Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Oncologic and Perioperative Outcomes of Different Surgical Approaches for Rectal Cancer: A Systematic Review and Network Meta-Analysis of Randomized Controlled Trials

Jun-hu Wang
Surgery，Chongqing University Jiangjin Hospital
Jin-dou Li
Surgery，Chongqing University Jiangjin Hospital
Peng Tang
Surgery，Chongqing University Jiangjin Hospital
Zhourong Su
suzhourong@163.com

Chongqing University Jiangjin Hospital

Research Article

Keywords: Rectal Cancer, Surgical Approaches, Laparoscopic Surgery, Efficacy, Safety

Posted Date: November 1st, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10960124/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Additional Declarations: No competing interests reported.

Abstract

Background

This study aims to systematically compare the clinical efficacy and safety of four surgical methods: open total mesorectal excision (OpTME), laparoscopic-assisted total mesorectal excision (LapTME), robotic-assisted total mesorectal excision (RoTME), and transanal total mesorectal excision (TaTME), to provide evidence-based guidance for clinical decision-making.

Methods

We conducted a systematic search and a frequentist network meta-analysis of randomized controlled trials (RCTs) up to June 30, 2025 to evaluate the relative efficacy and safety of different surgical methods.

Results

A total of 19 RCTs involving 6,887 rectal cancer patients were included. Results showed that neither TaTME (hazard ratio [HR]: 1.12, 95% CI: 0.97–1.28) nor RoTME (HR: 1.01, 95% CI: 0.95–1.08) showed no significant improvement over LapTME. Although TaTME (HR: 0.84) and RoTME (HR: 0.71) demonstrated a trend toward reduced overall recurrence rates, the differences were not statistically significant. There were also no significant differences in positive circumferential margin rates among the groups. The OpTME group exhibited a higher risk of postoperative complications (relative risk [RR]: 1.15), while TaTME (RR: 0.97) and RoTME (RR: 0.83) showed a downward trend.

Conclusions

Current evidence suggests trends favoring TaTME and RoTME for certain efficacy endpoints (e.g., recurrence) and safety outcomes (e.g., postoperative complications), but none of these differences reached statistical significance compared with LapTME. Of note, important outcomes such as anastomotic leak, sphincter preservation, and functional recovery were not assessed due to insufficient data across trials. Therefore, clinical decisions should be based on surgical experience, institutional resources, and patient-specific factors until higher-quality evidence emerges.

1 Introduction

Colorectal cancer represents a significant public health burden worldwide, with rectal cancer accounting for approximately 40% of all cases. According to the latest GLOBOCAN estimates, colorectal cancer is the third most common malignant tumor globally and the third leading cause of cancer-related deaths(1, 2). The current standard treatment for rectal cancer is total mesorectal excision (TME), which involves complete removal of the rectum and the surrounding mesorectal fascia to achieve better oncological outcomes(3). TME can be performed via abdominoperineal resection (APR) or low anterior resection, and the choice of procedure depends on individual patient characteristics, anatomical considerations, and tumor features(4).

Traditionally, TME has been performed using open total mesorectal excision (OpTME)(4). However, minimally invasive surgical (MIS) techniques such as laparoscopic-assisted total mesorectal excision (LapTME), robotic-assisted total mesorectal excision (RoTME), and transanal total mesorectal excision (TaTME) techniques have been increasingly applied in clinical practice. While numerous randomized controlled trials (RCTs) have compared these approaches against open surgery or each other, their findings remain inconsistent. For instance, some studies suggest that LapTME reduces wound infections and hospital stay(4, 5), but others highlight technical limitations such as restricted visualization and instrument maneuverability in the deep pelvis. Similarly, TaTME may improve distal margin visualization via a “bottom-up” approach, yet concerns about local recurrence persist. Robotic surgery offers enhanced ergonomics and stable platforms(6, 7) but is associated with longer operative times and higher costs(8, 9), without clear superiority in oncologic outcomes (9, 10). More importantly, head-to-head comparisons

among the three minimally invasive techniques are scarce, and pairwise meta-analyses have yielded conflicting conclusions. As a result, the optimal surgical approach for rectal cancer remains undefined.

This study therefore conducted a systematic review and network meta-analysis (NMA), aiming to compare the direct and indirect effects of two or more treatment options. This approach offers a unique advantage in evaluating competitive surgical techniques. The aim is to provide evidence-based guidance for surgical decision-making and to clarify the priority directions for future research in the field of rectal cancer management.

2 Materials and Methods

2.1 Data sources and search strategy

A systematic literature search was conducted in the PubMed, Web of Science, Embase, and Cochrane Central Register of Controlled Trials. The complete search strategies for each database, including all Boolean operators, field tags, and filters, are provided in Supplementary Material S1. An example for PubMed is as follows: (“Rectal Neoplasms”[MeSH] OR “Rectum”[tiab] AND “cancer”[tiab] OR “rectal tumor” [tiab] OR “rectal carcinoma” [tiab]) AND (“Laparoscopy”[MeSH] OR “Laparoscopic”[tiab] OR “Robotic Surgical Procedures”[MeSH] OR “Robotics”[tiab] OR “Transanal Endoscopic Surgery”[MeSH] OR “Transanal”[tiab] OR “Open Surgery”[tiab] OR “Total Mesorectal Excision”[tiab]). We did not search trial registries, gray literature, or conference proceedings. However, we manually screened the reference lists of all included studies and relevant systematic reviews to identify additional eligible trials. The search scope covered the creation date of each database up to June 30, 2025. Literature screening was limited to English-language publications.

This systematic review followed the PRISMA 2020 guidelines. The completed PRISMA checklist is provided in Supplementary Material S2.

2.2 Inclusion and exclusion criteria

Inclusion criteria were as follows: Study type: randomized controlled trials (RCTs). Study subjects: patients with histologically confirmed rectal adenocarcinoma (other rectal tumors such as neuroendocrine tumors, GIST, or squamous cell carcinoma were excluded). Comparison of at least two of the following surgical approaches for total mesorectal excision: OpTME, LapTME, RoTME, or TaTME. Primary outcome measures: efficacy endpoints, including overall survival rate (OS): Extracted as the hazard ratio (HR) with 95% confidence interval as reported. When multiple follow-up time points were available, we used the longest follow-up to capture mature survival data; Recurrence: Defined as any recurrence (local recurrence, distant metastasis, or combined); and circumferential resection margin (CRM) positivity: Defined according to each trial’s reported threshold (most commonly ≤ 1 mm from the mesorectal fascia; a few trials used ≤ 2 mm). Secondary outcome measures: Postoperative complications: Defined as any complication occurring within 30 days of surgery (or during the same hospital stay). Specific complications (e.g., anastomotic leakage, ileus, wound infection) were not analyzed separately because they were not consistently defined or reported across the included RCTs. Therefore, we used the overall postoperative complication rate as the primary safety endpoint. The overall complication rate (any grade) was extracted when available; 30-day mortality: Defined as death from any cause within 30 days of surgery. This definition was consistently used across all included trials that reported this outcome. We also considered disease-free survival (DFS) as a potential endpoint. However, after reviewing the 19 included RCTs, we found that DFS was reported inconsistently across studies (e.g., definitions varied, some trials censored non-cancer deaths while others did not, and several trials did not report DFS at all). Given this heterogeneity and the risk of outcome reporting bias, DFS was not included in the network meta-analysis. Overall survival and overall recurrence were prioritized as the primary efficacy endpoints.

Exclusion criteria were as follows: Case reports, reviews, opinion articles, etc. Animal experiments and studies involving children or adolescents will not be included. Studies with incomplete data or unclear research methods are excluded. Studies previously published elsewhere.

2.3 Operational definitions of surgical approaches and handling of procedural heterogeneity

The four surgical approaches were defined as follows:

OpTME: Conventional open total mesorectal excision performed through a midline laparotomy. Laparoscopic assistance for diagnostic purposes only (e.g., staging laparoscopy) was allowed, but the TME dissection had to be completed via open technique.

