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Robotic versus laparoscopic surgery for rectal cancer: an updated systematic review and meta-analysis of randomized controlled trials

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Abstract

Background The usage of robotic surgery in rectal cancer was increasing, but there was an ongoing debate as to whether it provided any benefit. The aim of this study was to evaluate the safety, efficacy, and prognosis of elective rectal resection for rectal cancer by robotic surgery compared with conventional laparoscopic surgery.

Method Electronic databases were searched from their inception to 1 February 2024, for randomized controlled trials (RCTs) involving a comparison between robotic surgery (RS) and laparoscopic surgery (LS) and performed a meta-analysis of all RCTs according to Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines.

Results 11 RCTs including a total of 3107 cases were identified. Compared with LS, RS had a significantly lower conversion rate (odds ratio: 0.42; 95% confidence interval: 0.28 to 0.63; $P<0.0001$), lower reoperation rate (odds ratio: 0.454; 95% confidence interval: 0.31 to 0.94; $P=0.03$), more lymph nodes harvested (mean difference: 0.67; 95% confidence interval: 0.30 to 1.04; $P=0.0004$), a smaller incidence of positive circumferential margin (CRM) (odds ratio: 0.59; 95% confidence interval: 0.41 to 0.85; $P=0.004$). RS had less time to first autonomous urination (mean difference: -0.78; 95% confidence interval: -1.15 to -0.41; $P<0.0001$), less time to first defecation (mean difference: -0.40; 95% confidence interval: -0.78 to -0.01; $P=0.04$) and less time to first flatus (mean difference: -0.45; 95% confidence interval: -0.89 to -0.01; $P=0.04$), more operating time (mean difference: 23.46; 95% confidence interval: 15.76 to 31.16; $P<0.00001$). Overall postoperative complication, short-term postoperative complication, estimate blood loss, hospital stays, Intraoperative complication, postoperative mortality, preventive ostomy rates, readmission did not differ significantly between approaches. ($P>0.05$).

Conclusion Compared to laparoscopic surgery, robotic surgery demonstrated superior safety, efficacy, and prognosis. This meta-analysis supports that RS is a safe and effective option.

Keywords Robotic rectal surgery, Laparoscopic rectal surgery, Randomized controlled trials, Meta-analysis

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Introduction

Rectal cancer is one of the most common malignancies and represents a significant cause of morbidity and mortality worldwide [1]. Since the advent of minimally invasive techniques in gastrointestinal surgery, both laparoscopic and robotic approaches have witnessed a steady increase in utilization for rectal cancer procedures. The laparoscopic approach has demonstrated superior short-term outcomes and facilitated quicker postoperative recovery when compared to traditional open surgery [2, 3]. However, its application in rectal cancer surgery, particularly for tumors located in the lower rectum, remains challenging due to anatomical constraints. Robotic surgery addresses many of these challenges by offering enhanced 3-D visualization, improved dexterity, reduced tremors, motion scaling, and a shorter learning curve [4–6]. While numerous meta-analyses comparing robotic rectal surgery (RS) and laparoscopic rectal surgery (LS) have been conducted, many suffer from small sample sizes, and some yield inconsistent results [7–15]. Despite numerous prior meta-analyses comparing RS versus LS, the evidence supporting the superiority of robotic approach over laparoscopy remained inconclusive. Previous systematic reviews and meta-analyses primarily relied on observational comparative studies. However, more recent reports have shifted their focus to a limited number of RCTs with inadequate sample sizes. Therefore, we conducted an extensive literature search and analysis, expanding the sample size to assess the potential advantages of RS versus LS in terms of safety, efficacy, and prognosis.

Method

Design

This meta-analysis of RCTs was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

Search strategy

According to the PICOT framework. Patients: Patients with rectal cancer who underwent surgical intervention. Interventions: Robotic rectal surgery. Comparison: Laparoscopic rectal cancer. Outcome: short-term results, quality of surgery and pathological outcomes. Type of study: RCT. PubMed, Embase and the Cochrane Library were searched from their inception to 1 February 2024. The search strategy included the following terms: "robotic", "laparoscopic", "rectal carcinoma", "rectal cancer", "proctectomy", "total mesorectal excision", "randomized", and "trial", utilized either as keywords or MeSH terms. The complete search string used for the literature search in PubMed is provided in Appendix S1.

Study selection

Two independent authors (J.Y.Z, H.Y.Z) screened the retrieved articles from the initial literature search, removing duplicate studies and discarding irrelevant ones. Eligibility studies were then further assessed independently by the two authors, either in abstract form or in full text, to determine if they met the inclusion criteria. Any disagreements regarding study selection between the two authors were resolved through discussion and consensus, or by consulting a third independent author (X.J.W).

Data collection

Two reviewers (J.Y.Z and H.Y.Z) independently extracted the pertinent data from the included studies, including details such as the first author, publication year, country, characteristics of the study population, gender ratio, and study outcomes. The second author (H.Y.Z) verified all extracted data. In cases of disagreement, a third author (X.J.W) was consulted for resolution.

Risk of bias assessment

Risk of bias was analyzed using the Cochrane risk assessment tool.

