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Long-Term Outcomes of Robotic Versus Laparoscopic Total Mesorectal Excisions

A Propensity-Score Matched Cohort study of 5-year survival outcomes

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Objective: To compare long-term outcomes between laparoscopic and robotic total mesorectal excisions (TMEs) for rectal cancer in a tertiary center.

Background: Laparoscopic rectal cancer surgery has comparable long-term outcomes to the open approach, with several advantages in short-term outcomes. However, it has significant technical limitations, which the robotic approach aims to overcome.

Methods: We included patients undergoing laparoscopic and robotic TME surgery between 2013 and 2021. The groups were compared after propensity-score matching. The primary outcome was 5-year overall survival (OS). Secondary outcomes were local recurrence (LR), distant recurrence (DR), disease-free survival (DFS), and short-term surgical and patient-related outcomes.

Results: A total of 594 patients were included, and after propensity-score matching 215 patients remained in each group. There was a significant difference in 5-year OS (72.4% for laparoscopy *vs* 81.7% for robotic, $P = 0.029$), but no difference in 5-year LR (4.7% *vs* 5.2%, $P = 0.850$), DR (16.9% *vs* 13.5%, $P = 0.390$), or DFS (63.9% *vs* 74.4%, $P = 0.086$). The robotic group had significantly less conversion (3.7% *vs* 0.5%, $P = 0.046$), shorter length of stay [7.0 (6.0–13.0) vs 6.0 (4.0–8.0), $P < 0.001$), and less postoperative complications (63.5% *vs* 50.7%, $P = 0.010$).

Conclusions: This study shows a correlation between higher 5-year OS and comparable long-term oncological outcomes for robotic TME surgery compared to the laparoscopic approach. Furthermore, lower conversion rates, a shorter length of stay, and a less minor postoperative complications were observed. Robotic rectal cancer surgery is a safe and favorable alternative to the traditional approaches.

Keywords: laparoscopy, long-term outcomes, rectal cancer, robotic, total mesorectal excision

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All data used was extracted from a prospective research database and already had ethical approval (IRAS ID 293129). The project was registered with the R&D department at Portsmouth Hospitals University NHS Trust.

All patients included in the study provided written consent to treatment, data capture, and publication upon enrollment into the Portsmouth colorectal cancer database.

The data is available in the Portsmouth Colorectal Cancer Database.

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INTRODUCTION

Surgical resection is the mainstay treatment for rectal cancers, using the "total mesorectal excision" (TME) technique, and can be performed using either open or minimally invasive approaches, such as the laparoscopic, robotic, and transanal approaches.[1] The laparoscopic approach has been proven to have similar long-term outcomes compared to the open approach, with several advantages in short-term outcomes.[2,3] Though the laparoscopic approach is increasingly used in the UK (from 48% in 2013 to 66% in 2021), a substantial percentage of patients are still treated with an open resection (20% in 2021). A possible explanation might be the technical limitations and challenges in advanced tumors in a narrow pelvis. A possible symptom depicting this might be the relatively high conversion rate of 3 to 13%, which has remained stable in the UK for the past few years.[4]

A robot-assisted approach has the potential to overcome some of these limitations. Technical advantages of the robot-assisted approach include an increased range of instrument movement, a fixed surgeon-controlled 3D camera for a stable operative view, and the ability to filter out tremors.[5] Although its safety for use in rectal cancer surgery has been reported, several randomized controlled trials could not show the superiority of the robotic approach over the laparoscopic approach.[6–8] More recently, the robotic versus laparoscopic surgery for middle and low rectal cancer (REAL) trial showed fewer positive circumferential resection margins (CRM), reduced length of stay (LOS), less postoperative complications (Clavien Dindo II or higher), less conversion, and less intraoperative complications. However, long-term data of both the REAL trial and the robotic-assisted vs conventional laparoscopic surgery on risk of conversion to open laparotomy among patients undergoing resection for rectal

cancer trial are still awaited.[9] Other studies, like the robotic vs. TaTME rectal surgery study, are currently ongoing but have not yet published any data.[10]

Large-scale data regarding the longitudinal follow-up of robotic rectal cancer surgery is scarce. A recent systematic review by Simillis et al[11] did not contain any overall survival (OS) data for robotic patients, and Qiu et al[12] showed more than 50% heterogeneity after pooling, making the results unreliable. A Korean study showed comparable 5-year overall and oncological survival between the robotic and laparoscopic approach, and a recent Dutch study showed comparable 3-year overall and oncological survival between the laparoscopic, robotic, and transanal approach.[13,14] Other studies regarding this subject are either small, not comparative, or only compared the robotic with an open approach.[7,15–19]

Therefore, this study aims to compare the perioperative and long-term outcomes of robotic and laparoscopic TMEs for rectal and rectosigmoid cancers in a large retrospective, single-center cohort study.

METHODS

Study Design

This is a retrospective, single-center cohort study analyzing the long-term outcomes of consecutive robotic and laparoscopic resections for rectal and rectosigmoid tumors performed in parallel between 2013 and 2021, utilizing propensity-score matching to minimize covariate bias.