LapTME: Total mesorectal excision performed entirely via laparoscopic ports (with or without hand-assisted technique). Specimen extraction was performed through a mini-laparotomy or natural orifice (if reported), but the TME dissection itself was completed laparoscopically.

RoTME: Total mesorectal excision using a robotic surgical system (e.g., da Vinci Si, Xi, or SP) for the pelvic dissection. Procedures using robotic assistance only for a portion of the dissection (e.g., laparoscopic splenic flexure mobilization followed by robotic TME) were categorized as RoTME provided the mesorectal dissection was completed robotically. Pure robotic (full robotic) and hybrid robotic-laparoscopic procedures were included under RoTME.

TaTME: Total mesorectal excision performed via a transanal approach using dedicated platforms (e.g., Transanal Endoscopic Operation [TEO] or Transanal Minimally Invasive Surgery [TAMIS]), with or without concurrent abdominal laparoscopic assistance. If the TME dissection was completed transanally, the procedure was categorized as TaTME irrespective of whether the abdominal phase was laparoscopic or robotic.

Intraoperative conversion: Procedures that were converted to a different technique (e.g., LapTME converted to OpTME) were analyzed according to the intention-to-treat (ITT) principle as originally randomized. This approach preserves the randomization and avoids bias from selective exclusion of conversions.

APR vs. sphincter-preserving surgery: Both abdominoperineal resection (APR) and low anterior resection (LAR) were included. These were analyzed together because individual trial data stratified by procedure type were not available.

2.4 Data extraction

Two researchers independently reviewed the titles and abstracts to identify studies relevant to the topic. Full texts of potentially eligible articles were retrieved and assessed by two independent reviewers. Data from the included studies were extracted by two independent reviewers. The extracted information included: basic study characteristics (first author, year of publication), participant characteristics (age, total number of participants, number of participants allocated to each surgical approach), types and methods of surgical intervention, and outcome data. Any disagreements during the screening or extraction process were resolved through discussion among the reviewers, with consultation of a third reviewer if necessary.

2.4 Quality assessment

The reviewers used the revised Cochrane Risk of Bias Tool (RoB 2.0) to assess the risk of bias in the study(11). The assessment covered five domains: (1) randomization process, (2) deviations from intended interventions, (3) missing outcome data, (4) measurement of the outcome, and (5) selection of the reported result. Each domain was judged as “low risk”, “some concerns”, or “high risk”. An overall risk-of-bias judgment was then assigned to each study. Any disagreements between reviewers were resolved through discussion or by consulting a third reviewer.

2.5 Statistical analysis

A frequentist network meta-analysis was performed using the R package netmeta (version 2.9-0; Rücker et al., 2024). A random-effects model with the restricted maximum likelihood (REML) estimator was applied to account for anticipated between-study heterogeneity. Heterogeneity was quantified using the I^2 statistic, with thresholds of 25%, 50%, and 75% indicating low, moderate, and high heterogeneity, respectively. The random-effects model was selected a priori because clinical and methodological heterogeneity (e.g., differences in tumor stage, neoadjuvant regimens, surgeon experience) was anticipated. To explore potential sources of heterogeneity, we qualitatively compared study characteristics and performed sensitivity analyses (leave-one-out and fixed-effect model comparisons. For time-to-event outcomes (overall survival and recurrence), hazard ratios

(HRs) with 95% confidence intervals (CIs) were estimated. For binary outcomes (circumferential resection margin positivity, postoperative complications, and 30-day mortality), relative risks (RRs) with 95% CIs were calculated.

Network graphs were generated using the netgraph function to visualize direct comparisons between interventions. Ranking probabilities were derived using P-scores, which are the frequentist analogue of SUCRA (Surface Under the Cumulative Ranking curve) and are calculated within the netmeta framework based on the point estimates and standard errors of all pairwise comparisons. P-scores range from 0 (worst) to 1 (best) and were used to construct cumulative ranking curves.

The transitivity assumption—that the distribution of effect modifiers is similar across different treatment comparisons—was evaluated by comparing key clinical and methodological characteristics (tumor stage, neoadjuvant therapy use, tumor height, and study design) across the treatment arms. No systematic differences were identified that would violate transitivity, although residual confounding cannot be excluded.

Due to the open-loop structure of the evidence network (i.e., absence of direct comparisons for several pairwise contrasts such as RoTME vs. TaTME), formal assessment of consistency between direct and indirect evidence was not possible. Node-splitting methods could not be applied because there were no closed loops. To assess potential small-study effects and publication bias, we generated comparison-adjusted funnel plots for the primary outcomes (overall survival, recurrence, and CRM positivity) using the netfunnel function in the netmeta package. Asymmetric funnel plots may indicate publication bias or other small-study effects. All statistical analyses were conducted using R software (version 4.3.3) with the netmeta package.

3 Results

3.1 Study selection and study characteristics

The search strategy flowchart for this study is shown in Fig. 1. The systematic literature search initially identified a total of 6,124 records from the following electronic databases: PubMed (n = 1,203), the Cochrane Library (n = 694), Web of Science (n = 801), and Embase (n = 3,426). After removing 2,020 duplicate records, 4,104 unique articles remained for title and abstract screening. Of these, 3,952 records were excluded as they did not meet the predefined inclusion criteria. The full texts of the remaining 152 articles were sought for retrieval, of which 109 were not retrieved (e.g., conference abstracts without full data, non-English publications, or unavailable full texts). After reviewing the full texts of 43 articles, 24 were excluded due to inconsistency of outcome indicators (n = 15), unavailable data (n = 1), or not being randomized controlled trials (n = 8). Ultimately, 19 RCTs meeting all inclusion criteria were included in the quantitative and qualitative synthesis(12–30). Notable heterogeneity across trials was observed in patient characteristics (e.g., tumor stage, neoadjuvant therapy protocols, surgical indications) and study design (single-center vs. multicenter, geographic region). These differences are summarized in Table 1, while a detailed summary of baseline tumor characteristics, neoadjuvant treatments, CRM definitions, and follow-up durations for each included trial is provided in Supplementary Table S1. Among the included RCTs, several studies explicitly stated that participating surgeons had completed a predefined learning curve or certification process (e.g., Feng 2022, Jayne 2017, Liu 2023), whereas others did not report surgeon experience. This variability is a potential source of between-study heterogeneity.

Table 1
Characteristics of included studies

Study	Study location	Multicenter (Yes or No)	Age, mean	Preoperative radiotherapy (Yes or No)	Patients	Open	Laparoscopic	Robotic	Transanal
Andrew 2015	Australia	Yes	65.0	Yes	473	235	238	0	0
Aracil 2022	Spain	Yes	68.0	Yes	105	0	50	0	55
Arteaga 2006	Spain	No	66.6	Yes	40	20	20	0	0
Debakey 2018	Egypt	No	53.4	Yes	45	0	24	21	0
Denost 2016	France	No	63.0	Yes	100	0	50	0	50
Eduardo 2003	Brazil	No	59.1	Yes	28	15	13	0	0
Feng 2022	China	Yes	59.1	Yes	1171	0	585	586	0
Feng Q 2022	China	No	58.2	Yes	347	0	173	174	0
Fujii 2014	Japan	No	80.1	Yes	200	100	100	0	0
James 2015	American	Yes	57.7	Yes	481	239	242	0	0
Jayne 2017	United Kingdom	Yes	58.0	Yes	471	0	234	237	0
Jeong 2014	Korea	Yes	59.1	Yes	340	170	170	0	0
Kang 2010	Korea	Yes	59.1	Yes	340	170	170	0	0
Lezoche 2012	American	No	66.0	Yes	100	50	50	0	0
Liu 2023	China	Yes	58.0	No	1089	0	545	0	544
Martijn 2013	Netherland	Yes	66.8	Yes	1044	345	699	0	0
Min Kim 2017	Korea	No	60.4	NR	139	0	73	69	0
Seung 2009	Korea	No	63.2	No	113	0	57	56	0
Zeng 2019	China	No	56.1	Yes	261	0	133	0	128

Note: NR: Not reported.

