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RESEARCH

Impact of surgical site infection on short- and long-term outcomes of robot-assisted rectal cancer surgery: a two-center retrospective study

Shuangming Lin[1] · Hao Zeng[1,2] · Xiaojie Wang[2] · Xueyi Xue[1] · Yushuo Chen[1] · Baodong Liao[1] · Ying Huang[2] · Dongbo Xu[1] · Pan Chi[2]

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Abstract

Purpose Robot-assisted surgery has increasingly gained recognition in the treatment of rectal cancer. This study aimed to assess the incidence of surgical site infection (SSI) that underwent robot-assisted radical rectal cancer surgery and to evaluate their influence on patient outcomes.

Methods A retrospective analysis was conducted on 360 patients who underwent robot-assisted radical rectal cancer surgery between 2017 and 2024 at Fujian Medical University Union Hospital and Longyan First Affiliated Hospital of Fujian Medical University. The patients were categorized into surgical site infection and non-surgical site infection groups based on the presence of surgical site infection. Baseline clinicopathological characteristics, perioperative details, and follow-up data were analyzed. Univariate and multivariate logistic regression analyses were performed to identify independent predictors of surgical site infection, and Cox proportional hazards regression models were utilized to evaluate factors influencing overall survival.

Results The study found that 44 out of 360 patients (12.2%) developed surgical site infection. Multivariate analysis indicated that positive perineural invasion (OR 3.59, 95% CI 1.50–8.62, $P = 0.004$) is an independent risk factor for SSI. Low anterior resection (OR 0.26, 95% CI 0.09–0.73, $P = 0.011$), preservation of the left colonic artery (OR 0.20, 95% CI 0.09–0.44, $P < 0.001$), and neoadjuvant therapy (OR 0.45, 95% CI 0.23–0.89, $P = 0.021$) were associated with reduced risks of SSI. The presence of SSI was significantly associated with a reduction in overall survival (HR 3.43, 95% CI 1.30–9.04, $P = 0.012$). The risk of developing surgical site infection increases with the number of risk factors, and patients with two or more risk factors have a much higher risk of developing SSI.

Conclusions This study identified perineural invasion as an independent risk factor for the development of SSI that underwent robot-assisted radical rectal cancer surgery. Low anterior resection, preservation of the left colonic artery, and neoadjuvant therapy emerged as protective factors. Moreover, the presence of surgical site infection was significantly correlated with poorer overall survival.

Keywords Surgical site infection · Robot-assisted surgery · Rectal cancer · Overall survival · Risk factors

Shuangming Lin, Hao Zeng, and Xiaojie Wang contributed equally to this work and should be considered co-first authors.

✉ Ying Huang
hy9033sy@sina.com

✉ Dongbo Xu
xdb2292388@sina.com

✉ Pan Chi
chipan363@163.com

1 Department of Gastroenterology and Anorectal Surgery, Longyan First Affiliated Hospital of Fujian Medical University, No.105 Jiuyi North Road, LongyanFujian Province 364000, China

2 Department of Colorectal Surgery, Fujian Medical University Union Hospital, No.29 Xinquan Road, FuzhouFujian Province 350001, China

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Introduction

Colorectal cancer ranks as the third most common malignancy worldwide and is the second leading cause of cancer-related mortality. Despite significant advancements in early detection and therapeutic strategies, the persistently high morbidity and mortality associated with colorectal cancer continue to represent a substantial global public health challenge [1]. The current standard of care for treating locally advanced rectal cancer involves a multimodal approach, which includes preoperative neoadjuvant radiotherapy followed by total mesorectal excision (TME) [2]. Robot-assisted rectal cancer surgery has emerged as a means to overcome several technical limitations inherent to conventional laparoscopic procedures, thereby enhancing the precision and efficacy of radical resections [3]. As a result, robotic surgery has become a focal point of ongoing research and innovation.

Surgical site infection (SSI) is a frequent complication following rectal cancer surgery, with serious implications for postoperative recovery and overall prognosis [4]. Due to the inherently high risk of contamination in rectal surgery, SSI are particularly prevalent in this context. The development of SSI not only extends hospitalization and escalates healthcare costs, but it also heightens the risk of severe complications, such as sepsis and multiorgan failure, which can compromise long-term survival [5, 6]. Therefore, the identification and management of SSI risk factors in robot-assisted rectal resection are crucial for optimizing patient outcomes and improving long-term prognosis.

The impact of abdominal infections in robot-assisted rectal cancer surgery remains inadequately understood. Although robotic surgery enables surgeons to perform minimally invasive procedures with enhanced visualization and more intuitive, precise control of surgical instruments [7], its effectiveness in reducing the incidence of SSI and improving prognosis has not been conclusively demonstrated. This study aims to evaluate the incidence of abdominal infections in robot-assisted rectal cancer surgery and assess their impact on short-term outcomes and long-term prognosis. By providing clinicians with evidence-based data, this study seeks to promote the use of robotic-assisted surgery in the treatment of rectal cancer, ultimately improving patient prognosis and quality of life.