Outcomes

The primary outcomes were postoperative complication rates, short-term postoperative complication rates, conversion rates, harvested lymph nodes and positive positive circumferential margin (CRM) rates. The secondary outcomes were intraoperative complication rates, postoperative mortality, preventive ostomy rates, readmission rates, reoperation rates, operative time, estimated blood loss, first flatus, first defecation, first autonomous urination and hospital stays. For each study, patient characteristics were extracted according to availability. For each study, patient characteristics were extracted according to availability. We used postoperative complication rates, short-term postoperative complication rates, conversion rates, intraoperative complication rates, postoperative mortality, and estimated blood loss to assess the safety of the surgery. Harvested lymph nodes, positive CRM rates, operative time, and preventive ostomy rates were used to evaluate the efficacy of the surgery. Readmission rates, reoperation rates, first flatus, first defecation, first autonomous urination, and hospital stays were used to assess the prognosis of the surgery.

Statistical analysis

Continuous variables were pooled using weighted mean difference (WMD) with 95% confidence interval (CI), while odds ratio (OR) with 95% CI was applied to perform the statistical analysis for dichotomous variables. Statistical heterogeneity was evaluated using the χ [2] test with significance set at $P < 0.10$, and heterogeneity was quantified using the I [2] statistic. This study defined I [2] of 25%, 50%, and 75% as low, moderate, and high heterogeneity, respectively [16]. We utilized a random-effects model for the data analysis procedure when $I^2 > 40\%$, as it takes into account the almost inevitable natural variation between studies, particularly in surgical research. $P < 0.05$ was considered statistically significant. Funnel plots was used to assess publication bias. If the data on continuous outcomes were reported as medians and range or mean and interquartile range, we estimated the mean and standard deviation according to Luo and Wan's methods [17, 18]. Meta-analysis was conducted by Review Manager Version 5.4. $P < 0.05$ was considered significant. Through sensitivity analysis conducted by leave-one-out analyses, we sought to gain a deeper understanding of the sources of heterogeneity and strengthen the robustness of the results.

Results

Study selection and characteristics

The study selection process, following the PRISMA guidelines, is illustrated in Fig. 1. Initially, a total of 407 studies were identified. After removing 104 duplicate studies using Endnote software, 264 studies were excluded based on screening of titles and abstracts. Subsequently, eleven studies meeting the inclusion criteria were identified through a thorough full-text evaluation [19–29]. The publication years of these studies ranged from 2008 to 2023, with a cumulative sample size of 3107 participants. The essential characteristics of the included studies and the extracted data are summarized in Table 1.

Risk of bias assessment

The evaluation results regarding the quality of the study and the risk of bias are depicted in Fig. 2.

Outcomes

The comparison of primary and secondary outcomes between RS and LS is presented in Table 2.

Primary outcomes

Pooling the data from 9 studies that assessed overall postoperative complications in 2675 patients showed no significant difference between the RS and LS groups (odds ratio: 0.86; 95% confidence interval: 0.62 to 1.19; $P = 0.35$) (Fig. 3). 6 studies including 2240 patients reported short-term postoperative complications showed no significant difference between the two groups (odds ratio: 0.92; 95% confidence interval: 0.62 to 1.36; $P = 0.67$) (Fig. 4). RS had a significantly lower conversion rate in 9 studies included 2614 patients (odds ratio: 0.42; 95% confidence interval: 0.28 to 0.63; $P < 0.0001$) (Fig. 5), more lymph nodes harvested in 10 studies included 3056 patients (mean difference: 0.67; 95% confidence interval: 0.30 to

