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RESEARCH

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Comparison of laparoscopic versus robot-assisted sugery for rectal cancer after neo-adjuvant therapy: a large volume single center experience

Heyuan Zhu[1,2], Jingyu Zou[1,2], Hongfeng Pan[1,2], Ying Huang[2*] and Pan Chi[2]

Abstract

Purpose This study aims to assess the short- and long-term outcomes of rectal cancer patients undergoing robotic versus laparoscopic surgery after receiving neo-adjuvant therapy. There is a lack of clarity on this topic, necessitating a comprehensive comparison.

Method Between January 2017 and December 2021, consecutive patients who underwent laparoscopic and robotic rectal resection at a major public medical center were enrolled. All participants received neo-adjuvant chemoradiotherapy (nCRT) before surgery. The primary objective of this study was to assess the sphincter preservation rate and the rate of conversion to open surgery, using propensity score matching (PSM) analysis. Secondary endpoints included 5-year disease-free survival (DFS), 5-year overall survival (OS), short-term postoperative complications, long-term oncological prognosis, and the occurrence of low anterior resection syndrome (LARS).

Result A total of 575 patients diagnosed with rectal cancer participated in the cohort study, with 183 individuals undergoing robotic surgery and 392 undergoing laparoscopic surgery. Patients in the robotic group tended to be younger and had higher ypT, cT, and cN stages, lower tumor locations, and higher rates of extramural vascular invasion (EMVI) and circumferential resection margin (CRM) positivity. PSM resulted in 183 patients in the robotic group and 187 in the laparoscopic group. We found a higher sphincter preservation rate in robotic group compared with laparoscopic group (92.9% vs. 86.1%, $P=0.033$), with no significant difference in conversion to open surgery($P>0.05$). The robotic group had a higher incidence of postoperative chylous ascites (4.9% vs. 1.1%, $P=0.029$) and potentially lower sepsis occurrence (0% vs. 1.6%, $P=0.085$). No significant differences were observed in long-term oncological prognosis or 5-year survival rates ($P>0.05$). The median survival time for each group was 34 months. Subgroup analysis of 76 rectal cancer patients who underwent intersphincteric resection (ISR) surgery indicated that those who selected robotic surgery had higher cN and cT stages. Furthermore, no statistically significant differences were observed in short-term and long-term clinical outcomes, LARS, OS time, and DFS time between the two surgical modalities. The primary outcomes of interest, specifically the rate of sphincter preservation and the rate of conversion to open laparotomy, showed no significant differences.

*Correspondence:
Ying Huang
hy9033sy@sina.com

Full list of author information is available at the end of the article

Conclusion Robotic surgery for rectal cancer, following preoperative nCRT, demonstrates comparable technical safety and oncological outcomes to laparoscopic surgery. Further comprehensive studies are needed to to confirm the potential advantages of robotic surgical interventions.

Keywords Rectal cancer, Laparoscopic surgery, Robotic surgery, Neo-adjuvant chemoradiotherapy, Short-term prognosis, Long-term prognosis, Low anterior resection syndrome, Propensity-score matching analysis

Introduction

Colorectal cancer ranks as the third most prevalent cancer globally and is leading cause of cancer-related fatalities. Approximately 40% of colorectal cancer cases manifest in the rectum [1, 2]. Surgical technique study have reported local recurrence rates exceeding 20% [3]. Advancements in surgical techniques and the development of specialized instruments for rectal cancer have highlighted numerous advantages of minimally invasive surgery compared with traditional open procedures, including reduced blood loss, accelerated bowel recovery, and shorter hospital stays, while maintaining comparable long-term oncological outcomes [3, 4].

Nevertheless, there are persistent challenges with conventional laparoscopic surgery in rectal cancer procedures. The use of long and rigid instruments imposes inherent limitations, particularly for lower rectal cancers within the narrow confines of the pelvis. This limitation is evidenced by increased rates of positive circumferential resection margin observed in conventional laparoscopic surgery compared to open surgery for rectal procedures, as demonstrated in two randomized controlled trial studies (RCT) [5, 6].

For patients with advanced and locally advanced rectal cancer, nCRT is recommended prior to surgery to eliminate occult micrometastases and increase the rate of pathological complete response, thereby improving the prognosis of patients who cannot be cured by surgery alone [7]. However, nCRT inevitably inflicts damage upon normal cells, which may lead to tissue edema and fibrosis [8–10]. Particularly in obese patients or those with pelvic stenosis, this can complicate surgical procedures by obscuring anatomical landmarks.

Robotic surgery holds promise in overcoming these limitations by offering a three-dimensional perspective of the surgical field, flexible maneuverability of instruments, and a stable camera platform [11, 12]. These advantages may address the challenges of laparoscopy in rectal surgeries, particularly in narrow pelvises following nCRT [13, 14]. However, the impact of robotic surgery on rectal cancer patients who have undergone nCRT remains uncertain, given the limited evidence with conflicting results in small-sample retrospective studies and the absence of RCTs.

Therefore, this study aims to compare the postoperative outcomes and short- and long-term tumor outcomes between robotic and laparoscopic surgery in rectal cancer patients after nCRT, using PSM analysis.

Method

Between January 2017 and December 2021, a cohort of 1,576 patients underwent either robotic or laparoscopic surgery for rectal cancer at the Department of Colorectal Surgery, Union Hospital Affiliated to Fujian Medical University. 575 patients received nCRT and met the inclusion criteria for the study.

Rectal cancer was defined as pathologically confirmed adenocarcinoma located within 15 cm from the anal margin. All surgical procedures were performed by a team of highly skilled surgeons, each with over 350 annual laparoscopic or robotic colorectal cancer surgeries.To ensure the robustness of the study, cases from the initial study period for robotic surgery (March 2016 to December 2016) were excluded, ensuring that surgeons had effectively overcome the learning curve for robotic surgery. The choice of surgical technique was determined at the surgeon's discretion, considering tumor stage, location, and the availability of the Da Vinci surgical system (Intuitive Surgical, Sunnyvale, CA).

To improve the validity and reliability of the results, patients without undergoing nCRT ($n = 814$), with unspecified types of surgery ($n = 29$), stage IV disease ($n = 90$), open surgery ($n = 16$), recurrent cancer ($n = 9$), synchronous or heterogeneous colorectal cancer ($n = 7$), or lacked crucial baseline information such as pathological T or N stage or tumor distance from the anal margin ($n = 36$) were excluded from the analysis (see Fig. 1). Ethical approval for this study was obtained from the Institutional Review Committee at Union Hospital Affiliated to Fujian Medical University.