The network analysis of all outcome indicators showed that there was no statistically significant difference in the bias information standards between the consistency model and the inconsistency model, indicating that there was no inconsistency in the trial data. The network diagram of the research results is shown in Fig. 2. The pairwise comparison results of different

surgical treatment regimens are presented in a league table format (see Table 2). The surgical procedures were ranked based on the area under the cumulative curve (Fig. 3).

Table 2
League table

2.1 Overall Survival			
Laparoscopic	**Robotic**	**Transanal**	
Laparoscopic	0.99 (0.92–1.06)	0.90 (0.78–1.03)	
0.99 (0.92–1.06)	**Robotic**		
0.90 (0.78–1.03)	0.91 (0.78–1.06)	**Transanal**	
2.2 CRM Positivity			
Laparoscopic	**Open**	**Robotic**	**Transanal**
Laparoscopic	0.88 (0.55–1.41)	1.22 (0.78–1.92)	0.99 (0.30–3.25)
0.88 (0.55–1.41)	**Open**		
1.22 (0.78–1.92)	1.39 (0.72–2.67)	**Robotic**	
0.99 (0.30–3.25)	1.12 (0.31–4.05)	0.81 (0.23–2.89)	**Transanal**
2.3 Overall Recurrence			
Laparoscopic	**Open**	**Robotic**	**Transanal**
Laparoscopic	0.79 (0.52–1.21)	1.40 (0.68–2.88)	1.19 (0.98–1.44)
0.79 (0.52–1.21)	**Open**		
1.40 (0.68–2.88)	1.77 (0.77–4.06)	**Robotic**	
1.19 (0.98–1.44)	1.50 (0.94–2.38)	0.85 (0.40–1.78)	**Transanal**
2.4 30-day Mortality			
Laparoscopic	**Open**	**Robotic**	**Transanal**
Laparoscopic	0.72 (0.43–1.21)	0.77 (0.17–3.48)	1.09 (0.69–1.73)
0.72 (0.43–1.21)	**Open**		
0.77 (0.17–3.48)	1.06 (0.21–5.27)	**Robotic**	
1.09 (0.69–1.73)	1.52 (0.76–3.04)	1.43 (0.29–6.95)	**Transanal**
2.5 Postoperative Complication rate			
Laparoscopic	**Open**	**Robotic**	**Transanal**
Laparoscopic	0.87 (0.72–1.06)	1.20 (0.95–1.51)	1.03 (0.75–1.43)
0.87 (0.72–1.06)	**Open**		
1.20 (0.95–1.51)	1.37 (1.01–1.86)	**Robotic**	
1.03 (0.75–1.43)	1.18 (0.81–1.73)	0.86 (0.58–1.28)	**Transanal**

Notably, the evidence network contained no direct comparisons for several pairwise contrasts, including RoTME versus TaTME, RoTME versus OpTME, and TaTME versus OpTME. Consequently, the network formed an open-loop structure, which precluded formal assessment of consistency between direct and indirect evidence. Therefore, all indirect comparisons should be interpreted with caution, as the validity of network meta-analysis relies on the assumption of consistency.

3.2 Quality assessment

Of the included studies, 18 used randomizations, and 1 study had unclear randomization. Among these, 10 studies did not mention the method of allocation concealment and were therefore classified as “unclear.” Regarding blinding, 7 studies were open-label trials and were classified as “high risk.” Two studies mentioned double-blinding and were classified as “low risk.” Ten studies did not mention blinding in the literature and were therefore classified as “unclear.” The completeness of study results, selective publication, and other biases were all classified as “low risk,” as no significant risks were identified after reviewing the full text of the studies. See Fig. 4 for details on the quality of the literature.

3.3 Overall survival, recurrence and CRM positivity

In terms of efficacy, compared with LapTME, TaTME (OS HR: 1.12, 95% CI: 0.97, 1.28) and RoTME (OS HR: 1.01, 95% CI: 0.95, 1.08) did not show any improvement in overall survival. Heterogeneity across studies was low (I^2 = 0%). There was a trend toward improved overall recurrence rates (TaTME HR: 0.84, 95% CI: 0.69–1.02; RoTME HR: 0.71, 95% CI: 0.35–1.46), but this trend did not reach statistical significance. Heterogeneity was moderate (I^2 = 32%). Similarly, the overall recurrence rate (OpTME HR: 1.26, 95% CI: 0.83–1.92) and positive CRM (OpTME HR: 1.14, 95% CI: 0.71–1.83; RoTME HR: 0.82, 95% CI: 0.52–1.28; TaTME HR: 1.01, 95% CI: 0.31–3.34) also did not show significant differences among the groups (Fig. 5a–c).Heterogeneity was moderate (I^2 = 65%).

3.4 30-day Mortality and Postoperative complication rate

In terms of safety, TaTME technology reduces the risk of patient mortality compared to LapTME (relative risk RR: 0.91, 95% CI: 0.58–1.45), while OpTME and RoTME technologies increase the risk of patient mortality to some extent (OpTME RR: 1.39, 95% CI: 0.82–2.34; RoTME RR: 1.31, 95% CI: 0.29–5.94). Heterogeneity was low (I^2 = 18%). Patients who underwent OpTME had a higher incidence of postoperative complications (RR: 1.15, 95% CI: 0.94–1.40), while those who underwent TaTME and RoTME had a reduced risk of complications (TaTME RR: 0.97, 95% CI: 0.70–1.34; RoTME RR: 0.83, 95% CI: 0.66–1.05) (Fig. 6a–b). Heterogeneity was moderate (I^2 = 41%).

3.5 Ranking probabilities (P-scores)

To further quantify the probabilistic rankings displayed in Fig. 3, we calculated P-scores (the frequentist analogue of SUCRA) for each outcome. The ranking patterns were as follows. For overall survival, Laparoscopic TME (LapTME) showed the most favorable ranking, followed by Robotic TME (RoTME), Transanal TME (TaTME), and Open TME (OpTME). For recurrence, RoTME ranked highest, then TaTME, LapTME, and OpTME. For circumferential resection margin positivity, RoTME again had the highest probability of being best, followed by LapTME, TaTME, and OpTME. Regarding safety outcomes, RoTME ranked highest for reducing postoperative complications, followed by TaTME, LapTME, and OpTME. For 30-day mortality, TaTME had the most favorable ranking, followed by LapTME, RoTME, and OpTME. These ranking probabilities are consistent with the hazard ratios and relative risks presented in Table 2 and Figs. 5–6, but none of the differences reached statistical significance (all 95% confidence intervals crossed the null). We acknowledge that differences in surgeon experience and learning curve phases across the included RCTs (particularly for RoTME and TaTME) could not be adjusted for due to inconsistent reporting.

3.6 Summary of key statistical findings

A condensed summary of the main effect estimates, heterogeneity, and ranking probabilities is presented in Table 3. For the two most clinically relevant comparisons (RoTME vs. LapTME and TaTME vs. LapTME), none of the effect estimates reached statistical significance (all 95% CIs crossed the null). Heterogeneity was low to moderate for most outcomes (I^2 range: 0%–65%), with the highest heterogeneity observed for CRM positivity (I^2 = 65%). P-score rankings consistently placed RoTME highest for oncologic outcomes (overall survival: 0.72, recurrence: 0.78, CRM: 0.74) and TaTME highest for 30-day mortality (0.65).

