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# Proficient surgeons enhance conversion rates and sphincter preservation in robotic rectal cancer surgery with comparable long-term outcomes: a comparative study with laparoscopy in a large-volume center in China

Xiaojie Wang[1], Yangyang Wang[1], Zhifen Chen[1], Zhifang Zheng[1], Shenghui Huang[1], Yanwu Sun[1], Ying Huang[1*] and Pan Chi[1*]

## Abstract

**Background** Despite theoretical advantages, skepticism persists about robotic rectal cancer surgery due to the lack of evidence of benefit. This study aims to compare oncological and functional results of robotic-assisted surgery to laparoscopy, focusing on proficient surgeons with expertise in both techniques.

**Methods** This retrospective study reviewed and compared 1304 patients who underwent either robotic surgery ($n=295$) or laparoscopic surgery ($n=1009$) for rectal cancer. The surgical procedures were performed by a team of highly skilled surgeons who individually carry out more than 350 laparoscopic or robotic colorectal cancer surgeries over the course of their career. Perioperative outcomes, recurrence data, and intestinal function outcomes were compared between groups with a propensity score matching (PSM) method. The primary outcomes were sphincter preservation and conversion to open laparotomy. Secondary endpoints included 3-year disease-free survival (DFS), 3-year overall survival (OS), complications, and the occurrence of low anterior resection syndrome (LARS). Fisher's exact test and χ2 were used to compare discrete variables between groups, while parametric (t-test) and nonparametric (U test, Kruskal–Wallis) tests were used for continuous outcomes, as appropriate. The Kaplan–Meier and log-rank tests were employed to analyze and compare the DFS and OS outcomes.

**Results** The patients in the robotic group were younger, with a higher cN stage, positive EMVI and CRM, and a lower tumor location compared to the patients in the laparoscopic group. The robotic group also had more neoadjuvant chemoradiotherapy, causing an imbalance in (y)pT and (y)pN stage. Following PSM, all covariates were effectively balanced between the two groups. The robotic group had significantly higher sphincter preservation rates (94.0% vs. 84.4%, $P<0.001$) and no conversions to open laparotomy, while the laparoscopic group had 7 cases (0 vs. 2.5%,

*Correspondence:
Ying Huang
hy9033sy@sina.com
Pan Chi
chipan363@163.com

P = 0.015). There were no significant differences observed in diverting ileostomy, operative time, estimated blood loss, complications, margin involvement, or duration of hospitalization. The median follow-up was 31 months. No significant differences were found between the robotic and laparoscopic groups in terms of 3-year OS (94.1% vs. 93.3%, P = 0.812) and DFS (85.9% vs. 84.7%, P = 0.797). The robotic group had similar rates of recurrence in various sites, including local, liver, lung, bone, and peritoneal metastases. Major LARS occurred in 11.3% of patients, while minor LARS occurred in 14.8% with no significant differences between the groups (P = 0.54).

**Conclusion** Comparable complication rates, 3-year OS, and DFS were found between robotic and laparoscopic rectal cancer surgery. Furthermore, it shed light on supplementary benefits associated with this approach, such as decreased conversion rates and enhanced sphincter preservation, particularly when performed by skilled surgeons in specialized, high-volume medical facilities.

**Keywords** Laparoscopic surgery, Robotic surgery, Oncologic outcome, Rectal neoplasm, Sphincter preservation, Conversions to open laparotomy

## Introduction

The utilization of minimally invasive surgical techniques, such as laparoscopy and robotic surgery, has gained prominence as a viable alternative to open surgery for patients afflicted with rectal cancer. Laparoscopic surgery has not only shown superior short-term outcomes, including faster recovery of bowel function and reduced morphine requirement, compared to open surgery, but it has also produced comparable long-term oncologic outcomes. This includes similar disease-free survival (DFS) rates and recurrence rates [1, 2]. However, the technical demands of laparoscopic surgery are significantly heightened when confronted with rectal cancers due to the inherent narrowness, intricate anatomy, and limited visual field within the pelvic cavity.

The robotic system offers a range of advanced technologies, including superior 3-dimensional views, enhanced dexterity, and tremor-free operation. Hence, the capabilities of the robotic system are optimized for intricate procedures. However, skepticism remains due to the lack of significant additional benefits and higher cost burden [3–7]. The conversion rate to open surgery served as a significant indicator, highlighting the technological edge that robotic-assisted surgery had in rectal cancer resections. This metric was particularly crucial in assessing the procedure's effectiveness in minimizing the need for open surgical interventions. This rate was used as the primary outcome in the ROLARR trial [8] and as a secondary outcome in a retrospective multicentre study [9]. The existing multicentre study generally indicated a lower conversion rate for robotic rectal cancer surgery compared to laparoscopic surgery, with rates of 1.4% and 8.8%, respectively [9]. However, based on the ROLARR trial, robotic surgery for rectal cancer did not exhibit a substantial decrease in the conversion rate compared to laparoscopy [8]. On the other hand, the prevention of permanent stoma is a paramount consideration impacting the quality of life for individuals afflicted with rectal cancer [10]. A multitude of researchers have promoted the inclusion of abdominoperineal resection (APR) rates as a critical quality indicator for assessing the effectiveness of rectal cancer treatment services [11]. Furthermore, the rate of sphincter preservation has been employed as the primary outcome measure in evaluating the technological advantages of robotic-assisted total mesorectal excision (TME), particularly in surmounting the challenges associated with a purely laparoscopic approach in the management of rectal cancer patients [12]. However, the debate surrounding the ability of robots to achieve the highest rate of sphincter preservation remains contentious [13]. Consequently, sphincter preservation and the rate of conversion to open laparotomy were selected as the primary outcomes in the present study.