Materials and methods

Study design and population

We retrospectively analyzed data from 360 patients with pathological rectal cancer (RC) who underwent robotic-assisted radical rectal cancer surgery at Fujian Medical University Union Hospital and Longyan First Affiliated Hospital of Fujian Medical University between 2017 and 2024. In this study, 295 patients received treatment at the Union Hospital of Fujian Medical University, while 68 patients were treated at the Longyan First Hospital of Fujian Medical University (Fig. 1). The patient characteristics, pathological and surgical manifestations, and postoperative histological findings documented in our medical records and database were

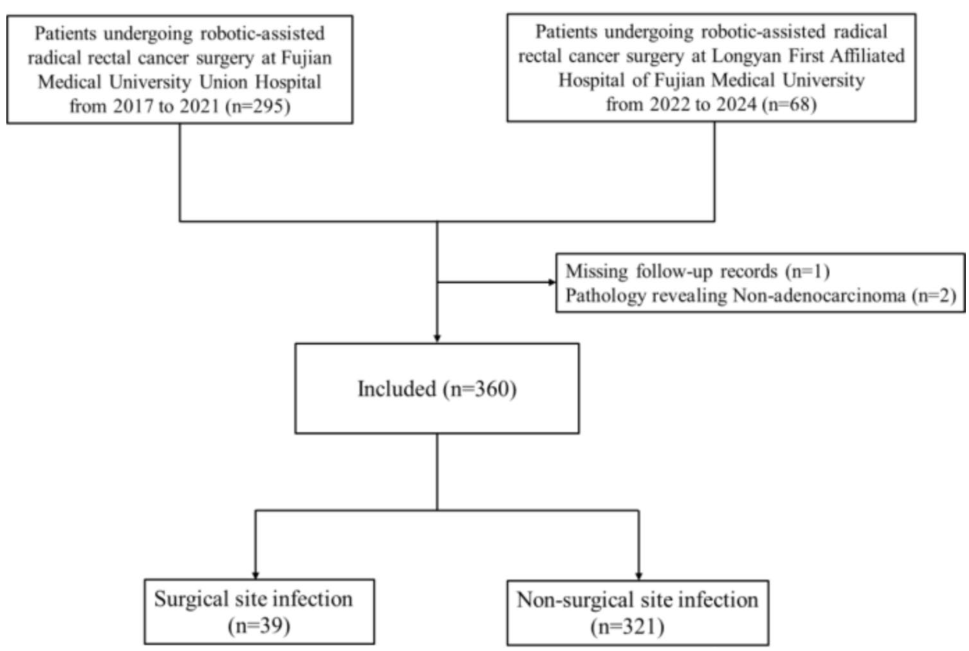

Fig. 1 Flowchart of patient cohort definition

uniformly consistent with adenocarcinoma. This study followed the recommended items in the STROBE statement and was designed and reported according to the standards for reporting case–control studies.

The main objective of this study was to evaluate short-term postoperative complications, so only all complications occurring within 30 days after surgery were counted, including surgical site infection anastomotic leaks, pulmonary infections, and small bowel obstruction. Late anastomotic leakage, anastomotic stenosis, or incisional hernia was not observed in this study.

Surgical site infection (SSI) is categorized into two types: wound SSI, which can be either superficial or deep, and organ/space SSI. Wound SSIs refer to infections occurring at the incision site. Organ/space SSI, on the other hand, involves intra-abdominal or pelvic abscesses, which are accumulations of pus within the abdomen or pelvis. The diagnosis of such abscesses is generally established through advanced imaging modalities, including ultrasonography and computed tomography (CT). The presence of clinical anastomotic leakage may be concomitant with these infections, although it is not a requisite for diagnosis [8]. According to SSI, the patients were divided into the SSI group and the non-SSI group. The following information was used for the analysis of this study: baseline information, tumor location, pathological information, surgical details, postoperative hospitalization, and follow-up information. The World Health Organization (WHO) BMI classification for Asian populations was used in this study. Low body weight (BMI < 18.5 kg/m^2) is defined as a body mass index (BMI) below the normal range, reflecting possible malnutrition or underweight. Normal weight (BMI 18.5–24.9 kg/m^2) is considered a healthy weight range. Overweight/obesity (BMI ≥ 25.0 kg/m^2) includes overweight and obesity. Postoperative anastomotic leakage [9], an abnormal connection at the anastomotic site after surgery, results in the escape of intestinal contents or inflammatory fluids into the abdominal cavity or out through a drain. Patients present with symptoms such as fever, abdominal pain, bloating, or abnormal bowel function. Turbid fluid or fluid-containing feces is discharged from the wound or drain. Elevated peripheral blood leukocytes or significant elevation of C-reactive protein, CT examination is the gold standard for the diagnosis of anastomotic leakage, showing fluid or gas collection around the anastomosis and enhanced images of the suspected leakage site.

Inclusion and exclusion criteria

Inclusion criteria: (1) patients with a confirmed diagnosis of rectal cancer based on postoperative pathological examination, treated between January 2017 and December 2024 at the two study centers; (2) all surgical procedures were conducted by a consistent and specialized surgical team; (3) patients with comprehensive clinicopathological data and complete follow-up records; (4) patients aged 18 years or older. Exclusion criteria: (1) patients identified with distant metastasis of the tumor during preoperative assessment or intraoperative exploration, precluding radical surgical intervention; (2) patients diagnosed with two or more concurrent malignant tumors during either the preoperative or postoperative follow-up period; (3) patients who underwent emergency surgical procedures due to complications such as tumor perforation, obstruction, or bleeding; (4) patients with a diagnosis of familial adenomatous polyposis.

Surgery and perioperative management

This study was conducted across two centers, involving a comprehensive preoperative evaluation for all patients, which included imaging studies, laboratory tests, and detailed medical history assessments, to determine their suitability for undergoing robotic-assisted rectal cancer surgery. All robotic-assisted rectal cancer surgeries were performed by experienced surgical teams from Fujian Medical University Union Hospital and Longyan First Affiliated Hospital of Fujian Medical University. Each attending surgeon on the surgical team had received specialized training in robotic surgery and possessed extensive experience in performing robotic-assisted procedures. The lead surgeon operated the Da Vinci Surgical System throughout the surgeries, ensuring precise and effective surgical interventions.