Table 3
Summary of key statistical findings for each outcome

Outcome	Comparison	Effect estimate (95% CI)	I^2 (%)	P-score (rank of best)
Overall survival	RoTME vs. LapTME	HR = 1.01 (0.95–1.08)	0	RoTME: 0.72 (1st)
Recurrence	TaTME vs. LapTME	HR = 0.84 (0.69–1.02)	32	TaTME: 0.65 (1st)
CRM positivity	RoTME vs. LapTME	RR = 0.82 (0.52–1.28)	65	RoTME: 0.74 (1st)
Postoperative complications	RoTME vs. LapTME	RR = 0.83 (0.66–1.05)	41	RoTME: 0.82 (1st)
30-day mortality	TaTME vs. LapTME	RR = 0.91 (0.58–1.45)	18	TaTME: 0.72 (1st)

Note: For each outcome, the comparison with the highest clinical interest (minimally invasive technique vs. LapTME) is shown. Heterogeneity is reported as I^2. P-scores range 0–1; higher indicates better ranking (efficacy) or lower risk (safety). All confidence intervals cross the null, indicating no statistically significant differences.

3.7 Sensitivity analyses

To assess the robustness of our findings, we performed leave-one-out sensitivity analyses for outcomes with at least three contributing studies (CRM positivity and 30-day mortality). For each outcome, we sequentially excluded each contributing study and recalculated the pooled effect estimate. No single study exclusion altered the direction or statistical significance of the effect estimate; all 95% confidence intervals continued to include the null value (1.0). Detailed results are presented in Supplementary Table S2. Additionally, we compared the random-effects model (REML) with a fixed-effect model; the effect estimates and conclusions were unchanged. These sensitivity analyses support the robustness of our main findings.

3.8 Publication bias assessment

Comparison-adjusted funnel plots for overall survival, recurrence, and CRM positivity showed no clear evidence of asymmetry (Supplementary Figure S1). This suggests that small-study effects or publication bias are unlikely to have substantially influenced the results. However, due to the limited number of studies per direct comparison, these findings should be interpreted cautiously.

4 Discussion

This study presents an updated network meta-analysis comparing the efficacy and safety of four surgical approaches (OpTME, LapTME, RoTME, and TaTME) for rectal cancer. The key finding is that none of the minimally invasive techniques (RoTME, TaTME, or LapTME) demonstrated statistically significant superiority over the others for overall survival, recurrence-free survival, and circumferential margin negativity rate.

Before discussing potential technical explanations, it is important to note that the following mechanistic hypotheses are derived from the general surgical literature and are not directly tested or confirmed by our data. From a technical perspective, robotic surgery has been associated with potential oncological trends, such as improved accuracy of pelvic fascia anatomy via three-dimensional magnified visualization and enhanced autonomic nerve identification using articulated wrist instruments (31). However, these theoretical benefits did not translate into statistically significant differences in the pooled analysis. For example, the hazard ratio for overall survival (RoTME vs. LapTME) was 1.01 (95% CI: 0.95–1.08), and for recurrence it was 0.71 (95% CI: 0.35–1.46), both with confidence intervals crossing the null. Moreover, the potential technical advantages may be offset by procedural complexity: prolonged operative times during the early learning curve phase increase the risk of anesthesia-related complications (32), which may explain the numerically higher (but not statistically significant) 30-day mortality rate observed for RoTME (RR = 1.31, 95% CI: 0.29–5.94).

The transanal approach showed trends toward certain safety endpoints, such as potentially faster recovery and preservation of abdominal wall nerves, as suggested by some descriptive studies(33, 34). However, none of these trends reached statistical significance in our analysis. For instance, the relative risk for postoperative complications (TaTME vs. LapTME) was 0.97 (95% CI: 0.70–1.34), and for 30-day mortality it was 0.91 (95% CI: 0.58–1.45). Furthermore, caution is warranted regarding oncological outcomes: the “anatomical blind spot” during transanal dissection may contribute to heterogeneity in circumferential resection margin positivity(35, 36), as reflected in the wide confidence interval (TaTME vs. LapTME: RR = 1.01, 95% CI: 0.31–3.34).

Our findings must be interpreted within the context of the existing evidence synthesized through network meta-analyses. Recent analyses by Seow et al. (2023) (37) and de 'Angelis et al. (2025)(38) have provided valuable insights into the comparative effectiveness of TME approaches, focusing respectively on a broad range of perioperative and histopathological outcomes with literature searches current to 2020 and 2024. The present study extends this body of work in several critical directions. First, by including RCTs published up to June 2025, our analysis incorporates the most recent long-term data from pivotal trials, ensuring its conclusions reflect the contemporary surgical landscape. And places a stronger emphasis on long-term patient-important outcomes—specifically overall survival and recurrence—rather than surrogate pathological endpoints. More fundamentally, while prior syntheses have heavily weighed surrogate pathological endpoints, our analysis was explicitly designed to prioritize direct comparisons of long-term patient-important outcomes, specifically overall survival and recurrence, alongside comprehensive safety profiles. This focus reveals a crucial and nuanced finding: despite probabilistic rankings favoring certain minimally invasive techniques for specific endpoints, none demonstrated statistically significant superiority across the core efficacy and safety measures that most directly inform clinical decision-making. Consequently, our conclusions diverge from interpretations that suggest a clear hierarchy based on intermediate outcomes. Instead, we emphasize a pragmatic, evidence-based equipoise, underscoring that the optimal surgical approach cannot be universally prescribed but must be individualized, integrating surgeon proficiency, institutional resources, and specific patient factors. Despite the probabilistic rankings favoring certain minimally invasive techniques, none of the differences reached statistical significance in our analysis, which aligns with the overarching conclusion of prior NMAs that no single technique is clearly superior. This updated synthesis not only refreshes the evidence timeline but also reframes the discussion towards the practical implications of current data for personalized surgical strategy in rectal cancer.

The validity of any network meta-analysis rests on the assumptions of transitivity (similar distribution of effect modifiers across different treatment comparisons) and consistency (agreement between direct and indirect evidence). We could not formally test consistency because the network had an open-loop structure (no closed loops). However, we qualitatively evaluated transitivity by comparing the following potential effect modifiers across the treatment arms of the included RCTs: Tumor location and stage: All studies enrolled mid to low rectal cancer (≤ 15 cm from anal verge) and clinical stages T2-T4 (mostly T3). No systematic differences across comparisons were identified. Neoadjuvant chemoradiotherapy: The proportion of patients receiving neoadjuvant therapy varied across studies (21%–100%), but within each direct comparison it was balanced. The random-effects model accounts for this between-study heterogeneity. Surgical procedure type (APR vs. LAR): Most trials did not report outcomes stratified by APR/LAR, and the distribution of APR across studies is unknown. This represents a potential violation of transitivity because the oncologic risk profile differs between APR and LAR. We have acknowledged this limitation. Learning curve and surgeon experience: Studies varied substantially in surgeon experience and learning curve phase (some required prior case completion, others did not). This may bias indirect comparisons, and we could not adjust for it quantitatively. Calendar period and evolving technology: Older trials (2003–2010) predominantly used open or laparoscopic techniques, while newer trials (2015–2023) introduced robotic and transanal approaches. Temporal improvements in outcomes could bias indirect comparisons that mix studies from different eras.Overall, while no major violations of transitivity were evident for tumor characteristics and neoadjuvant therapy, we cannot rule out violations related to surgical procedure type, learning curve, and calendar period. Therefore, indirect comparisons—particularly those involving robotic and transanal techniques—should be interpreted with caution. Future individual patient data meta-analyses or larger, well-designed RCTs that control for these effect modifiers are needed to confirm or refute our findings.

Surgery-related outcomes such as operative time, intraoperative blood loss, and surgical cost were not subjected to network meta-analysis. Although most trials reported operative time and blood loss, definitions varied and these outcomes are heavily influenced by surgeon experience, learning curve, and case complexity. Surgical cost was reported in only a few trials and is highly context-dependent. Therefore, a reliable NMA for these endpoints was not feasible.

In addition to the inherent advantages of the NMA methodology, this study only included RCTs to minimize heterogeneity and bias in the analysis, thereby strengthening the results. However, this study also has potential limitations. First, outcome definitions varied modestly across the included RCTs. For overall survival, median follow-up times ranged from 12 to 60 months, which may affect the comparability of hazard ratios. For recurrence, most studies reported "any recurrence," but a few reported only local recurrence. For CRM positivity, nearly all trials used the ≤ 1 mm threshold, although a minority used ≤ 2 mm.