Treatment and follow-up

All patients underwent comprehensive preoperative staging, including a digital rectal examination, colonoscopy, chest radiography, endorectal ultrasound examination (ERUS), abdominopelvic computed tomography (CT), and pelvic magnetic resonance imaging (MRI). Patients with clinical T3/4 tumors presenting with threatened mesorectal fascia (< 1 mm due to tumor or lymph nodes), regardless of N stage, received nCRT. Surgery was scheduled 6–10 weeks after completing preoperative radiotherapy.

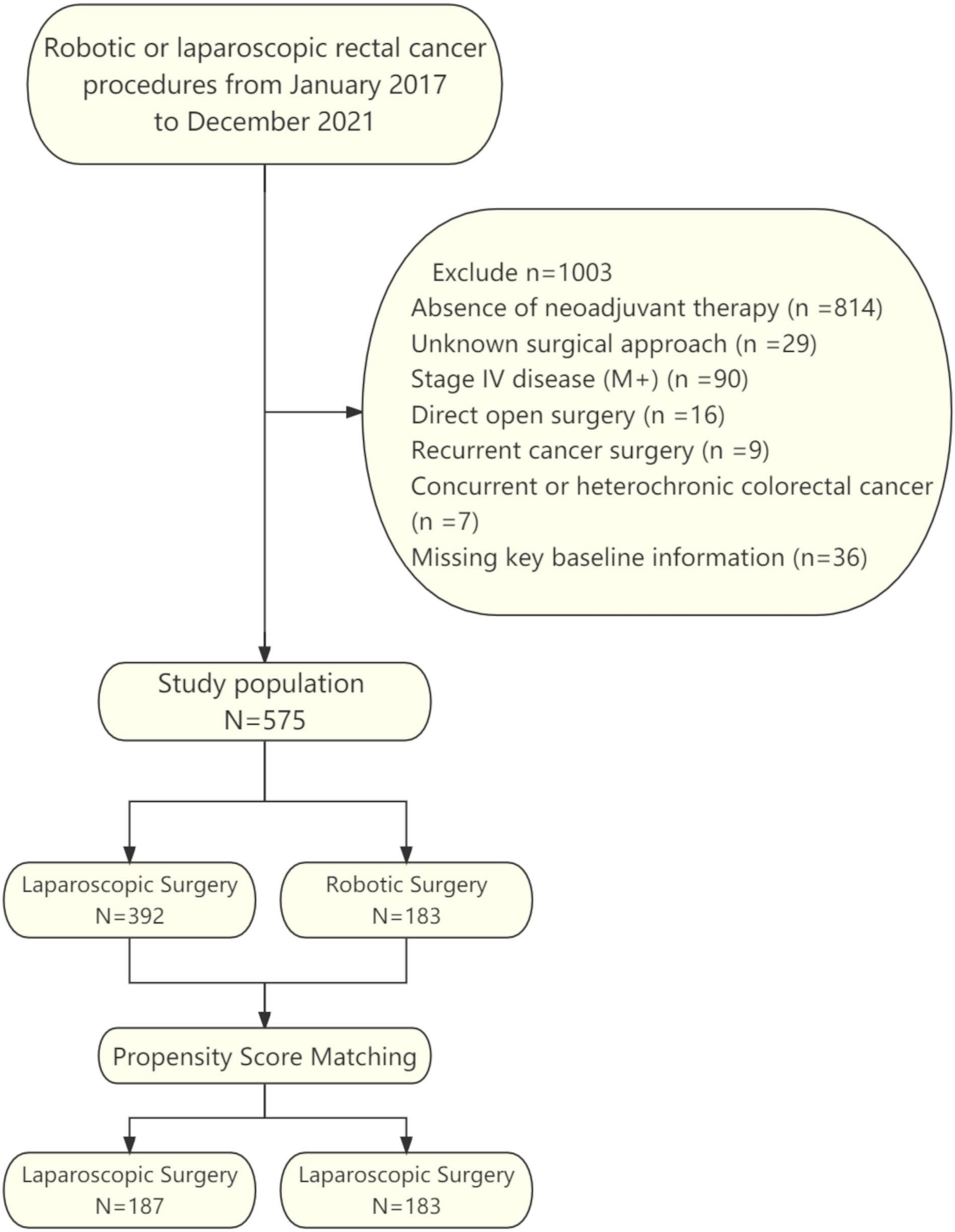

Fig. 1 Inclusion and exclusion criteria for the study

For patients with rectal cancer, our center will undertake the following preoperative preparations:

1. Mechanical Bowel Preparation:

1. Patients without obstructive symptoms: On the day prior to surgery, oral administration of Polyethylene Glycol was performed.
2. Patients with tumors blocking colonoscope passage but without obstructive symptoms: Upon admission, patients were provided with a low-residue semi-fluid diet and prescribed lactulose. On the day before surgery, Polyethylene Glycol was administered in small doses multiple times orally, and a cleansing enema was given if necessary, based on the condition of the last bowel movement.
3. Patients with significant obstructive symptoms who were unsuitable for intestinal stenting: On the day prior to surgery, a rectal cleansing enema was administered, and an additional cleansing enema was given on the morning of surgery.

2. Preoperative oral antibiotics: On the day prior to surgery, patients are administered metronidazole in combination with gentamicin.

Before surgery, all patients were informed about both robotic and laparoscopic surgical techniques. They were advised that no empirical evidence indicating the superiority of one procedure over the other. The potential advantages of robotic assistance in pelvic dissection were explained, along with the higher cost of RMB 30,000 for robotic surgery compared to the laparoscopic approach, aligning with surgical pricing standards in the Fujian province.

All patients underwent standard surgical resection, with mid/low rectal cancers undergoing total mesorectal excision (TME) and high rectal cancers undergoing partial mesorectal excision with a distal margin of at least 5 cm. Robotic procedures were performed using the da Vinci surgical system, with a single docking and the robotic cart positioned beside the patient's left lower quadrant. The robotic system was utilized for primary vascular ligation, sigmoid colon mobilization, and mesorectal dissection. Both the Si and Xi generations of the da Vinci Surgical System are employed in our practice. The choice between these two systems is determined by the availability of the surgical machinery and the scheduling of operating room slots. Subsequent steps, including anastomosis and, if needed, splenic flexure colon mobilization, were carried out in the same manner as laparoscopic surgery after removing the robot cart from the patient's bed. To ensure a 1 centimeter clear distal margin during surgery, rectal palpation or rectoscopy was performed by an assistant following rectal mobilization and prior to linear stapling closure. The criteria for temporary ileostomy and postoperative care were consistent for both approaches.

