ORIGINAL ARTICLE

The impact of robotic total mesorectal excision on survival of patients with rectal cancer—a propensity matched analysis

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Abstract

Introduction Robotic surgery can overcome some limitations of laparoscopic total mesorectal excision (L-TME), improving the quality of the surgery. We aim to compare the medium-term oncological outcomes of L-TME vs. robotic total mesorectal excision (R-TME) for rectal cancer.

Methods A retrospective analysis was performed including patients who underwent L-TME or R-TME between 2011 and 2017. Patients presenting with metastatic disease or R1 resection were excluded. From a total of 680 patients, 136 cases of R-TME were matched based on age, gender, stage and time of follow-up with an equal number of patients who underwent L-TME. We compared 3-year disease-free survival (DFS) and overall survival (OS).

Results Major complications were lower in the robotic group (13.2% vs. 22.8%, $p = 0.04$), highlighting the anastomotic leakage rate (7.4% vs. 16.9%, $p = 0.01$).

The 3-year DFS rate for all stages was 69% for L-TME and 84% for R-TME ($p = 0.02$). For disease stage III, the 3-year DFS was significantly higher in the R-TME group. OS was also significantly superior in the robotic group for every stage, reaching 86% in stage III.

In the multivariate analysis, R-TME was a significant positive prognostic factor for distant metastasis (OR 0.2 95% CI 0.1, 0.6, $p = 0.001$) and OS (OR 0.2 95% CI 0.07, 0.4, $p = 0.000$). Moreover, major complications were also found to have a negative impact on OS (OR 8.3 95% CI 3.2, 21.6, $p = 0.000$).

Conclusion R-TME for rectal cancer can achieve better oncological outcomes compared with L-TME, especially in stage III rectal cancers. However, a longer follow-up period is needed to confirm these findings.

Keywords Robotic surgery · Laparoscopic surgery · Rectal cancer · Oncologic outcome · Total mesorectal excision · Survival

Introduction

The fundamental principles of total mesorectal excision (TME) surgery postulated by Bill Heald [1] were to perform surgery in the anatomical and embryological plane. This improved outcomes for rectal cancer patients in particular, reducing local recurrence. A few clinical trials across the globe have shown comparable outcomes between open and laparoscopic TME [2, 3]. The minimally invasive approach has several advantages [2, 3]. However, the adoption of laparoscopic total mesorectal excision (L-TME) worldwide remains low and varies between 15 and 45%. This is linked to a flat learning curve in L-TME.

Robotic surgery can offer some distinct advantages that can overcome some of these limitations of L-TME. The evolution of the technique has resulted in more advanced instruments for colorectal surgery, which make easier the dissection in a narrow pelvis, low rectal tumour and anatomical complexity. Thus, the true benefit of these advances will be the quality of the specimen resected which leads to reduced local recurrence and improved survival.

To date, there are only a few reports comparing oncologic outcomes of robotic and laparoscopic surgery [4]. None of them has demonstrated a significant difference between these 2 approaches, although there is a trend towards better

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oncological outcomes after a robotic total mesorectal excision (R-TME). Therefore, we aimed to compare the medium-term oncological results of L-TME vs. R-TME with rectal cancer.

Methods

A retrospective analysis was performed based on a prospectively maintained database, including patients who had undergone L-TME or R-TME in a single centre over a 7-year period (January 2011–December 2017). A total of 680 patients were initially included for further analysis. Inclusion criteria were as follows: rectal tumour at baseline which would be considered to require a complete TME and underwent either laparoscopic or robotic anterior resection with a stapled colorectal anastomosis. Patients presenting with metastatic disease or those whom underwent palliative resection were excluded from the study, leaving 639 patients for analysis.

Tumours were classified according to the distance between the tumour and the anal margin and the anatomical extent of the disease (TNM Classification of Malignant Tumours, 7th edition—employed in our centre until December 2017).

Patients were divided into 2 groups, based on the type of surgical intervention: L-TME or R-TME. Data recorded included patient demographics (sex, age, BMI, ASA), preoperative staging, postoperative complications (Dindo-Clavien), pathological report and oncological outcomes.

Primary endpoint was to compare 3-year disease free survival (DFS) and overall survival (OS). The 3-year DFS was defined as the percentage of patients alive without recurrence of disease at 3 years measured from the date of surgery. The 3-year OS was defined as the time from surgery to death from any cause. Secondary outcomes included postoperative complications (30 days) and pathological assessment of the quality of the specimen.

Local recurrence was defined as any clinical/radiological or histologic evidence of tumour relapse at the primary site. Distant metastases were diagnosed by CT scan.

The patient allocation to each arm was based on surgeon's preferred approach and access to a robotic theatre.

Statistical analysis

Descriptive statistics are presented with mean and standard deviation (SD) or median and interquartile range (IQR) for quantitative variables.