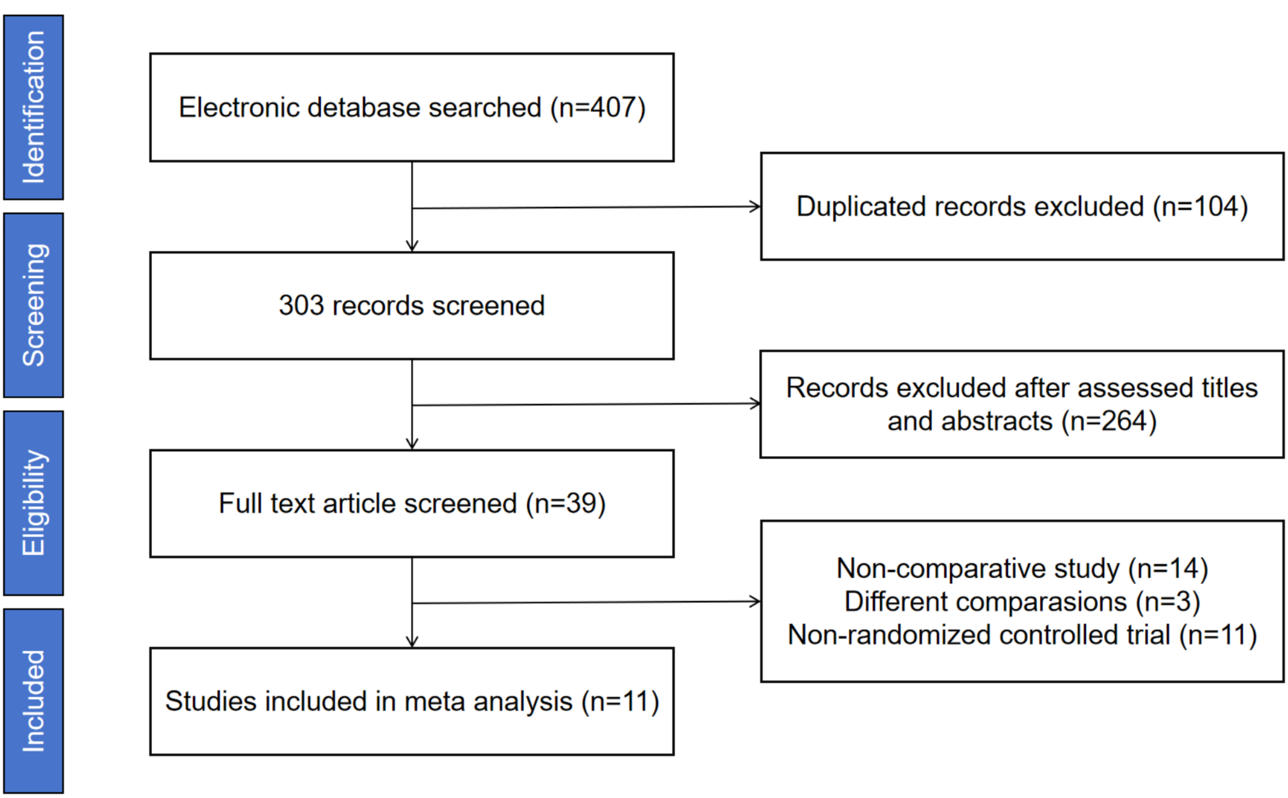

Fig. 1 Study selection diagram for meta-analysis of RS and LS procedures

Table 1 Characteristics of trials included in the meta-analysis

Study	Country	Single-/Multi-center	Number of Procedures	Robotic system	RS vs. LS				
					Number of Patients	Male Gender, %	Age (Year), Mean ± SD	BMI (kg/m^2), Mean ± SD	Neoadjuvant Therapy, %
Baik SH 2008	Korea	single-center	NA	da Vinci	18 vs. 18	66.1 vs. 59.6	60.3 ± 8.3 vs. 63.2 ± 10.4	23.4 ± 3.0 vs. 23.2 ± 2.7	8.9 vs. 12.3
Patriti A 2009	Italy	single-center	NA	da Vinci	29 vs. 37	38.5 vs. 33.3	68 ± 10 vs. 69 ± 10	24.2 ± 6.2 vs. 25.4 ± 6.44	24.1 vs. 5.4
Wang Gang2016	China	single-center	10	da Vinci	71 vs. 66	100 vs. 100	60.3 ± 6.74 vs. 58.7 ± 7.45	22.9 ± 2.31 vs. 22.4 ± 2.62	18.3 vs. 16.7
Xu J 2017	China	single-center	NA	da Vinci	173 vs. 176	NA	NA	NA	NA
Kim MJ 2017	Korea	single-center	30	da Vinci	66 vs. 73	77.3 vs. 71.2	60.4 ± 9.7 vs. 59.7 ± 11.7	NA	NA
Jayne D 2017	UK	multi-center	30	NA	237 vs. 234	67.9 vs. 67.9	64.4 ± 10.98 vs. 65.5 ± 11.93	NA	NA
Debakey Y 2018	Egypt	single-center	NA	da Vinci	21 vs. 24	42.4 vs. 54.2	53.4 ± 9.26 VS 50.3 ± 7.19	NA	57.1 vs. 45.8
Tolstrup Rikkle 2018	Denmark	single-center	10	da Vinci	25 vs. 26	72 vs. 77	63 ± 10.9 vs. 68 ± 9.9	27 ± 4.5 vs. 28 ± 4.3	26.2 vs. 28.6
Feng Q 2022.11	China	multi-center	50	da Vinci	586 vs. 585	60.8 vs. 60.5	59.1 ± 11.0 vs. 60.7 ± 9.8	23.5 ± 3.3 vs. 23.5 ± 3.1	43.3 vs. 43.9
Feng Q 2022.12	China	single-center	50	da Vinci	174 vs. 173	62.1 vs. 65.3	58.2 ± 9.6 vs. 59.5 ± 10.9	NA	21.3 vs. 20.2
Park JS 2023	Korea	multi-center	100	NA	151 vs. 144	64.2 vs. 68.8	65.5 ± 11.4 vs. 67.2 ± 10.1	23.9 ± 3.3 vs. 23.5 ± 2.8	50.3 vs. 47.2

Abbreviations: RS, Robotic Surgery; LS, Laparoscopic Surgery; SD, Standard deviation; BMI, Body mass index; NA, Not available

1.04; $P = 0.0004$) (Fig. 6), and a smaller incidence of positive CRM in 6 studies included 2623 patients (odds ratio: 0.59; 95% confidence interval: 0.41 to 0.85; $P = 0.004$) (Fig. 7).

Secondary outcomes

RS has a lower reoperation rate compared to LS (odds ratio: 0.454; 95% confidence interval: 0.31 to 0.94; $P = 0.03$) (Fig. 8). less time to first autonomous urination (days) (mean difference: -0.78; 95% confidence interval: -1.15 to -0.41; $P < 0.0001$) (Fig. 9), less time to first defecation (days) (mean difference: -0.40; 95% confidence interval: -0.78 to -0.01; $P = 0.04$) (Fig. 10) and less time to first flatus (days) (mean difference: -0.45; 95% confidence interval: -0.89 to -0.01; $P = 0.04$) (Fig. 11), more operating time(mins) (mean difference: 23.46; 95% confidence interval: 15.76 to 31.16; $P < 0.00001$) (Fig. 12). intraoperative complication rates, postoperative mortality, preventive ostomy rates, readmission rates, estimated blood loss (ml), and hospital stays (days) did not differ significantly between groups (Fig. 13).