Patients diagnosed with pathologic stage II/III tumors or those who underwent nCRT were recommended to receive adjuvant chemotherapy based on 5-fluorouracil. Postoperative surveillance was conducted at three-month intervals during the initial two-year period, followed by annual assessments thereafter. Each visit included imaging studies such as chest radiography and abdominopelvic MRI or CT. Colonoscopy was performed within three months to one year post-surgery, with annual repeats thereafter. Positron emission tomography (PET) was implemented as necessary to improve diagnostic accuracy.

Definition

The primary outcome focused on sphincter preservation and the necessity for conversion to open surgery. Secondary endpoints encompassed 5-year OS rate,5-year DFS rate, additional short-term and long-term outcomes, and the occurrence of LARS. Pathological specimens were meticulously examined to determine the pathological TNM stage and microsurgical margin. A positive peri-pathological margin was defined as a margin without cancer measuring < 1 mm. Sphincter preservation included surgical procedures aimed at cancer management, such as anastomosis between the colon and rectum or anus, specifically anterior resection and ISR. Patients retaining the sphincter with ileal circumstomy or transcolostomy at the time of transfer were also considered to have retained the sphincter.

Conversion laparotomy entailed the use of an open surgical wound during any stage of mesenteric dissection. However, it's important to note that performing low-level anastomosis and/or specimen extraction through a small abdominal wound was permissible and did not constitute conversion surgery. OS was defined as the duration from surgery until death or final confirmation of survival, and DFS was the duration from surgery until first recurrence, metastasis, or death from any cause, whichever came first. Local recurrence referred to tumor growth in the pelvic cavity regardless of its direction or relationship with anastomosis. Distant recurrence was defined as tumor recurrence outside the pelvis, including metastasis to the liver, lungs, bone, or peritoneum.

Postoperative intestinal function was evaluated using the Chinese version of the LARS scoring system [15], comprising five questions related to intestinal function. Each participant's response was scored based on symptom severity: a score ranging from 0 to 20 indicates no LARS; a score ranging from 21 to 29 indicates mild LARS; and a score ranging from 30 to 42 indicates severe LARS.

Statistical analysis

Patients were stratified into two groups: participants undergoing laparoscopic surgery and those undergoing robotic surgery. Fisher's exact test and chi-square test were employed to compare discrete variables between the groups, while parametric tests (Student's t-test) and non-parametric tests (Mann-Whitney U, Kruskal-Wallis) were used, as appropriate, to compare continuous outcomes. DFS and OS were summarized using the Kaplan-Meier method, with the log-rank test applied for comparison.

PSM was conducted using a logistic regression model for each patient to address baseline confounders between the groups. Covariates included age, sex, body mass index (BMI), tumor distance from the anal margin, EMVI, CRM, histological type, ypT stage, ypN stage, cT stage, and cN stage. One-to-one matching was performed with a caliper width of 0.2 without replacement. Baseline characteristics, including operative outcomes, postoperative complications, and pathological findings, which were not included in the propensity score model, were subsequently compared between laparoscopic surgery and robotic surgery. A level of $p<0.05$ was considered statistically significant. Furthermore, we conducted a subgroup analysis comparing laparoscopic surgery with robotic surgery in patients from the ISR group and the non-ISR group. All statistical analyses were conducted using R (version 3.5.1) and SPSS (version 26).

Results

Baseline characteristics

A total of 575 patients with rectal cancer who underwent nCRT were included in the dataset. The robotic surgery group comprised 183 cases, while the laparoscopic surgery group consisted of 392 cases. PSM was performed for both groups, resulting in 183 cases in the robot group and 187 cases in the laparoscopic group.

Table 1 displays the baseline characteristics of patients before and after PSM. Before PSM, the results in Table 1 indicated that the patients in robotic surgery is younger than those in laparoscopic group. Furthermore, patients in the robotic group exhibited higher positive rates for clinical tumor stage (cT stage), clinical lymph node stage (cN stage), EMVI, and CRM. They also had a lower tumor location compared to those in the laparoscopic

Table 1 Baseline characteristics

	Unmatched patient			matched patient		
Variable	**Laparoscopic surgery**	**Robotic surgery**	***p*-value**	**Laparoscopic surgery**	**Robotic surgery**	***p*-value**
N	**392**	**183**		**187**	**183**	
Gender						
Male	**256(65.3%)**	**117(63.9%)**	**0.748**	**123(65.8%)**	**117(63.9%)**	**0.711**
Female	**136(34.7%)**	**66(36.1%)**		**64(34.2%)**	**66(36.1%)**	
Age	**59.8(56.3,62.2)**	**56.9(54.1,60.1)**	**0.006**	**57.5(54.2,60.9)**	**57.2(54.3,60.4)**	**0.63**
Body mass index, kg/m2	**23.1 (20.8, 24.6)**	**22.7(20.8, 24.9)**	**0.728**	**22.1(20.2,24.1)**	**22.8(20.5,25.2)**	**0.056**
Hypertension	**86(21.9%)**	**40(21.9%)**	**0.983**	**43(23.0%)**	**40(21.9%)**	**0.793**
Diabetes	**35(8.9%)**	**21(11.5%)**	**0.337**	**21(11.2%)**	**21(11.5%)**	**0.941**
(y)pT			**0.029**			**0.508**
T0-2	**193(49.2%)**	**108(59.0%)**		**104(55.6%)**	**108(59.0%)**	
T3-4	**199(50.8%)**	**75(41.0%)**		**83(44.4%)**	**75(41.0%)**	
(y)pN			**0.995**			**0.463**
N0	**305(77.8%)**	**142(77.6%)**		**139(74.3%)**	**142(77.6%)**	
N1-2	**87(22.2%)**	**41(22.4%)**		**48(25.7%)**	**41(22.4%)**	
cT			**0.006**			**0.792**
T1-2	**42(10.9%)**	**7(3.9%)**		**8(4.5%)**	**7(3.9%)**	
T3-4	**342(89.1%)**	**172(96.1%)**		**171(95.5%)**	**172(96.1%)**	
cN			**< 0.001**			**0.395**
N0	**237(61.7%)**	**76(45.2%)**		**84(12.2%)**	**76(3.9%)**	
N1-2	**147(38.3%)**	**103(57.5%)**		**95(87.8%)**	**103(96.1%)**	
Tumor distance to anal verge (cm)	**6(4.0,8.0)**	**5(4.0,7.0)**	**< 0.001**	**5(3.0,7.0)**	**5(4.0,7.0)**	**0.53**
Positive EMVI	**124(32.3%)**	**82(45.8%)**	**0.002**	**87(46.5%)**	**82(44.8%)**	**0.741**
Circumferential margin involvement	**81(21.1%)**	**74(41.3%)**	**< 0.001**	**72(38.5%)**	**74(40.4%)**	**0.703**
Histopathology			**0.709**			**0.707**
Adenocarcinoma	**373(95.2%)**	**174(95.1%)**		**175(93.6%)**	**174(95.1%)**	
Mucinous adenocarcinoma	**17(4.3%)**	**7(3.8%)**		**10(5.3%)**	**7(3.8%)**	
Signet ring adenocarcinoma	**2(0.5%)**	**2(1.1%)**		**2(1.1%)**	**2(1.1%)**	

EMVI, extramural venous invasion

group, indicating more challenging and complex surgical cases. All patients in both groups successfully completed preoperative nCRT.

