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Outcomes of Laparoscopic Versus Robotic-assisted Surgery for Colorectal Cancer: A systematic Review and Meta-analysis

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ABSTRACT

Background: Laparoscopic (LCS) and robotic-assisted colorectal surgery (RACS) are commonly utilized minimally invasive procedures for colorectal cancer (CRC). However, their comparative effectiveness remains debated. This systematic review and meta-analysis examined short-term outcomes between LCS and RACS to support clinical decision-making.

Methods: A systematic search of PubMed, Cochrane Library, Science Direct, and Web of Science was performed following Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) principles. Fourteen studies (n=14) comparing LCS and RACS in CRC patients were included. Primary outcomes were operation time and hospital length of stay (LOS). Secondary outcomes post-operative complications. Data were pooled using random-effects models, with heterogeneity measured via I^2 statistics.

Results: Concerning operative Time, RACS required considerably longer operations than LCS (SMD: -0.67, 95% CI: -1.10 to -0.23; I^2=92.9%). RACS revealed a small but substantial reduction in LOS (SMD: 0.32, 95% CI: 0.13–0.51; I^2=96.1%). LCS had fewer overall complications (RR: 0.76, 95% CI: 0.61–0.96), including decreased anastomotic leak (RR: 0.79) and readmission rates (RR: 0.87). When considering operative efficiency, RACS required considerably longer operations than LCS. RACS was consistently more expensive, with costs reported to be up to 50% greater in some studies.

Conclusions: LCS remains the standard minimally invasive method due to its considerably shorter operative times, lower costs, and a superior safety profile—demonstrated by fewer overall complications, including reduced anastomotic leaks and readmissions. RACS may assist specific patients (e.g., difficult pelvic dissections) but lacks wide advantages to support frequent use. Further randomized trials are needed to identify their ideal role.

KEYWORDS: Colorectal Cancer, Robotic Surgery, Laparoscopic Surgery, Outcomes, Minimally Invasive Surgery, Short Term..

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INTRODUCTION

The third most frequent diagnosis and leading cause of cancer-related mortality for both sexes in the United States is colorectal cancer [1]. It is the second most frequent cause of cancer-related death globally [2]. Due to the extensive use of colonoscopy screening, incidence rates have been declining in Western countries. However, the disease is becoming more common in younger adults [3].

The majority of colon cancers are sporadic, with about 5% being caused by inherited genetic mutations, primarily Lynch syndrome (also known as familial adenomatous polyposis or HNPCC) and familial adenomatous polyposis (FAP). Over the course of several years, the normal colon epithelium gives way to invasive cancer, which often follows a sequence that is defined by the accumulation of genetic mutations, the creation of adenoma, and the following carcinogenesis (adenoma-carcinoma sequence) [4, 5]. Alternative pathways, such those involving DNA mismatch repair (MMR) and the BRAF gene, may be followed by some tumors [6].

It is advised to screen for colon cancer, which can be done in a number of ways. Organizations have different policies on the start and continuation of screening [7]. To diagnose colon cancer, a tissue sample must be taken, often during a colonoscopy. Every newly identified colon cancer should undergo a baseline carcinoembryonic antigen (CEA) test, a thorough colonoscopy, and screening for common genetic alterations. The majority of patients with invasive cancer need a baseline computed tomography (CT) scan of the chest and abdomen [8].

For confined, early-stage colon cancer, surgical resection is the primary treatment option. Among prognostic indicators, the pathological stage is the most significant. The stage determines whether more treatment is required, which may involve immunotherapy, chemotherapy, or, in rare cases, radiation. In order to identify local recurrences and metastatic disease, which may be cured with multimodality therapy, surveillance is essential after treatment. Palliative systemic therapy is used to increase survival and quality of life in cases of disease that cannot be resected or that has spread widely [9-11].

Over the past few decades, there has been a tremendous advancement in the surgical resection of CRC processes. Laparoscopic surgery has historically improved patient outcomes for CRC without adversely compromising safety or oncological results [12-14]. The development of robotic and robot-assisted surgeries in more recent years has greatly reduced the morbidity and mortality attributed to surgery while also aiding surgeons in performing procedures [15]. However, when compared to traditional laparoscopic surgery, robotic-assisted laparoscopic surgery does not significantly lower the likelihood of conversion to open laparotomy in individuals who have rectal adenocarcinoma appropriate for curative resection. According to a prior study, when conducted by surgeons with different levels of robotic surgery experience, robotic-assisted laparoscopic surgery does not offer an advantage in rectal cancer resection [16]. Additionally, a different study showed that the quality of complete mesorectal excision (TME) and postoperative morbidity, improvement in bowel function, and overall quality of life for patients with rectal cancer were equivalent for both robot-assisted and laparoscopic surgery [17]. However, a previous meta-analysis demonstrated that, in comparison to laparoscopic surgery, robot-assisted surgery for rectal cancer resulted in identical oncological results, shorter hospital stays, more rapid recovery rates for bowel function, lower conversion rates, along with longer operative times [18]. Additionally, a network meta-analysis indicated that robot-assisted colorectal surgery (RACS) may be a better option for patients with colorectal cancer (CRC) due to its shorter hospital stay, a reduced risk of complications, mortality, and lower blood loss when compared to laparoscopic-assisted colorectal surgery (LACS) and open surgery [19]. A meta-analysis also showed that while RACS resulted in longer surgeries and higher costs than LACS, patients with colorectal cancer who had both procedures had comparable lengths of stay, blood loss, time of first flatus, conversion to open surgery rates, total number of harvested lymph nodes, and complication rates [20].

The field of RACS research is rapidly evolving. Thus, the purpose of this meta-analysis was to evaluate the effectiveness of laparoscopy and robot-assisted surgery in the management of colorectal cancer. These findings may contribute to the body of knowledge supporting physicians' and patients' decisions on CRC surgery.