The main indications for preoperative neoadjuvant therapy for patients with locally advanced rectal cancer (LARC) that is resectable include patients with clinical stage cT3-4 or with regional lymph node metastasis and no distant metastasis. Especially for patients with low rectal cancer, if the tumor location is close to the anal sphincter and the patient has a strong willingness to preserve the anus, neoadjuvant therapy can be chosen after full communication with the patient, and the surgical plan can be decided according to the evaluation of the efficacy after surgery [10]. Patients of advanced age or with comorbid metabolic disease should have the LCA preserved whenever possible, as the colonic border arterial arch in these patients may have a restricted blood supply due to atherosclerosis or microangiopathy, and preservation of the LCA improves anastomotic perfusion proximally, thereby reducing the risk of anastomotic leakage. In patients with rectal cancer after neoadjuvant therapy, the decision to preserve the LCA is based on the patient's underlying condition. In patients with familial adenomatous polyposis or Lynch syndrome, preservation of the LCA reserves vascularity for possible future reoperation [11]. Patients with descending colonic rotation have an anatomically abnormal vascular arch, and not preserving the LCA may result in extensive intestinal ischemia. Failure to preserve LCA and positive IMA root lymph nodes are independent risk factors for distant recurrence after rectal cancer surgery [12]. To ensure complete lymph node dissection, the LCA is preserved in such patients. When mesenteric tension is too high and free bowel is insufficient to complete a low-tension anastomosis, we consider dissecting the LCA to reduce anastomotic tension.

Preoperative bowel preparation is performed in strict accordance with international guidelines and our center's standardized procedures. Implementation details of bowel preparation: mechanical bowel preparation [13]: the day before surgery, patients take a polyethylene glycol electrolyte solution for bowel cleansing, with the dose adjusted to the patient's weight. Bowel cleansing is usually recommended to be completed within 12–24 h prior to surgery to ensure that intraoperative bowel contents are minimized. The principles of antibiotic administration in this study were as follows: the first dose of broad-spectrum antibiotics was given intravenously within 30 to 60 min after the induction of anesthesia to ensure that blood levels reached effective levels at the start of surgery [14]. In dual-center patients requiring surgery, the following should be implemented: if the duration of surgery is more than 3 h or the intraoperative bleeding is more than 1500 ml, the antibiotic dose should be increased according to the duration of surgery and the amount of bleeding. Postoperative antibiotics should not be given for more than 24 h. In patients with severe intraoperative contamination or complex surgery, this may be extended to 48 h. The choice of antibiotics is based on the coverage of the target strain and the individual patient.

The indications for stoma creation have been formulated according to international guidelines and clinical practice [15, 16], taking into account the specific situation of the patient, and mainly include patients with high risk of anastomotic leakage, such as patients with very low tumor location, patients who received neoadjuvant therapy prior to the operation, patients with high intraoperative anastomotic tension, or patients with poor blood supply. Patients are with poor systemic conditions, such as advanced age, malnutrition, or severe comorbidities. Patients are with poor intraoperative bowel conditions, high risk of contamination of bowel contents, or inadequate intraoperative bowel cleansing. The placement of an abdominal drain is determined on a case-by-case basis, mainly in patients with high-risk anastomotic leaks, cases with significant intraoperative contamination, or heavy bleeding. Patients require real-time monitoring of the nature and amount of intra-abdominal fluid. Anal drains are mainly used in low anastomotic surgery, especially in anal preservation surgery, to reduce localized anastomotic fluid collection and to reduce pressure. Abdominal drains are usually removed within 48–72 h postoperatively with clear drainage or significantly reduced volume and no signs of infection. Anal drains are usually removed within 2–3 days after surgery, but the exact time depends on the patient's recovery.

The standard protocol for regular postoperative follow-up for patients in this study is as follows: patients were reviewed every 3–6 months during the first 2 years post-surgery, every 6 months during the 3rd and 4th years, and subsequently every 6–12 months from the 5th year onwards. Laboratory tests conducted during follow-up include routine blood tests, routine biochemical tests, and serum tumor markers, among others. Imaging examinations performed during follow-up consist of ultrasound, computed tomography (CT), positron emission tomography (PET) (specifically for the detection of recurrent lesions), and gastroenteroscopy. The survival follow-up methodology adhered to the guidelines of the American Joint Committee on Cancer (AJCC) [9]. Patients were followed up through multiple methods, including outpatient visits, the electronic medical record system, and telephone callbacks, to ensure the completeness and accuracy of the data.

Statistical analysis

Continuous variables were expressed as mean ± standard deviation, and comparisons of categorical variables between the two groups were performed using the chi-square test (chi-square test). Survival curves for overall survival (OS) and disease-free survival (DFS) were generated by the Kaplan–Meier method and compared by the log-rank test. OS was defined as the time interval from the date of surgical treatment to the date of death or the date of the last follow-up. DFS was defined as the time interval from the date of surgical intervention to the date of tumor recurrence, metastasis, death, or the date of the last follow-up. Multivariate survival analyses were performed using Cox proportional hazards regression models to identify independent prognostic factors for OS. Logistic univariate regression analysis was used to identify potential risk factors for SSI. Variables with a P-value of less than 0.05 in the univariate analysis were subsequently included in a multivariate logistic regression model to identify independent predictors of SSI. For risk stratification, chi-square tests were used to assess the association between the number of risk factors identified in the multivariate analyses (0–1, 2, or 3) and the risk of SSI. In addition, relative risk (RR) and corresponding 95% confidence intervals (CI) were calculated using the rest of the population as the reference group (RR = SSI risk in patients with N risk factors / SSI risk in the rest of the population). Statistical significance was defined as $P < 0.05$. All statistical analyses were performed using R software (version 4.3.1).