Portsmouth Hospitals University NHS Trust is a tertiary referral center for colorectal cancer, has performed laparoscopic rectal cancer resections since the early 2000s, and started using the robotic approach in 2012. A prospectively maintained research database has been kept since 2008, including elective laparoscopic and robotic cases. Data regarding 6 surgeons (3 robotic and 3 laparoscopic) in the unit was registered in this database. The robotic and laparoscopic groups included only data from their respective expert surgeons, and surgeons were past their learning curves for their respective approaches at the time of data capture (estimated 35 robotic/laparoscopic procedures based on existing literature).[14,20] All patients were discussed at the colorectal multidisciplinary team meetings and treated according to local and national NHS guidelines and protocols. Allocation to a laparoscopic or robotic approach was based on which surgeon the patients were referred to and the availability of robotic theater lists.

Medical ethical approval was acquired, and this study was performed in accordance with the strengthening the reporting of observational studies in epidemiology guidelines for observational studies (Appendix 1, http://links.lww.com/AOSO/A311).[21]

Patients

All consecutive patients curatively treated with a TME for rectal and rectosigmoid cancer between May 2013 and February 2021 at Portsmouth Hospitals University were included. Patients were excluded if (1) they had undergone open surgery, (2) more than 50% of their data was missing, and (3) an abdominal perineal excision of the rectum (APER) was performed. APERs were excluded because this category embodied a broad array of subcategories in how extended the resections were, and including them could introduce significant bias in the matching process. Based on the retrospective nature of our study, the fact that our hospital underwent digitalization during the last few years, and the fact that a number of patients received follow-up care in other centers, we anticipated some missing data for certain variables. We performed our analyses on all data remaining after the aforementioned exclusions and accepted missing values up to 10%.

Preoperative diagnostics included patient demographics, tumor histology, and staging, including a computed tomography (CT) scan of the chest, abdomen, and pelvis and magnetic resonance imaging (MRI) of the pelvis. Indications for neoadjuvant chemoradiation (neoCRT) were tumors with threatened/suspicious CRM. Patients underwent short-course or long-course neoCRT after multidisciplinary team discussion, with clinical restaging and surgery performed 10 to 12 weeks thereafter. Neoadjuvant protocols in the neoCRT group were either short-course neoadjuvant radiotherapy (25 Gy in 5 fractions over 5 weekdays) or long-course neoadjuvant chemoradiotherapy (45–50 Gy in 25 fractions over 5 weeks) with concomitant chemotherapy [3 months of CAPOX (capecitabine and oxaliplatin) or FOLFOX (folinic acid, fluorouracil, and oxaliplatin)]. Adjuvant therapy consisted of 45 Gy in 25 fractions. All patients underwent preoperative mechanical bowel preparation.[22] Surgical approach was discussed and decided according to the surgeon's preference, patient's opinion, and platform availability. Standard oncological robotic TME was performed using the da Vinci (Si/X/Xi) surgical system according to availability.[23] Clinical and oncological outcomes were recorded in patient notes. Postoperatively, all patients (laparoscopic and robotic) were managed with the standard enhanced recovery program and followed national UK follow-up guidelines for rectal cancer management.[24]

Outcomes and Definitions

Outcomes of this study were determined before any statistical analysis. The primary outcome for this study was 5-year OS, defined as the percentage of patients alive at 5 years follow-up. Secondary endpoints included 5-year local recurrence (LR), 5-year distant recurrence (DR), 5-year disease-free survival (DFS), and short-term outcomes. LR was defined as any tumor mass in the pelvis, either pathologically proven or suspect for recurrence on radiological imaging. DR was defined as any distant metastasis, either pathologically proven or suspect for recurrence on radiological imaging that showed growth on consecutive imaging. DFS was defined as the percentage of patients alive at 5 years follow-up without any recurrent disease.

Baseline characteristics included sex (male/female), American Society of Anesthesiologists-classification (I/II, III, or IV), age at surgery (years), body mass index (BMI, kg/m^2), preoperative T-staging (T1/T2, T3, or T4), preoperative N-staging (N0/N1/N2), preoperative M-staging (M0/M1), history of abdominal surgery (yes/no), preoperative chemoradiation (none/short-course radiotherapy preoperative/chemoradiation preoperative), tumor site (rectum/rectosigmoid), low-rectal tumor on pelvic MRI (yes/no), year of surgery, CRM-staging on MRI (positive/negative), tumor height from the anorectal junction (ARJ) on MRI in cm, and extra-mural venous invasion positivity on MRI (no/yes).