METHODS

Search strategy

The short-term outcomes of robotic-assisted surgery and laparoscopic surgery in patients with colorectal cancer were compared in this systematic review and meta-analysis. Four main databases—PubMed, Cochrane Library, Science Direct, and Web of Science—were thoroughly searched electronically. In addition to "laparoscopy" and "robot-assisted surgery", the search strategy included the following keywords and MeSH terms: "colorectal neoplasms", "colorectal cancer", "colorectal tumor", and "colorectal carcinoma". There were no limitations on the age of participants, the year of publishing, or the geographical area.
The reference lists of the included articles and review papers were manually checked to make sure no pertinent studies were missed. To find any unpublished or grey literature, a secondary search was conducted. For every database, the search strategy was modified.

Eligibility and Selection Criteria for the Study

Inclusion Criteria

1. Study Design: All original research studies comparing laparoscopic and robotic-assisted colorectal cancer surgery were included, including randomized controlled trials, cohort studies, and case-control studies. Excluded were animal studies, in vitro research, case reports, and case series.
2. Population: Adults with a colorectal cancer diagnosis who are at least 18 years old.
3. Intervention: Surgery for colorectal cancer with robotic assistance.
4. Comparator: Laparoscopic surgery for colorectal cancer.
5. Research presenting at least one primary outcome (operation time, length of hospital stay) or secondary outcome (complication rates) were included.
6. Language: Only publications in English were selected.

Requirements for Exclusion

1. Studies in languages other than English.
2. Non-original research, such as conference abstracts without full text, editorials, reviews, and meta-analyses.
3. Research that did not compare laparoscopic and robotically assisted surgery.

Extraction and Management of Data

After determining the suitability of the titles and abstracts, two independent reviewers evaluated the full texts of the selected research. Using a standardized form, data extraction was carried out, recording patient demographics, colorectal cancer details, and study characteristics (author, year, country, and study design). A third reviewer was consulted or discussed in order to address any discrepancies.

Bias Assessment Risk

Using the proper tools, the included studies' methodological quality was assessed:
The Cochrane Risk of Bias Tool (ROB 2) was used to assess randomized controlled trials (RCTs).
The Risk of Bias in Non-randomized Studies-of-Interventions (ROB-I) checklist was applied to non-randomized studies. JBI

(Joanna Briggs Institute) tool was used to evaluate case control studies. Egger's regression test and funnel plots were used to evaluate publication bias if at least five studies were included ($p < 0.01$ was deemed significant). Sensitivity analysis was performed by sequentially eliminating studies one by one according to quality score and sample size in order to assess their influence on overall outcomes.

Statistical Analysis and Data Synthesis

Depending on the degree of heterogeneity, either a fixed-effects or random-effects model was used to pool study-specific effect estimates (risk ratios [RR] or standardized mean differences [SMD]). Analysis of subgroups by type of complication was done. R software, version 4.2.1, was used to conduct statistical analyses.

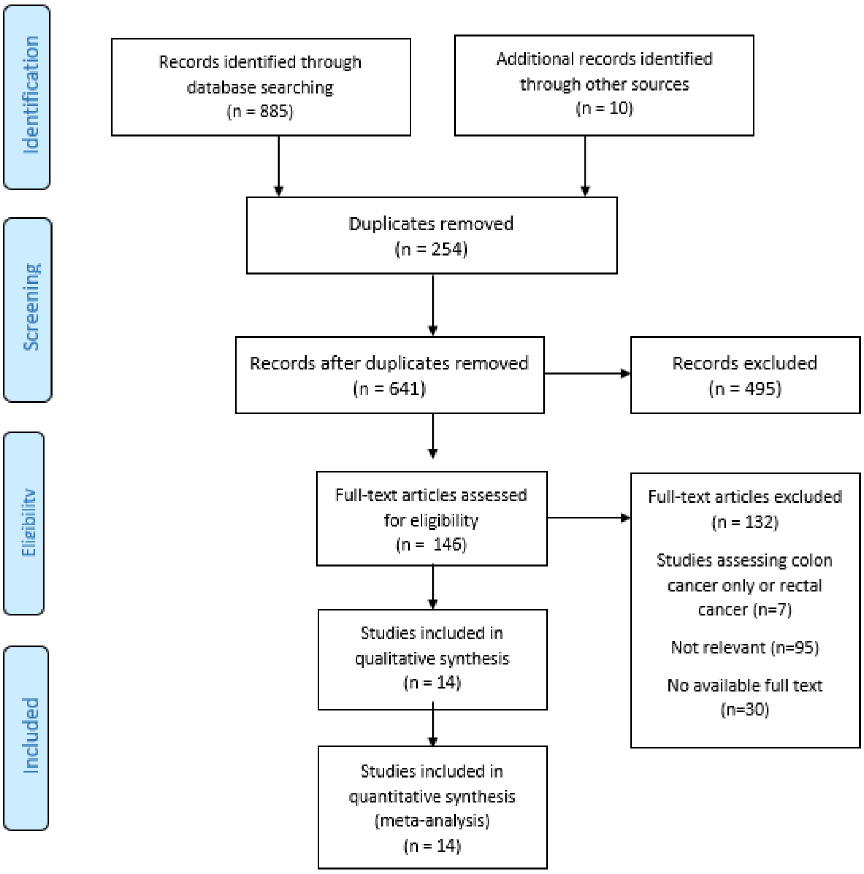


Figure 1: PRISMA flow diagram

RESULTS

The systematic review identified 885 records through database searches and 10 records through manual searches using a thorough search strategy. Abstracts and titles were used to screen 641 entries after duplication was eliminated. Roughly, 641 complete-text articles were assessed for eligibility during the screening phase, whereas 495 records were excluded. A careful review led to the exclusion of 146 full-text papers. Fourteen studies with quantitative data were included in the meta-analysis (Figure 1).