Previous research showed that robotic techniques resulted in a longer duration of surgery compared to laparoscopic surgery, but as surgeons gain experience, the robotic approach can be more time-efficient [14, 15]. Hence, the accumulation of surgical experience plays a crucial role in highlighting the benefits of robotic rectal cancer surgery.

The purpose of this study is to explore the potential advantages of robotic-assisted rectal cancer surgery in comparison to laparoscopy. The study will specifically focus on a group of highly skilled surgeons who possess expertise in both surgical techniques. These surgeons are defined as individuals who perform more than 350 laparoscopic or robotic colorectal cancer surgeries over the course of their career. The primary outcomes were sphincter preservation and conversion to open laparotomy. Secondary endpoints included 3-year DFS, 3-year overall survival (OS), complications, and the occurrence of low anterior resection syndrome (LARS).

## Methods

### Patients

From January 2017 to December 2021, a total of 1576 consecutive patients underwent robotic or laparoscopic rectal cancer surgery at the Department of Colorectal Surgery of the Affiliated Union Hospital of Fujian Medical University. Rectal cancer was defined as a pathologically confirmed adenocarcinoma located within a distance of 15 cm from the anal verge. This surgical procedure was expertly executed by a team of highly skilled surgeons who individually carry out more than 350 laparoscopic or robotic colorectal cancer surgeries over the course of their career. The initial robotic rectal cancer surgery was performed in March 2016; therefore, cases during the initial learning period (March 2016 to December 2016) of robotic surgery were excluded from this study.

Patients who met the following criteria were excluded from the analysis: those who underwent open surgery, had stage IV disease, underwent surgery for recurrent cancer, had synchronous or metachronous colorectal cancer, had missing data on crucial baseline information such as pathological T or N stages or tumor distance to the anal verge. Additionally, patients with specific pathological types, including rectal malignant melanoma, rectal stromal tumor, and rectal neuroendocrine tumor, were also excluded from the analysis (Fig. 1).

The current research received ethical approval from the Institutional Review Board of the Affiliated Union Hospital of Fujian Medical University under the reference number 2023KY222.

### Treatment and follow-up

All diagnoses, treatments, and follow-up were conducted in accordance with the guidelines outlined in the Chinese Protocol of Diagnosis and Treatment of Colorectal Cancer [16]. This protocol, initially released by the National Health and Family Planning Commission in 2010, has undergone three revisions during the study period in 2015, 2017, and 2020 [17]. Specifically, all patients had preoperative staging assessments as recommended, including a digital rectal examination, colonoscopy, chest radiography, endorectal ultrasound examination (ERUS), abdominopelvic computed tomography (CT), and pelvic magnetic resonance imaging (MRI). According to the guidelines [16], both ERUS and pelvic MRI were recommended for local staging assessments of rectal cancer. ERUS demonstrated higher accuracy in evaluating T1-T2 stages, whereas MRI showed higher accuracy in

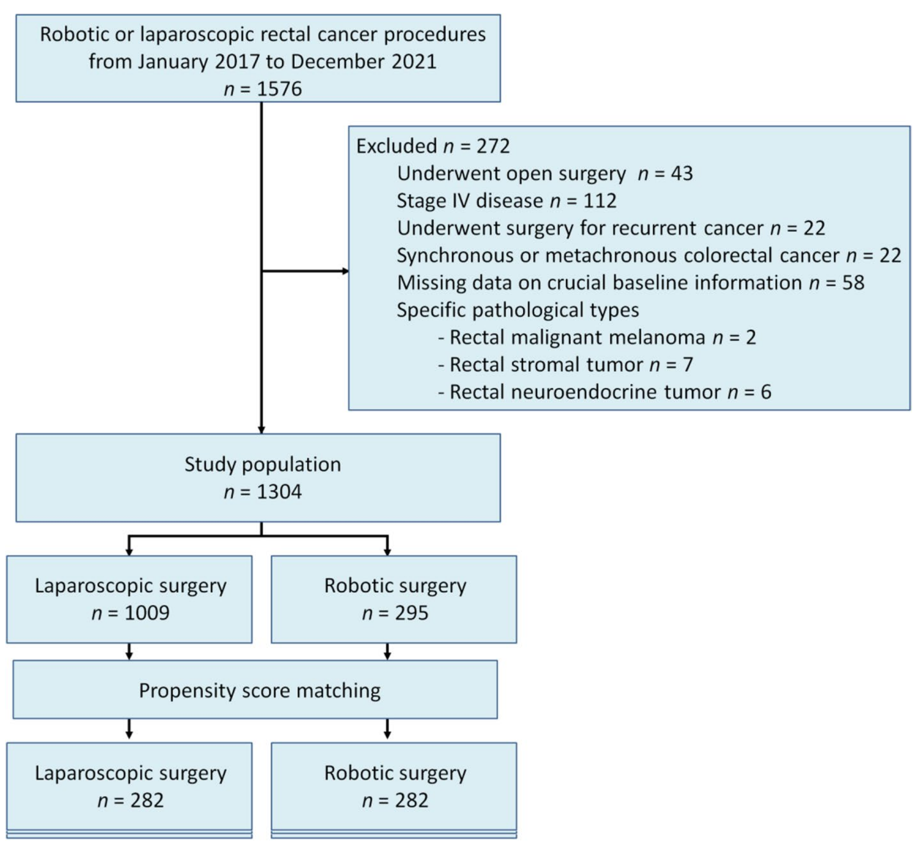


**Fig. 1** Flowchart of patient cohort definition

evaluating locally advanced stages. Neoadjuvant chemoradiotherapy was given to patients with clinical T3/4 and threatened mesorectal fascia (< 1 mm due to tumor or lymph nodes), regardless of N stage. Surgery was recommended 6–10 weeks after preoperative radiotherapy.