Results

Baseline clinicopathological characteristics

In this study, patients were stratified into two cohorts according to the presence or absence of surgical site infections (SSIs): the non-SSI group ($n = 316$) and the SSI group ($n = 44$). Within the SSI group, the infections were further categorized as incisional infections ($n = 5$), abdominal infections ($n = 32$), and combined incisional and abdominal infections ($n = 7$). Notable differences were observed between the groups in several clinicopathological characteristics. The SSI group exhibited a significantly higher proportion of underweight patients (25.00% vs. 9.49%, $P = 0.009$). Furthermore, the preservation of the left colonic artery was significantly more prevalent in the non-SSI group ($P < 0.001$). The incidence of neoadjuvant chemoradiotherapy (nCRT) was also significantly higher in the non-SSI group (58.23% vs. 40.91%, $P = 0.03$). A significant variation in the surgical approach was observed between the groups ($P = 0.026$), with a larger proportion of patients in the SSI group undergoing low anterior resection (63.64%) compared to other surgical techniques. Analysis of the pathological T-stage (pT) revealed a significant difference between the two groups ($P = 0.025$). Although no significant difference was found in lymph node status (pN) between the groups, the SSI group had a slightly higher proportion of patients classified as pN1 and pN2. Perineural invasion (PNI) was significantly more prevalent in the SSI group (36.36% vs. 12.03%, $P < 0.001$). Postoperative pulmonary infections were markedly more frequent in the SSI group compared to the non-SSI group (22.73% vs. 3.48%, $P < 0.001$). While the incidence of small bowel obstruction was higher in the SSI group, the difference did not reach statistical significance (4.55% vs. 0.95%, $P = 0.056$). Furthermore, the incidence of SSI after low anterior resection (LAR) was 63.63%, but the incidence of LAR with stoma was 19.17%. Five of 31 anastomotic leaks were diagnosed as SSI (11.36%). No significant differences were found between the groups regarding the incidence of anastomotic leakage or anastomotic bleeding. Additionally, there were no significant differences between the groups in terms of age, gender, hypertension, diabetes, or the distance between the tumor and the anal verge (Table 1).

Survival analysis

The relationship between clinicopathological factors and overall survival (OS) at 1, 3, and 5 years following robot-assisted radical rectal cancer surgery was analyzed. Age, BMI, hypertension, pathological T-stage, neoadjuvant chemoradiotherapy, pulmonary infection, and surgical site infection (SSI) were found to be significantly associated with overall survival according to the log-rank test (Supplementary 1, $P < 0.05$). The median follow-up times were 32 months for the non-SSI group and 22 months for the SSI group. The 3-year overall survival rate was significantly lower in the SSI group compared to the non-SSI group (74.5% vs. 93.1%; $P < 0.001$). However, there were no significant differences in disease-free survival (DFS) between the two groups (Fig. 2A, B). Overall survival was significantly lower in patients who experienced abdominal infections compared to those without such infections, while the impact on disease-free survival did not reach statistical significance (Fig. 2C, D). In contrast, incisional infections were not associated with a significant difference in either overall survival or disease-free survival (Fig. 2E, F).

Univariate and multivariate analyses for surgical site infection

In this study, both univariate and multivariate logistic regression analyses were conducted to identify factors associated with the development of SSI following robot-assisted radical rectal cancer surgery (Table 2). The univariate analysis revealed several factors significantly correlated with an increased risk of SSI. Underweight patients exhibited a higher likelihood of developing SSI (OR 2.99, 95% CI 1.34–6.67, $P = 0.007$). Additionally, patients with advanced pathological T stages, particularly those with T4 tumors, demonstrated a markedly elevated risk of SSI (OR 3.40, 95% CI 1.03–11.24, $P = 0.045$). The presence of positive perineural invasion (PNI) was strongly associated with the occurrence of SSI (OR 4.18, 95% CI 2.07–8.43, $P < 0.001$). Conversely, certain factors were associated with a reduced likelihood of SSI. Patients who underwent low anterior resection had a significantly lower risk of SSI compared to those who underwent abdominoperineal resection (OR 0.21, 95% CI 0.06–0.72, $P = 0.012$). Similarly, preservation of the left colic artery (LCA) (OR 0.20, 95% CI 0.09–0.44, $P < 0.001$) and the administration of neoadjuvant therapy (OR 0.50, 95% CI 0.26–0.94, $P = 0.032$) were both associated with a decreased risk of SSI. In the multivariate logistic regression analysis, positive perineural invasion (OR 3.45, 95% CI 1.48–8.05, $P = 0.004$) emerged as independent risk factors for the increased incidence of SSI. Conversely, low anterior resection (OR 0.21, 95% CI 0.06–0.72, $P = 0.012$), preservation of LCA (OR 0.33, 95% CI 0.13–0.85, $P = 0.021$), and the administration of neoadjuvant therapy (OR 0.38, 95% CI 0.18–0.82, $P = 0.014$) remained significantly associated with a reduced risk of SSI.