Furthermore, we were unable to analyze specific complications such as anastomotic leakage due to inconsistent definitions and incomplete reporting across trials. Future RCTs should standardize the definition and reporting of individual complications to enable more granular meta-analyses. Second, the transitivity assumption—that the distribution of effect modifiers is similar across comparisons—was evaluated qualitatively and appeared plausible, but residual confounding cannot be excluded. Moreover, the sparse network (open-loop structure, few studies per direct comparison) limits the precision of indirect estimates and precludes formal consistency testing. Therefore, our findings, particularly those based on indirect evidence, should be interpreted as hypothesis-generating rather than definitive. Thirdly, while we focused on comparative efficacy and safety through traditional oncological and perioperative endpoints, our analysis did not assess several patient-centered functional outcomes that are increasingly recognized as critical in rectal cancer surgery. Specifically, data on anastomotic leak rates, rates of sphincter preservation, and detailed functional sequelae—such as urinary, sexual, and bowel dysfunction—as well as health-related quality of life measures (e.g., EORTC QLQ-C30 or CR29 modules) were not systematically reported or were inconsistently defined across the included RCTs, precluding their meaningful synthesis in this NMA. The absence of these endpoints represents a significant gap, as they directly impact postoperative recovery, long-term patient well-being, and the perceived success of surgical treatment beyond survival metrics. Future high-quality RCTs and meta-analyses should prioritize the standardized collection, reporting, and comparative analysis of these patient-reported outcome measures (PROMs) and functional endpoints. This will provide a more holistic evidence base, enabling patients and clinicians to make decisions that optimally balance oncological efficacy with functional preservation and quality of life. Fourth, a major methodological limitation of our NMA is the lack of direct head-to-head RCTs for several key comparisons (e.g., robotic vs. transanal, robotic vs. open, transanal vs. open). As a result, the network had an open-loop structure, making it impossible to formally assess consistency between direct and indirect evidence. While we used a frequentist random-effects model and presented all pairwise estimates with confidence intervals, the credibility of indirect comparisons remains inherently uncertain in the absence of consistency testing. Readers should therefore interpret the indirect comparisons, particularly those involving treatments that have never been directly compared, with appropriate caution. Future RCTs directly comparing these novel techniques (e.g., RoTME vs. TaTME) are urgently needed to close the evidence loop and enable formal consistency assessment. Fifth, the included RCTs exhibited substantial clinical heterogeneity in tumor stage, neoadjuvant treatment regimens, surgical indications (LAR vs. APR), and surgeon/institutional experience. While we were unable to perform formal subgroup analyses or meta-regression due to insufficiently granular data reporting (e.g., outcomes not stratified by tumor stage or neoadjuvant type) and the limited number of studies per comparison. Consequently, the impact of these potential effect modifiers on our findings remains unknown. Future individual patient data meta-analyses are needed to explore these sources of heterogeneity. Nonetheless, our sensitivity analyses (leave-one-out and random-vs-fixed-effect model comparisons) suggested that the main findings are robust to the exclusion of any single study and to the choice of modeling approach. Sixth, the learning curve associated with novel surgical techniques (RoTME and TaTME) represents a significant source of potential bias. Several of the included RCTs were conducted during the early adoption phase of these techniques, while others originated from high-volume, specialized centers with extensive experience (e.g., Feng 2022 [REAL] from a high-volume Chinese center; Jayne 2017 [ROLARR] included surgeons with varying experience levels). Pooling trials at different stages of the learning curve may obscure true differences in efficacy and safety, as outcomes improve with accumulating surgical experience. Unfortunately, we could not perform quantitative adjustments for the learning curve because the primary RCTs did not consistently report surgeon-specific case volumes, training requirements, or learning curve phase (e.g., number of prior cases before trial initiation). Consequently, the impact of surgical expertise on our findings remains unknown. Future RCTs of novel surgical techniques should standardize reporting of surgeon experience (e.g., number of prior procedures, certification of competency) and consider learning curve as a stratification factor. Until then, our results should be interpreted with caution, particularly for comparisons involving techniques with steep learning curves. In addition, limiting the search to English-language publications may have introduced language bias, as relevant studies published in other languages could have been missed. However, major RCTs in rectal cancer surgery are typically published in English, and we manually reviewed reference lists to mitigate this risk. Finally, although we performed comparison-adjusted funnel plots to assess publication bias, the small number of studies per direct comparison (most comparisons had fewer than 10 studies) limits the power and reliability of these visual assessments. Thus, the possibility of publication bias cannot be completely excluded. And, the protocol was not prospectively registered. Although we followed PRISMA 2020, the absence of prior registration may increase the risk of reporting bias. We did not analyze DFS due to inconsistent reporting and definitional heterogeneity across the included RCTs. However, overall survival and overall recurrence together provide a comprehensive assessment of oncologic efficacy.

5 Conclusions

In summary, this network meta-analysis of 19 randomized controlled trials involving 6,887 patients found no statistically significant differences between any of the four surgical approaches (OpTME, LapTME, RoTME, and TaTME) for overall survival, recurrence, circumferential resection margin positivity, postoperative complications, or 30-day mortality. Important outcomes such as anastomotic leak, sphincter preservation, and functional recovery were not evaluated due to insufficient data across the included trials. While probabilistic rankings (P-scores) suggested trends favoring robotic TME for oncological outcomes and transanal TME for safety outcomes, these did not reach statistical significance. Therefore, until higher-quality evidence emerges, the choice of surgical technique should be based on surgeon experience, institutional resources, and patient-specific factors, rather than claims of superiority. Future research should prioritize randomized trials directly comparing novel techniques (e.g., RoTME vs. TaTME), standardize outcome reporting, include long-term functional and quality-of-life metrics, and systematically document surgeon experience and learning curve parameters.

Abbreviations

OpTME
Open Total Mesorectal Excision
LapTME
Laparoscopic-assisted Total Mesorectal Excision
RoTME
Robotic-assisted Total Mesorectal Excision
TaTME
Transanal Total Mesorectal Excision
TME
Total Mesorectal Excision
HR
Hazard Ratio
CI
Confidence Interval
RR
Relative Risk
RCT
Randomized Controlled Trial
OS
Overall Survival
CRM
Circumferential Resection Margin
LOS
Length of Stay
MeSH
Medical Subject Headings
NMA
Network Meta-Analysis
RoB
Risk of Bias
APR
Abdominoperineal Resection
MIS
Minimally Invasive Surgery
EORTC QLQ-C30

European Organisation for Research and Treatment of Cancer Quality of Life Questionnaire Core 30
CR29
Colorectal Cancer-specific Quality of Life Questionnaire

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests

Funding

The work was not funded by any funding.

Author Contribution

Junhu Wang and Zhourong Su were responsible for the research conception and design; Jindou Li and Peng Tang were responsible for data collection and processing; Junhu Wang and Jindou Li were responsible for data analysis and interpretation; Junhu Wang was responsible for the initial draft of the paper; Zhourong Su was responsible for the critical revision of the knowledge content; All authors were responsible for the final approval of the published version. All authors confirm their responsibility for the accuracy and completeness of the work and agree to be responsible for any issues in the research.