The decision of whether to employ robots or laparoscopy for surgical procedures was primarily guided by surgeons, yet it was ultimately determined through a collaborative effort between surgeons and patients. In general, experienced colorectal specialists tended to show a preference for utilizing robotic platforms when treating complex cases of rectal cancer, particularly those involving lower tumor positions and advanced stages of the disease. Furthermore, the decision to employ robotic surgery was also influenced by factors such as the scheduling of the robotic platform. Before surgery, patients were informed about robotic and laparoscopic surgical techniques. It was clarified that there was no evidence showing one procedure was better than the other, but robotic assistance may aid in pelvic dissection. Both approaches had better short-term outcomes than open surgery for rectal cancer. Patients choosing robotic surgery were informed of the additional cost of RMB 30,000 compared to laparoscopic surgery, following pricing standards in Fujian province.

All patients underwent standard surgical resection, with mid/low rectal cancers receiving total mesorectal excision (TME) and high rectal cancers receiving partial mesorectal excision with a distal margin of at least 5 cm. Robotic procedures were conducted using the da Vinci surgical system, with a single docking. The robotic system was utilized for primary vascular ligation, sigmoid colon mobilization, and mesorectal dissection. In case of intersphincteric resection (ISR), we have implemented a unique approach to intersphincteric dissection by exclusively utilizing an abdominal method using either robotic or laparoscopic techniques. Following completion of these steps, the robot cart was removed from the patient's bed, and the anastomosis and splenic flexure colon mobilization, if necessary, were performed in the same manner as laparoscopic surgery.

Patients with stage II/III tumors and those who had neoadjuvant chemoradiation were advised to undergo 5-fluorouracil-based adjuvant chemotherapy. Postoperative surveillance included imaging studies, chest radiography, abdominopelvic MRI/CT, and annual colonoscopy. Visits occurred every three months for the first two years, followed by annual assessments.

### Definition

The primary outcomes were sphincter preservation and conversion to open laparotomy. Secondary endpoints included 3-year DFS, 3-year OS, complications, and the occurrence of LARS. A positive pathological circumferential resection margin (CRM) was defined as the presence of a cancer-free margin ≤ 1 mm. Sphincter preservation was defined as cancer-directed surgical procedures involving an anastomosis between the colon and the rectum or anus, specifically including anterior resection and ISR. Patients who underwent sphincter preservation while being diverted with a loop ileostomy or loop transverse colostomy were also considered as having undergone sphincter preservation. Conversion to open laparotomy encompassed the utilization of a laparotomy wound during any stage of the mesorectal dissection. DFS was defined as the time from surgery to the first recurrence, metastasis, or death from any cause. OS was defined as the time from surgery to death or the last confirmed date of being alive. Local recurrence was characterized by tumor growth in the pelvic cavity, irrespective of its direction or relationship with the anastomosis. Distant recurrences were defined as tumor recurrence outside the pelvic cavity, including metastases to the liver, lung, bone, or peritoneum.

The Chinese version of the LARS score system was used to evaluate postoperative intestinal function [18]. Scores of 0–20 indicated no LARS, 21–29 indicated minor LARS, and 30–42 indicated major LARS. Follow-up assessments were conducted from November 2022 to July 2023 using a LARS score questionnaire. Scores were obtained one year after anterior resection or stoma reversal.

### Statistical analysis

All statistical analyses were conducted using R (version 3.5.1) and STATA (version 15.0; StataCorp, College Station, TX, USA). The patients were divided into two groups: the laparoscopic surgery group and the robotic surgery group. Fisher's exact test and $\chi 2$ were used to compare discrete variables between groups, while parametric (t-test) and nonparametric (U test, Kruskal–Wallis) tests were used for continuous outcomes, as appropriate. The Kaplan–Meier method was used to summarize DFS and overall survival OS, and a log-rank test was used to compare them. To balance the baseline confounders between the groups, propensity score matching (PSM) was performed for each patient using a logistic regression model. The covariates included in the model were age, tumor distance to the anal verge, receipt of neoadjuvant chemoradiotherapy, status of extramural venous invasion (EMVI) measured by MRI, status of CRM involvement measured by MRI, ypT stage, and ypN stage. One-to-one matching without replacement was performed with a 0.01 caliper width. A significance level of $P < 0.05$ was considered statistically significant.

## Results

### Baseline characteristics

During the study period, a total of 1,304 patients underwent either robotic surgery ($n=295$) or laparoscopic surgery ($n=1{,}009$) for rectal cancer. Following PSM, 282 matched pairs were created. The baseline characteristics of patients before and after PSM are presented in Table 1. Prior to PSM, it was observed that patients in the robotic group were younger compared to those in the laparoscopic group. Additionally, patients in the robotic group exhibited a higher cN stage, a higher incidence of positive EMVI and CRM as measured by MRI, and a lower tumor location compared to those in the laparoscopic group. Furthermore, a greater proportion of patients in