Postoperative pathological tumor stage (ypT stage) and postoperative pathological lymph node stage (ypN stage) were lower in the robotic group than in the laparoscopic group. However, this difference could be attributed to variations in participant numbers between the two groups. Following PSM treatment, all covariates between both groups were effectively balanced, rendering them comparable without any significant differences noted between their respective datasets.

Additionally, a subgroup analysis was conducted within the ISR cohort, comparing the laparoscopic surgery group with the robotic surgery group (Table 2). This series comprised a total of 76 patients, with 27 cases in the laparoscopic surgery group and 49 cases in the robotic surgery group. The analysis revealed that the robotic group had higher cN and cT staging. No significant differences were observed in the remaining baseline characteristics.

Short-term clinical outcomes

Following PSM, both groups exhibited a median tumor-to-sphincter distance of 5 cm (Table 3). Differences were observed in the choice of operation between the two surgical types. The laparoscopic group showed a higher preference for Anterior Resection (AR) (66.1% vs. 78.6%), while the robotic group favored intersphincteric resection (ISR) (26.8% vs. 7.5%). Rates for abdominoperineal resection (APR) were similar between the two groups (7.1% vs. 13.9%).

Superior sphincter retention was observed in the robotic group compared to the laparoscopic group based on primary evaluation measures (92.9% vs. 86%, $p = 0.033$), with no significant difference in the rate of conversion to laparotomy during surgery between the two groups (1.1% vs. 0.5%, $p = 0.570$). Additionally, a higher incidence of postoperative chylous ascites was observed in the robotic group compared to the laparoscopic group (4.5% vs. 1.1%, $p = 0.029$), while a lower likelihood of postoperative sepsis was observed (0% vs. 1.6%, $p = 0.085$).

Moreover, there were no significant differences in the incidence rates of anastomotic leakage, anastomotic

Table 2 ISR & non-ISR baseline characteristics

Variable ISR non-ISRcopic surgery
Robotic surgeryP valueLaparoscopic surgeryobotic surgery
***P* value**

N	27	49		365	134	
Gender			0.256			0.757
Male	19(70.4%)	28(57.1%)		237(64.9%)	89(66.4%)	
Female	8(29.6%)	21(42.9%)		128(35.1%)	45(33.6%)	
Age	53.56(53.11,53.61)	56.67(56.223,56.72)	0.361	54.31(53.62,55.41)	55.12(54.68,56.82)	0.496
Body mass index, kg/m2	22.87(22.41,23.47)	22.67(22.21,23.29)	0.796	22.29(21.92,22.35)	22.79(22.42,22.85)	0.154
Hypertension	5(18.5%)	11(22.4%)	0.688	81(22.2%)	29(21.6%)	0.895
Diabetes	3(11.1%)	3(6.1%)	0.44	32(8.8%)	18(13.4%)	0.124
(y)pT			0.601			0.103
T0-2	16(59.3%)	32(65.3%)		177(48.5%)	76(56.7%)	
T3-4	11(40.7%)	17(34.7%)		188(51.5%)	58(43.3%)	
(y)pN			0.303			0.977
N0	24(88.9%)	39(79.6%)		281(77.0%)	103(76.9%)	
N1-2	3(11.1%)	10(20.4%)		84(23.0%)	31(23.1%)	
cT			0.04			0.015
T1-2	19(70.4%)	22(45.8%)		35(9.8%)	4(3.1%)	
T3-4	8(29.6%)	26(54.2%)		322(90.2%)	127(96.9%)	
cN			0.016			< 0.001
N0	7(25.9%)	3(6.3%)		218(61.1%)	54(41.2%)	
N1-2	20(74.1%)	45(93.8%)		139(38.9%)	77(58.8%)	
Tumor distance to anal verge (cm)	3.85(3.32,4.26)	3.94(3.41,4.34)	0.786	6.30(6.29,6.68)	5.85(5.7,6.23)	0.07
Positive EMVI	10(37.0%)	19(38.8%)	0.881	114(31.2%)	63(47.0%)	0.001
Circumferential margin involvement	7(25.9%)	21(42.9%)	0.143	74(20.3%)	53(39.6%)	< 0.001
Histopathology			0.561			0.525
Adenocarcinoma	26(96.3%)	44(89.8%)		347(95.1%)	130(97.0%)	
Mucinous adenocarcinoma	1(3.7%)	4(8.2%)		16(4.4%)	3(2.2%)	
Signet ring adenocarcinoma	0	1(2.0%)		2(0.5%)	1(0.7%)	

Table 3 Short-term outcomes

	Unmatched patient			matched patient		
Variable	**Laparoscopic surgery**	**Robotic surgery**	***p*-value**	**Laparoscopic surgery**	**Robotic surgery**	***p*-value**
N	**392**	**183**		**187**	**183**	
Surgical procedure			**< 0.001**			**< 0.001**
Anterior resection	**322(82.1%)**	**121(66.1%)**		**147(78.6%)**	**121(66.1%)**	
Intersphincteric resection	**27(6.9%)**	**49(29.8%)**		**14(7.5%)**	**49(26.8%)**	
Abdominoperineal resection	**43(11.0%)**	**13(7.1%)**		**26(13.9%)**	**13(7.1%)**	
Sphincter preservation	**349(89.0%)**	**170(92.9%)**	**0.145**	**161(86.1%)**	**170(92.9%)**	**0.033**
Conversion to laparotomy	**5(1.3%)**	**2(1.1%)**	**0.852**	**3(0.5%)**	**2(1.1%)**	**0.67**
Diverting ostomy	**287(73.2%)**	**145(79.2%)**	**0.12**	**142(75.9%)**	**145(79.2%)**	**0.447**
Anastomotic leakage	**18(4.6%)**	**12(6.6%)**	**0.324**	**11(5.9%)**	**12(6.6%)**	**0.5**
Anastomotic bleeding	**1(0.3%)**	**1(0.5%)**	**0.58**	**1(0.5%)**	**1(0.5%)**	**0.988**
Intraabdominal infection	**16(4.1%)**	**7(3.8%)**	**0.884**	**11(5.9%)**	**7(3.8%)**	**0.778**
Wound infection	**3(0.8%)**	**3(1.6%)**	**0.337**	**2(1.1%)**	**3(1.6%)**	**0.635**
Pneumonia	**10(97.4%)**	**2(98.9%)**	**0.255**	**4(2.1%)**	**2(1.1%)**	**0.426**
Chylous ascite	**11(2.8%)**	**9(4.9%)**	**0.198**	**2(1.1%)**	**9(4.9%)**	**0.029**
Early postoperative small bowel obstruction	**5(1.3%)**	**1(0.5%)**	**0.432**	**3(1.6%)**	**1(0.5%)**	**0.325**
Sepsis	**3(0.8%)**	**0**	**0.235**	**3(1.6%)**	**0(0%)**	**0.085**
Neural invasion	**39(9.9%)**	**19(10.4%)**	**0.872**	**21(11.2%)**	**19(10.4%)**	**0.793**
Vascular invasion	**11(2.8%)**	**4(2.2%)**	**0.703**	**4(2.1%)**	**4(2.2%)**	**0.975**
Lymph nodes retrieved	**16(11.0, 22.0)**	**14(9.0, 18.0)**	**< 0.001**	**15.0 (9.0, 19.0)**	**14.0 (9.0, 18.0)**	**0.24**