Sensitivity analysis

The analysis results are shown in Appendix S2.

Publication bias

The funnel plots for assessing publication bias for results with at least ten studies are presented in the supplementary material (Figure S1 and S2).

Discussion

Improvements in surgical techniques were important in advancing the field of rectal cancer treatment. This study examined the outcomes of robotic surgery versus laparoscopic surgery for rectal cancer based on evidence from RCTs and included 11 RCTs that randomized 3,107 patients into two groups. The sample size in this study was larger than in previous studies. As the sample size increased, the evidence became more robust. RS gained popularity due to its advantages in navigating the narrow pelvic cavity compared to LS [30, 31]. This study aimed to conduct a comprehensive and critical analysis of multicenter and large RCT samples regarding the use of RS, providing valuable evidence for clinical decision-making. Our meta-analysis revealed that the RS group exhibited a lower conversion rate to laparotomy, lower positive CRM rates, increased lymph node harvested, faster postoperative recovery of bowel function, and reduced reoperation rates compared to the LS group. However, the operation time in the RS group was longer. No significant differences were observed between the two groups in terms of postoperative mortality, overall postoperative

Fig. 2 The risk-of-bias assessment of each included study

Table 2 Outcomes of comparison between RS and LS

Outcomes	Studies	RS Patients	LS Patients	WMD/OR (95%CI)	*P**	Study Heterogeneity			
						χ^2	df	I^2, %	*P**
Postoperative complication rates	9	1329	1346	0.86 (0.62, 1.19)	0.35	17.48	8	54	**0.03**
Short-term postoperative complication rates	6	1116	1124	0.92 (0.62, 1.36)	0.67	13.94	5	64	**0.02**
Conversion rates	9	1306	1308	0.42 (0.28, 0.63)	<**0.0001**	8.80	7	20	0.27
Harvested lymph nodes	10	1526	1530	0.67 (0.30, 1.04)	**0.0004**	11.50	9	22	0.24
Positive CRM rates	6	1321	1302	0.59 (0.41, 0.85)	**0.004**	1.75	5	0	0.88
Intraoperative complication rates	5	1213	1205	0.78 (0.58, 1.05)	0.10	4.32	4	7	0.36
Postoperative mortality	2	607	609	0.63 (0.08, 4.89)	0.66	0.21	1	0	0.64
Preventive ostomy rates	5	1011	966	1.03 (0.74, 1.44)	0.84	8.50	4	53	0.07
Readmission rates	3	781	782	0.66 (0.38, 1.14)	0.14	2.26	2	12	0.32
Reoperation rates	3	781	782	0.54 (0.31, 0.94)	**0.03**	0.13	2	0	0.94
Operating time	11	1551	1556	23.46 (15.76, 31.16)	<**0.00001**	305.13	10	97	<**0.00001**
Estimated blood loss	7	1200	1344	-12.94 (-27.57, 1.70)	0.08	208.57	6	89	<**0.00001**
Time to first flatus	6	1038	1049	-0.45 (-0.89, -0.01)	**0.04**	120.90	5	96	<**0.00001**
Time to first defecation	2	652	658	-0.40 (-0.78, -0.01)	**0.04**	2.19	1	54	0.14
Time to first autonomous urination	3	933	934	-0.78 (-1.15, -0.41)	<**0.0001**	13.03	2	85	**0.001**
hospital stays	9	1329	1346	-0.68 (-1.50, 0.14)	0.10	45.48	7	85	<**0.00001**

Abbreviations: RS, Robotic Surgery; LS, Laparoscopic Surgery; WMD, weighted mean difference; OR, odds ratio; CI, confidence interval; df, degrees of freedom

*Statistically significant results are shown in bold

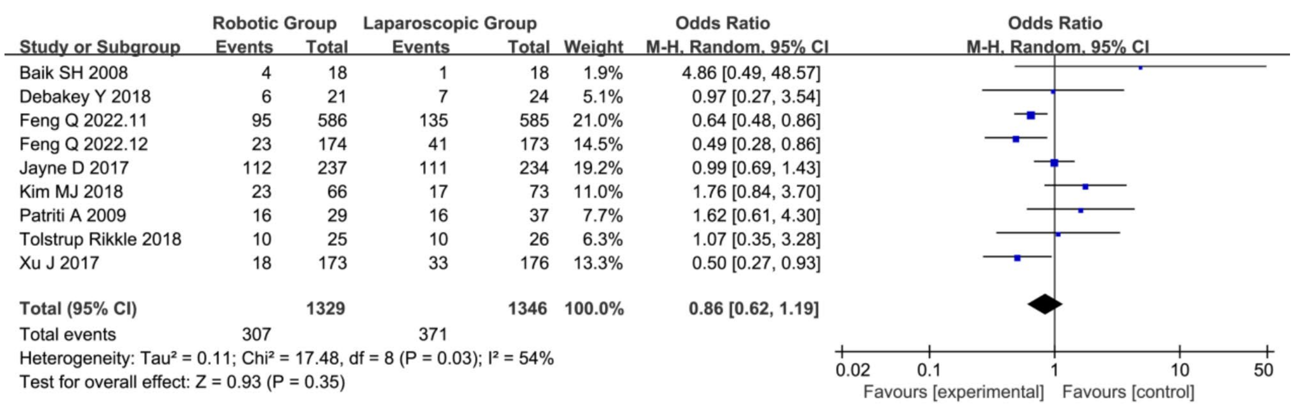

Fig. 3 Forest plot of comparison between robotic rectal surgery RS and laparoscopic rectal surgery LS in terms of overall postoperative complications