Tumor location was based on preoperative imaging (MRI pelvis or, if unavailable, CT-pelvis/endoscopy), utilizing the sigmoidal take-off as described by d'Souza et al.[25,26] If this information was unavailable, tumor location was based on distance from the ARJ on CT-scan or endoscopy report (in that order), with a distance <15 cm from the ARJ defined as a rectal tumor, and a distance = 15 to 18 cm as rectosigmoid. A low-rectal tumor was defined according to the low rectal cancer definition, meaning that the lower border was at or below the origin of the levator muscles on the pelvic sidewall.[27]

Intra- and postoperative outcomes included type of surgery (TME with anastomosis/TME with end colostomy), additional resection performed (yes/no), operative time, LOS, blood loss, conversion rate, postoperative complications [none, minor (grade 1 and 2), or major (grade 3a/b, 4, and 5)], stoma formation, high output stoma's, anastomotic leakages [according to ISREC (The International Study Group of Rectal Cancer) classification],

adjuvant chemotherapy, and readmissions and reoperations within 31 days. Conversion was defined as any unplanned extension of the extraction site during surgery, and complications were classified according to the Clavien-Dindo classification.[28]

Pathological and survival outcomes included pathological CRM status, distal resection margin (DRM) status, extra-mural venous invasion status, pathological T- and N-staging, number of lymph nodes harvested, mortality <31 and <91 days, follow-up time, and cause of death related to disease. Pathological staging was modified according to the American Joint Committee on Cancer 8th edition staging system during data review.[29] CRM was classified as positive (≤1 mm) or negative (>1 mm).

Statistical Analysis

Prematching data were analyzed for each group, including means and standard deviations for normally distributed data and medians and interquartile ranges for non-normally distributed data. Bivariate categorical data were analyzed using the χ^2 test or Fisher exact test. All other categorical data were analyzed using Fisher exact test. Post-hoc analyses were performed using either the Bonferroni correction test or nominal symmetry test to determine which subanalyses were significant. Numerical data was analyzed using either an unpaired *T* test or Mann–Whitney *U* test, depending on the distribution of data. Kaplan–Meier curves or Cox regression analysis was used for calculating time-to-event data.

Propensity-score matching was performed using 1-on-1 nearest-neighbor matching with a caliper of 0.1 and without replacement. Variables used for matching were sex, American Society of Anesthesiologists classification, age at surgery, BMI, preoperative TNM staging, history of abdominal surgery, preoperative chemoradiation, tumor site, and low rectal cancer on MRI.

A standardized mean difference (SMD) less than 0.1 was considered appropriate, indicating successful matching. Missing data for matching were imputed using multiple imputations in SPSS (Statistical Package for the Social Sciences, v 28.0), considering the type of missing data was missing at random or completely at random.

Postmatching analyses were conducted using Wilcoxon test for continuous data, McNemar test for categorical data, and log-rank test with Kaplan–Meier curves for time-to-event data.