Table 1 Baseline characteristics

Variables	Non-surgical site infection N=316	Surgical site infection N=44	*p*-value
Age, years			0.230
<50	76 (24.05%)	7 (15.91%)	
>=50	240 (75.95%)	37 (84.09%)	
Sex			0.820
Female	106 (33.54%)	14 (31.82%)	
Male	210 (66.46%)	30 (68.18%)	
BMI, kg/m 2			0.009
Normal weight	212 (67.09%)	26 (59.09%)	
Underweight	30 (9.49%)	11 (25.00%)	
Obesity/Overweight	74 (23.42%)	7 (15.91%)	
Hypertension			0.090
No	245 (77.53%)	29 (65.91%)	
Yes	71 (22.47%)	15 (34.09%)	
Diabete			0.138
No	277 (87.66%)	35 (79.55%)	
Yes	39 (12.34%)	9 (20.45%)	
Pathological T stage			0.025
T0	51 (16.14%)	7 (15.91%)	
T1	53 (16.77%)	4 (9.09%)	
T2	72 (22.78%)	6 (13.64%)	
T3	125 (39.56%)	20 (45.45%)	
T4	15 (4.75%)	7 (15.91%)	
Pathological N stage			0.346
N0	227 (71.84%)	27 (61.36%)	
N1	60 (18.99%)	12 (27.27%)	
N2	29 (9.18%)	5 (11.36%)	
Liver metastasis			0.747
No	306 (96.84%)	43 (97.73%)	
Yes	10 (3.16%)	1 (2.27%)	
Lung metastasis			0.883
No	300 (94.94%)	42 (95.45%)	
Yes	16 (5.06%)	2 (4.55%)	
Bone metastasis			0.453
No	312 (98.73%)	44 (100.00%)	
Yes	4 (1.27%)	0 (0.00%)	
Neoadjuvant chemoradiotherapy			0.030
No	132 (41.77%)	26 (59.09%)	
Yes	184 (58.23%)	18 (40.91%)	
Surgical approach			0.026

Univariate and multivariate analyses for overall survival

In this study, univariate and multivariate Cox regression analyses were employed to identify factors influencing overall survival following robot-assisted radical rectal cancer surgery (Table 3). The univariate Cox regression analysis revealed several factors significantly associated with diminished overall survival. Patients aged 50 years or older demonstrated a higher hazard ratio (HR) for reduced overall survival (HR 7.57, 95% CI 1.02–56.1, $P=0.048$). The presence of hypertension was also significantly correlated with poorer overall

Table 1 (continued)

Abdominoperineal resection	13 (4.11%)	6 (13.64%)	
Intersphincteric resection	68 (21.52%)	10 (22.73%)	
Low anterior resection	235 (74.37%)	28 (63.64%)	
Left colic artery			<0.001
Absence	22 (6.96%)	12 (27.27%)	
Presence	294 (93.04%)	32 (72.73%)	
Anal drainage tube			0.151
Absence	282 (89.24%)	36 (81.82%)	
Presence	34 (10.76%)	8 (18.18%)	
Perineural invasion			<0.001
Absence	278 (87.97%)	28 (63.64%)	
Presence	38 (12.03%)	16 (36.36%)	
Vascular tumor thrombus			0.173
Absence	281 (88.92%)	36 (81.82%)	
Presence	35 (11.08%)	8 (18.18%)	
Pulmonary infection			<0.001
No	305 (96.52%)	34 (77.27%)	
Yes	11 (3.48%)	10 (22.73%)	
Chylous leak			0.231
No	306 (96.84%)	44 (100.00%)	
Yes	10 (3.16%)	0 (0.00%)	
Small bowel obstruction			0.056
No	313 (99.05%)	42 (95.45%)	
Yes	3 (0.95%)	2 (4.55%)	
Anastomotic leak			0.487
No	290 (91.77%)	39 (88.64%)	
Yes	26 (8.23%)	5 (11.36%)	
Anastomotic bleeding			0.516
No	313 (99.05%)	44 (100.00%)	
Yes	3 (0.95%)	0 (0.00%)	
Anal verge distance	6.00 (5.00-8.00)	6.75 (5.00-10.00)	0.154

survival outcomes (HR 3.63, 95% CI 1.63–8.11, $P = 0.002$). Although neoadjuvant chemoradiotherapy exhibited a protective trend, it did not reach statistical significance (HR 0.45, 95% CI 0.19–1.02, $P = 0.055$). Lung metastasis was associated with a significantly heightened risk of adverse outcomes (HR 4.72, 95% CI 1.76–12.65, $P = 0.002$). Patients with bone metastasis exhibited a markedly elevated risk (HR 11.80, 95% CI 3.52–39.59, $P < 0.001$) in comparison to those without bone metastasis. Additionally, the occurrence of SSI was significantly associated with decreased overall survival (HR 3.57, 95% CI 1.39–9.14, $P = 0.008$). In the multivariate Cox regression analysis, hypertension (HR 2.63, 95% CI 1.14–6.05, $P = 0.023$) and bone metastasis (HR 9.89, 95% CI 1.73–56.49, $P = 0.010$) remained independent predictors of reduced overall survival. Furthermore, the presence of SSI continued to be independently associated with a significant reduction in overall survival (HR 3.43, 95% CI 1.30–9.04, $P = 0.012$).