A case-control 1:1 design was applied to minimise baseline differences between the laparoscopic and the robotic group. Patients were propensity matched into those 2 groups. Confounding variables used to compute the propensity score were age, gender, BMI, tumour stage and duration of follow-up (less than 6 months, up to 1 year, between 1 and 2 years, 2 and 3 years, and more than 3 years). The rest of the analysis

was performed using the matched patients by surgical approach.

Comparison of differences between groups was carried out using chi-squared analysis. Differences between median values of the groups were assessed using Mann-Whitney U test. Odds ratios (OR) were computed for dichotomous and continuous risk factors between groups and logistic regression was performed, selecting those variables that showed a $p < 0.25$ in the univariate analysis. A time-to-event analysis was performed using the Kaplan-Meier method and comparisons were analyzed by the log-rank test.

All statistical analyses were conducted using the SPSS® version 22 software (SPSS, Inc., Chicago, IL, USA) and p-values of < 0.05 were considered statistically significant.

Results

Between January 2011 and December 2017, 680 TME were performed in our centre. According to the inclusion criteria, 639 were included for analysis. The majority of patients were men (66%), with a median age of 68 (15) years. The median follow-up of the 639 patients was 37.4 (45) months. A total of 463 (73.5%) TME were performed laparoscopically and 176 (27.5%) robotically.

Two groups, each of 136 patients (Fig. 1), were matched for age, gender, BMI, stage and duration of follow-up.

The rate of conversion was higher in the L-TME group (3.7% vs. 0%, $p = 0.03$), and the LOS was significantly longer (7 vs. 6 days, $p = 0.001$). Perioperative complications are shown in Table 1. Major complications were lower in the robotic group (13.2% vs. 22.8%, $p = 0.04$), highlighting the anastomotic leakage rate, which was 7.4% in the R-TME vs. 16.9% in the L-TME group ($p = 0.01$).

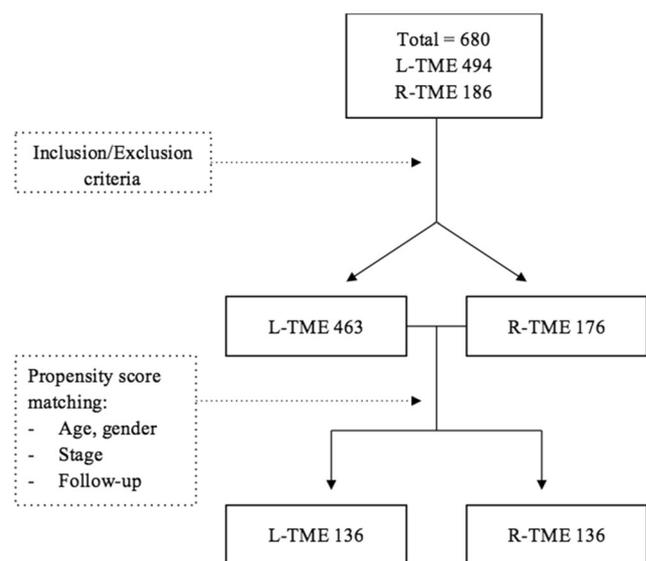Fig. 1 Flowchart of patient selection

Table 1 Patients' characteristics and postoperative pathological outcomes after propensity score matching

	L-TME n = 136	R-TME n = 136	p value
Age (median–IQR−) (year)	69 (14)	68 (16)	p = 0.545
Sex (male:female) (%)	76:24	76:24	p = 1
BMI	27 (6)	27 (5)	p = 0.635
ASA			p = 0.096
I–II	74%	83%	
III	26%	17%	
MRI			
Tumour distance from ARJ (median–IQR−) (cm)	6 (9)	6 (6)	p = 0.160
CRM+	16.2%	21.1%	p = 0.362
EMVI+	40.7%	38.8%	p = 0.812
Neoadjuvant chemoradiotherapy	16.2%	20.6%	p = 0.348
TRG (%)			p = 0.267
1	16.6%	3.8%	
2	44.5%	50%	
3	27.8%	23.1%	
4	0	15.4%	
5	11.1%	7.7%	
Conversion to open	3.7%	0	p = 0.03
Dindo-Clavien			p = 0.04
I–II	77.2%	86.8%	
III–V	22.8%	13.2%	
Anastomotic leak (AL)	16.9%	7.4%	p = 0.01
Radiological leak	12.7%	5.8%	
Reoperation due to AL	4.2%	1.6%	
LOS (median days)	7 (8)	6 (6)	p = 0.02
Adjuvant chemotherapy			p = 0.532
Stage II	17%	13%	p = 0.682
Stage III	65%	61%	
Follow-up (median months–IQR−)	28 (61)	25 (34)	p = 0.067
Histopathology			
TNM stage (%)			p = 1
0	0.7%	0.7%	
I	31.6%	31.6%	
II	30.1%	30.1%	
III	37.5%	37.5%	
T (%)			p = 0.067
0	0.7%	0.7%	
1	12.5%	11%	
2	24.4%	36%	
3	52.9%	48.5%	
4	9.5%	3.8%	
N (%)			p = 0.658
1	23.5%	26.4%	
2	14%	11%	
Grade of differentiation			p = 0.752
Well	3.8%	4.5%	
Moderate	88.6%	90.3%	
Poor	4.8%	2.2%	
Mucinous	2.9%	3%	
Tumour size (median–IQR−) (mm)	30 (15)	35 (20.5)	p = 0.373