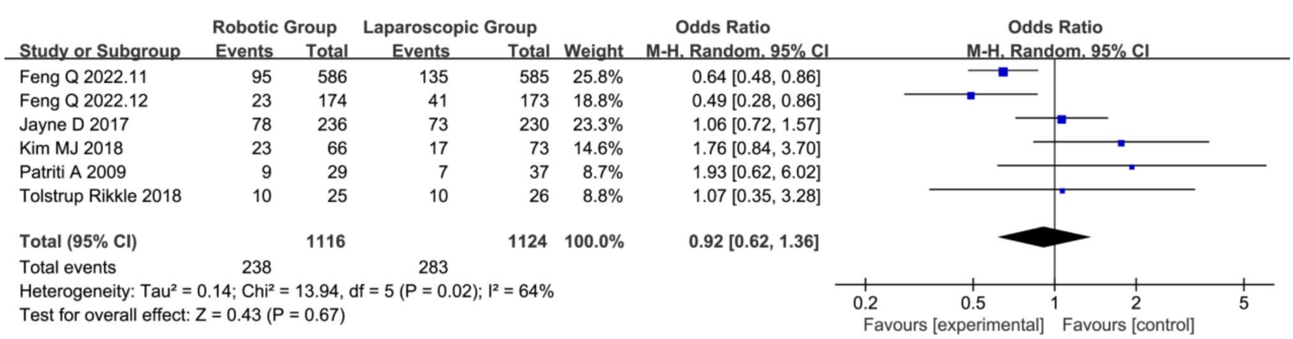

Fig. 4 Forest plot of comparison between robotic rectal surgery RS and laparoscopic rectal surgery LS in terms of short-term postoperative complications

complications, short-term postoperative complications, readmission rates, intraoperative complications, rates of preventive ostomy, length of hospital stays, and estimated blood loss.

The conversion rate was a significant factor linked to postoperative complications, adverse outcomes, and mortality [32, 33], bearing both short- and long-term clinical relevance in rectal cancer surgery [34, 35]. Previous studies indicated that RS did not have an advantage

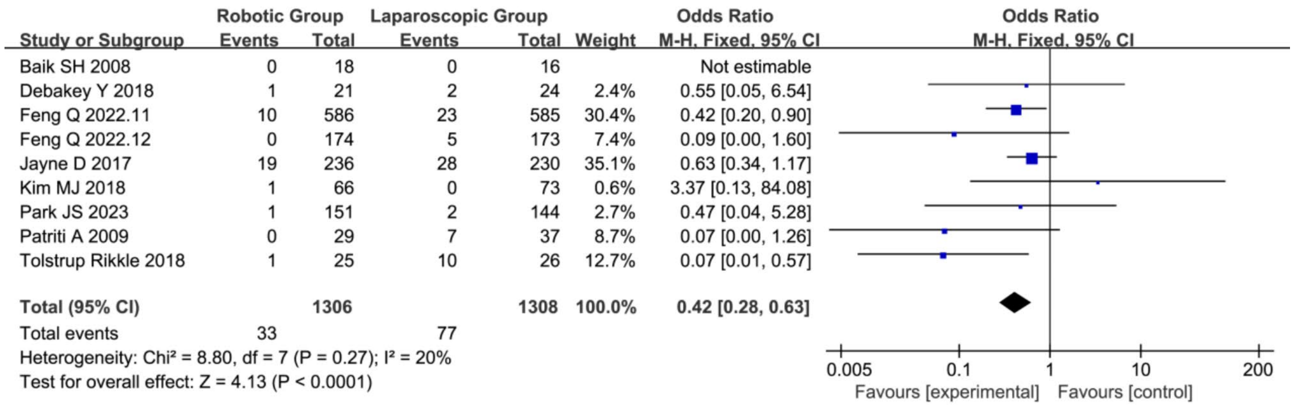

Fig. 5 Forest plot of comparison between robotic rectal surgery RS and laparoscopic rectal surgery LS in terms of conversion rate

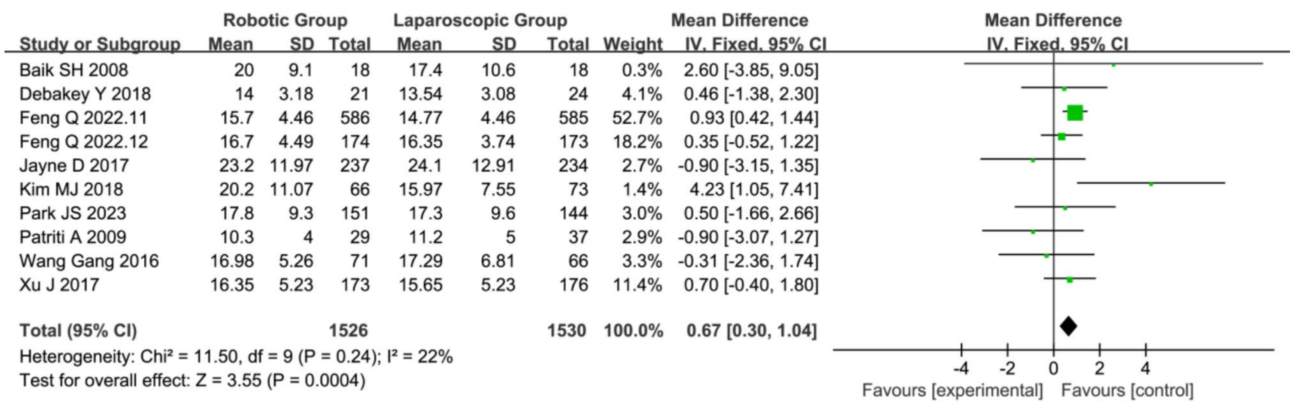

Fig. 6 Forest plot of comparison between robotic rectal surgery RS and laparoscopic rectal surgery LS in terms of lymph nodes harvested