Risk stratification for SSI

According to the logistic multivariate analysis, there were three significant correlates (perineural invasion, preservation of the left colonic artery, and neoadjuvant chemoradiotherapy) that could be used to stratify SSI. The number of risk factors was significantly associated with an increased risk of SSI ($P < 0.001$). Compared with the overall population, patients with 1 or fewer risk factors had a lower risk, whereas patients with 2 or more risk factors had a significantly higher risk. The risk of SSI was 10.06% for patients with 0–1 risk factor (RR = 0.823, 95% CI 0.155–0.407) and 33.33% for patients with 2 risk factors (RR = 2.727. 95% CI 0.155–0.407). Table 4 shows the relationship between the number of risk factors and the risk of SSI.

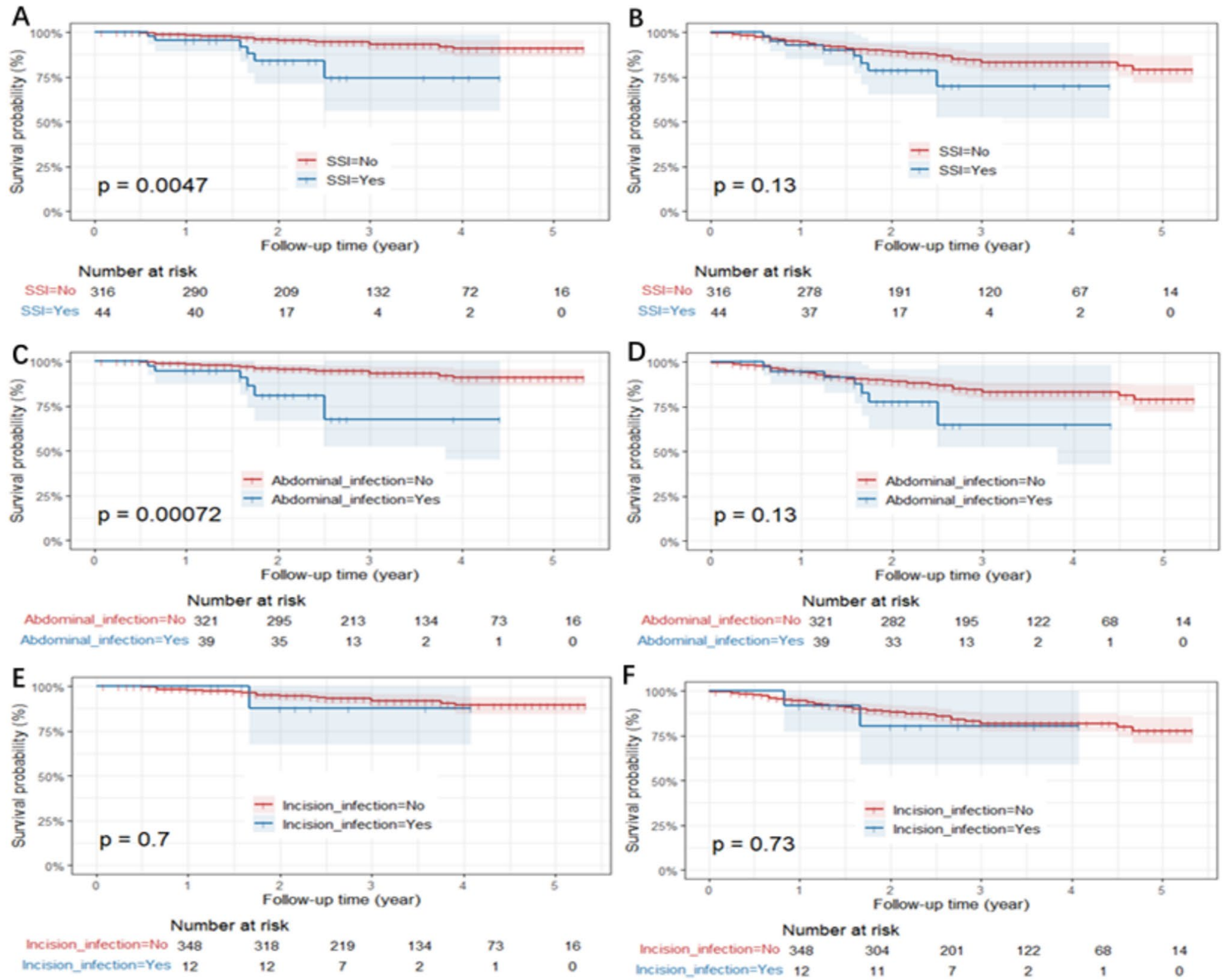

Fig. 2 Kaplan–Meier survival curves for the prognostic impact of surgical site infection (SSI), abdominal infection, and incisional infection on overall survival (OS) and disease-free survival (DFS). Surgical site infection: **A**, OS. **B**, DFS. Abdominal infection: **C**, OS. **D**, DFS. Incisional infection: **E**, OS. **F**, DFS

Discussion

This study examined the risk factors associated with the development of surgical site infection (SSI) after robot-assisted radical rectal cancer surgery and investigated how these factors affect the survival prognosis of patients. The findings suggest that the occurrence of SSI has a considerable impact on both postoperative recovery and long-term survival, and that a number of clinicopathological factors are significantly correlated with the incidence of SSI and overall survival prognosis.

