pai A, Marecik SJ, Park JJ, Melich G, Sulo S, Prasad LM (2015) Oncologic and clinicopathologic outcomes of robot-assisted total mesorectal excision for rectal cancer. Dis Colon Rectum 58(7):659–667. https://doi.org/10.1097/DCR.0000000000000385
44. Pigazzi A, Luca F, Patriti A, Valvo M, Ceccarelli G, Casciola L, Biffi R, Garcia-Aguilar J, Baek JH (2010) Multicentric study on robotic tumor-specific mesorectal excision for the treatment of rectal cancer. Ann Surg Oncol 17(6):1614–1620. https://doi.org/10.1245/s10434-010-0909-3
45. Baek S-J, Kim S-H, Cho J-S, Shin J-W, Kim J (2012) Robotic versus conventional laparoscopic surgery for rectal cancer: a cost analysis from a single institute in Korea. World J Surg 36(11):2722–2729
46. Bertani E, Chiappa A, Biffi R, Bianchi P, Radice D, Branchi V, Cenderelli E, Vetrano I, Cenciarelli S, Andreoni B (2011) Assessing appropriateness and quality-of-life short-term outcomes employing different treatment approaches. Int J Colorectal Dis 26:1317–1327
47. Morelli L, Guadagni S, Lorenzoni V, Di Franco G, Cobuccio L, Palmeri M, Caprili G, D'Isidoro C, Moglia A, Ferrari V (2016) Robot-assisted versus laparoscopic rectal resection for cancer in a single surgeon's experience: a cost analysis covering the initial 50 robotic cases with the da Vinci Si. Int J Colorectal Dis 31(9):1639–1648