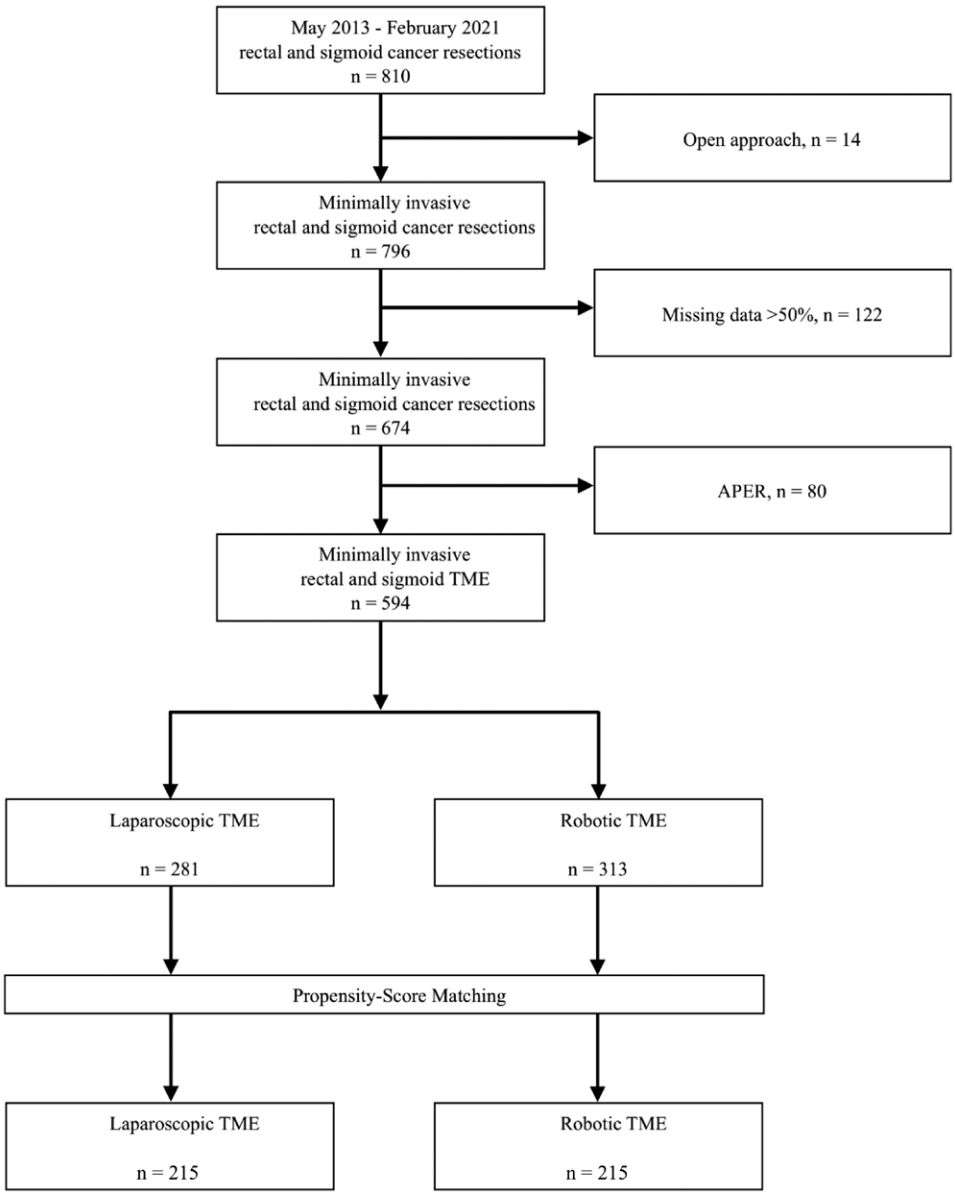

FIGURE 1. Consort flow diagram of patient selection.

TABLE 1.

Baseline Characteristics After Propensity-Score Matching

		Post-Matching Groups			
Variables		**Laparoscopic (n = 215)**	**Robotic (n = 215)**	***P* value**	**SMD**
Sex	Male	137 (63.7%)	146 (67.9%)	0.412	0.088
	Female	78 (36.3%)	69 (32.1%)		
ASA grade	I/II	184 (85.6%)	179 (83.3%)	0.488	0.095
	III	29 (13.5%)	35 (16.3%)		
	IV	2 (0.9%)	1 (0.5%)		
Age at surgery	Years	67.0 (60.0–75.0)	69.0 (60.0–76.0)	0.206	0.102
BMI	Kg/m^2	27.0 (24.0–29.9)	27.0 (24.0–29.0)	0.438	0.067
Preoperative T-staging	T1/T2	107 (49.8%)	111 (51.6%)	0.721	0.047
	T3	93 (43.3%)	91 (42.3%)		
	T4	15 (7.0%)	13 (6.0%)		
Preoperative N-staging	N0	126 (58.6%)	133 (61.9%)	0.809	0.072
	N1	71 (33.0%)	64 (29.8%)		
	N2	18 (8.4%)	18 (8.4%)		
Preoperative M-staging	M0	203 (94.4%)	203 (94.4%)	1.000	<0.001
	M1	12 (5.6%)	12 (5.6%)		
Previous abdominal surgery	No	163 (75.8%)	155 (72.1%)	0.445	0.085
	Yes	52 (24.2%)	60 (27.9%)		
Preoperative chemoradiation	None	184 (85.6%)	179 (83.3%)	0.643	0.067
	Short-course preop	3 (1.4%)	4 (1.9%)		
	Chemoradiation preop	28 (13.0%)	32 (14.9%)		
Tumor site	Rectum	143 (66.5%)	136 (63.3%)	0.450	0.068
	Rectosigmoid	72 (33.5%)	79 (36.7%)		
LOREC on MRI	No	180 (83.7%)	174 (80.9%)	0.361	0.073
	Yes	35 (16.3%)	41 (19.1%)		
Year surgery performed	2013	27 (12.6%)	32 (14.9%)	0.023*	NA
	2014	45 (20.9%)	31 (14.4%)		
	2015	30 (14.0%)	40 (18.6%)		
	2016	32 (14.9%)	32 (14.9%)		
	2017	24 (11.2%)	36 (16.7%)		
	2018	26 (12.1%)	18 (8.4%)		
	2019	30 (14.0%)*	19 (8.8%)*		
	2020	1 (0.5%)	6 (2.8%)		
	2021	0 (0%)	1 (0.5%)		
CRM on MRI	Positive	24 (11.7%)	26 (13.3%)	0.877	NA
	Negative	181 (88.3%)	170 (86.7%)		
	Missing data	10	19		
Height of tumor from anorectal junction	Cm on MRI	7.25 (5.0–10.0)	7.00 (4.9–10.0)	0.115	NA
	Missing data	65	55		
EMVI on MRI	No	133 (66.2%)	127 (66.8%)	1.000	NA
	Yes	68 (33.8%)	63 (33.2%)		
	Missing data	14	25		

Values are depicted as median (Q1–Q3) for non-normally distributed data and absolute value (% of total) for categorical data. A *P* value of <0.05 is considered significant. Bold values indicate statistically significant *P*-values.

*Post hoc analyses were completed to identify which factors were statistically significant.

ASA indicates American Society of Anesthesiologists; BMI, body mass index; CRM, circumferential resection margin; EMVI, extra-mural venous invasion; LOREC, low rectal cancer; M-staging, metastatic-staging; MRI, magnetic resonance imaging; N-staging, nodal-staging; NA, not applicable; preop, preoperative; SMD, standardized mean difference; T-staging, tumor-staging.