**Table 1** Baseline characteristics

| Variable | Unmatched patients | | | Propensity-matched patients | | |
|---|---|---|---|---|---|---|
| | Laparoscopic surgery | Robotic surgery | *p*-value | Laparoscopic surgery | Robotic surgery | *p*-value |
| N | 1009 | 295 | | 282 | 282 | |
| Gender | | | 0.54 | | | 0.79 |
| Male | 618 (61.2%) | 187 (63.4%) | | 181 (64.2%) | 177 (62.8%) | |
| Female | 391 (38.8%) | 108 (36.6%) | | 101 (35.8%) | 105 (37.2%) | |
| Age | | | < 0.001 | | | 0.13 |
| ~ 61 years | 475 (47.1%) | 182 (61.7%) | | 152 (53.9%) | 171 (60.6%) | |
| 60 ~ years | 534 (52.9%) | 113 (38.3%) | | 130 (46.1%) | 111 (39.4%) | |
| Body mass index (kg/m$^2$) | 22.5 (20.6, 24.7) | 22.7 (20.8, 25.1) | 0.20 | 22.4 (20.5, 24.4) | 22.7 (20.8, 25.1) | 0.10 |
| Diagnosis year | | | 0.12 | | | 0.49 |
| 2017 ~ 2019 | 597 (59.2%) | 190 (64.4%) | | 171 (60.6%) | 180 (63.8%) | |
| 2020 ~ 2021 | 412 (40.8%) | 105 (35.6%) | | 111 (39.4%) | 102 (36.2%) | |
| Hypertension | 264 (26.2%) | 63 (21.4%) | 0.11 | 65 (23.0%) | 61 (21.6%) | 0.76 |
| Diabetes | 121 (12.0%) | 37 (12.5%) | 0.84 | 26 (9.2%) | 36 (12.8%) | 0.23 |
| cT stage | | | 0.26 | | | 0.67 |
| T1 ~ 2 | 228 (22.6%) | 57 (19.3%) | | 52 (18.4%) | 57 (20.2%) | |
| T3 ~ 4 | 781 (77.4%) | 238 (80.7%) | | 230 (81.6%) | 225 (79.8%) | |
| cN stage | | | 0.017 | | | 0.11 |
| N0 | 317 (31.4%) | 71 (24.1%) | | 88 (31.2%) | 70 (24.8%) | |
| N1 ~ 2 | 692 (68.6%) | 224 (75.9%) | | 194 (68.8%) | 212 (75.2%) | |
| (y)pT stage | | | < 0.001 | | | 0.39 |
| T0 ~ 2 | 441 (43.7%) | 177 (60.0%) | | 157 (55.7%) | 168 (59.6%) | |
| T3 ~ 4 | 568 (56.3%) | 118 (40.0%) | | 125 (44.3%) | 114 (40.4%) | |
| (y)pN stage | | | 0.020 | | | 0.22 |
| N0 | 699 (69.3%) | 225 (76.3%) | | 228 (80.9%) | 215 (76.2%) | |
| N1 ~ 2 | 310 (30.7%) | 70 (23.7%) | | 54 (19.1%) | 67 (23.8%) | |
| Tumor distance to anal verge (cm) | 8.0 (6.0, 10.0) | 6.0 (5.0, 8.0) | < 0.001 | 6.0 (4.0, 8.0) | 6.0 (5.0, 8.0) | 0.68 |
| Positive EMVI | 238 (23.6%) | 100 (33.9%) | < 0.001 | 97 (34.4%) | 87 (30.9%) | 0.42 |
| Circumferential margin involvement measured by MRI | 105 (10.4%) | 86 (29.2%) | < 0.001 | 83 (29.4%) | 74 (26.2%) | 0.45 |
| Neoadjuvant chemoradiotherapy | 402 (39.8%) | 180 (61.0%) | < 0.001 | 171 (60.6%) | 168 (59.6%) | 0.86 |
| Histopathology | | | 0.56 | | | 1.00 |
| Adenocarcinoma | 926 (91.8%) | 276 (93.6%) | | 262 (92.9%) | 263 (93.3%) | |
| Mucinous adenocarcinoma | 76 (7.5%) | 17 (5.8%) | | 18 (6.4%) | 17 (6.0%) | |
| Signet ring adenocarcinoma | 7 (0.7%) | 2 (0.7%) | | 2 (0.7%) | 2 (0.7%) | |
| Differentiation | | | 0.97 | | | 0.55 |
| Well differentiated | 21 (2.1%) | 6 (2.0%) | | 4 (1.4%) | 6 (2.1%) | |
| Moderately differentiated | 878 (87.0%) | 228 (77.3%) | | 225 (79.8%) | 216 (76.6%) | |
| Poorly differentiated | 25 (2.5%) | 6 (2.0%) | | 10 (3.5%) | 6 (2.1%) | |
| Unknown | 85 (8.4%) | 55 (18.6%) | | 43 (15.2%) | 54 (19.1%) | |

*EMVI* Extramural venous invasion

the robotic group received neoadjuvant chemoradiotherapy compared to the laparoscopic group, resulting in an imbalance in (y)pT stage and (y)pN stage between the two groups. Following PSM, all covariates, including gender, age, body mass index, diagnosis year, hypertension history, diabetes history, cT stage, cN stage, (y)pT stage, (y)pN stage, tumor distance to anal verge, positive EMVI, CRM involvement measured by MRI, whether neoadjuvant chemoradiotherapy was received, tumor histopathology, and tumor differentiation, were effectively balanced between the two groups. The median tumor distance to the anal verge was found to be 6.0 cm in both the robotic group and the laparoscopic group ($P=0.68$). Regarding the involvement of adjacent structures (pT4b), it was observed that one cancer case in the robotic group had confirmed invasion of the levator. In the laparoscopic group, on the other hand, five cases showed involvement of adjacent structures, including one case each of levator, prostate, vaginal posterior wall, and two cases of uterus invasions. However, there was no statistically significant difference between the two groups in terms of rates of adjacent structure involvement (0.4% vs 1.8%, $P=0.22$).