Table 1 (continued)

	L-TME $n = 136$	R-TME $n = 136$	p value
EMVI+ (%)	23.1%	19.3%	$p = 0.472$
Lymph nodes harvested (median–IQR−) (%)	17 (10)	18 (10)	$p = 0.940$
DRM < 2 mm (%)	1%	0	$p = 0.424$
CRM+ (%)	3.1%	2.3%	$p = 0.518$
TME (%)			$p = 0.635$
Complete	96%	96.2%	
Nearly complete	4%	3%	
Incomplete	0	0.8%	

ASA, American Society of Anesthesiologists; *BMI*, body mass index; *CRM*, circumferential rectal margin; *DRM*, distal resection margin; *EMVI*, extramural vascular invasion; *LOS*, length hospital stay; *NS*, non-significant; *TME*, total mesorectal excision; *TRG*, tumour regression grade

Pathological outcomes were similar in both groups. The median tumour size in both groups was similar (35 mm vs. 30 mm in the L-TME, $p = 0.373$), as well as the percentage of extramural vascular invasion (EMVI) positive for small or large vessels (23% in the L-TME vs. 19% in the R-TME, $p = 0.472$), and the circumferential resection margin (CRM) involvement (3.1% vs. 2.3% in the R-TME, $p = 0.518$). Distal resection margin (DRM) was found affected in 1% of the patients in the L-TME group vs. none of them in the R-TME (Table 1).

The incidence of local recurrence was similar between groups (2.2% R-TME group vs. 2.9% L-TME). However, the development of distant metastasis is significantly higher in the L-TME (25.7% vs. 11.8% in the R-TME, $p = 0.003$).

The 3-year DFS rate was 69% in the laparoscopic group and 84% in the robotic group ($p = 0.02$). The 3-year OS rate was 70% in the L-TME groups and 97% in the R-TME group ($p = 0.000$). The differences on DFS and OS according to each stage between groups are shown in Table 2. The 3-year DFS

Table 2 The 3-year disease free survival (DFS) and overall survival (OS). Comparison between patients with laparoscopic and robotic TME

|	L-TME $n = 136$ (%)	R-TME $n = 136$ (%)	p value
Local recurrence	2.9	2.2	$p = 0.469$
Distant metastasis	25.7	11.8	$p = 0.003$
3-year DFS			
All stages	69	84	$p = 0.000$
Stage I	88	93	$p = 0.722$
Stage II	76	85	$p = 0.571$
Stage III	46	74	$p = 0.01$
3-year OS			
All stages	70	93	$p = 0.000$
Stage I	81	98	$p = 0.07$
Stage II	62	98	$p = 0.002$
Stage III	64	86	$p = 0.04$

for disease stage III was significantly higher in the R-TME group (74% vs. 46% in L-TME, $p = 0.004$). The OS was also significantly superior in the robotic group for every stage, reaching 86% in the stage III (Fig. 2).

In the univariate analysis, common factors that influence both the 3-years DFS and 3-years OS are shown in Table 3. In the multivariate analysis, we show the independent factors influencing local recurrence, distant metastasis and overall survival. The only independent factor influencing local recurrence were the major complications in the postoperative period (Dindo-Clavien ≥ III) (OR 6.3 95% CI 1.2, 33.3, $p = 0.03$). Moreover, major complications were also found to have a negative impact on the overall survival (OR 8.3 95% CI 3.2, 21.6, $p = 0.000$). The robotic approach was a significant positive prognostic factor for the development of distant metastasis (OR 0.2 95% CI 0.1, 0.6, $p = 0.001$) and the improvement of the OS (OR 0.2 95% CI 0.07, 0.4, $p = 0.000$). Also, the presence of extramural vascular invasion (EMVI) for small or large vessels is a prognostic risk factor of distant metastasis (OR 3 95% CI 1.3, 6.7, $p = 0.007$) and decreases in OS (OR 3.7 95% CI 1.4, 9.6, $p = 0.007$).

Discussion

The aim of this study was to investigate the impact of the R-TME on medium-term oncological outcomes of rectal cancer. This is the first study that has demonstrated an improvement in the 3-year DFS and OS with the robotic approach, reaching 74% and 86%, respectively, for disease stage III ($p < 0.05$). There is a lower rate of postoperative complications, which could account for some of the survival improvement.