Acknowledgements

Not applicable

Availability of data and materials

References

1. Filho AM, Laversanne M, Ferlay J, Colombet M, Piñeros M, Znaor A et al (2025) The GLOBOCAN 2022 cancer estimates: Data sources, methods, and a snapshot of the cancer burden worldwide. Int J Cancer 156(7):1336–1346
2. Copija A, Waniczek D, Witkoś A, Walkiewicz K, Nowakowska-Zajdel E (2017) Clinical Significance and Prognostic Relevance of Microsatellite Instability in Sporadic Colorectal Cancer Patients. Int J Mol Sci. ;18(1)
3. Heald RJ, Ryall RD (1986) Recurrence and survival after total mesorectal excision for rectal cancer. Lancet 1(8496):1479–1482
4. Fleshman JW, Smallwood N (2015) Current concepts in rectal cancer. Clin Colon Rectal Surg 28(1):5–11
5. Jiang W, Xu J, Cui M et al (2025) Laparoscopy-assisted versus open surgery for low rectal cancer (LASRE): 3-year survival outcomes of a multicentre, randomised, controlled, non-inferiority trial. Lancet Gastroenterol Hepatol 10(1):34–43

6. Kim NK, Kang J (2010) Optimal Total Mesorectal Excision for Rectal Cancer: the Role of Robotic Surgery from an Expert's View. J Korean Soc Coloproctol 26(6):377–387
7. Park S, Kim NK (2015) The Role of Robotic Surgery for Rectal Cancer: Overcoming Technical Challenges in Laparoscopic Surgery by Advanced Techniques. J Korean Med Sci 30(7):837–846
8. Prete FP, Pezzolla A, Prete F, Testini M, Marzaioli R, Patriti A et al (2018) Robotic Versus Laparoscopic Minimally Invasive Surgery for Rectal Cancer: A Systematic Review and Meta-analysis of Randomized Controlled Trials. Ann Surg 267(6):1034–1046
9. Scarpinata R, Aly EH (2013) Does robotic rectal cancer surgery offer improved early postoperative outcomes? Dis Colon Rectum 56(2):253–262
10. Trastulli S, Farinella E, Cirocchi R, Cavaliere D, Avenia N, Sciannameo F et al (2012) Robotic resection compared with laparoscopic rectal resection for cancer: systematic review and meta-analysis of short-term outcome. Colorectal Dis 14(4):e134–e156
11. Lu T, Lu C, Li H, Xing X, Deng X, Li X et al (2020) The reporting quality and risk of bias of randomized controlled trials of acupuncture for migraine: Methodological study based on STRICTA and RoB 2.0. Complement Ther Med 52:102433
12. Denost Q, Loughlin P, Chevalier R, Celerier B, Didailler R, Rullier E (2018) Transanal versus abdominal low rectal dissection for rectal cancer: long-term results of the Bordeaux' randomized trial. Surg Endosc 32(3):1486–1494
13. Zeng Z, Luo S, Chen J, Cai Y, Zhang X, Kang L (2020) Comparison of pathological outcomes after transanal versus laparoscopic total mesorectal excision: a prospective study using data from randomized control trial. Surg Endosc 34(9):3956–3962
14. Liu H, Zeng Z, Zhang H, Wu M, Ma D, Wang Q et al (2023) Morbidity, Mortality, and Pathologic Outcomes of Transanal Versus Laparoscopic Total Mesorectal Excision for Rectal Cancer Short-term Outcomes From a Multicenter Randomized Controlled Trial. Ann Surg 277(1):1–6
15. Fujii S, Ishibe A, Ota M, Yamagishi S, Watanabe K, Watanabe J et al (2014) Short-term results of a randomized study between laparoscopic and open surgery in elderly colorectal cancer patients. Surg Endosc 28(2):466–476
16. Arteaga González I, Díaz Luis H, Martín Malagón A, López-Tomassetti Fernández EM, Arranz Duran J, Carrillo Pallares A (2006) A comparative clinical study of short-term results of laparoscopic surgery for rectal cancer during the learning curve. Int J Colorectal Dis 21(6):590–595
17. Araujo SE, da Silva eSousa AH Jr., de Campos FG, Habr-Gama A, Dumarco RB, Caravatto PP et al (2003) Conventional approach x laparoscopic abdominoperineal resection for rectal cancer treatment after neoadjuvant chemoradiation: results of a prospective randomized trial. Rev Hosp Clin Fac Med Sao Paulo 58(3):133–140
18. Fleshman J, Branda M, Sargent DJ, Boller AM, George V, Abbas M et al (2015) Effect of Laparoscopic-Assisted Resection vs Open Resection of Stage II or III Rectal Cancer on Pathologic Outcomes: The ACOSOG Z6051 Randomized Clinical Trial. JAMA 314(13):1346–1355
19. Jayne D, Pigazzi A, Marshall H, Croft J, Corrigan N, Copeland J et al (2017) Effect of Robotic-Assisted vs Conventional Laparoscopic Surgery on Risk of Conversion to Open Laparotomy Among Patients Undergoing Resection for Rectal Cancer: The ROLARR Randomized Clinical Trial. JAMA 318(16):1569–1580
20. van der Pas MH, Haglind E, Cuesta MA, Fürst A, Lacy AM, Hop WC et al (2013) Laparoscopic versus open surgery for rectal cancer (COLOR II): short-term outcomes of a randomised, phase 3 trial. Lancet Oncol 14(3):210–218
21. Kang SB, Park JW, Jeong SY, Nam BH, Choi HS, Kim DW et al (2010) Open versus laparoscopic surgery for mid or low rectal cancer after neoadjuvant chemoradiotherapy (COREAN trial): short-term outcomes of an open-label randomised controlled trial. Lancet Oncol 11(7):637–645
22. Jeong SY, Park JW, Nam BH, Kim S, Kang SB, Lim SB et al (2014) Open versus laparoscopic surgery for mid-rectal or low-rectal cancer after neoadjuvant chemoradiotherapy (COREAN trial): survival outcomes of an open-label, non-inferiority, randomised controlled trial. Lancet Oncol 15(7):767–774
23. Lezoche E, Baldarelli M, Lezoche G, Paganini AM, Gesuita R, Guerrieri M (2012) Randomized clinical trial of endoluminal locoregional resection versus laparoscopic total mesorectal excision for T2 rectal cancer after neoadjuvant therapy. Br J Surg 99(9):1211–1218

24. Kim MJ, Park SC, Park JW, Chang HJ, Kim DY, Nam BH et al (2018) Robot-assisted Versus Laparoscopic Surgery for Rectal Cancer: A Phase II Open Label Prospective Randomized Controlled Trial. Ann Surg 267(2):243–251
25. Feng Q, Tang W, Zhang Z, Wei Y, Ren L, Chang W et al (2022) Robotic versus laparoscopic abdominoperineal resections for low rectal cancer: A single-center randomized controlled trial. J Surg Oncol 126(8):1481–1493
26. Baik SH, Kwon HY, Kim JS, Hur H, Sohn SK, Cho CH et al (2009) Robotic versus laparoscopic low anterior resection of rectal cancer: short-term outcome of a prospective comparative study. Ann Surg Oncol 16(6):1480–1487
27. Feng Q, Yuan W, Li T, Tang B, Jia B, Zhou Y et al (2022) Robotic versus laparoscopic surgery for middle and low rectal cancer (REAL): short-term outcomes of a multicentre randomised controlled trial. Lancet Gastroenterol Hepatol 7(11):991–1004
28. Debakey Y, Zaghloul A, Farag A, Mahmoud A, Elattar I (2018) Robotic-Assisted versus Conventional Laparoscopic Approach for Rectal Cancer Surgery, First Egyptian Academic Center Experience, RCT. Minim Invasive Surg 2018:5836562
29. Serra-Aracil X, Zarate A, Bargalló J, Gonzalez A, Serracant A, Roura J et al (2023) Transanal versus laparoscopic total mesorectal excision for mid and low rectal cancer (Ta-LaTME study): multicentre, randomized, open-label trial. Br J Surg 110(2):150–158
30. Ye F, Ruan L, Liu Z, Xie H, Wan T, Zhu W et al (2024) Postoperative urinary retention following transanal versus laparoscopic total mesorectal excision for rectal cancer: A randomized trial report from an experienced center. Heliyon 10(14):e34753
31. Han F, Xie Y, Zhong G et al (2025) da Vinci robotic-assisted micro-space dissection and autonomic nerve network preservation technique in the total mesorectal excision procedure for rectal cancer: a single-center, retrospective, observational, real-world study. J Robot Surg 19(1):425 Published 2025 Jul 26
32. Shinder BM, Farber NJ, Weiss RE, Jang TL, Kim IY, Singer EA et al (2017) Performing all major surgical procedures robotically will prolong wait times for surgery. Robot Surg 4:87–91
33. Zhang X, Chen J, He F, Du W, Li X, Yu X (2025) Comparing efficacy and safety of transanal vs. laparoscopic total mesorectal excision for middle and low rectal cancer: Updated meta-analysis. Eur J Surg Oncol 51(3):109559
34. Burghgraef TA, Sikkenk DJ, Crolla RMPH et al (2023) Assessing the learning curve of robot-assisted total mesorectal excision: a multicenter study considering procedural safety, pathological safety, and efficiency. Int J Colorectal Dis 38(1):9
35. Atallah S, Albert M, Monson JR (2016) Critical concepts and important anatomic landmarks encountered during transanal total mesorectal excision (taTME): toward the mastery of a new operation for rectal cancer surgery. Tech Coloproctol 20(7):483–494
36. Roodbeen SX, de Lacy FB, van Dieren S et al (2019) Predictive Factors and Risk Model for Positive Circumferential Resection Margin Rate After Transanal Total Mesorectal Excision in 2653 Patients With Rectal Cancer. Ann Surg 270(5):884–891
37. Seow W, Dudi-Venkata NN, Bedrikovetski S, Kroon HM, Sammour T (2023) Outcomes of open vs laparoscopic vs robotic vs transanal total mesorectal excision (TME) for rectal cancer: a network meta-analysis. Tech Coloproctol 27(5):345–360
38. de'Angelis N, Schena CA, Azzolina D, Carra MC, Khan J, Gronnier C et al (2025) Histopathological outcomes of transanal, robotic, open, and laparoscopic surgery for rectal cancer resection. A Bayesian network meta-analysis of randomized controlled trials. Eur J Surg Oncol 51(1):109481