The risks associated with colonic and rectal surgeries vary considerably, particularly due to the unique technical demands of rectal procedures. Rectal surgeries frequently require the formation of an ostomy, preoperative chemoradiotherapy, and total mesorectal excision (TME), often with a low anastomosis near the anal verge. These factors tend to prolong operative time and increase the potential for bacterial contamination [17]. Studies by Guillou and Biondo report a SSI rate of 9%, with the incidence of intra-abdominal or pelvic sepsis reaching 10%. Furthermore, the lower incidence of SSI in low anterior resection (LAR) compared to abdominoperineal resection (APR) is consistent with previous literature findings [18, 19]. This variation may be attributed to differences in surgical techniques, anatomical positioning, and the degree of tissue trauma involved in each procedure [20]. The introduction of robot-assisted technology in LAR has markedly improved surgical precision. Given the deep location of the lower rectum within the pelvis and the complexity of its surrounding anatomy, the three-dimensional high-definition visualization and enhanced dexterity of robotic instruments enable

Table 2 Univariate and multivariate analyses of risk factors for surgical site infections

Variable	Univariate analysis				Multivariate analysis			
	OR	95% CI		*P*-value	OR	95% CI		*P*-value
Age								
< 50 years	Reference							
≥ 50 years	1.67	0.72	3.91	0.234				
Sex								
Female	Reference							
Male	1.08	0.55	2.13	0.820				
BMI								
Normal weight	Reference				Reference			
Underweight	2.99	1.34	6.67	0.007	2.99	1.34	6.67	0.071
Obesity/overweight	0.77	0.32	1.85	0.561	0.69	0.27	1.77	0.440
Hypertension								
No	Reference							
Yes	1.78	0.91	3.51	0.093				
Diabetes								
No	Reference							
Yes	1.83	0.82	4.09	0.143				
Pathological T stage								
T0	Reference				Reference			
T1	0.55	0.15	1.99	0.362	0.29	0.07	1.19	0.085
T2	0.61	0.19	1.91	0.394	0.29	0.08	1.06	0.062
T3	1.17	0.46	2.93	0.774	0.53	0.18	1.54	0.243
T4	3.40	1.03	11.24	0.045	0.56	0.12	2.54	0.452
Pathological N stage								
N0	Reference							
N1	1.68	0.80	3.51	0.167				
N2	1.45	0.52	4.06	0.480				
Neoadjuvant chemoradiotherapy								
No	Reference				Reference			
Yes	0.50	0.26	0.94	0.032	0.38	0.18	0.82	0.014
Surgical approach								
Abdominoperineal resection	Reference				Reference			
Intersphincteric resection	0.32	0.10	1.03	0.056	0.35	0.09	1.28	0.112
Low anterior resection	0.26	0.09	0.73	0.011	0.21	0.06	0.72	0.012
Left colic artery								
Absence	Reference				Reference			
Presence	0.20	0.09	0.44	< 0.001	0.33	0.13	0.85	0.021
Anal drainage tube								
Absence	Reference							
Presence	1.84	0.79	4.29	0.156				
Perineural invasion								
Absence	Reference				Reference			
Presence	4.18	2.07	8.43	< 0.001	3.45	1.48	8.05	0.004
Vascular tumor thrombus								
Absence	Reference							
Presence	1.78	0.77	4.14	0.178				

surgeons to navigate confined spaces with greater accuracy. This is particularly advantageous when operating around delicate structures such as nerves and blood vessels. Park et al. highlight that the increased precision afforded by robotic assistance minimizes tissue trauma and subsequently reduces the incidence of postoperative complications [21].

Table 3 Univariate and multivariate analyses of risk factors for overall survival

Variable	Univariate analysis				Multivariate analysis			
	HR	95% CI		*P*-value	HR	95% CI		*P*-value
Age								
< 50 years	Reference				Reference			
≥ 50 years	7.57	1.02	56.1	0.048	5.57	0.74	42.18	0.096
Sex								
Female	Reference							
Male	1.90	0.71	5.08	0.202				
BMI								
Normal weight	Reference							
Underweight	2.18	0.85	5.57	0.104				
Obesity/overweight	0.36	0.08	1.57	0.173				
Hypertension								
No	Reference				Reference			
Yes	3.63	1.63	8.11	0.002	2.63	1.14	6.05	0.023
Diabetes								
No	Reference							
Yes	0.68	0.16	2.88	0.596				
Pathological T stage								
T0	Reference							
T1	0.00	0	Inf	0.997				
T2	0.25	0.05	1.22	0.086				
T3	0.94	0.35	2.52	0.907				
T4	3.00	0.81	11.04	0.098				
Pathological N stage								
N0	Reference							
N1	2.24	0.95	5.28	0.066				
N2	0.61	0.08	4.60	0.627				
Liver metastasis								
No	Reference							
Yes	2.86	0.67	12.16	0.155				
Lung metastasis								
No	Reference				Reference			
Yes	4.72	1.76	12.65	0.002	1.63	0.40	6.71	0.496
Bone metastasis								
No	Reference				Reference			
Yes	11.80	3.52	39.59	< 0.001	9.89	1.73	56.49	0.010
Neoadjuvant chemoradiotherapy								
No	Reference							
Yes	0.45	0.19	1.02	0.055				
Surgical approach								
Abdominoperineal resection	Reference							
Intersphincteric resection	0.29	0.06	1.44	0.129				
Low anterior resection	0.46	0.13	1.56	0.211				
Left colic artery								
Absence	Reference							
Presence	0.42	0.12	1.45	0.170				
Perineural invasion								
Absence	Reference							
Presence	2.24	0.82	6.06	0.114				

Table 3 (continued)

Variable	Univariate analysis				Multivariate analysis			
	HR	95% CI		*P*-value	HR	95% CI		*P*-value
Vascular tumor thrombus								
Absence	Reference							
Presence	1.44	0.43	4.85	0.558				
Anastomotic leak								
No	Reference							
Yes	0.49	0.07	3.66	0.490				
Surgical site infection								
No	Reference							
Yes	3.57	1.39	9.14	0.008	3.43	1.30	9.04	0.012