In the L-TME group, the 3-year DFS may appear lower than expected. However, our series included all stage patients and in comparison to COLOR II trial were T4, and T3b tumours were excluded; similar survival figures were reported (69% vs. 74.8%) [2]. Similar results were obtained when
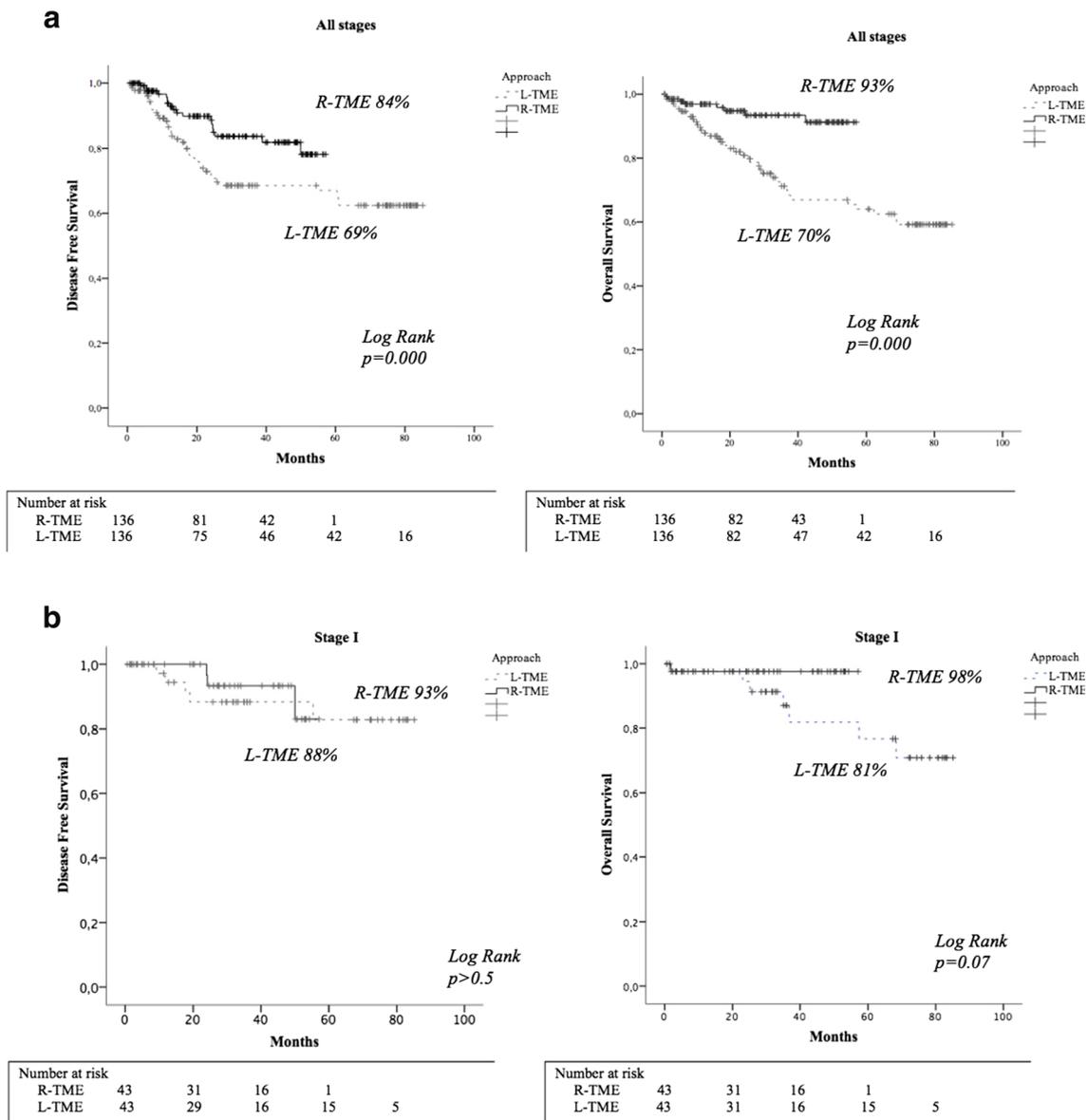
Fig. 2 Comparison of the 3-year DFS and OS between patients treated with L-TME and R-TME for rectal cancer. **a** All stages. **b** Stage I. **c** Stage II. **d** Stage III

analysing long-term results of the ALaCaRT trial [5], but, again, T4 tumours were not included in the study. A recent propensity-matched analysis including T4 tumours showed a 2-year DFS of 64.9% for stage III patients in the laparoscopic group [6].