Common characteristics of the selected studies

The characteristics of the included studies are summarized in Table 1. Reflecting a varied geographical representation, the studies covered a spectrum of countries—including the USA [21-23], Italy [24-27], France [28], the United Kingdom [29], Spain [30], Denmark [31], Slovenia [32], Japan [33], and China [34]. Study designs differed; retrospective observational studies were the most frequent, followed by prospective cohort studies, randomized controlled trials, and comparative studies. From as low as 30 patients [33] to over 80,000 [22], which used large databases like the Michigan Surgical Quality Collaborative (MSQC) and the American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP), the number of participants in each study varies greatly. This broad spectrum emphasizes the diversity in study scales. The quality assessment of all research is universally scored as "Moderate," reflecting a consistent level of methodological rigor across the board.

Table 1: Characteristics of the included studies

First author, year	Study Design	Country	Number of Patients	Quality assessment
Abdel Jalil, 2021 [21]	Retrospective observational	USA	2089	Moderate
Batool, 2018 [22]	Retrospective	USA	10,054 (MSQC), 80,535 (ACS-NSQIP)	Moderate
Bertani, 2011 [24]	Prospective cohort	Italy	195	Moderate
Butnari, 2024 [29]	Retrospective	United Kingdom	212	Moderate
D'Annibale, 2004 [25]	Comparative Study	Italy	106	Moderate
De'Angelis, 2018 [28]	Propensity Score Match Analysis	France	160	Moderate
Deutsch, 2012 [23]	Retrospective Review	USA	171	Moderate
Ferrara, 2015 [27]	Retrospective	Italy	100	Moderate
Jiménez Rodríguez, 2011 [30]	Randomized controlled trial	Spain	56	Moderate
Palomba, 2021 [26]	Retrospective Observational	Italy	83	Moderate
Pinar, 2018 [31]	Nationwide Register-Based	Denmark	9184	Moderate
Grosek, 2021 [32]	Retrospective Case-Control	Slovenia	83	Moderate
Sawada, 2015 [33]	Matched case-control study	Japan	30	Moderate
Xue, 2023 [34]	Retrospective cohort study	China	111	Moderate

MSQC: Michigan Surgical Quality Collaborative database, ACS-NSQIP: American College of Surgeons National Surgical Quality Improvement Program

Characteristics of patients in the included studies

Table 2 summarizes the characteristics of participants across the included studies, offering insights into demographics and clinical aspects that may influence outcomes in colorectal cancer surgery. The table includes characteristics such as age, gender distribution, body mass index (BMI), ASA (American Society of Anesthesiologists) score, and history of previous abdominal surgery.

Age data varied between studies, with median or mean ages often ranging from the early 60s to mid-70s, suggesting an older patient population commonly impacted by colorectal cancer. Some studies, explicitly focused on older patients (median age: 82) [34], whereas others [22, 24], found mean ages of 62–64 years. Gender distribution was usually balanced, while some studies observed slight male predominance. A greater proportion of females in the laparoscopic group (801 F vs. 980 M) was reported in a study [21], whereas others [33], had smaller cohorts with near-equal gender distribution.

BMI data were inconsistently reported, with some research providing means or medians (~24–26) [22] and others missing this parameter entirely. ASA ratings, which reflect preoperative physical status, were commonly stated, with most patients classified as ASA I–II (low to moderate risk). However, studies like [26] contained a substantial proportion of ASA III patients (greater risk), demonstrating diversity in patient comorbidities. Previous abdominal surgery was infrequently documented, limiting inferences about its influence. A few studies documented prior surgery rates (e.g., 11.6–32.6%) [28, 29], but most did not address this parameter.

Table 2: Characteristics of the participants in the included studies

First author, year	Age	Gender (M/F)	BMI	ASA Score	Previous Abdominal Surgery
Abdel Jalil, 2021 [21]	Median: 66 (RACR), 67 (LACR)	119/186 (RACR), 801/980 (LACR)	Not specified	Not specified	Not specified
Batool, 2018 [22]	Mean: 64 (OC), 62 (LC), 61 (RC)	1679/920 (OC), 2321/920 (LC), 681/119 (RC)	Mean: 26.1 (OC), 24.6 (LC), 26.1 (RC)	ASA 1-2: 80% (OC), 90% (LC), 85% (RC)	Not specified
Bertani, 2011 [24]	Mean: 63.4 (OCO), 62.0 (LCO), 62.5 (RCO)	29/16 (OCO), 17/13 (LCO), 16/18 (RCO)	Mean: 26.1 (OCO), 24.6 (LCO), 26.1 (RCO)	ASA 1-2: 80% (OCO), 90% (LCO), 85% (RCO)	Not specified
Butnari, 2024 [29]	Median: 68 (RCR), 71 (LCR)	56/44 (RCR), 59/53 (LCR)	Median: 27.2 (RCR), 28 (LCR)	ASA 1-2: 71% (RCR), 65.17% (LCR)	19% (RCR), 11.6% (LCR)
D'Annibale, 2004 [25]	Robotic: 64 ±13. Lap: 65 ±9	Robotic: 25M/28F. Lap: 29M/24F	NR	NR	NR
De'Angelis, 2018 [28]	≥70 years (matched: 43 robotic, 43 Lap)	Robotic: 20M/23F; Lap: 18M/25F	~24–26	Comparable after matching	Robotic: 32.6%. Lap: 25.6% (laparotomy)
Deutsch, 2012 [23]	Robotic (left): 54.6. Lap (left): 63.3	Robotic: 32M; Lap: 53M (right)	~25–28	Higher ASA in Lap right colectomy	NR