In the event of McNemar's test failing, data was recoded into a matrix and analyzed using a nominal symmetry test instead. A *P* value <0.05 was considered statistically significant. All pre-matching analyses were performed using IBM SPSS statistics for Windows, version 28.0.0 (IBM Corp., Armonk, NY). Propensity-score matching and all postmatching analyses were performed with Rstudio, using R version 4.1.2 (R Foundation for Statistical Computing, Vienna, Austria), with the "Matching", "tableone", and "tidyverse" packages.

RESULTS

Overall Results

A total of 810 patients were included in the study. After excluding patients who were ineligible due to any of the reasons described in the *methods* sections and outlined in Figure 1, a total of 594 eligible patients were included in the analysis: 281 laparoscopic and 313 robotic. After propensity-score matching, 215 patients remained in each group.

Comparison of Baseline Groups Before and After Matching

Baseline characteristics and outcomes for the unmatched groups are presented in Appendices 2 and 3, http://links.lww.com/AOSO/A311. Baseline characteristics for the matched groups are presented in Table 1. There were minor differences in age at the time of surgery (SMD = 0.102), but no differences in all other baseline characteristics after matching (SMD < 0.1), indicating good-quality matching.

After matching there was a significant difference in the number of surgeries performed in 2019 (14.0% laparoscopic *vs* 8.8% robotic, *P* = 0.023), but no differences in all the other years. There were no statistically significant differences in preoperative imaging.

Intra- and Postoperative Outcomes

There was significantly less conversion (3.7% *vs* 0.5%, *P* = 0.046) and shorter LOS [7.0 (6.0–13.0) *vs* 6.0 (4.0–8.0) days, *P* < 0.001] in the robotic group. Postoperative complication rate

TABLE 2.

Intra- and Postoperative Outcomes After Propensity-Score Matching

Intra- and Postoperative Outcomes		Laparoscopic (n = 215)	Robotic (n = 215)	P Value
Type of surgery performed	TME with anastomosis	205 (95.3%)	202 (94.0%)	0.663
	TME with end colostomy	10 (4.7%)	13 (6.0%)	
Additional resection performed	No	181 (87.4%)	176 (87.1%)	1.000
	Yes	26 (12.6%)	26 (12.8%)	
	Missing data	8	13	
Operation time (skin-to-skin)	Minutes	270 (240–300)	240 (210–290)	0.053
	Missing data	71	22	
Length of stay	Days	7.00 (6.0–13.0)	6.00 (4.0–8.0)	<0.001
	Missing data	1	0	
Blood loss	mL	75.0 (75.0–75.0)	0 (0–10.0)	<0.001
	Missing data	88	50	
Conversion	No	207 (96.3%)	214 (99.5%)	0.046
	Yes	8 (3.7%)	1 (0.5%)	
Postoperative complications	No	76 (36.5%)	106 (49.3%)	0.010
	Yes	132 (63.5%)	109 (50.7%)	
	Missing data	7	0	
Classification complications	None	76 (36.5%)*	106 (49.3%)*	0.022*
	Minor (grade 1/2)	107 (51.5%)*	82 (38.1%)*	
	Major (grade 3/4/5)	25 (12.0%)	27 (12.6%)	
	Missing data	7	0	
Stoma constructed	No	25 (11.6%)	67 (31.3%)	<0.001
	Ileostomy	176 (81.9%)	133 (62.1%)	
	Colostomy	14 (6.5%)	14 (6.6%)	
	Missing data	0	1	
High output stoma	No	156 (82.1%)	120 (81.6%)	0.322
	Yes	34 (17.9%)	27 (18.4%)	
	Missing data	7	0	
Anastomotic leakage	No	177 (86.8%)	173 (85.6%)	1.000
	Yes	27 (13.2%)	29 (14.4%)	
	Missing data	11	13	
ISREC classification leakage	A	14/26	13/28	1.000
	B	8/26	9/28	
	C	4/26	6/28	
	Missing data	1	1	
Adjuvant chemotherapy	No	140 (65.4%)	146 (67.9%)	0.682
	Yes	74 (34.6%)	69 (32.1%)	
	Missing data	1	0	
Readmission <31 days	No	181 (85.4%)	190 (88.8%)	0.280
	Yes	31 (14.6%)	24 (11.2%)	
	Missing data	3	1	
Reoperation <31 days	No	202 (95.3%)	201 (94.4%)	0.831
	Yes	10 (4.7%)	12 (5.6%)	
	Missing data	3	2	

Values are depicted as median (Q1–Q3) for non-normally distributed data and absolute value (% of total) for categorical data. A *P* value of <0.05 is considered significant. Bold values indicate statistically significant *P*-values.

*Post hoc analyses were completed to identify which factors were statistically significant.

ISREC indicates The International Study Group of Rectal Cancer; N, number; TME, total mesorectal excision.

Postoperative complications are graded according to the Clavien-Dindo classification.

was also lower (63.5% *vs* 50.7%, *P* = 0.010), characterized by a difference in minor complications (51.5% *vs* 38.1%, *P* = 0.022), but no difference in major complications. Operative time was comparable. Less stomas were constructed in the robotic group (88.4% *vs* 68.7%, *P* < 0.001). There were no statistically significant differences in other intra- and postoperative outcomes (Table 2).