Oncological outcomes of randomised control trials comparing R-TME vs. L-TME have not been published yet. However, previous descriptive studies showed equivalence in terms of DFS and OS [4, 7–9]. Baek et. al [10] reported similar rates of the 3-year DFS and OS (73.7% and 96.2%, respectively) for patients who underwent robotic surgery for stages I–III rectal cancer (84% and 93%, respectively, in our study). A multicentre study reported comparable short-term

oncological outcomes with robotic rectal cancer surgery, reaching 97% 3-year OS [11]. Kim et al. [12] recently published a propensity score matched analysis showing a trend towards improved DFS and OS with a robotic resection. Moreover, they also demonstrated that the robotic approach was a significant positive prognostic factor for OS. Our study strongly supports these findings.

The main difference between previously mentioned reports and the present study is the surgical procedure. The surgery in this study is performed entirely robotically, according to the single-docking technique described before [13], whilst a hybrid technique (robotic-assisted TME) is usually employed in other centres [4, 10], in
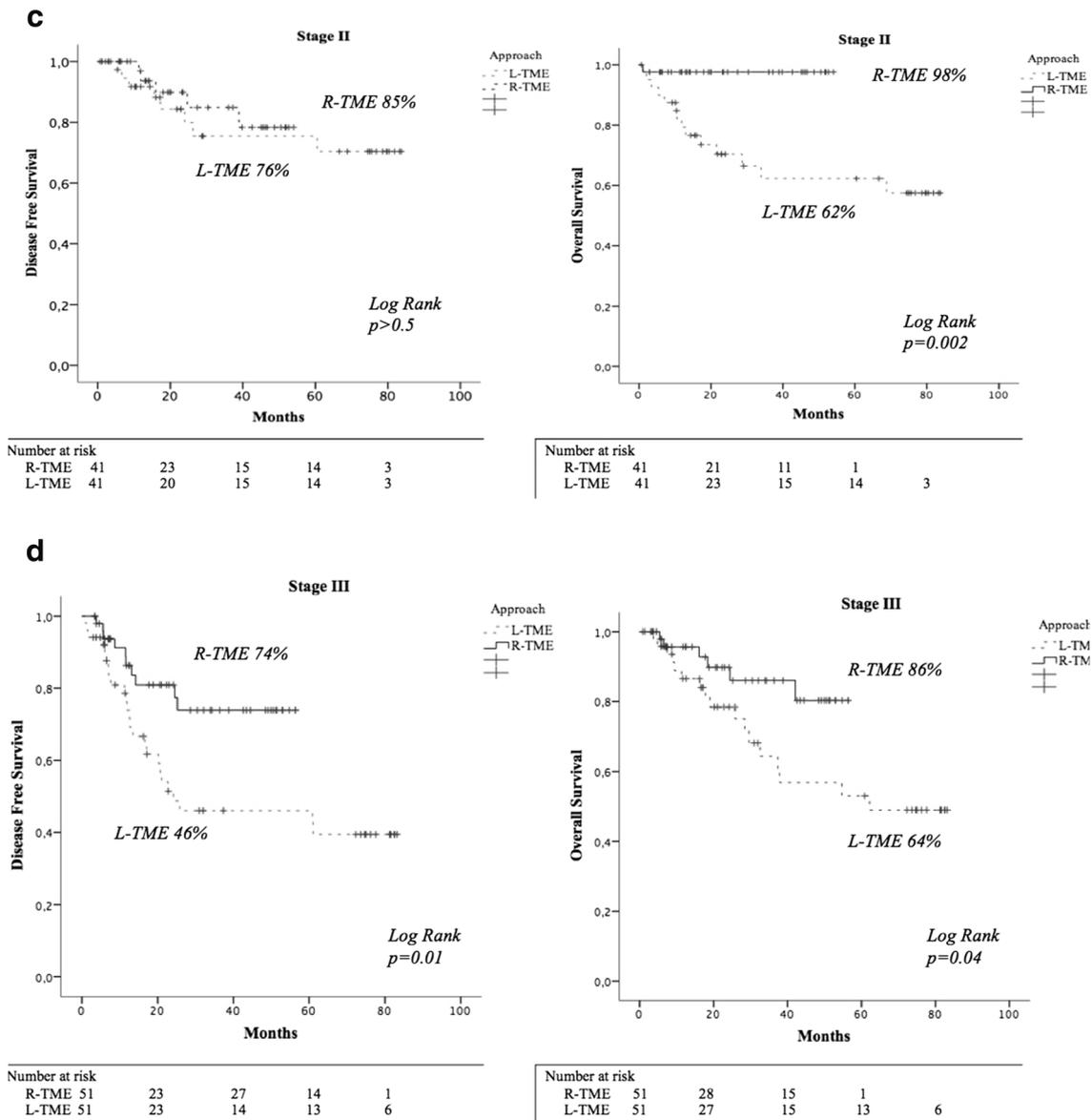
c

Stage II — Disease Free Survival / Overall Survival

d

Stage III — Disease Free Survival / Overall Survival

Fig. 2 continued.

which part of the procedure is performed laparoscopically. The advantages that the robot provides for this complex procedure are not reflected in a hybrid procedure.