Ferrara, 2015 [27]	~65 years	Robotic: 24M/18F. Lap: 34M/24F	NR	Charlson Index comparable	NR
Jiménez Rodríguez, 2011 [30]	68 (R), 61.5 (L)	12/16 (R), 17/11 (L)	28.59 (R), 26.75 (L)	ASA I-II/III: 14/14 (R), 20/8 (L)	Not specified
Palomba, 2021 [26]	73.7 (M), 75.25 (F)	50/33	Not specified	ASA 2: 43, ASA 3: 40	Not specified
Pinar, 2018 [31]	Not specified	50.3% (M), 49.7% (F)	Not specified	Not specified	Not specified
Grosek, 2021 [32]	67.5 (L), 66.8 (R)	23/26	27.2 (L), 27.5 (R)	ASA 2: 44, ASA 3: 36	Not specified
Sawada, 2015 [33]	64.5 (robotic), 64.0 (laparoscopic)	6/4 (robotic), 11/9 (laparoscopic)	21.98 (robotic), 24.1 (laparoscopic)	ASA II-III	2 (robotic), 3 (laparoscopic)
Xue, 2023 [34]	82 (both groups)	31/24 (robotic), 37/19 (laparoscopic)	23.8 (robotic), 23.3 (laparoscopic)	ASA II-IV	10 (robotic), 24 (laparoscopic)

Tumor characteristics across studies

Table 3 illustrates tumor characteristics throughout the included studies. The results demonstrated diversity in tumor sites, with most research addressing both colon and rectal tumors. Some studies [27, 28] gave thorough breakdowns, indicating higher proportions of right colon (51.2%) or rectal cancers (42.9%), while others grouped regions broadly. Tumor stage was inconsistently described, while several studies cited the AJCC (American Joint Committee on Cancer) classification, with stages ranging from I to IV. For example, Ferrara (2015) encompassed stages I–IIIc, while D'Annibale (2004) [25] covered stages 0–IV, suggesting different disease severity among cohorts.

Conversion rates—indicating conversions from minimally invasive to open surgery—were usually low but varied by technique. Robotic procedures revealed conversion rates from 0% (De'Angelis 2018) to 7.1% (Ferrara 2015), whereas laparoscopic rates ranged from 0% to 13.7% (Palomba 2021). Notably, some studies, like Abdel Jalil (2021), revealed no significant differences between robotic and laparoscopic techniques, whilst others, such as Deutsch (2012), noted significantly greater robotic conversion rates (7.1% vs. 3.4%). These differences may reflect technological obstacles, surgical experience, or patient selection biases.

Lymph node harvest, a crucial parameter for oncological sufficiency, was equivalent between robotic and laparoscopic procedures in most studies. D'Annibale (2004) found similar yields (robotic: 17 ±10; laparoscopic: 16 ±9), but Jiménez Rodríguez (2011) noted a nonsignificant trend toward higher lymph node retrieval in robotic cases (17.6 vs. 14.9). However, Ferrara (2015) reported a statistically significant advantage for robotics (18.8 ±12.2 vs. 14.6 ±7.5), suggesting possible benefits in some settings.

Surgical and Short-Term Outcomes

Operative timings generally favored laparoscopy, with robotic procedures requiring 30-60 minutes longer across multiple investigations [25]. However, robotic surgery revealed advantages in specific scenarios: reduced blood loss [34], lower conversion rates in challenging cases (Grosek 2021), and shorter hospital stays for certain procedures as left hemicolectomy (Palomba 2021). Complication rates showed no significant differences overall, with similar occurrences of anastomotic leaks (3.66-4.20%), surgical site infections, and ileus comparing techniques (Butnari 2024, Abdel Jalil 2021). The robotic platform appeared particularly advantageous in technically hard scenarios, such as pelvic dissection and sphincter-preserving surgeries, where its enhanced dexterity permitted precise maneuvers (D'Annibale 2004).

Oncological Outcomes

Both approaches yielded equal oncological adequacy. Lymph node harvest, a critical quality parameter, was typically equivalent (D'Annibale 2004), while three trials revealed moderate but considerable increases using robotics (Ferrara 2015, Jiménez Rodríguez 2011). Resection margins were consistently negative (R0) in over 95% of cases for both techniques (De'Angelis 2018). Long-term survival data from Pinar (2018) indicated no differences in 3-year disease-free or overall survival rates between robotic and laparoscopic groups, confirming equal oncological efficacy.

Table 3: Tumor characteristics

First author, year	Tumor Location	Tumor Stage	Conversion Rate	Lymph Node Harvest
Abdel Jalil, 2021 [21]	Colon and Rectum	Not specified	No significant difference	Not specified
Batool, 2018 [22]	Colon and Rectum	Not specified	Not specified	Not specified
Bertani, 2011 [24]	Colon and Rectum	Not specified	7% (LCO), 6% (RCO)	Not specified
Butnari, 2024 [29]	Colon and Rectum	Not specified	5% (RCR), 4.5% (LCR)	20 (RCR), 18.5 (LCR)
D'Annibale, 2004 [25]	Right colon, left colon, sigmoid, rectum (Table 1)	Stages 0–IV (Table 2)	Robotic: 2 to laparoscopy, 3 hand-assisted; Lap: 3 to laparotomy	Robotic: 17 ±10; Lap: 16 ±9
De’Angelis, 2018 [28]	Right colon (51.2%), left colon, rectum	I–IVa	0% after matching	Robotic: 17.7 ±9.25; Lap: 17.9 ±9.09