Table 4 ISR & non-ISR short-term outcomes

	ISR			non-ISR		
Variable	**Laparoscopic surgery**	**Robotic surgery**	***P* value**	**Laparoscopic surgery**	**Robotic surgery**	***P* value**
N	27	49		365	134	
Conversion to laparotomy	0	0	/	5(1.4%)	2(1.5%)	0.918
Diverting ostomy	27(100%)	47(95.9%)	0.287	260(71.2%)	98(73.1%)	0.676
Anastomotic leakage	3(11.1%)	8(16.3%)	0.536	15(4.1%)	4(3.0%)	0.561
Anastomotic bleeding	0	1(2.0%)	0.658	1(0.3%)	0	0.544
Intraabdominal infection	2(7.4%)	5(10.2%)	0.687	14(3.8%)	2(1.5%)	0.188
Wound infection	0	0	/	3(0.8%)	3(2.2%)	0.198
Pneumonia	1(3.7%)	0	0.175	9(2.5%)	2(1.5%)	0.512
Chylous ascite	1(3.7%)	2(4.1%)	0.935	10(2.7%)	7(5.2%)	0.175
Early postoperative small bowel obstruction	0	0	/	5(1.4%)	1(0.7%)	0.571
Sepsis	0	0	/	3(0.8%)	0	0.293
Neural invasion	0	4(8.2%)	0.127	39(10.7%)	15(11.2%)	0.871
Vascular invasion	0	0	/	11(3.0%)	4(3.0%)	0.987
Lymph nodes retrieved	13(13,14)	11(11,12)	0.234	13(13,14)	12(12,14)	0.65

bleeding, intraperitoneal infection, incision infection, pneumonia, and early postoperative small bowel obstruction between both groups. No significant differences were found regarding positive rates for EMVI and CRM, vascular invasion, nervous invasion, and number of lymph node dissections ($p > 0.05$). The postoperative hospital stay was similar between the two groups. There were no 30-day mortalities in either group.

Neither the laparoscopic surgery group nor the robotic surgery group experienced cases requiring conversion to open laparotomy. The subgroup analysis results demonstrated that there were no significant differences in short-term outcomes among patients who underwent either of the two surgical approaches (Table 4).

Long-term clinical outcomes

A total of 464 patients were included in the long-term prognosis analysis, focusing on local recurrence and metastasis, with a median follow-up time of 34 months in both groups. The comparison between groups revealed no significant difference in the 5-year OS rates(92.83% vs. 90.85% $P = 0.347$) and 5-year DFS rates(77.89% vs.

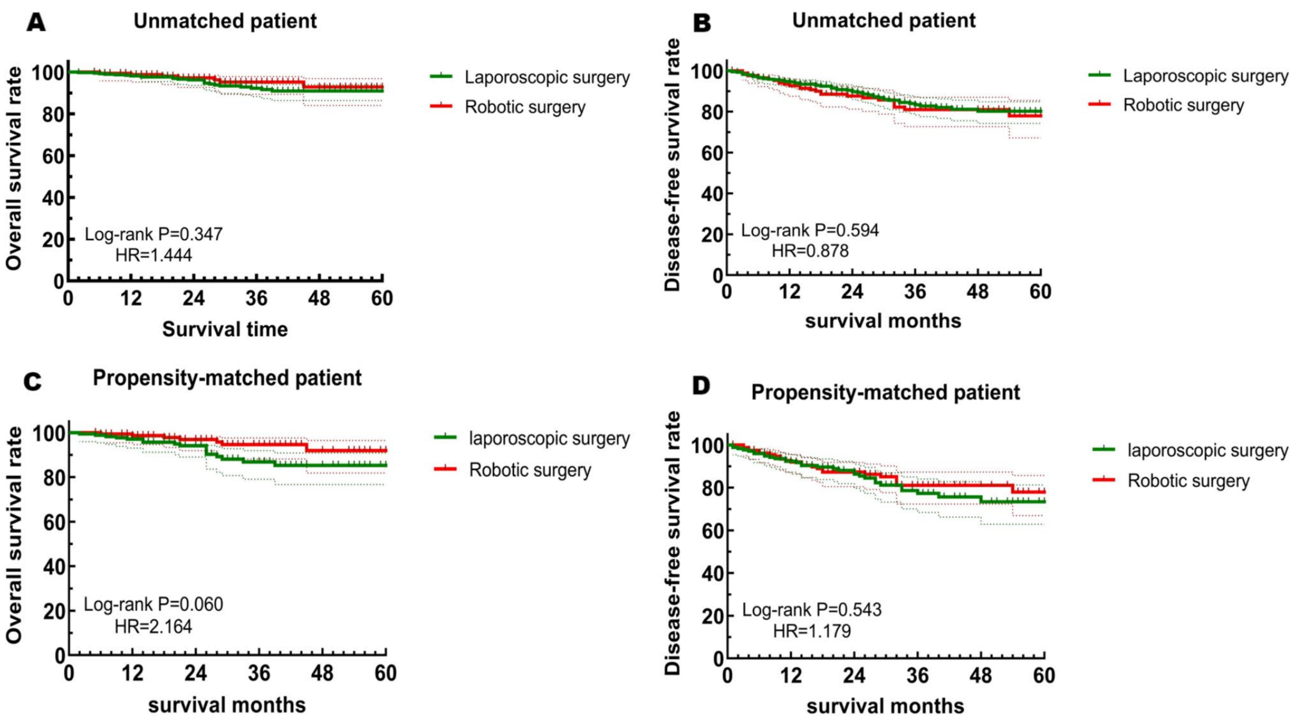

Fig. 2 Comparison of overall survival and disease-free survival rates between Laparoscopic and Robotic Surgery in the unmatched and propensity score matching patients. **A**. Comparison of overall survival rates between Laparoscopic and Robotic Surgery in the unmatched patients. **B**. Comparison of disease-free survival rates between Laparoscopic and Robotic Surgery in the unmatched patients. **C**. Comparison of overall survival rates between Laparoscopic and Robotic Surgery in the propensity score matching patients. **D**. Comparison of disease-free rates between Laparoscopic and Robotic Surgery in the propensity score matching patients