Conversion to open surgery did not occur in the R-TME group, whereas there were 5 cases in the L-TME group (3.7%), as previous studies noted [14, 15]. In the ROLARR trial, the rate of conversion to open surgery was lower than expected in both arms [16]; however, in a subgroup analysis of high-risk cases, it suggests a trend of less conversion in the R-TME group [17]. The technological advances of the robotic system allow the surgeon to perform a more safely dissection in a narrow pelvis. It reduces the need of conversion to open surgery and it may thereby decrease the rate of postoperative complications.

In a review of recent literature, the rate of complications is similar between groups [14, 18] even in obese patients, but the postoperative recovery is faster [19]. However, in the present study, the outcomes of the postoperative recovery were better in the R-TME group than in the L-TME group. These results are in accordance to the outcomes published in a recent meta-analysis [20]. Major complications occurred more frequently in the L-TME (Dindo-Clavien III–IV, 22.8% vs. 13.2% in the R-TME, $p = 0.04$). Among these patients, AL occurred in 16.9% in the L-TME compared with 7.4% in the R-TME ($p = 0.01$). Previous studies have demonstrated that major complications such as AL influence both local recurrence and survival [21, 22]. Consistent with these results, our study showed that the presence of complications Dindo-Clavien ≥

Table 3 Univariate and multivariate analysis of factors influencing Disease Free Survival and overall survival

	Local recurrence			Distal metastasis			Overall survival		
	Univariate	Multivariate (95% CI)	p	Univariate	Multivariate (95% CI)	p	Univariate	Multivariate (95% CI)	p
R-TME	0.7			0.003	0.2 (0.1–0.6)	0.001	0.000	0.2 (0.07–0.4)	0.000
Age (≥ 75)	0.09	2.4 (0.3–7.3)	0.9	0.5			0.000	4.3 (1.7–10.8)	0.002
Sex (Male)	0.5			0.4			0.2	0.8 (0.2–2.8)	0.8
BMI (≥ 30)	0.1	1.5 (0.2–8.9)	0.6	0.8			0.8		
ASA (≥ III)	0.6			0.3			0.003	1.8 (0.7–4.8)	0.2
Low rectum (< 5 cm ARJ)	0.4			0.4			0.6		
Preop radio	0.6			0.3			0.5		
Preop chemo	0.6			0.4			0.4		
Dindo ≥ III	0.1	6.3 (1.2–33.3)	0.03	0.25	1.3 (0.5–3.7)	0.6	0.000	8.3 (3.2–21.6)	0.000
LOS ≥ 8 days	0.5			0.01	1.8 (0.9–3.8)	0.1	0.005	0.8 (0.3–2.4)	0.7
Tumour size (≥ 3 cm)	0.1	3.2 (0.3–31.3)	0.3	0.6			0.07	1.3 (0.5–3.5)	0.6
TNM stage III	0.2	2.6 (0.4–14.9)	0.3	0.000	4.1 (1.9–8.9)	0.000	0.06	1.8 (0.7–4.7)	0.2
CRM < 1 mm	0.8			0.04	1.4 (0.2–13.9)	0.7	0.04	3.8 (0.4–42.2)	0.3
DRM < 2 mm	0.8			0.8			0.8		
EMVI+	0.6			0.000	3 (1.3–6.7)	0.007	0.006	3.7 (1.4–9.6)	0.007
TME Incomplete	0.8			0.8			0.8		
Differentiation (grades 3–4)	0.6			0.1	1.9 (0.5–7.3)	0.3	0.4		
Chemotherapy	0.6			0.007	0.9 (0.3–2.3)	0.8	0.6		

ARJ, anorectal junction; *ASA*, American Society of Anesthesiologists; *BMI*, body mass index; *CI*, confidence interval; *CRM*, circumferential resection margin; *DRM*, distal resection margin; *EMVI*, extramural vascular invasion; *TME*, total mesorectal excision; *L-TME*, laparoscopic TME; *R-TME*, robotic TME

III was an independent prognostic factor for local recurrence (OR 6.3 95% CI 1.2, 33.3, $p = 0.03$) and decreased overall survival in the multivariate analysis (OR 8.3 95% CI 3.2, 21.6, $p = 0.000$). Consequently to the higher rate of major postoperative complications, a longer LOS was detected in the L-TME group (7 vs. 6 days, $p = 0.01$), as published previously [7, 18, 23, 24]. This phenomenon could be responsible for the delay in starting adjuvant treatment and results in poor survival [25].

The rate of local recurrence at 3 years after surgery is very low after a robotic TME (2%), compared with previous robotic data that amount to 3.6% [9]. After laparoscopic or open surgery, outcomes reported a percentage near 5% in the COLOR II trial [2], similar to the percentage shown in a database over 20,000 patients [26]. The percentage of preoperative radiotherapy in our institution is low (20%), and the rate of complete response is only 3.8% in the R-TME group. However, it is not an independent prognostic factor for local recurrence in the multivariate analysis ($p > 0.05$). With the higher use of preoperative radiotherapy, we may see an increase in complete response but this may potentially increase the risk of postoperative complications.