Deutsch, 2012 [23]	Right/left colon	NR	Robotic: 7.1%; Lap: 3.4%	Right: Robotic 21.1 vs Lap 18.7; Left: Lap higher
Ferrara, 2015 [27]	Right colon (31%), left colon (26.1%), rectum (42.9%)	I–IIIc (AJCC 7th edition)	Robotic: 7.1%; Lap: 3.4%	Robotic: 18.8 ±12.2; Lap: 14.6 ±7.5
Jiménez Rodríguez, 2011 [30]	Sigmoid, Rectum	T1-T2/T3: 15/13 (R), 21/7 (L)	7.14% (both groups)	17.6 (R), 14.9 (L)
Palomba, 2021 [26]	Right, Left, Rectosigmoid, Rectum	Not specified	3.1% (R), 13.7% (L)	21.5 (R), 16.7 (L)
Pinar, 2018 [31]	Colon, Rectum	T1-T4, N0-N2	Not specified	17.6 (R), 14.9 (L)
Grosek, 2021 [32]	Colon, Upper Rectum	T1-T3	13.5% (L), 0% (R)	20 (L), 24 (R)
Sawada, 2015 [33]	Left-sided colon and rectum	I-III	0% (robotic), 5% (laparoscopic)	14 (robotic), 13 (laparoscopic)
Xue, 2023 [34]	Colon and rectum	I-IV	1.8% (robotic), 0% (laparoscopic)	15 (robotic), 14 (laparoscopic)

Special Populations and Cost Considerations

Robotic surgery showed particular promise in older patients, with studies demonstrating safe deployment in octogenarians (Xue 2023) and equivalent outcomes to laparoscopy in matched cohorts (De'Angelis 2018). This cost gap was not offset by consistent clinical advantages, raising doubts regarding value-based implementation (Bertani 2011).

Meta-analysis

Figure 2 gives a graphic comparison of operative times between laparoscopic and robotic procedures for colorectal cancer across several studies. The figure indicates that robotic surgery tends to have longer operative times compared to laparoscopic surgery in most circumstances. The pooled SMD for operating time in Figure 2 reveals a statistically significant difference between robotic and laparoscopic colorectal surgery, with robotic procedures taking longer surgery time (SMD: -0.67, 95% CI, -1.10: - 0.23). The value of the SMD suggests a moderate effect size, implying the difference in operative time is clinically important. However, the significant heterogeneity (I^2: 92.9%, p<0.001) revealed substantial variability among studies

Figure 3 illustrates the comparison of hospital length of stay after laparoscopic compared to robotic surgery for CRC. The pooled SMD indicated a small but statistically significant reduction in LOS for robotic surgery compared to laparoscopy (SMD: 0.32, 95/5 CI: 0.13: 0.51). However, the significant heterogeneity (I^2: 96.1%, p<0.001) revealed substantial variability among studies. Figure 4 illustrates the Comparison of Postoperative Complications Between Laparoscopic and Robotic Colorectal Surgery. The pooled risk ratio (RR) demonstrated statistically significant lower postoperative complications in case of laparoscopic compared to robotic procedures (RR: 0.76, 95% CI: 0.61-0.96). By performing subgroup analysis based on complication type, laparoscopic procedures demonstrated significantly lowered post anastomotic leak (RR: 0.79, 95% CI: 0.68-0.92), readmission within 30 days (RR: 0.87, 95% CI: 0.79-0.95). There were non-significantly decreased surgical site infection (RR: 0.67, 95% CI: 0.33-1.35), mortality after 30 days (RR: 0.92, 95% CI: 0.34-2.48) in case of laparoscopic compared to robotic procedures. Incisional hernia was greater in laparoscopic surgeries (RR:1.30, 95% CI: 0.10-16.60) although the difference was not statistically significant.

Risk of bias assessment

Figure S.2.1 (Supplementary file 2), Risk of Bias Graph by (Joanna Briggs Institute) JBI Tool, offers a detailed evaluation of two studies—Grossk 2021 and Sawada 2015—across ten domains (D1–D10). Both studies received positive ratings ("+") for all domains, showing low risk of bias in critical areas such as group comparability, adequate matching of cases and controls, standardized exposure measurement, identification and handling of confounding factors, and statistical analysis. This supports robust methodological quality in these investigations, with no serious problems in design or execution.

Figure S.2.2, Risk of Bias Summary by JBI Tool, presents a larger perspective but lacks specific study-level data. The checklist reiterates the same ten areas as the first figure, albeit the accompanying visual representation of bias distribution (0%–100%) is incomplete, with no clear indication of how many studies were evaluated as "Unclear" or "Low" risk.