Figures

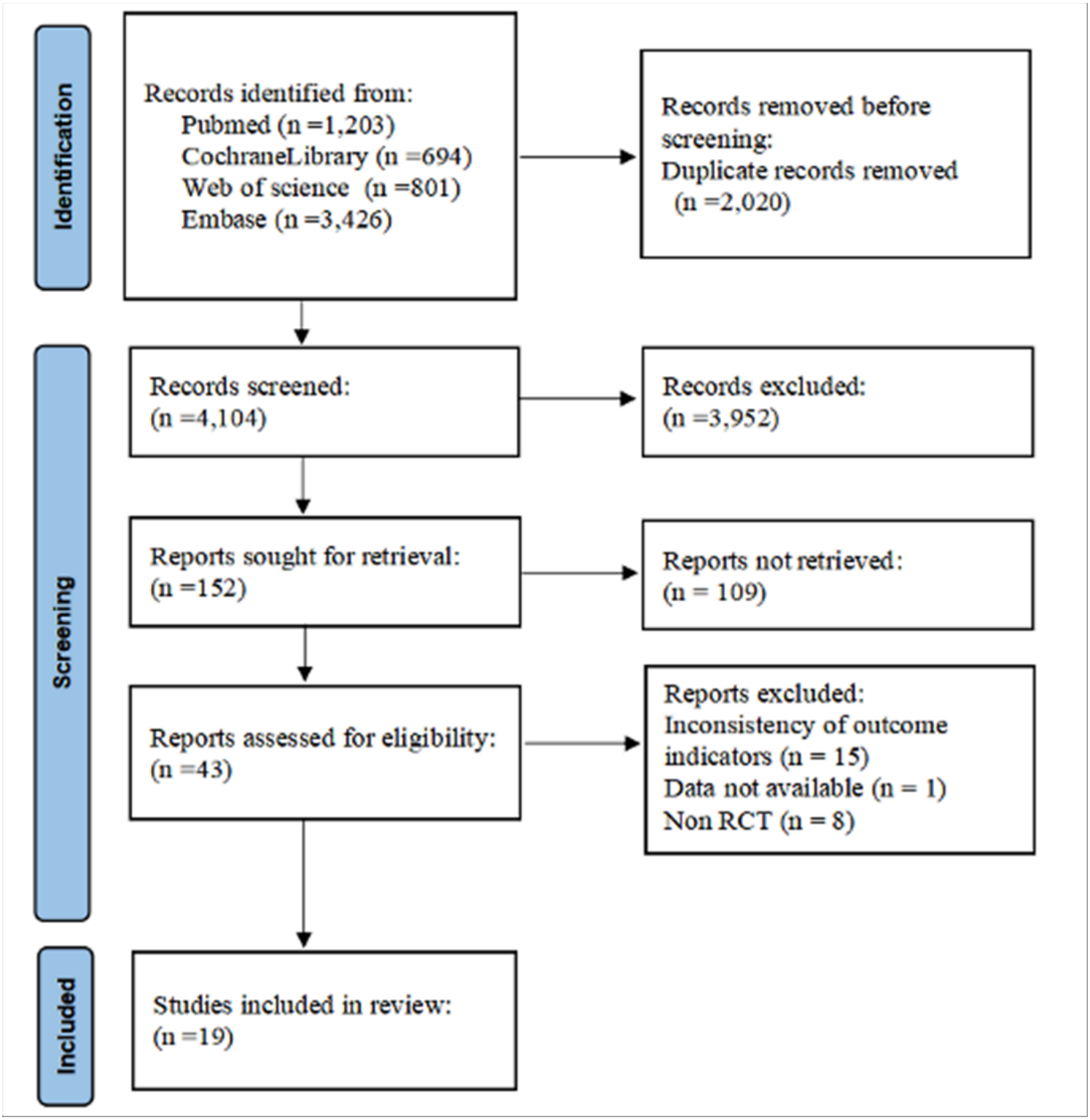


Figure 1

Research Screening Flowchart.

Image not available with this version

Figure 2

Network diagrams of treatment comparisons for each outcome. Each node (circle) represents a surgical approach: OpTME (open total mesorectal excision), LapTME (laparoscopic-assisted total mesorectal excision), RoTME (robotic-assisted total mesorectal excision), and TaTME (transanal total mesorectal excision). Each edge (line) connects two approaches that have been directly compared in at least one randomized controlled trial (RCT). The thickness of an edge is proportional to the number of RCTs supporting that direct comparison. The layout of the network does not imply any statistical superiority or ranking. Numerical effect estimates (hazard ratios, relative risks, and 95% confidence intervals) for all pairwise comparisons are provided in Table 2. Panels (a) to (e) correspond to: (a) overall survival, (b) recurrence, (c) circumferential resection margin (CRM) positivity, (d) postoperative complication rate, and (e) 30-day mortality.