The quality of the TME specimen remains a concern in L-TME. In the CLASICC trial, the patients on the laparoscopic group were found to have a higher rate of CRM involvement [27]. The ACOSOG Z6051 [28] and the ALaCaRT [29] trials also failed trying to demonstrate the non-inferiority of the L-TME. Some of the inherent difficulties of laparoscopic surgery such as 2D image, a fulcrum effect, limited access to narrow pelvis and amplification of tremor has been overcome by the increased use of robotic technology for TME surgery. Robots offer a 3D view, along with EndoWrist instruments and stability of the operating platform. It may also reduce operator fatigue, a potentially influential factor in major surgical procedures. Thus, this control allows surgeons to replicate the principles of open TME surgery in a minimal access fashion. Other recent studies have demonstrated at least non-inferiority of R-TME regarding pathological results [30]. Although the findings of the ROLARR trial [16] failed to show better pathological outcomes, the sample size was small. In addition, in Table 1, we show a lower rate of CRM involved in the robotic group, which is even better than the results of the ROLARR trial [16] (CRM < 1 mm in 5.1% of cases) and lower than the data out of Korea [9]. However, in our study, the mesorectal grade was complete in a similar percentage of patients in both groups (95%), whilst previous findings suggested better results in the robotic approach [14, 31]. The technological advantage of the robotic system leads to

superior histopathological outcomes and hence an improvement in long-term survival.

The key question remains if long-term oncological outcomes are better in robotic rectal cancer surgery. This remains unanswered with the present evidence. Data from trials from Korea has shown no difference in outcomes between laparoscopic and robotic surgery [4]. However, rectal cancer surgery is very centralised in Korea, resulting in high volume surgeons performing over 300 cases per year, and the positive patient profile with a low BMI allows successful undertaking of laparoscopic rectal cancer surgery. Higher conversion rates in L-TME are seen in the European population and the literature supports a reduced conversion rate with the use of robotic approach [16, 32].

This is a retrospective non-randomised study, so there are some inevitable biases. As most of the patients who underwent L-TME were operated earlier, it could be a bias regarding the learning curve. However, the 3 participating surgeons in this study had significant experience in TME surgery at the beginning of this study with over a hundred TME procedures performed individually. The good outcomes presented in this study can only be achieved by a specialised team of robotic surgery experts at a high-volume centre. Thus, the results in our single institutional study may not be generalised to all situations.

Comparison between these two groups may have been influenced by patient and tumour-related factors including age, gender, BMI, tumour stage or follow-up. In order to minimise this, we undertook a comparison between two groups matched for these confounders. The propensity score matching is a useful method for reducing biases between groups. The propensity-matching methodology did not include neoadjuvant chemoradiotherapy and MRI risk factors (EMVI, tumour deposits), which may have led to heterogeneity or biases; however, the two groups were similar on these accounts.

Conclusions

R-TME for rectal cancer can achieve better oncological outcomes compared with L-TME, especially in stage III rectal cancers. The robotic approach has demonstrated to be a significant positive prognostic factor for local recurrence and overall survival, due to the better postoperative outcomes.

However, a longer follow-up period is needed to confirm the oncologic findings and to support the general adoption of the robotic system for rectal cancer surgery.

References

1. Heald RJ (1988) The 'Holy Plane' of rectal surgery. J R Soc Med 81(9):503–508
2. Bonjer HJ, Deijen CL, Abis GA, Cuesta MA, van der Pas M, de Lange-de Klerk ES, Lacy AM, Bemelman WA, Andersson J, Angenete E, Rosenberg J, Fuerst A, Haglind E, COLOR II Study Group (2015) A randomized trial of laparoscopic versus open surgery for rectal cancer. N Engl J Med 372(14):1324–1332
3. 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
4. Park EJ, Cho MS, Baek SJ, Hur H, Min BS, Baik SH, Lee KY, Kim NK (2015) Long-term oncologic outcomes of robotic low anterior resection for rectal cancer: a comparative study with laparoscopic surgery. Ann Surg 261(1):129–137
5. Stevenson ARL, Solomon MJ, Brown CSB et al (2018) disease-free survival and local recurrence after laparoscopic-assisted resection or open resection for rectal cancer: the Australasian laparoscopic cancer of the rectum randomized clinical trial. Ann Surg 269(4):596–602
6. Manchon-Walsh P, Aliste L, Biondo S et al (2016) A propensity-score-matched analysis of laparoscopic vs open surgery for rectal cancer in a population-based study. Color Dis 21(4):441–450
7. Baek SJ, Al-Asari S, Jeong DH et al (2013) Robotic versus laparoscopic coloanal anastomosis with or without intersphincteric resection for rectal cancer. Surg Endosc 27(11):4157–4163
8. Cho MS, Baek SJ, Hur H et al (2015) Short and long-term outcomes of robotic versus laparoscopic total mesorectal excision for rectal cancer: a case-matched retrospective study. Medicine 94(11):e522
9. 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
10. 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
11. 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
12. Kim J, Baek SJ, Kang DW, Roh YE, Lee JW, Kwak HD, Kwak JM, Kim SH (2017) Robotic resection is a good prognostic factor in rectal cancer compared with laparoscopic resection: long-term survival analysis using propensity score matching. Dis Colon Rectum 60(3):266–273
13. Ahmed J, Siddiqi N, Khan L, Kuzu A, Parvaiz A (2016) Standardized technique for single-docking robotic rectal surgery. Color Dis 18(10):O380–o384