Table 5 Recurrence data and intestinal function outcomes

	Unmatched patient			Matched patient		
Variable	Laparoscopic surgery	Robotic surgery	*p*-value	Laparoscopic surgery	Robotic surgery	*p*-value
N	301	163		159	179	
Local recurrence	5(1.7%)	4(2.5%)	0.554	3(2.0%)	4(2.5%)	0.793
Liver metastases	18(5.5%)	14(7.8%)	0.298	10(9.4%)	14(7.8%)	0.552
Lung metastases	17(5.2%)	5(2.8%)	0.209	9(5.6%)	5(2.8%)	0.199
Bone metastases	2(0.6%)	4(2.2%)	0.105	1(0.6%)	4(2.2%)	0.215
Peritoneal metastases	1(0.3%)	1(0.6%)	0.661	1(99.4%)	1(99.4%)	0.944
LARS①			0.61			0.557
No	238(72.3%)	134(74.9%)		114(70.4%)	134(74.9%)	
Minor	45(13.7%)	19(10.6%)		23(14.2%)	19(10.6%)	
Major	46(14.0%)	26(14.5%)		25(15.4%)	26(14.5%)	

①LARS, Low anterior resection syndrome

Data were obtained from 464 patients

80.17% $P=0.594$). After conducting PSM comparison, no significant difference was observed in the 5-year DFS rate(77.91% vs. 73.75% $P=0.543$) between the two groups. However, it is worth noting that the robot group exhibited a non-significant trend of better 5-year OS rate compared to laparoscopic group (91.91% vs. 85.25% $P=0.060$), as illustrated in Fig. 2. Regarding local recurrence and metastasis (including liver, lung, bone, and peritoneal metastasis), no statistical difference was found between the two surgical approaches (see Table 5). Additionally, LARS scores were conducted on 508 patients with sphincter preservation, revealing similar incidences of severe and mild LARS in both groups.

The subgroup analysis revealed that there were no significant differences in long-term outcomes and LARS scores between patients who underwent the two surgical approaches (Table 6). Additionally, no differences were observed in the 5-year OS and DFS rates between the two groups (Fig. 3).

Table 6 ISR & non-ISR recurrence data and intestinal function outcomes

	ISR			non-ISR		
Variable	**Laparoscopic surgery**	**Robotic surgery**	***P* value**	**Laparoscopic surgery**	**Robotic surgery**	***P* value**
N	24	48		305	131	
Local recurrence	0	0	/	5(1.8%)	4(3.3%)	0.359
Liver metastases	2(8.3%)	2(4.2%)	0.467	15(4.9%)	3(2.3%)	0.206
Lung metastases	3(12.5%)	4(8.3%)	0.574	15(4.9%)	10(7.6%)	0.264
Bone metastases	1(4.2%)	2(4.2%)	0.986	1(0.3%)	2(1.5%)	0.165
Peritoneal metastases	0	0	/	1(0.3%)	1(0.8%)	0.537
LARS			0.937			0.455
No	16(66.7%)	34(70.8%)		222(72.8%)	100(76.3%)	
Minor	4(16.7%)	7(14.6%)		4(13.4%)	12(9.2%)	
Major	4(16.7%)	7(14.6%)		42(13.8%)	19(14.5%)	
Data were obtained from 72 patients.				Data were obtained from 436 patients.		

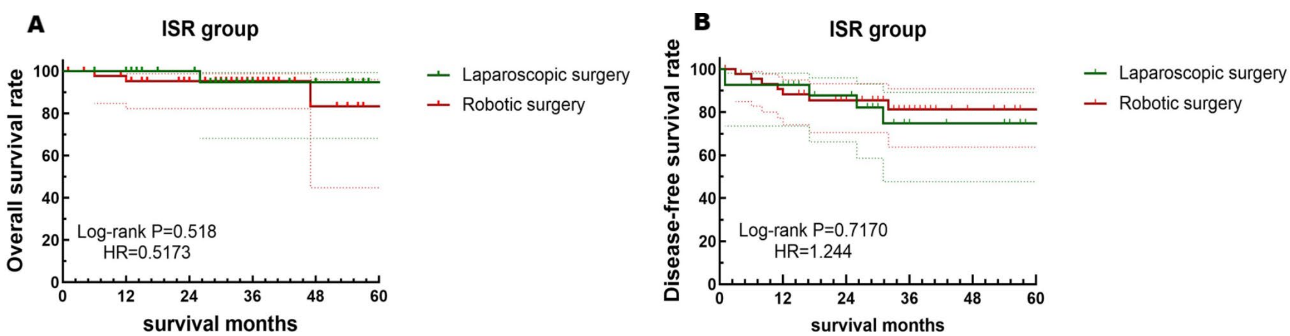

Fig. 3 Comparative analysis of overall survival and disease-free survival rates in the ISR cohort: Laparoscopic Surgery versus Robotic Surgery. **A**. Comparison of overall survival rates in the ISR cohort: Laparoscopic versus Robotic Surgery. **B**. Comparison of disease-free rates in the ISR cohort: Laparoscopic versus Robotic Surgery

Discussion

This cohort study investigates the short- or long-term survival outcomes in patients with neo-adjuvant rectal cancer who underwent either robotic or laparoscopic surgery. The robotic surgery group demonstrated distinct characteristics, which is in line with prior findings [16]. Compared with the robotic group, the laparoscopic group had a younger age distribution and lower tumor location, while demonstrating higher cT and cN stage, along with a greater incidence of EMVI and CRM involvement rate as determined by MRI.