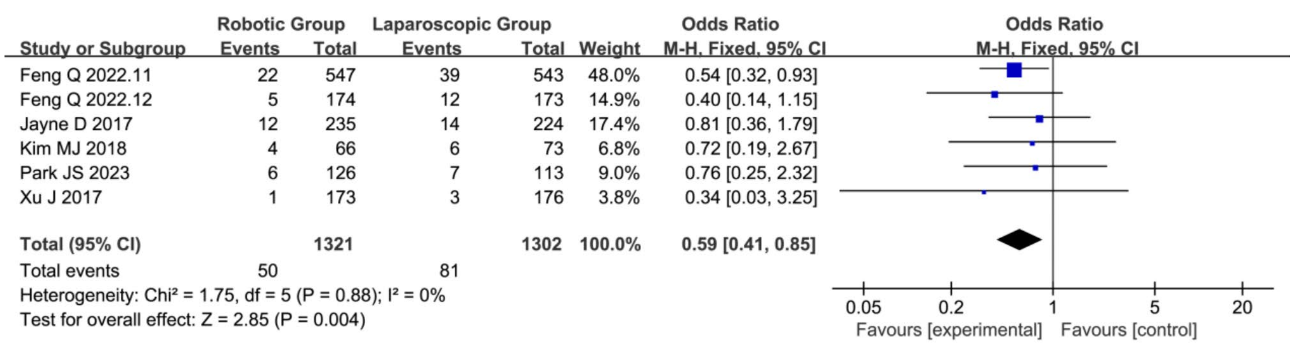

Fig. 7 Forest plot of comparison between robotic rectal surgery RS and laparoscopic rectal surgery LS in terms of positive CRM

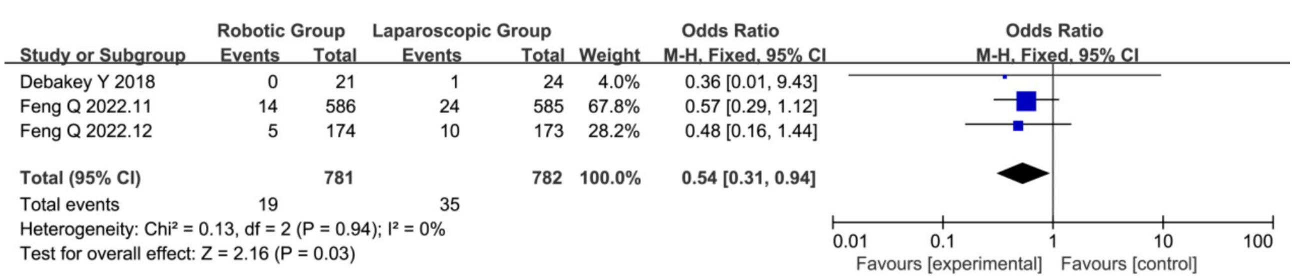

Fig. 8 Forest plot of comparison between robotic rectal surgery RS and laparoscopic rectal surgery LS in terms of reoperation rate

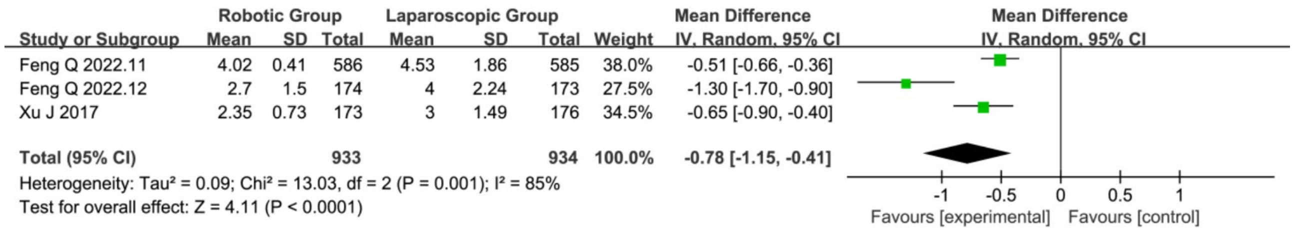

Fig. 9 Forest plot of comparison between robotic rectal surgery RS and laparoscopic rectal surgery LS in terms of time to first autonomous urination (days)

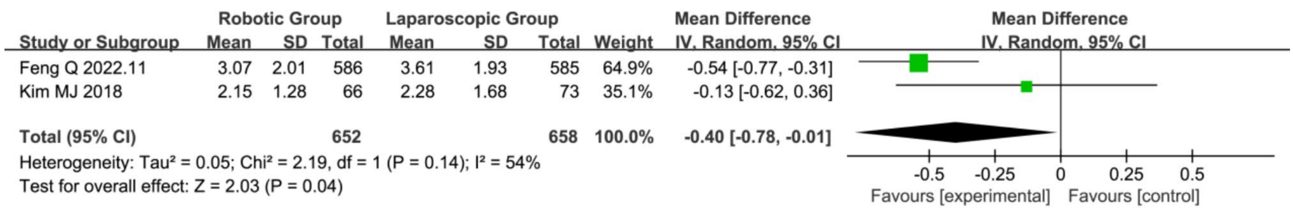

Fig. 10 Forest plot of comparison between robotic rectal surgery RS and laparoscopic rectal surgery LS in terms of time to first defecation (days)