14. Baik SH, Kwon HY, Kim JS et al (2009) Robotic versus laparo-scopic low anterior resection of rectal cancer: short-term outcome of a prospective comparative study. Ann Surg Oncol 16(6):1480–1487

15. Polat F, Willems LH, Dogan K, Rosman C (2019) The oncological and surgical safety of robot-assisted surgery in colorectal cancer: outcomes of a longitudinal prospective cohort study. Surg Endosc 33(11):3644–3655. https://doi.org/10.1007/s00464-018-06653-2

16. 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

17. Wright JD (2017) Robotic-assisted surgery: balancing evidence and implementation. Jama. 318(16):1545–1547

18. Kang J, Yoon KJ, Min BS, Hur H, Baik SH, Kim NK, Lee KY (2013) The impact of robotic surgery for mid and low rectal cancer: a case-matched analysis of a 3-arm comparison–open, laparoscopic, and robotic surgery. Ann Surg 257(1):95–101

19. Gorgun E, Ozben V, Costedio M, Stocchi L, Kalady M, Remzi F (2016) Robotic versus conventional laparoscopic rectal cancer sur-gery in obese patients. Color Dis 18(11):1063–1071

20. Sun XY, Xu L, Lu JY, Zhang GN (2019) Robotic versus conven-tional laparoscopic surgery for rectal cancer: systematic review and meta-analysis. Minim Invasive Ther Allied Technol 28(3):135–142. https://doi.org/10.1080/13645706.2018.1498358

21. Bell SW, Walker KG, Rickard MJ, Sinclair G, Dent OF, Chapuis PH, Bokey EL (2003) Anastomotic leakage after curative anterior resection results in a higher prevalence of local recurrence. Br J Surg 90(10):1261–1266

22. Odermatt M, Miskovic D, Flashman K, Khan J, Senapati A, O'Leary D, Thompson M, Parvaiz A (2015) Major postoperative complications following elective resection for colorectal cancer de-crease long-term survival but not the time to recurrence. Color Dis 17(2):141–149

23. Cheng CL, Rezac C (2018) The role of robotics in colorectal sur-gery. BMJ 360:j5304

24. Asklid D, Gerjy R, Hjern F, Pekkari K, Gustafsson UO (2019) Robotic vs laparoscopic rectal tumour surgery: a cohort study. Color Dis 21(2):191–199

25. Arhi CS, Burns EM, Bouras G, Aylin P, Ziprin P, Darzi A (2018) Complications after discharge and delays in adjuvant chemotherapy following colonic resection: a cohort study of linked primary and secondary care data. Color Dis 21(3):307–314

26. Herold ALP, Matzel K, O'Connell PR (2017) Coloproctology. Springer, Berlin Heidelberg

27. Guillou PJ, Quirke P, Thorpe H et al (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

28. 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 resec-tion vs open resection of stage II or III rectal cancer on pathologic outcomes: the ACOSOG Z6051 randomized clinical trial. Jama. 314(13):1346–1355

29. Stevenson AR, Solomon MJ, Lumley JW, Hewett P, Clouston AD, Gebski VJ, Davies L, Wilson K, Hague W, Simes J, ALaCaRT Investigators (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

30. Aselmann H, Kersebaum JN, Bernsmeier A, Beckmann JH, Möller T, Egberts JH, Schafmayer C, Röcken C, Becker T (2018) Robotic-assisted total mesorectal excision (TME) for rectal cancer results in a significantly higher quality of TME specimen compared to the laparoscopic approach-report of a single-center experience. Int J Color Dis 33(11):1575–1581

31. Milone M, Manigrasso M, Velotti N et al (2019) Completeness of total mesorectum excision of laparoscopic versus robotic surgery: a review with a meta-analysis. Int J Color Dis 34(6):983–991

32. Ahmed J, Cao H, Panteleimonitis S, Khan J, Parvaiz A (2017) Robotic vs laparoscopic rectal surgery in high-risk patients. Color Dis 19(12):1092–1099