The robotic-assisted ISR procedures, an key measure for sphincter preservation, is more common compared to those performed laparoscopically [17, 18]. The complexity of the operation may be attributed to the low location of the tumour and the limited visibility afforded by the ISR approach [19]. nCRT frequently leads to tissue oedema and obscure anatomical planes, further complicating ISR procedures.These restricted field of view can make it challenge to adequately expose the surgical site, elevating the risk of straying into incorrect anatomical planes [20].

Robotic technology improves the anatomical visualization, facilitating the identification and accessibility of the intersphincteric space between the internal and external sphincters for transabdominal surgery in ISR [21]. Previous studies have demonstrated no statistically significant difference in prognosis between robotic and laparoscopic surgery [22–24]. Moreover, robotic surgery also exhibits potential advantages for patients with complex conditions following neoadjuvant therapy, such as those with low tumor location, severe pelvic adhesion, and high cT stage [11, 25]. However, these studies have limitations, including the absence of PSM and variations in the proportion of nCRT received between groups.

To address these limitations, our study used PSM analyses to mitigate potential selection bias and adjust for significant differences in baseline characteristics among patients with rectal cancer to ensure comparability between the two groups, this is the advantage of our experiment compared to previous experiments. The characteristics considered in the PSM analyses included cT staging, cN staging, EMVI, CRM, sphincter preservation, intraoperative conversion to open surgery, complications, tumor recurrence, and survival outcomes demonstrated statistical significance. Our study, therefore, provide empirical evidence for subsequent comparative investigation on the two procedures.

Robotic-assisted surgery offers distinct advantages in the execution of ISR, which is particularly beneficial in the context of complex and challenging cases such as low or ultralow rectal cancer surgeries [26, 27]. Consequently, there is a preference for utilizing robotic surgery for ISR in these situations. However, the analytical results may not have adequately accounted for the adjustment of ISR rates. To enhance the precision of our study, we performed a separate subgroup analysis for ISR cases. Patients in the robotic surgery group exhibited higher cN and cT stages, leading to a clinical preference for robotic surgery in managing these complex cases as determined by the surgical team. However, our analysis revealed no observed differences in short-term outcomes, long-term outcomes, or LARS scores between the two surgical approaches for ISR. Concurrently, this affirms the feasibility and safety of the treatment options.Through more refined cohort selection and subgroup analysis, a better understanding of the strengths and limitations of each technique can be achieved, thereby providing stronger support for clinical decision-making.

The short-term prognostic advantages of the two surgical methods were analyzed, showing that the robot group exhibited a higher rate of sphincter preservation.The avoidance of a permanent stoma is a paramount concern for individuals diagnosed with rectal cancer, as it holds equal importance to achieving cancer remission [28]. With the increased utilization of nCRT, enhanced comprehension of tumor biology, and advancements in surgical techniques and stapling devices, the prevalence of sphincter-preserving surgery has significantly increased. Robotic surgery serves as an option to address the challenging issues faced by patients.

Previous reports have confirmed that up to 20% of patients undergoing low or ultra-low anterior resection for rectal cancer develop anastomotic leaks, which are directly associated with increased local recurrence and reduced OS in these patients [4, 25, 29–31]. Prophylactic temporary ileostomy has been demonstrated to effectively decrease the incidence of anastomotic leaks, thereby improving patient outcomes. Consequently, we posit that the routine implementation of prophylactic temporary ostomy is highly necessary for high-risk patients prone to anastomotic leaks, such as those with pelvic stenosis, obesity, diabetes mellitus, anemia, severe comorbidities, preoperative chemoradiation, inflammatory bowel disease, poor blood supply to the anastomosis, and high tension at the anastomotic site, in order to protect the anastomosis.

Wound infection and intra-abdominal infection are postoperative complications that warrant our close attention [28]. Guidelines and literature suggest that in the era of enhanced recovery after surgery, mechanical bowel preparation and oral antibiotics prior to minimally invasive surgery for rectal procedures can reduce the incidence of surgical site infections, anastomotic leaks, and postoperative sepsis, and effectively improve patient treatment outcomes and prognosis [32–35]. Our center adheres to this perspective and conducts thorough bowel preparation preoperatively, along with instructing patients to orally take metronidazole and gentamicin.

The assurance of tumor-free surgical margins ensures the safety of the procedure and guarantees the prognosis of the patients.Some medical centers may employ nanometer-scale carbon marking of the lesion site preoperatively, or place anastomotic markers under endoscopic guidance, to ensure that the resection margin is more than 1 centimeter away from the tumor [36, 37]. In our center, we have an assistant perform rectal palpation or use a colonoscope to ensure the distance of the resection margin, thereby ensuring the safety of the surgery.

A previous comparative study demonstrated that robotic surgery exhibited superior sphincter preservation capacity (86% vs. 74%, $P=0.045$) and more favorable intraoperative bleeding and conversion rates compared to laparoscopic surgery for patients with rectal tumors at the same location [38]. However, in that study cohort, there was an imbalance in the distribution of nCRT between the robotic and laparoscopic groups. The multicenter REAL trials have indicated that robotic surgery holds promise for improving the rate of LAR, although the preservation of the sphincter was not the primary outcome [39].

After addressing the limitations by using PSM analysis, our study also found that the robotic group demonstrated a statistically significant 6.8% higher rate of sphincter preservation compared to the laparoscopic group ($P<0.05$), under the skilled guidance of experienced surgeons. These results support those reported in existing studies and emphasise the potential advantages of robotic surgery in preserving sphincter function. An innovative component of our study involves evaluating postoperative bowel function in two groups of patients who underwent intersphincter preservation, with the aim of assessing the incidence of mild or severe LARS. The importance of this study is underscored by the notable prevalence of sphincter preservation and the preference for ISR surgery within the robotic surgery group. Moreover, the adoption of this scoring system allows for a thorough assessment of patient prognosis and recovery.The findings indicated no significant disparity in the occurrence of mild, moderate, and severe LARS between the two cohorts, thereby substantiating the safety and favorable prognosis associated with robotic surgery.

Moreover, we observed a higher incidence of postoperative chylous ascites in patients undergoing robotic surgery compared to those undergoing laparoscopic surgery (4.9% vs. 1.1%, $p=0.029$), consistent with the clinical outcomes we observed during the postoperative period. This finding may be explained by several factors: in robotic surgery, the use of an ultrasonic knife for dissection of the submesenteric artery root leads to shorter operation durations but compromises the coagulation of lymphatic vessels. Additionally, the absence of force feedback in robotic systems increases the risk of surgeons inadequately sealing the inferior mesenteric arterial sheath, which is densely populated with lymphatics. This incomplete closure can subsequently result in chylous ascites.