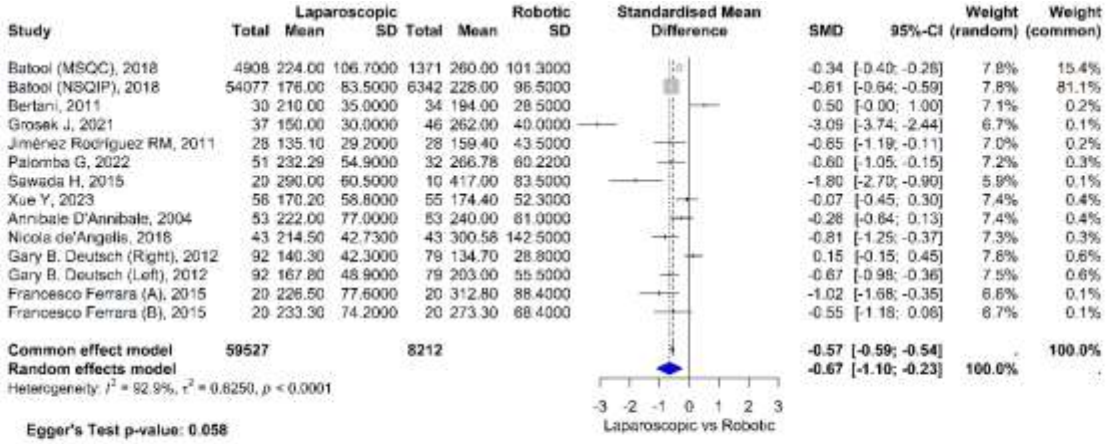
Figure S.2.3 presents a risk of bias evaluation using the ROBINS-I (Risk Of Bias In Non-randomized Studies of Interventions) tool, analyzing twelve studies across seven categories. The Risk of Bias Graph from ROBINS-I Tool indicates diversity in methodological rigor among the included studies. Abdel Jalil 2021 was the only study graded low risk ("+") across most categories, including confounding, selection bias, and classification of therapies, indicating strong study design. In contrast, the majority of studies (e.g., Batool 2018, Bertani 2011) were evaluated with intermediate risk in many areas, particularly in confounding, departures from intended interventions, and missing data. This highlights constraints such as unmeasured confounders, potential selection biases, or insufficient outcome reporting, which could influence the validity of their findings. Figure S.2.4, the Risk of Bias Summary by ROBINS-I Tool provides a visual picture of overall bias distribution but lacks specificity. While it lists all seven domains, the accompanying bar graph (0%–100%) does not clearly quantify the proportion of research assessed as low or moderate risk, nor does it address high-risk evaluations. Key concerns observed include frequent moderate-risk ratings for confounding bias (D1) and missing data bias (D5), which are crucial for understanding non-randomized trials.

Table S.3.4. shows the risk of bias assessment of the included RCT by ROB2 tool, the overall quality was moderate.

Publication bias assessment

In addition to the Egger's test results, which were not statistically significant, Figures 5, 6, and 7 show funnel plots that were likely symmetrical. No significant publication bias was identified.

Figure 2: Comparison between operative time of Laparoscopic versus robotic surgery for colorectal cancer

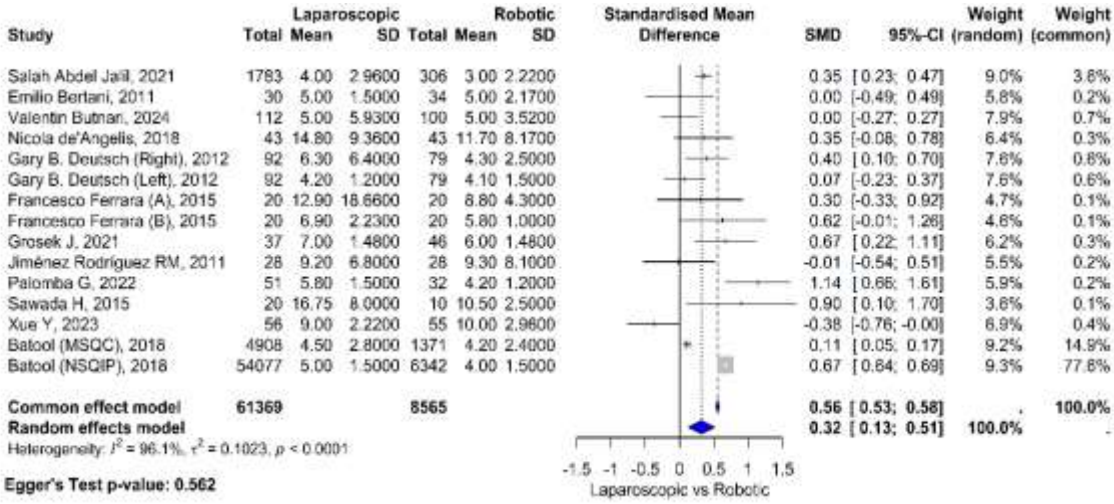


Study	Laparoscopic			Robotic			SMD	95%-CI	Weight (random)	Weight (common)
	Total	Mean	SD	Total	Mean	SD				
Batool (MSQC), 2018	4908	224.00	106.7000	1371	260.00	101.3000	-0.34	[-0.40; -0.28]	7.8%	15.4%
Batool (NSQIP), 2018	54077	176.00	83.5000	6342	228.00	96.5000	-0.61	[-0.64; -0.59]	7.8%	81.1%
Bertani, 2011	30	210.00	35.0000	34	194.00	28.5000	0.50	[-0.00; 1.00]	7.1%	0.2%
Grosek J, 2021	37	150.00	30.0000	46	262.00	40.0000	-3.09	[-3.74; -2.44]	6.7%	0.1%
Jiménez Rodríguez RM, 2011	28	135.10	29.2000	28	159.40	43.5000	-0.65	[-1.19; -0.11]	7.0%	0.2%
Palomba G, 2022	51	232.29	54.9000	32	266.78	60.2200	-0.60	[-1.05; -0.15]	7.2%	0.3%
Sawada H, 2015	20	290.00	60.5000	10	417.00	83.5000	-1.80	[-2.70; -0.90]	5.9%	0.1%
Xue Y, 2023	56	170.20	58.8000	55	174.40	52.3000	-0.07	[-0.45; 0.30]	7.4%	0.4%
Annibale D'Annibale, 2004	53	222.00	77.0000	53	240.00	61.0000	-0.28	[-0.64; 0.13]	7.4%	0.4%
Nicola de'Angelis, 2018	43	214.50	42.7300	43	300.58	142.5000	-0.81	[-1.25; -0.37]	7.3%	0.3%
Gary B. Deutsch (Right), 2012	92	140.30	42.3000	79	134.70	28.8000	0.15	[-0.15; 0.45]	7.6%	0.6%
Gary B. Deutsch (Left), 2012	92	167.80	48.9000	79	203.00	55.5000	-0.67	[-0.98; -0.36]	7.5%	0.6%
Francesco Ferrara (A), 2015	20	226.50	77.6000	20	312.80	88.4000	-1.02	[-1.68; -0.35]	6.6%	0.1%
Francesco Ferrara (B), 2015	20	233.30	74.2000	20	273.30	68.4000	-0.55	[-1.18; 0.08]	6.7%	0.1%
Common effect model	**59527**			**8212**			**-0.57**	**[-0.59; -0.54]**	.	**100.0%**
Random effects model							**-0.67**	**[-1.10; -0.23]**	**100.0%**	.