Pathological, Oncological, and Survival Outcomes

There were no statistically significant differences in pathological outcomes. Pathological CRM positivity was comparable between the groups (2.0% *vs* 2.8%, *P* = 1.000). Median follow-up was comparable between the laparoscopic and robotic groups [36.0 (20.75–53.0) vs 40.0 (25.0–56.5) months, *P* = 0.359]. There was a statistically significant difference in 5-year OS (72.4% laparoscopic *vs* 81.7% for robotic, *P* = 0.029), but there was no difference in 5-year LR (5.2% *vs* 4.7%, *P* = 0.850), DR (16.9% *vs* 13.5%, *P* = 0.390), or DFS (63.9% *vs* 74.4%, *P* = 0.086) between the groups. The pathological, oncological, and survival outcomes are presented in Table 3 and Figure 2.

DISCUSSION

The aim of this study was to compare the long-term survival and oncological outcomes of laparoscopic and robotic rectal cancer surgery. There was a correlation with higher 5-year OS in the robotic group (72.4% *vs* 81.7%, *P* = 0.029), but no significant differences in LR, DR, or DFS. There were also improved short-term perioperative outcomes in favor of the robotics group (lower conversion rate, shorter LOS, and fewer minor postoperative complications).

This study showed a significant improvement of the 5-year OS in the robotic group, which is unusual compared to existing literature. Qiu et al[12] and Simillis et al[11] performed extensive systematic reviews and meta-analyses of existing literature and found no differences in any long-term outcomes between surgical approaches, but had either no data on 5-year OS or

TABLE 3.

Pathological, Oncological, and Survival Outcomes After Propensity-Score Matching

Pathological, Oncological, and Survival Outcomes		Laparoscopic (n = 215)	Robotic (n = 215)	*P* Value
Pathological CRM positivity	No	199 (98.0%)	206 (97.2%)	1.000
	Yes	4 (2.0%)	6 (2.8%)	
	Missing data	12	3	
Pathological DRM positivity	No	209 (99.5%)	212 (99.5%)	1.000
	Yes	1 (0.5%)	1 (0.5%)	
	Missing data	5	2	
Pathological EMVI positivity	None	150 (70.4%)	168 (78.1%)	1.000
	Extramural	56 (26.3%)	41 (19.1%)	
	Intramural	7 (3.3%)	6 (2.8%)	
	Missing data	2	0	
Pathological T-staging	T0	3 (1.5%)	1 (0.5%)	0.156
	T1	25 (12.3%)	26 (12.4%)	
	T2	50 (24.6%)	73 (34.8%)	
	T3	109 (53.7%)	98 (46.7%)	
	T4a	3 (1.5%)	5 (2.4%)	
	T4b	13 (6.4%)	7 (3.3%)	
	Missing data	12	5	
Pathological N-staging	N0	136 (63.6%)	140 (65.1%)	0.404
	N1	51 (23.8%)	53 (24.7%)	
	N2	27 (12.6%)	22 (10.2%)	
	Missing data	1	0	
Lymph node harvest	Amount of nodes	21.0 (16.0–28.0)	20.0 (15.0–25.5)	0.136
<31 days mortality	No	212 (98.6%)	210 (100%)	0.248
	Yes	3 (1.4%)	0 (0%)	
	Missing data	0	5	
<91 days mortality	No	210 (97.7%)	209 (99.5%)	0.221
	Yes	5 (2.3%)	1 (0.5%)	
	Missing data	0	5	
Follow-up	Months	36.0 (20.75–53.0)	40.0 (25.0–56.5)	0.359
	Missing data	47	28	
Local recurrence	No	199 (95.7%)	202 (96.2%)	1.000
	Yes	9 (4.3%)	8 (3.8%)	
	Missing data	7	5	
Time until LR	Months	18.7 (21.8)	16.3 (10.0)	0.689
		11.0 (6.0–18.0)	12.0 (10.3–24.8)	
Distant recurrence	No	178 (85.6%)	184 (87.6%)	0.630
	Yes	30 (14.4%)	26 (12.4%)	
	Missing data	7	5	
DR descriptive	Liver	13/30	9/26	NA
	Lung	8/30	11/26	
	Liver and lung	4/30	2/30	
	Peritoneum	2/30	1/26	
	Other	3/30	3/26	
Time until DR	Months	24.6 (18.1)	20.4 (13.3)	0.625
		21.0 (11.5–32.0)	22.0 (11.0–24.0)	
Cause of death related to disease	No	20 (43.5%)	9 (36.0%)	0.480
	Yes	26 (56.5%)	16 (64.0%)	
	Missing data	0	2	

Values are depicted as means (SD) for normally distributed data, median (Q1–Q3) for non-normally distributed data, and absolute value (% of total) for categorical data. A *P* value of <0.05 is considered significant.