The prevalence of chylous ascites in colorectal cancer varies from 1.0 to 7.8%, particularly among patients who have undergone nCRT [40, 41]. In our center, the prevalence ranges from 1.1 to 4.9%, which aligns with existing reports. Studies have indicated that patients with chylous ascites was younger than those without (52.4 years vs. 56.4 years, $P = 0.043$). Additionally, a higher proportion of patients in the chylous ascites group undergo minimally invasive procedures such as laparoscopic and robotic surgeries, with robotic surgery demonstrating the highest incidence of postoperative chylous ascites (6.9%, 6/86), followed by laparoscopic surgery (4.2%, 26/618) and open surgery (1.0%, 2/192,$P = 0.021$) [41]. The available data suggests an association between chylous ascites and an increased number of lymph node excisions, potentially attributed to the vulnerability of the extensive lymphatic channels within the lymph nodes during vascular structure skeletonization [42]. The findings of this study suggest that surgeons should prioritize the protection of lymphatic vessels during lower mesenteric artery sheath surgery for rectal cancer to effectively prevent postoperative chylorrhea and minimize potential prolongation of hospital stay. Additionally, our findings also indicate that robotic surgery may potentially confer a favorable impact on the occurrence of postoperative sepsis. However, further clinical investigations are warranted to substantiate this benefit.

Until now, the evidence on the long-term oncologic outcomes of robotic versus laparoscopic surgery in patients with neo-adjuvant rectal cancer remains limited. In our study, we observed no significant disparities in the long-term prognosis of colorectal cancer patients following nCRT, including local recurrence and metastasis (such as liver, lung, bone, and abdominal implant metastases). Specifically, there was no discrepancy in 5-year OS and 5-year DFS rates between the two groups. However, upon scrutinizing PSM scores, while 5-year DFS rates remained unaffected, we detected potential variances in 5-year OS rates. These findings may suggest potential advantages of robotic surgery in oncological contexts. An previous retrospective study suggested that robotic surgery emerged as a favorable prognostic factor for OS and cancer-specific survival, indicating potential oncological benefits of the robotic operation [16, 43–45], This statement supports with our finding, further affirming the promising prognostic potential of robotic surgery. A recent study demonstrated that in colorectal cancer cases following nCRT, particularly among patients with stage III yp and adverse prognostic factors, the rates of DFS and local recurrence-free survival were notably elevated in the robotic surgery cohort compared to the laparoscopic surgery cohort [46].The synthesis of these findings, alongside our results, hints at a potential beneficial impact of robotic surgery on the long-term prognosis of colorectal cancer patients undergoing nCRT. However, further studies are warranted to substantiate this conclusion in the future. Ultimately, it should be emphasized that for patients with low or ultra-low rectal cancer, complex cases such as these should be referred to high-volume medical centers and operated on by experienced surgeons. This approach will reduce the incidence of postoperative complications, increase the rate of sphincter preservation, decrease the rate of conversion to open laparotomy, and thereby maximize patient benefit [47].

We conducted a separate subgroup analysis specifically for ISR cases. Within the robotic surgery group, patients presented with higher cN and cT stages, which precipitated a clinical inclination towards robotic surgery for the management of these complex cases, as adjudged by the surgical team. Nonetheless, our analysis did not discern any significant differences in short-term clinical outcomes, long-term clinical outcomes, LARS scores, OS, or DFS between the two surgical approaches for ISR. When employing robotic surgery for more challenging ISR cases, neither the short-term nor long-term oncological and functional prognoses were compromised. It is important to note that a subgroup analysis limited to ISR cases may not fully capture the extent of the benefit in enhancing the rate of sphincter preservation, as only sphincter-saving surgery is included. Moreover, within the ISR subgroup, the purported superiority of robotic surgery in reducing the conversion rate to open surgery did not achieve statistical significance, a limitation attributed to the small sample size. In the context of this study, there were no instances of conversion to open surgery in either group within the ISR subgroup.

Our study possesses several limitations. Firstly, as our study is a retrospective analysis conducted at a single center, it may introduce biases in the selection of surgical methods, such as selection bias and residual bias. To mitigate the impact of potential selection bias, we employed PSM methodology. However, residual bias may still persist. Additionally, the absence of detailed surgical complication data in our retrospective analysis precluded the application of a Clavien-Dindo classification. We are committed to incorporating this aspect into our forthcoming studies to enhance the robustness of our research findings. Secondly, comparing clinical outcomes between robotic surgery, laparoscopic surgery, and open surgery in complex rectal cancer operations is challenging due to significant differences in patient characteristics associated with each approach. For instance, procedures involving urine diversion or ileostomy are typically conducted via open surgery rather than robotic surgery, as our facility currently does not utilize robotics for these indications. Lastly, it's essential to consider the additional costs associated with robotic surgery.

Conclusion

This study confirms the effectiveness of robotic surgery for rectal cancer following nCRT regarding the improvement in sphincter-preservation over laparoscopy. However, the risk of chylous ascites might be higher in robotic surgery, emphasising the importance of sufficient coagulation of lymphatic vessels around IMA during resection of IMA lymph nodes. In addition, the oncological safety of robotic surgery for rectal cancer following nCRT was confirmed. Nevertheless, additional well-designed and rigorous studies are warranted to fully ascertain the comparative benefits of robotic surgery versus laparoscopic surgery post-nCRT.

Abbreviations

nCRT	Neo-adjuvant chemoradiotherapy
PSM	Propensity score matching
DFS	Disease-free survival
OS	Overall survival
LARS	Low anterior resection syndrome
EMVI	Extramural vascular invasion
CRM	Circumferential resection margin
ISR	Intersphincteric resection
RCT	Randomized controlled trials
ERUS	Endorectal ultrasound
CT	Computed tomography
MRI	Magnetic resonance imaging
TME	Total mesorectal excision
PET	Positron emission tomography
BMI	Body mass index
AR	Anterior Resection
APR	Abdominoperineal resection

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Author contributions
HZ and YH contributed to conception and design of the study. HZ, JZ, HP, YH and PC organized the database. HZ performed the statistical analysis and wrote the first draft of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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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

Ethical approval and consent to participate
This retrospective study was subject to approval by the Institutional Review Board of Fujian Medical University Union Hospital (2024KY166). The study was conducted in compliance with the ethical standards of the Declaration of Helsinki and the current ethical guidelines. Considering the retrospective nature of the study and following a thorough review, the IRB granted a waiver for obtaining informed consent from the patients involved.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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Author details
[1]Union Medical College, Fujian Medical University, No. 1 Xuefu North Road, Fuzhou, Fujian, China
[2]Department of Colorectal Surgery, Union Hospital, Fujian Medical University, 29 Xin-Quan Road, Fuzhou 350001, Fujian, People's Republic of China

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