### Short-term outcomes

The short-term outcomes of patients before and after PSM are presented in Table 2. Following the implementation of PSM, there was a comparable utilization of anterior resection between the two groups. However, the robotic group exhibited a higher proportion of ISR (20.2% vs. 9.9%) and a lower proportion of abdominoperineal resection (6.0% vs. 15.6%) compared to the laparoscopic group. The preservation rates of the sphincter were significantly higher in the robotic group compared to the laparoscopic group (94.0% vs. 84.4%, $P<0.001$). The robotic group did not experience any conversions to open laparotomy, whereas the laparoscopic group had 7 cases (0 vs. 2.5%, $P=0.015$). There was a non-significant trend of longer operative time in the robotic

**Table 2** Short-term outcomes

| Variable | Unmatched patients | | | Propensity-matched patients | | |
|---|---|---|---|---|---|---|
| | Laparoscopic surgery | Robotic surgery | *p*-value | Laparoscopic surgery | Robotic surgery | *p*-value |
| N | 1009 | 295 | | 282 | 282 | |
| Surgical procedure | | | < 0.001 | | | < 0.001 |
| Anterior resection | 918 (91.0%) | 216 (73.2%) | | 210 (74.5%) | 208 (73.8%) | |
| Intersphincteric resection | 41 (4.1%) | 62 (21.0%) | | 28 (9.9%) | 57 (20.2%) | |
| Abdominoperineal resection | 50 (5.0%) | 17 (5.8%) | | 44 (15.6%) | 17 (6.0%) | |
| Sphincter preservation | 959 (95.0%) | 278 (94.2%) | 0.55 | 238 (84.4%) | 265 (94.0%) | < 0.001 |
| Conversion to laparotomy | 16 (1.6%) | 0 (0.0%) | 0.031 | 7 (2.5%) | 0 (0.0%) | 0.015 |
| Operative time (min) | 190.0 (160.0, 226.0) | 205.0 (185.0, 220.0) | 0.27 | 185.0 (160.0, 241.0) | 205.0 (185.0, 220.0) | 0.41 |
| Estimated blood loss (mL) | 30.0 (20.0, 50.0) | 50.0 (20.0, 50.0) | 0.52 | 30.0 (10.0, 50.0) | 50.0 (20.0, 50.0) | 0.17 |
| Diverting ostomy | 574 (56.9%) | 220 (74.6%) | < 0.001 | 218 (77.3%) | 209 (74.1%) | 0.43 |
| Distal margin | | | 0.23 | | | 1.00 |
| Negative | 1009 (100.0%) | 294 (99.7%) | | 282 (100.0%) | 281 (99.6%) | |
| Positive | 0 (0.0%) | 1 (0.3%) | | 0 (0.0%) | 1 (0.4%) | |
| Pathologic circumferential margin | | | 1.00 | | | 1.00 |
| Negative | 1005 (99.6%) | 294 (99.7%) | | 280 (99.3%) | 281 (99.6%) | |
| Positive | 4 (0.4%) | 1 (0.3%) | | 2 (0.7%) | 1 (0.4%) | |
| Neural invasion | 124 (12.3%) | 33 (11.2%) | 0.68 | 20 (7.1%) | 32 (11.3%) | 0.11 |
| Lymph nodes retrieved | 16.0 (11.0, 22.0) | 14.0 (9.0, 18.0) | < 0.001 | 15.0 (9.0, 19.0) | 14.0 (9.0, 18.0) | 0.19 |
| Anastomotic leakage | 57 (5.6%) | 27 (9.2%) | 0.042 | 17 (6.0%) | 23 (8.2%) | 0.41 |
| Anastomotic bleeding | 9 (0.9%) | 2 (0.7%) | 1.00 | 3 (1.1%) | 1 (0.4%) | 0.62 |
| Intraabdominal infection | 46 (4.6%) | 12 (4.1%) | 0.87 | 10 (3.5%) | 12 (4.3%) | 0.83 |
| Wound infection | 7 (0.7%) | 4 (1.4%) | 0.28 | 3 (1.1%) | 4 (1.4%) | 1.00 |
| Pneumonia | 41 (4.1%) | 6 (2.0%) | 0.11 | 12 (4.3%) | 6 (2.1%) | 0.23 |
| Chylous ascite | 36 (3.6%) | 10 (3.4%) | 1.00 | 6 (2.1%) | 9 (3.2%) | 0.60 |
| Early postoperative small bowel obstruction | 10 (1.0%) | 2 (0.7%) | 1.00 | 6 (2.1%) | 2 (0.7%) | 0.29 |
| Sepsis | 7 (0.7%) | 0 (0.0%) | 0.36 | 1 (0.4%) | 0 (0.0%) | 1.00 |
| Duration of hospitalization (d) | 8.0 (6.0, 11.0) | 7.0 (6.0, 10.0) | 0.14 | 7.0 (6.0, 11.0) | 7.0 (6.0, 10.0) | 0.10 |

group compared to the laparoscopic group (220.0 min vs. 185.0 min, $P=0.41$), and the estimated blood loss was similar between the two groups (30.0 mL vs. 50.0 mL, $P=0.17$). There were no significant differences between the groups in terms of undergoing a diverting ileostomy or experiencing postoperative complications such as anastomotic leakage, anastomotic bleeding, intra-abdominal infection, wound infection, pneumonia, chylous ascites, early postoperative small bowel obstruction, and sepsis. Both groups exhibited rare occurrences of distal margin involvement and pathologic circumferential margin involvement, with similar rates. The duration of hospitalization was also similar between the two groups (7.0 days vs. 7.0 days, $P=0.10$).

#### Long-term outcomes

The analysis included 1256 patients for whom oncologic outcomes and recurrence data were available. The median follow-up period was 31 months (interquartile range: 16–45). In the robotic group, the 3-year OS rate was 94.4%, while in the laparoscopic group it was 94.3% ($P=0.883$). The 3-year DFS rate was 84.2% in the robotic group and 87.3% in the laparoscopic group ($P=0.282$). After PSM, there were no significant differences between the robotic and laparoscopic groups in terms of 3-year OS (94.1% vs. 93.3%, $P=0.812$) and 3-year DFS (85.9% vs. 84.7%, $P=0.797$) (Fig. 2). Notably, the robotic group exhibited no statistically significant variations in recurrence rates across various sites, including local recurrence, liver metastases, lung metastases, bone metastases, and peritoneal metastases (Table 3).