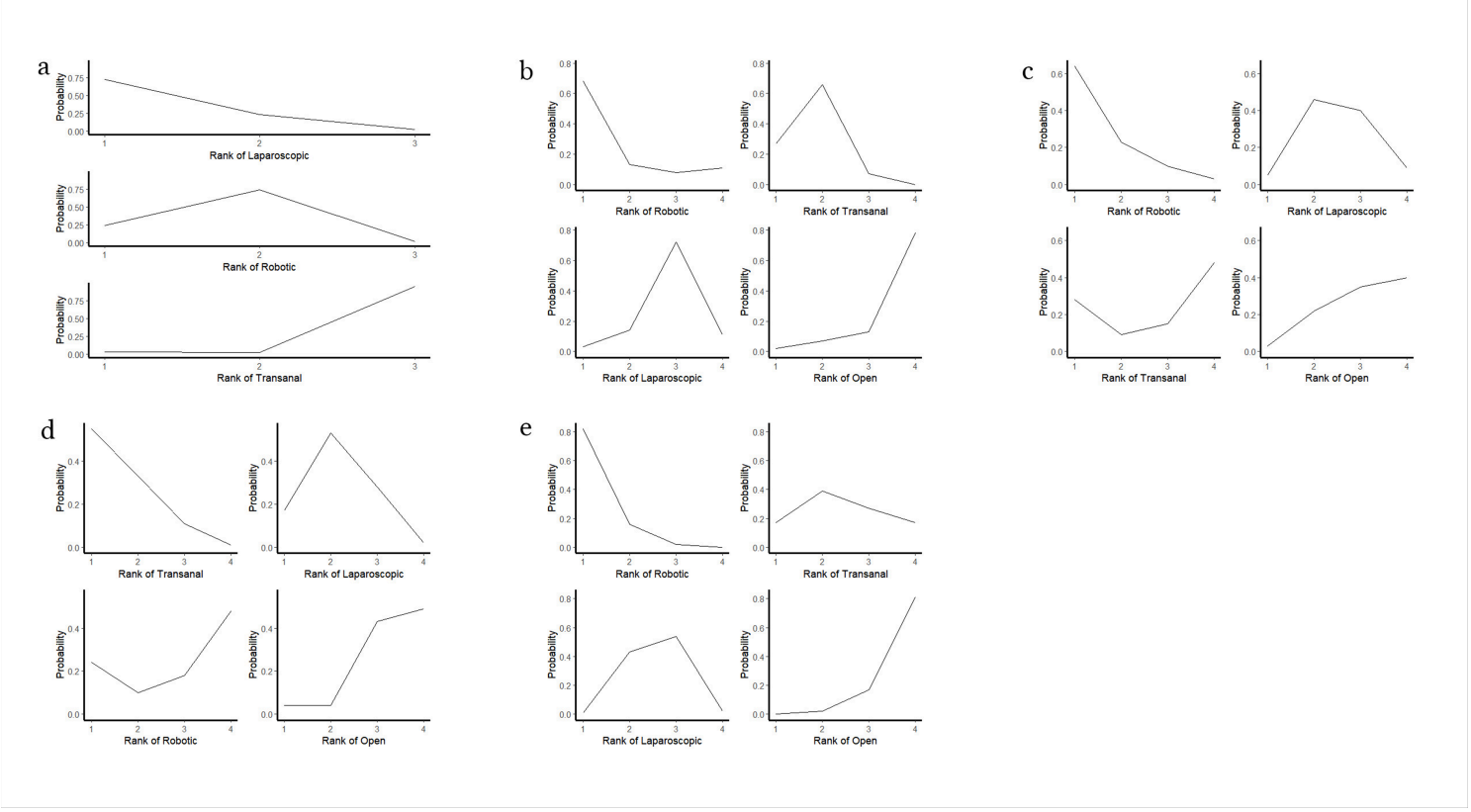


Figure 3

Cumulative ranking curves (based on P-scores) for each outcome. Each panel corresponds to one clinical outcome: (a) overall survival, (b) recurrence, (c) circumferential resection margin (CRM) positivity, (d) postoperative complication rate, and (e) 30-day mortality.

The x-axis (rank) runs from 1st (best) to 4th (worst). The y-axis shows the cumulative probability. A curve that rises steeply to the upper left indicates a higher probability of being top-ranked. P-scores (frequentist analogue of SUCRA) summarize the ranking; higher values indicate better efficacy or lower safety risks.

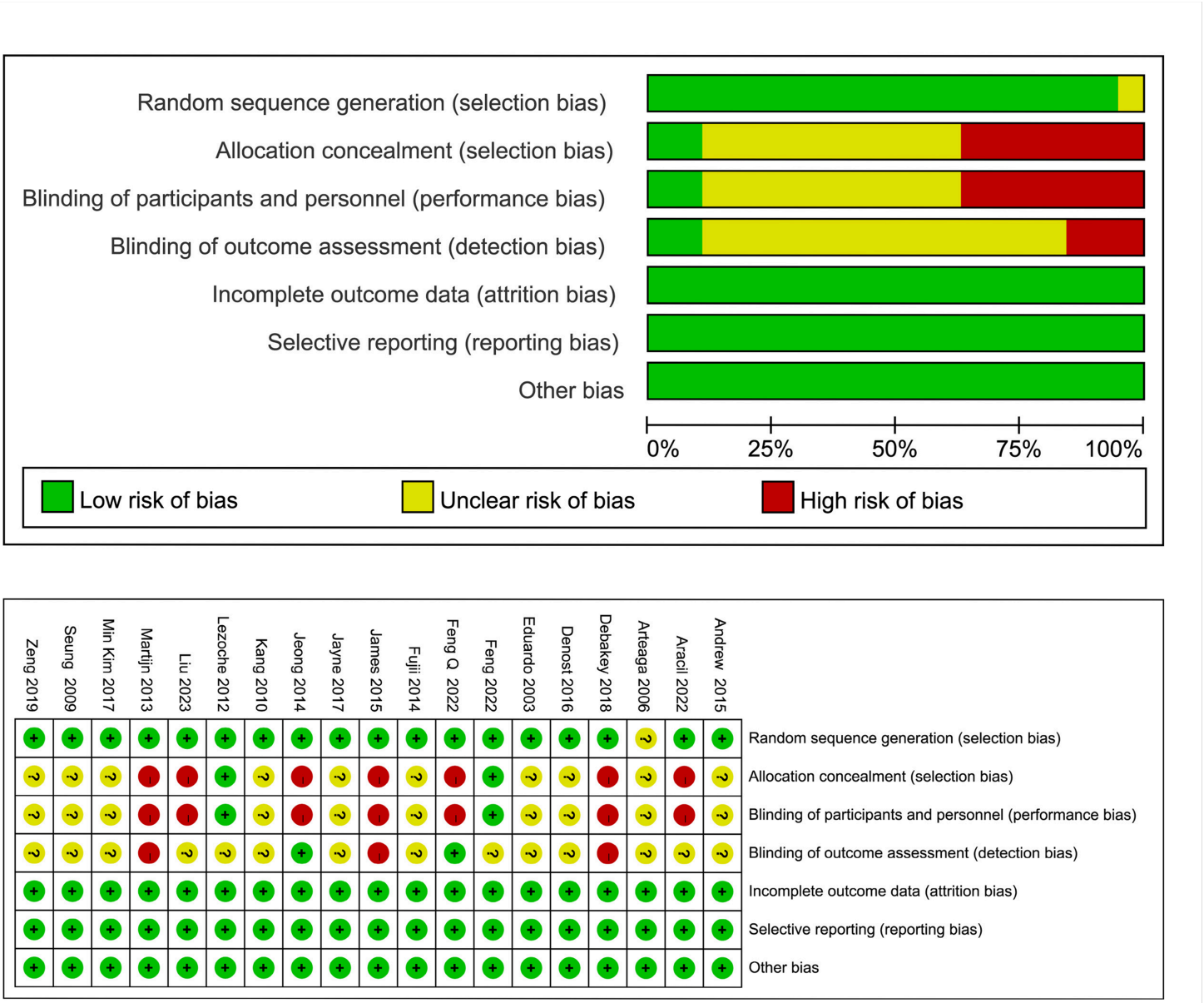


Figure 4

Quality assessment of included studies.

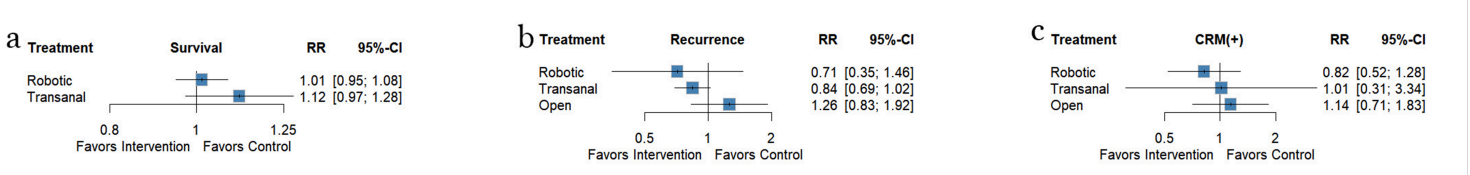


Figure 5

Forest plot a) Overall survival; b) Recurrence; c) CRM positivity.



Figure 6

Forest plot a) Postoperative complication rate; b) 30-day Mortality.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table.docx
- SupplementaryMaterial.docx