CRM, circumferential resection margin; DFS, disease-free survival; DR, distant recurrence; DRM, distal resection margin; EMVI, extra-mural venous invasion; LR = local recurrence; N, number; N-staging, nodal-staging, NA, not applicable; T-staging, tumor-staging.

very heterogeneous data in their analyses.[11,12] Though there have been several recent studies on long-term outcomes for robotic rectal cancer surgery, these either compared to open surgery or had no comparator at all, limiting the value of their findings for our study.[17–19]

There have been a couple of studies looking at similar cohorts, though. Lim et al[13] found comparable 5-year overall and oncological survival outcomes between the robotic and laparoscopic approach, as did Burghgraef et al[14] in a more recent, 3-way propensity-score matched analysis of 3-year overall and oncological survival between the laparoscopic, robotic, and transanal approaches.[14] There are very few studies looking at 5-year long-term oncological outcomes, and the few that do focus specifically on intersphincteric resections.[30–32] A couple of studies, however, showed improved OS in favor of the robotic approach.[15,33] Kim et al[33] performed a propensity-score matching on their data and found robotic surgery to be an independent significant prognostic factor for OS, though their initial analysis did not show statistical significance, and they only achieved a statistically significant difference in OS in favor of the robotic group after multivariate analysis.[33]

Although the data shows a significant improvement in 5-year OS in favor of the robotics group, there's no clear explanation for what caused this difference. There were no significant differences in LR, DR (including metastatic site), or DFS, nor any significant differences in major complications, readmissions, reoperations, or short-term mortality, which are all commonly associated with a difference in OS. Though there is a significant difference in the number of surgeries performed in 2019, this is in favor of the laparoscopic group (14.0% *vs* 8.8%, $P = 0.023$),

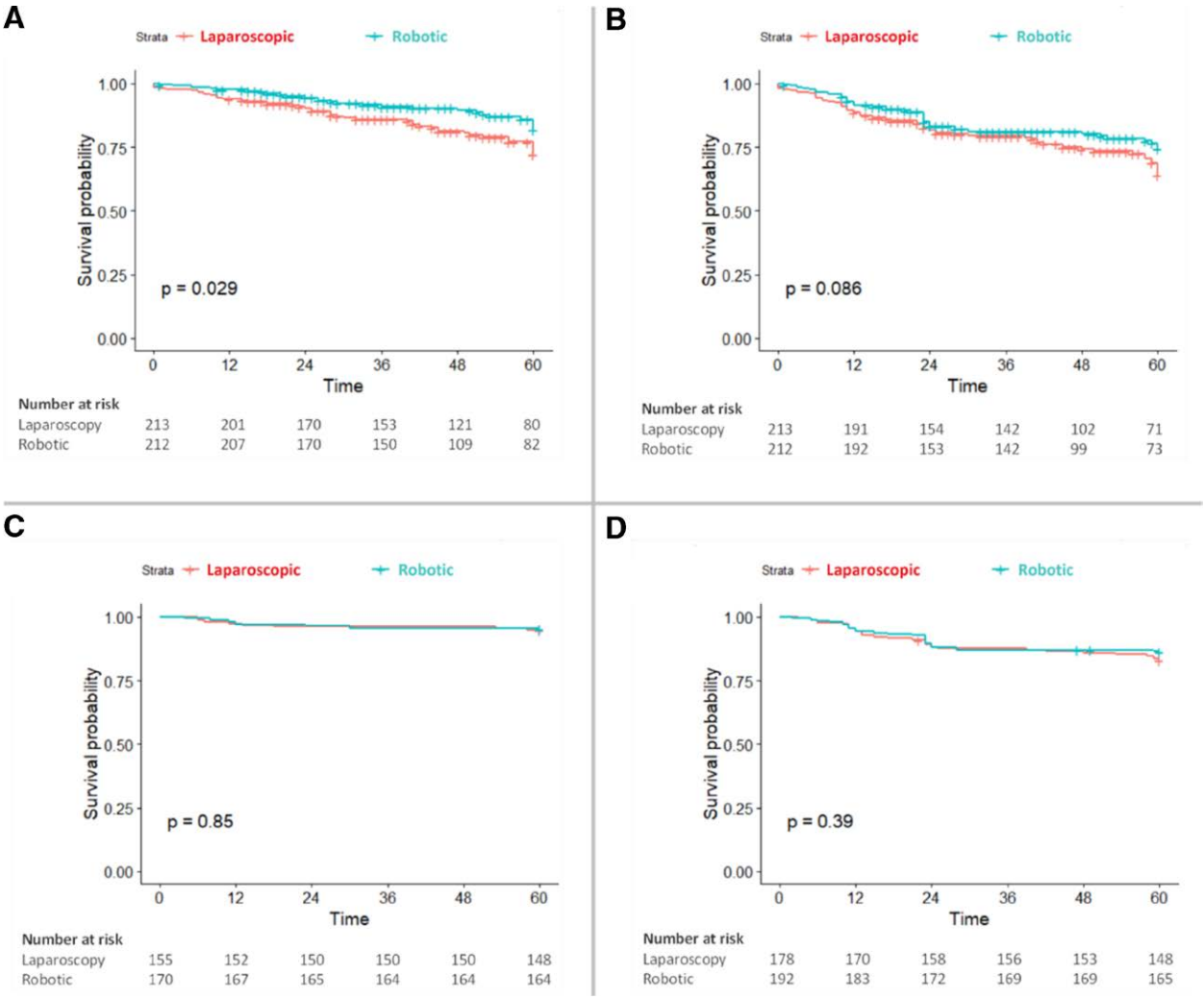

FIGURE 2. Kaplan–Meier curves and log-rank tests for 5-year overall survival (72.4% for laparoscopy *vs* 81.7% for robotic, $P = 0.029$), disease-free survival (63.9% *vs* 74.4%, $P = 0.086$), local recurrence (4.7% *vs* 5.2%, $P = 0.850$), and distant recurrence (16.9% *vs* 13.5%, $P = 0.390$) after propensity-score matching.