Heterogeneity: $I^2 = 92.9\%$, $\tau^2 = 0.6250$, $p < 0.0001$

Egger's Test p-value: 0.058

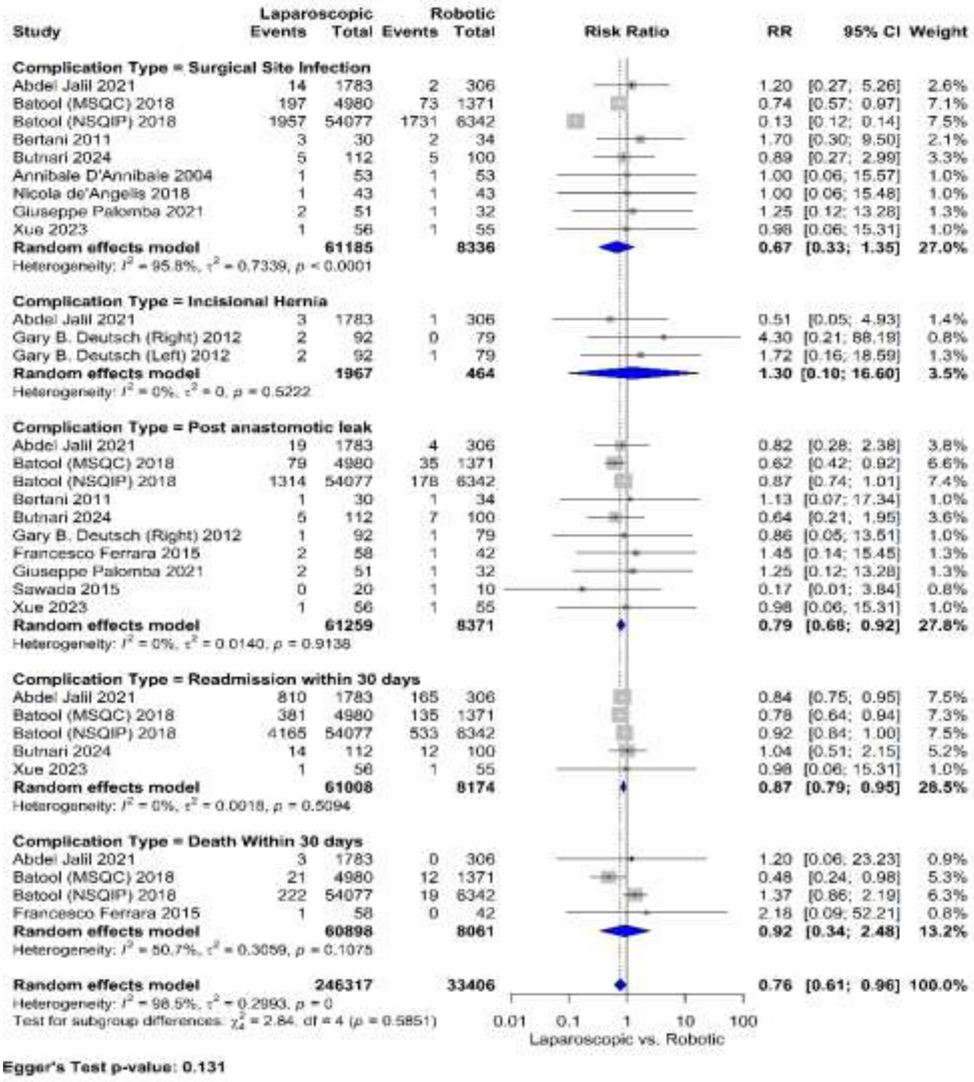
Figure 3: Comparison between hospital length of stay after Laparoscopic versus robotic surgery for colorectal cancer



Study	Laparoscopic			Robotic			SMD	95%-CI	Weight (random)	Weight (common)
	Total	Mean	SD	Total	Mean	SD				
Salah Abdel Jalil, 2021	1783	4.00	2.9600	306	3.00	2.2200	0.35	[0.23; 0.47]	9.0%	3.8%
Emilio Bertani, 2011	30	5.00	1.5000	34	5.00	2.1700	0.00	[-0.49; 0.49]	5.8%	0.2%
Valentin Butnari, 2024	112	5.00	5.9300	100	5.00	3.5200	0.00	[-0.27; 0.27]	7.9%	0.7%
Nicola de'Angelis, 2018	43	14.80	9.3600	43	11.70	8.1700	0.35	[-0.08; 0.78]	6.4%	0.3%
Gary B. Deutsch (Right), 2012	92	6.30	6.4000	79	4.30	2.5000	0.40	[0.10; 0.70]	7.6%	0.8%
Gary B. Deutsch (Left), 2012	92	4.20	1.2000	79	4.10	1.5000	0.07	[-0.23; 0.37]	7.6%	0.6%
Francesco Ferrara (A), 2015	20	12.90	18.6600	20	8.80	4.3000	0.30	[-0.33; 0.92]	4.7%	0.1%
Francesco Ferrara (B), 2015	20	6.90	2.2300	20	5.80	1.0000	0.62	[-0.01; 1.26]	4.6%	0.1%
Grosek J, 2021	37	7.00	1.4800	46	6.00	1.4800	0.67	[0.22; 1.11]	6.2%	0.3%
Jiménez Rodríguez RM, 2011	28	9.20	6.8000	28	9.30	8.1000	-0.01	[-0.54; 0.51]	5.5%	0.2%
Palomba G, 2022	51	5.80	1.5000	32	4.20	1.2000	1.14	[0.66; 1.61]	5.9%	0.2%
Sawada H, 2015	20	16.75	8.0000	10	10.50	2.5000	0.90	[0.10; 1.70]	3.6%	0.1%
Xue Y, 2023	56	9.00	2.2200	55	10.00	2.9600	-0.38	[-0.76; -0.00]	6.9%	0.4%
Batool (MSQC), 2018	4908	4.50	2.8000	1371	4.20	2.4000	0.11	[0.05; 0.17]	9.2%	14.9%
Batool (NSQIP), 2018	54077	5.00	1.5000	6342	4.00	1.5000	0.67	[0.64; 0.69]	9.3%	77.8%
Common effect model	**61369**			**8565**			**0.56**	**[0.53; 0.58]**	.	**100.0%**
Random effects model							**0.32**	**[0.13; 0.51]**	**100.0%**	.