Table 4 Association of the number of risk factors with the risk of surgical site infections

Risk factors	Overall	0–1	2	*P*-value
No. of patients	360	328	30	NA
Risk of surgical site infection (%)	12.22	10.06	33.33	< 0.001
Relative risk (95% CI)	1	0.823 (0.155, 0.407)	2.727 (0.155, 0.407)	NA

In contrast, APR necessitates a more extensive resection, involving both abdominal and perineal incisions and often resulting in a permanent ostomy. The broader surgical exposure and greater complexity inherent in APR contribute to a higher risk of infection. Factors such as surgical access, emergency surgery, duration of surgery, massive intraoperative blood loss, malnutrition, and diabetes mellitus were significantly associated with the occurrence of SSI in both open and laparoscopic surgeries [22, 23]. The lower incidence of SSI in laparoscopic surgery compared to open surgery may be related to the fact that laparoscopic surgery is less invasive, has a smaller incision, and has a faster postoperative recovery [23]. In open surgery, the incision length and the degree of intraoperative contamination have a more significant effect on SSI. This study provides a new perspective to think about incisional infections. Perineural invasion (PNI) is widely regarded as a key risk factor in tumor pathology as it promotes direct interaction of tumor cells with nerve cells. This interaction promotes deep invasion of malignant cells into surrounding tissues, disrupting the structural integrity of the tissue and weakening immune defenses, thereby increasing the risk of infection [24]. Tumor invasion often penetrates deep into the peripheral neural structures, which allows for a wider surgical resection involving more layers of tissue, which in turn leads to a prolonged surgical time. In PNI-positive patients, tumor invasion into surrounding tissues and damage to local blood vessels and nerves further exacerbate the problem of intraoperative blood loss and local tissue hypoxia, which increases the risk of infection development [25]. Prolonged intraoperative manipulation and massive blood loss can lead to impaired function of the immune system, especially the weakening of the local immune response, which compromises wound healing and thus increases the risk of postoperative surgical site infections. The combination of immune system suppression and surgical trauma as well as intraoperative blood loss may make it easier for bacteria to colonize the surgical site and cause infection [26]. Therefore, PNI-positive patients with locally advanced cancer may be more susceptible to SSIs due to the longer duration of surgery, higher intraoperative blood loss, and impaired local immune function, suggesting that clinics should provide more detailed postoperative management for these patients, strengthen infection prevention and control measures, and closely monitor the postoperative recovery process.

The findings of this study indicate that preservation of the left colonic artery, along with neoadjuvant therapy, may serve as a protective factor in reducing the incidence of SSI. The left colonic artery is the primary source of blood supply to a specific segment of the colon. Preserving this artery during surgery ensures adequate perfusion to the distal colon and the anastomotic region, which facilitates tissue healing and reduces the risk of anastomotic leakage due to ischemia. This observation is consistent with our previous study [11]. Most studies have identified neoadjuvant therapy as a risk factor for SSI [27, 28]. Bailey's research highlights the critical role of angiogenesis in the growth, progression, and metastasis of various solid tumors. Since angiogenesis is also essential for wound healing, pharmacological agents that target the angiogenic pathway may inadvertently disrupt this process, potentially increasing the risk of postoperative complications such as wound dehiscence, surgical site bleeding, and infection [29]. However, other studies have indicated that neoadjuvant therapy does not significantly influence the incidence of SSI [30, 31]. The preoperative treatment group may tend to select patients who are in better physical condition, have fewer comorbidities, or are able to tolerate radiotherapy, and the underlying health status of these patients may help to reduce the risk of postoperative infections. Neoadjuvant therapy patients usually receive stricter perioperative management, including nutritional support, optimization of immune function, and more frequent postoperative monitoring, which may indirectly reduce the incidence of infection. The results of the present study may reflect more of an advantage in specific clinical practice conditions and deserve further validation and exploration.

This study has several limitations. Firstly, although the study employed a dual-center design, the small sample size may have constrained the statistical power and generalizability of the findings. This limitation may have affected the ability to comprehensively assess certain variables and their associations with SSI and prognosis. Secondly, the absence of some key surgery-related variables may have restricted a thorough analysis of the mechanisms underlying SSI occurrence and its associated risk factors. Third, we did not include a more detailed nutritional assessment tool, and our exploration of the relationship between nutrition and SSI was incomplete. The inclusion of this variable needs to be focused on in future studies. Additionally, the relatively short follow-up period may be insufficient to fully evaluate the long-term impact of SSI on patient outcomes. Therefore, these findings should be interpreted with caution and require further validation in studies that incorporate a broader range of surgery-related variables and extended follow-up durations. Finally, due to the geographic and institutional constraints of the sample, the external validity of the results must be confirmed through large-scale, multicenter studies to ensure applicability across diverse populations.

Conclusion

In conclusion, this study suggests that surgical site infections may be a key factor in the prognosis of patients with rectal cancer. The occurrence of SSI was significantly associated with poorer overall survival outcomes, suggesting their important role in postoperative recovery and long-term survival. This result highlights the need for prevention and management of SSI during the treatment of rectal cancer to improve the long-term prognosis of patients.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Ethical approval The study was ethically reviewed and approved by the Ethics Committees of both research centers; the study protocol adhered to the ethical guidelines of the 1975 Declaration of Helsinki.

Competing interests The authors declare no competing interests.

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