Data on postoperative intestinal function were available for analysis in a total of 1,087 patients. The occurrence of major LARS was observed in 11.3% of patients, while minor LARS was observed in 14.8% of patients. No significant differences were found in the rates of

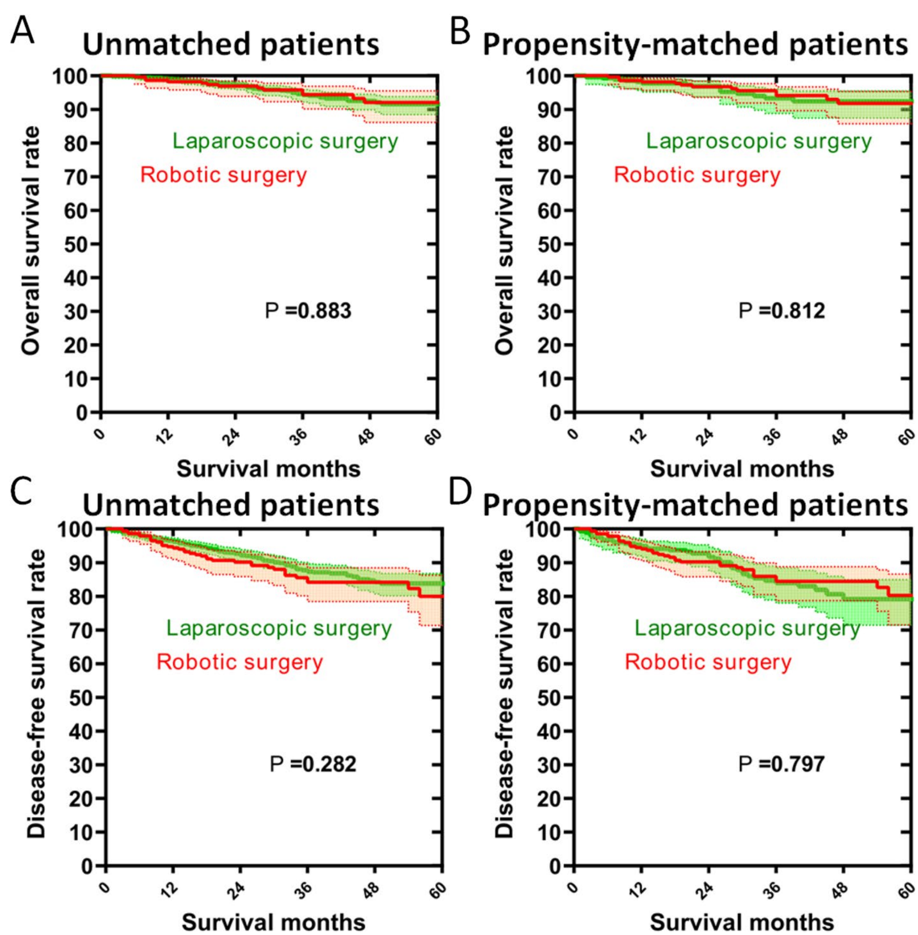


**Fig. 2** Comparison of survival between the robotic surgery group and laparoscopic surgery group. **A** Overall survival of unmatched patients. **B** Overall survival of propensity-matched patients. **C** Disease-free survival of unmatched patients. **D** Disease-free survival of propensity-matched patients

**Table 3** Recurrence data and intestinal function outcomes

| Variable | Unmatched patients | | | Propensity-matched patients | | |
|---|---|---|---|---|---|---|
| | Laparoscopic surgery | Robotic surgery | *p*-value | Laparoscopic surgery | Robotic surgery | *p*-value |
| N | 971 | 294 | | 276 | 281 | |
| Local recurrence | 29 (3.0%) | 13 (4.4%) | 0.26 | 8 (2.9%) | 12 (4.3%) | 0.50 |
| Liver metastases | 28 (2.9%) | 9 (3.1%) | 0.84 | 11 (4.0%) | 9 (3.2%) | 0.66 |
| Lung metastases | 30 (3.1%) | 16 (5.4%) | 0.074 | 17 (6.2%) | 15 (5.3%) | 0.72 |
| Bone metastases | 4 (0.4%) | 4 (1.4%) | 0.090 | 2 (0.7%) | 4 (1.4%) | 0.69 |
| Peritoneal metastases | 6 (0.6%) | 2 (0.7%) | 1.00 | 1 (0.4%) | 2 (0.7%) | 1.00 |
| LARS[a] | | | 0.40 | | | 0.54 |
| No | 602 (74.0%) | 201 (73.6%) | | 173 (77.2%) | 190 (73.1%) | |
| Minor | 125 (15.4%) | 36 (13.2%) | | 27 (12.1%) | 35 (13.5%) | |
| Major | 87 (10.7%) | 36 (13.2%) | | 24 (10.7%) | 35 (13.5%) | |

*LARS* Low anterior resection syndrome

[a] Data were obtained from 1087 patients

minor or major LARS between the groups (before PSM, $P=0.40$; after PSM, $P=0.54$).

## Discussion

It has been established that an increased surgeon volume correlates with reduced adverse outcomes in colorectal cancer surgery. However, there is a significant lack of consensus regarding the volume thresholds that define highly skilled surgeons, with both annual surgical volume and cumulative volume being criteria used. This variation is presumably due to the diverse health service to population ratios observed across different regions and countries [19]. In studies from various regions, including those often categorized as Western, a surgeon was considered to have a high volume if they had performed an annual surgical volume of over 20 to 40 colorectal surgeries. In Asian regions, such as Japan or Taiwan, a cumulative volume threshold of 200 to 561 colorectal surgeries was used to identify high-volume surgeons [19]. A population-based study in Taiwan characterized high-volume surgeons as those who had performed 321 or more colorectal surgeries [20]. Additionally, a Japanese study, focusing specifically on rectal cancer surgery, applied a cutoff of 500 procedures and established a link between this threshold and decreased blood loss [21]. Building on these international standards, in the context of China, the present study defined a highly skilled surgeon as one who has individually carried out more than 350 laparoscopic or robotic colorectal cancer surgeries throughout their career. This definition aligns with the reported cutoffs and reflects an adaptation to the local context while respecting the global standards established in the field.