and there is no difference in the other years of surgery performed, which does not explain a difference in OS in favor of the robotic group. We found no significant difference in the cause of death related to disease (56.5% *vs* 64.0%, $P = 0.480$) and know from hospital protocols and audits that there was no difference on time to surgery between the groups. It could be that the robotic group had a shorter time to adjuvant chemotherapy after surgery, due to an improved postoperative recovery (influenced by a shorter LOS and less minor postoperative complications), or that there were other competing medical issues and that this had an influence on the OS, but unfortunately, this data was not available and remains a limitation of the retrospective design.

There were also several statistically significant differences in short-term outcomes in favor of the robotic group, which are consistent with recent literature, particularly the recently published randomized controlled trial from the REAL group.[9] They published significant differences in favor of the robotic group for conversion to open surgery, LOS, and postoperative complications, which aligns with our data. In contrast to our data, they also reported significant differences in intraoperative complications and postoperative CRM-positivity in favor of the robotics group. Our postoperative CRM-positivity rates, however, were much lower in both groups (2.0% laparoscopic and 2.8% robotic) than the CRM involvement reported in the REAL trial (respectively 7.2% and 4.0%), the ROLARR trial (5.1%), and in Bonjer et al[2] (10% in both groups), despite a higher preoperative CRM involvement on MRI scans of 11.7% and 13.2% in our groups.[6,9] Pathological DRM positivity was also very low in our cohort, with only one positive DRM in each group (0.5%). We believe these findings support the short-term benefits of robotic surgery in the treatment of rectal cancer, although there is a risk of selection bias due to the fact that some of these trials included APER's.

In contrast to published literature, our analyses also included low rectosigmoid tumors treated with a TME in the comparisons. However, our median heights from the ARJ were 7.25 (5.0–10.0) laparoscopically and 7.00 (4.9–10.0) robotically, which shows that most tumors were below the sigmoidal take-off. Furthermore, due to the propensity-score matching, all the rectosigmoid tumors were matched, which reduces the risk of bias between the groups.

Retrospective data studies are, however, subject to several weaknesses and biases, such as covariate bias, risk of information bias, and risk of confounding (by indication). We have attempted to minimize these risks by propensity-score matching the 2 groups on as many relevant covariates as possible, and through this hope to account for the possible selection biases and risks of confounding factors for our primary and secondary endpoints.

The only variable with an SMD >0.1 was the age at surgery (SMD = 0.102), which could theoretically lead to some bias in the analyses, but the median age was higher in the robotic group [69.0 (60.0–76.0) robotic *vs* 67.0 (60.0–75.0) laparoscopic].

Propensity-score matching can also lead to weaknesses, due to residual confounding. A strength of this study is the number of inclusions remaining even after propensity-score matching.

The prospectively maintained research database was externally validated by an independent biostatistician, and long-term outcomes were checked regularly and updated for the entire database. The long study interval brings both strengths and weaknesses to the methodology.

Though our data strongly suggests a lower incidence of minor postoperative complications in the robotic group compared to the laparoscopic group, it must be mentioned that this grade of postoperative complications has historically been subject to a risk of reporting bias. Minor complications are often not accurately recorded, as no radiological or surgical intervention is generally performed.

There is the possibility that the difference in OS is not related to the surgery, but to other factors, and it is important to take this into consideration. Granting all this, we believe in the validity of this data and hypothesize that there might be a yet-to-be-discovered factor influencing the survival outcomes in these patients. Robotic surgery is still a novel approach, and we are currently only at the advent of the possibilities for this technology. The benefits of robotic surgery on oncological survival are still under evaluation, and there is a real need for high-quality, methodologically sound research on the subject.

In conclusion, this study shows a correlation between higher 5-year OS and comparable long-term oncological outcomes for robotic TME surgery compared to the laparoscopic approach. It also shows statistically significantly improved short-term outcomes in conversion rate, LOS, and minor postoperative complications. Robotic rectal cancer surgery is a safe and favorable alternative to the laparoscopic approach, and further research is warranted to explore these potential benefits.

Authors contribution

Conceptualization, Writing—review and editing: R.D., M.L.W.R, T.A.B, S.S, S.M, G.N.P, F.S, J.S.K. Methodology: R.D., M.L.W.R, T.A.B, J.S.K. Formal analysis and investigation: R.D., M.L.W.R, T.A.B, S.M, J.S.K. Writing—original draft preparation: R.D., M.L.W.R, T.A.B, J.S.K. Supervision: J.S.K. All authors approved the final version of the manuscript.

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