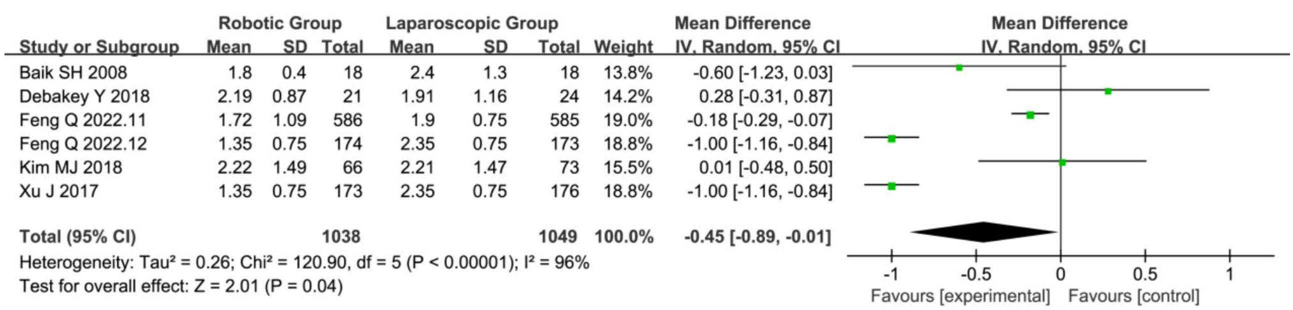

Fig. 11 Forest plot of comparison between robotic rectal surgery RS and laparoscopic rectal surgery LS in terms of time to first flatus (days)

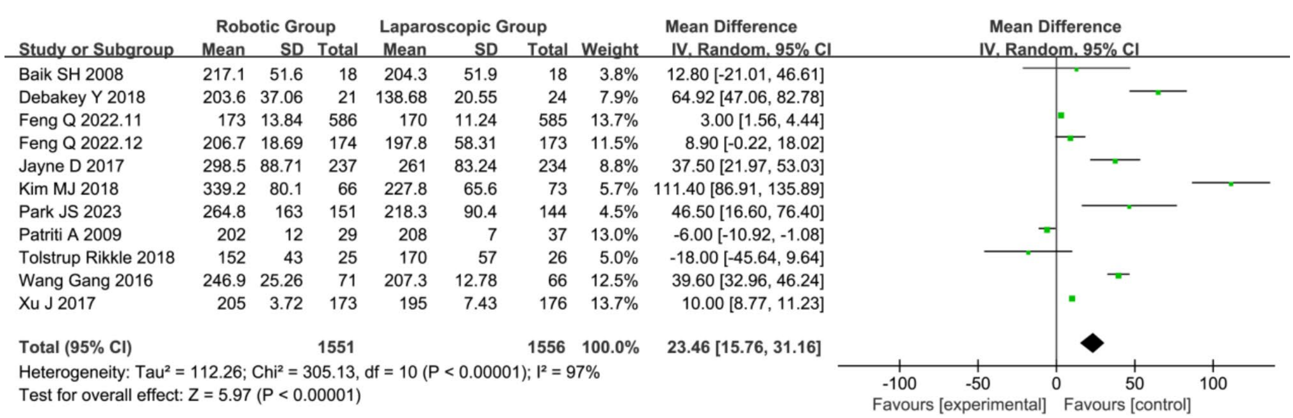

Fig. 12 Forest plot of comparison between robotic rectal surgery RS and laparoscopic rectal surgery LS in terms of operating time (mins)

over LS in terms of the conversion rate [23]. This meta-analysis revealed a significantly lower overall pooled conversion rate in patients who underwent robotic surgery compared to those who underwent laparoscopic surgery.

Previous studies indicated the clinical and physiological superiority of laparoscopic surgery over open surgery [36, 37]. However, our meta-analysis revealed that patients in the RS group did not exhibit a significant difference in length of hospital stay compared to those in the LS group. Interestingly, the RS group demonstrated a significantly shorter time for achieving first autonomous urination, flatus, and defecation compared to the LS group. This suggested that patients who underwent robotic surgery experienced reduced surgical trauma and faster recovery of bowel function compared to those who underwent laparoscopic surgery. A low reoperation