In this study, patients assigned to the robotic group had distinct characteristics compared to the laparoscopic group, which were consistent with a previous study [22]. They were younger, had lower tumor positions, higher cN stage, a higher prevalence of EMVI, and involvement of CRM measured by MRI, and a higher rate of receiving neoadjuvant chemoradiotherapy. The decision on whether to use robots or laparoscopy for surgical procedures was initially influenced by surgeons, but ultimately, it was a joint effort between surgeons and patients. The aforementioned findings demonstrated that skilled colorectal specialists tend to favor the use of robotic platforms when dealing with intricate rectal cancer cases. Since these factors have implications for sphincter preservation, conversion, complications, and survival outcomes, case matching was conducted to adjust for these variables.

The absence of a permanent stoma is considered a paramount concern for individuals diagnosed with rectal cancer, as it is deemed equally significant as achieving a cure for the cancer [23]. The prevalence of sphincter-preserving surgery has experienced an upsurge due to the concurrent increase in the utilization of neoadjuvant chemoradiotherapy, enhanced comprehension of tumor biology, and advancements in stapling devices. Nevertheless, it is worth noting that the competence of surgeons can significantly impact the effectiveness of sphincter preservation [24, 25]. A retrospective cohort study unveiled a significant disparity in the rates of sphincter-preserving surgery among 10 hospitals, exhibiting a wide range from 12 to 73%, with an average rate of 52% [26]. When performed by experienced surgeons, laparoscopic low rectal cancer surgery yielded a significantly higher sphincter preservation rate of 71.7% compared to the 65.0% rate observed in open surgery, as demonstrated by the multicenter LASER trial conducted in 22 tertiary hospitals across China [27]. In the present study, compared to laparoscopy, the implementation of robotic surgery by skilled surgeons led to a noteworthy 9.6% rise in sphincter preservation rates ($P < 0.001$). This improvement is particularly remarkable considering that the laparoscopic group had already achieved a relatively high sphincter preservation rate of 84.4%. The recent multicenter REAL trial also revealed a comparable pattern of enhancement in sphincter preservation through the utilization of robotic surgery for middle and low rectal cancer (83.1% vs. 77.3%) [28].

The variability in sphincter-preservation procedures was traditionally attributed to colorectal specialization and hospital/surgeon volume [29]. Prior to surgery, surgeons evaluated the possibility of removing rectal cancer that extended into the anal canal while preserving the anal sphincter mechanism and achieving satisfactory oncological and functional outcomes. However, performing an ISR for low-lying rectal cancer posed significant technical challenges. At our center, we have deviated from the conventional ISR approach by adopting a completely abdominal method for intersphincteric dissection, without performing perineal intersphincteric space dissection. Our technique involved exposing the posterior adhesion line between the puborectalis muscle and rectal wall, which allowed us to enter the intersphincteric space along the dissection plane on the dorsolateral side of the rectum. Additionally, we dissected and transected the hiatal ligament at the posterior side. In cases where we performed a transabdominal approach for ISR, we ensured an adequate distal margin of 1 or 2 cm by mobilizing the distal bowel wall for 3 cm from the lower edge of the tumor. We then used a flexible linear stapler to cut the distal margin and performed a staple anastomosis [30]. Even in cases where a combined approach with ISR was necessary, we consistently followed the abdominal method for intersphincteric dissection. We ensured the mobilization of the distal bowel wall beyond the lower edge of the tumor before proceeding with the perineal portion. Finally, we transected the distal margin and performed a hand-sewn anastomosis. As a result, the transabdominal approach to intersphincteric dissection proved to be the most challenging step in ISR, and the use of robotic assistance potentially facilitated this step compared to laparoscopy, ultimately contributing to the success of ISR. In the present study, the robotic group exhibited a higher proportion of ISR (20.2% vs. 9.9%) compared to the laparoscopic group.

The present study discovered that patients who underwent sphincter preservation, despite the higher incidence of ISR associated with robotic surgery, exhibited similar postoperative intestinal function between the groups. The incidence of major LARS in the present study was observed to be 10.7% in the laparoscopic group and 13.5% in the robotic group. These findings fall within the range of 10.0% to 72.1% reported in 36 studies included in a recent meta-analysis [31]. However, the overall incidence of major LARS in the present study was lower than the average rate of 44%. It is crucial to acknowledge that the evaluation of LARS symptoms through the LARS score is subjective, and there was a significant range of time intervals for the restoration of intestinal continuity. This may explain the wide variation in the reported range of major LARS [31] and the relatively lower incidence observed in the present study. However, it is worth noting that our study did not record the time intervals for the restoration of intestinal continuity, which is a limitation. Furthermore, it is known that anastomotic leakage can worsen the symptoms of LARS due to the aggravation of anastomotic stricture with fibrosis of surrounding tissue, as well as pudendal neuropathy with lumbosacral plexopathy. Since the rate of anastomotic leakage in the present study was slightly lower than the average level [8, 32], this could partially account for the relatively lower incidence of major LARS observed. Lastly, it is important to acknowledge the potential presence of selection bias, reporting bias, and social desirability bias in the present study. The response rate in the study was 87.9%, which may introduce some degree of selection bias.

The conversion rate is crucial for evaluating the benefits of robotic rectal cancer surgery, reflecting advantages in complex procedures [33]. It has been observed that the conversion rate is associated with unfavorable short-term and long-term outcomes [34, 35]. It is imperative to acknowledge that the conversion serves as an indicator of surgical performance and task efficiency, and its outcome is substantially influenced by the surgical proficiency of the operating surgeons [35]. The ROLARR trial stood as the sole adequately powered randomized controlled trial investigating robotic surgery for rectal cancer conversion rates. However, the trial did not yield substantial evidence to support a decrease in conversion rates for robotic surgery, irrespective of surgeons' proficiency [8]. The trial had an overall conversion rate to open laparotomy of 10.1%, higher than our current study's 1.2% rate. Including surgeons with varying expertise may diminish the benefits of robotic surgery. It's important to note that in the ROLARR trial, robotic surgery was still a relatively new approach, while laparoscopy was well-established, potentially introducing bias in the comparisons. Previous analyses have suggested that the results of the ROLARR trial may have been influenced by the learning curve effects [36]. Thus, our current study minimized this bias by excluding cases from the initial learning period of robotic surgery and involving experienced surgeons in both techniques. Our study presented empirical evidence that substantiated the superiority of robotic surgery over laparoscopy in terms of conversion rate, particularly among surgeons with a substantial level of experience. It is noteworthy to emphasize that laparoscopy already exhibited a commendably low conversion rate of 2.5%. However, it is important to recognize that rectal cancer patients in Asian countries exhibited a lower BMI compared to their counterparts in Western countries. Severe obesity was linked to higher conversion rates and poorer short-term outcomes after colorectal surgery, although this trend was somewhat alleviated with a minimally invasive approach [37]. In our study, the average BMI was 22, which was relatively low compared to the participants in the ROLARR trial. In the ROLARR trial, over 38% of patients were overweight (BMI 25.0–29.9), and 23% were obese (BMI over 30). Furthermore, the adjusted analysis of the ROLARR trial revealed a significantly higher likelihood of conversion in obese patients compared to underweight or normal-weight patients.

In a previous meta-analysis, robotic-assisted surgery for rectal cancer was correlated with an increased operative time compared to laparoscopic surgery [15]. Consistent with these findings, the ROLARR trial also noted a mean operative time that was 37.5 min longer for the robotic-assisted laparoscopic group versus the laparoscopic group, a difference possibly due to the learning curve effect [8]. In our study, we observed a numerically longer operative time of 35 min in the robotic group compared to the laparoscopic group, yet this increase was not statistically significant ($P=0.41$). This may be explained by the notion that the use of robotic technology by experienced surgeons could lead to greater time efficiency. Furthermore, the present study, in line with the ROLARR trial [8], found no significant difference in hospital stay duration between the two groups.

Limited literature exists comparing long-term oncologic outcomes of robotic and laparoscopic surgery for rectal cancer. A recent meta-analysis found no significant difference in 3-year recurrence-free survival and OS between the two surgical techniques, regardless of surgeon experience [5]. A prior retrospective study provided evidence that robotic surgery was identified as a favorable prognostic factor for OS and cancer-specific survival, indicating potential oncologic advantages [22]. Another retrospective analysis conducted at a single-center tertiary academic institution revealed that robotic surgery for mid/low rectal cancer was particularly beneficial for a subgroup of patients with advanced rectal cancer who had a poor response (ypT3/4) to neoadjuvant chemoradiation [38]. In the present study, the 3-year OS and 3-year DFS rates were comparable between the robotic and laparoscopic groups, with no statistically significant differences in recurrence rates across various sites in trained hands. Despite the 3-year DFS being commonly used as a surrogate endpoint for 5-year OS [39], it is crucial to recognize that DFS can vary over an extended period. Consequently, it is important to conduct a more extensive follow-up of our cohort in relation to this new minimally invasive technology. Moreover, it is imperative to analyze the long-term outcomes derived from randomized trials, such as the REAL trial and the ROLARR trial.

This study is subject to certain limitations. Firstly, it is important to emphasize that our study is a retrospective analysis, which does not offer robust evidence for establishing causality regarding the benefits of laparoscopic or robotic surgery. The present study is inherently susceptible to patient selection bias due to notable demographic disparities between the groups. Despite our efforts to address this bias by employing adjusted data through a PSM method, it could not completely eradicate all forms of bias. Secondly, it is worth mentioning that both laparoscopic and robotic procedures were performed exclusively by highly experienced surgeons with a substantial case volume. Consequently, the findings of our study, conducted within a single institution, may not be readily applicable to all scenarios. Thirdly, due to the retrospective nature of the study, certain oncological surgical quality control indicators, such as the quality of the mesorectum, were not evaluated. Nevertheless, it is worth highlighting that the study did observe low rates of positive CRM and DRM (both less than 1%). Regarding short-term outcomes, the current data set did not include information on readmission rates, an area that warrants further investigation in our future studies. Lastly, the issue of increased cost associated with robotic procedures should not be disregarded.

## Conclusion

This study provided empirical evidence supporting the feasibility and efficacy of implementing robotic rectal cancer surgery, despite its inherent technical complexity. Comparable complication rates and long-term oncological outcomes were found between robotic rectal cancer surgery and laparoscopy. Furthermore, it shed light on supplementary benefits associated with this approach, such as decreased conversion rates and enhanced sphincter preservation, particularly when performed by skilled surgeons in specialized, high-volume medical facilities.

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**Authors' contributions**
Xiaojie Wang authored the manuscript, while Yangyang Wang gathered the data. All authors participated in data analysis, manuscript revisions, and approved the submission.

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**Data availability**
The data used and/or analyzed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Ethics approval and consent to participate**
The current research was approved by the Institutional Review Board of the Affiliated Union Hospital of Fujian Medical University under the reference number 2023KY222. All data were collected and analyzed anonymously. This retrospective study qualifies for a waiver of informed consent by the ethics committee.

**Consent for publication**
Not Applicable.

**Competing interests**
The authors declare no competing interests.

**Author details**
[1]Department of Colorectal Surgery, Union Hospital, Fujian Medical University, 29 Xin-Quan Road, Fuzhou, Fujian 350001, People's Republic of China.

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