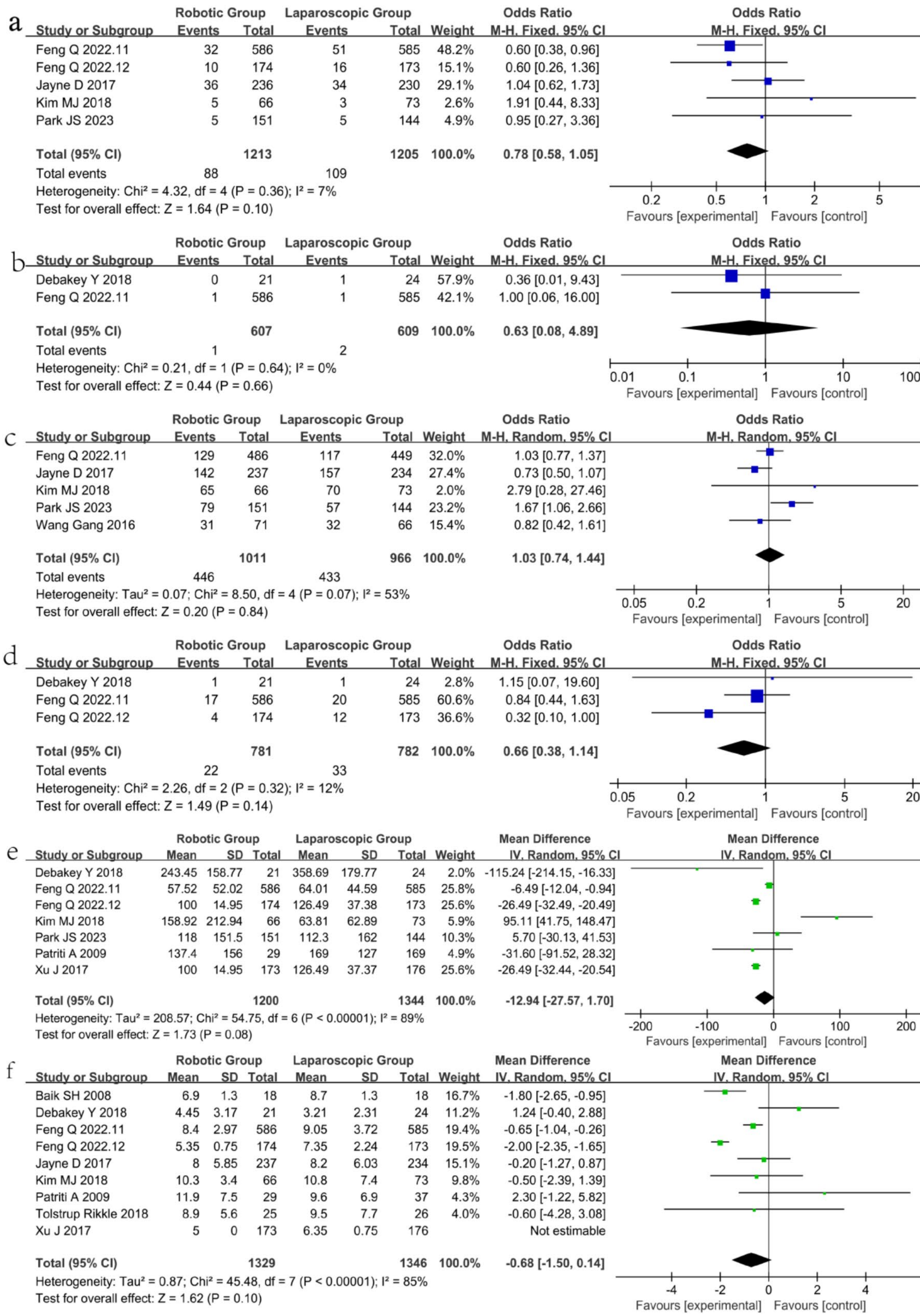

Fig. 13 Forest plot of comparison between robotic rectal surgery RS and laparoscopic rectal surgery LS in terms of secondary outcomes without statistical significance. (**a**) Intraoperative complication rates; (**b**) postoperative mortality; (**c**) preventive ostomy rates; (**d**) readmission rates; (**e**) estimated blood loss (ml); (**f**) hospital stays (days)

rate typically signifies a higher surgical success rate and a reduced occurrence of postoperative complications, making it an important indicator of surgical quality. The increased sample size and inclusion of new RCTs bolstered the statistical power of this meta-analysis. Notably, this study marked the first time that RS demonstrated a lower reoperation rate compared to LS, suggesting superior surgical quality and a favorable prognosis associated with RS.

Limitation

This meta-analysis exclusively comprised randomized controlled trials, and the number of RCTs included was relatively modest. Several RCTs had insufficient data on both primary and secondary endpoints, primarily due to short follow-up durations, and did not address the impact of cost implications. Furthermore, variations in surgical indications, matching criteria, operative techniques, and outcome measurement methods were observed across the included studies, potentially leading to substantial between-study heterogeneity. Pooling of data using the random-effects model cannot completely eliminate the effect of heterogeneity. Future research could address these gaps, including cost-effectiveness and patient-specific benefits (e.g., elderly or anatomically complex cases). this study is the absence of prospective registration on platforms.

Conclusion

This study included the largest number of RCTs comparing RS versus LS to date, making it the largest meta-analysis in terms of sample size, Notably, it is the first investigation to observe a lower reoperation rate for RS compared to LS. Current evidence suggests that RS may offer advantages in surgical quality and recovery. Nevertheless, the longer operating time of surgery and higher cost associated with RS, coupled with the uncertain long-term prognosis, further multicenter and large-scale RCT samples are still needed to confirm our findings.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12893-025-02805-z.

Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Supplementary Material 4

Supplementary Material 5

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Author contributions
JY Zou and HY Zhu collected data and wrote the manuscript, YQ Tang prepared the figures and tables, Y Huang and P Chi provided suggestions for revisions, and XJ Wang provided guidance. All authors reviewed the manuscript.

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Data availability
Data is provided within the supplementary information files.

Declarations

Ethics approval and consent to participate
This study does not require ethics approval.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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