Heterogeneity: $I^2 = 96.1\%$, $\tau^2 = 0.1023$, $p < 0.0001$

Egger's Test p-value: 0.562



	Laparoscopic		Robotic				
Study	**Events**	**Total**	**Events**	**Total**	**RR**	**95% CI**	**Weight**
Complication Type = Surgical Site Infection							
Abdel Jalil 2021	14	1783	2	306	1.20	[0.27; 5.26]	2.6%
Batool (MSQC) 2018	197	4980	73	1371	0.74	[0.57; 0.97]	7.1%
Batool (NSQIP) 2018	1957	54077	1731	6342	0.13	[0.12; 0.14]	7.5%
Bertani 2011	3	30	2	34	1.70	[0.30; 9.50]	2.1%
Butnari 2024	5	112	5	100	0.89	[0.27; 2.99]	3.3%
Annibale D'Annibale 2004	1	53	1	53	1.00	[0.06; 15.57]	1.0%
Nicola de'Angelis 2018	1	43	1	43	1.00	[0.06; 15.48]	1.0%
Giuseppe Palomba 2021	2	51	1	32	1.25	[0.12; 13.28]	1.3%
Xue 2023	1	56	1	55	0.98	[0.06; 15.31]	1.0%
Random effects model		**61185**		**8336**	**0.67**	**[0.33; 1.35]**	**27.0%**
Heterogeneity: $I^2 = 95.8\%$, $\tau^2 = 0.7339$, $p < 0.0001$							
Complication Type = Incisional Hernia							
Abdel Jalil 2021	3	1783	1	306	0.51	[0.05; 4.93]	1.4%
Gary B. Deutsch (Right) 2012	2	92	0	79	4.30	[0.21; 88.19]	0.8%
Gary B. Deutsch (Left) 2012	2	92	1	79	1.72	[0.16; 18.59]	1.3%
Random effects model		**1967**		**464**	**1.30**	**[0.10; 16.60]**	**3.5%**
Heterogeneity: $I^2 = 0\%$, $\tau^2 = 0$, $p = 0.5222$							
Complication Type = Post anastomotic leak							
Abdel Jalil 2021	19	1783	4	306	0.82	[0.28; 2.38]	3.8%
Batool (MSQC) 2018	79	4980	35	1371	0.62	[0.42; 0.92]	6.6%
Batool (NSQIP) 2018	1314	54077	178	6342	0.87	[0.74; 1.01]	7.4%
Bertani 2011	1	30	1	34	1.13	[0.07; 17.34]	1.0%
Butnari 2024	5	112	7	100	0.64	[0.21; 1.95]	3.6%
Gary B. Deutsch (Right) 2012	1	92	1	79	0.86	[0.05; 13.61]	1.0%
Francesco Ferrara 2015	2	58	1	42	1.45	[0.14; 15.45]	1.3%
Giuseppe Palomba 2021	2	51	1	32	1.25	[0.12; 13.28]	1.3%
Sawada 2015	0	20	1	10	0.17	[0.01; 3.84]	0.8%
Xue 2023	1	56	1	55	0.98	[0.06; 15.31]	1.0%
Random effects model		**61259**		**8371**	**0.79**	**[0.68; 0.92]**	**27.8%**
Heterogeneity: $I^2 = 0\%$, $\tau^2 = 0.0140$, $p = 0.9138$							
Complication Type = Readmission within 30 days							
Abdel Jalil 2021	810	1783	165	306	0.84	[0.75; 0.95]	7.5%
Batool (MSQC) 2018	381	4980	135	1371	0.78	[0.64; 0.94]	7.3%
Batool (NSQIP) 2018	4165	54077	533	6342	0.92	[0.84; 1.00]	7.5%
Butnari 2024	14	112	12	100	1.04	[0.51; 2.15]	5.2%
Xue 2023	1	56	1	55	0.98	[0.06; 15.31]	1.0%
Random effects model		**61008**		**8174**	**0.87**	**[0.79; 0.95]**	**26.5%**
Heterogeneity: $I^2 = 0\%$, $\tau^2 = 0.0018$, $p = 0.5094$							
Complication Type = Death Within 30 days							
Abdel Jalil 2021	3	1783	0	306	1.20	[0.06; 23.23]	0.9%
Batool (MSQC) 2018	21	4980	12	1371	0.48	[0.24; 0.98]	5.3%
Batool (NSQIP) 2018	222	54077	19	6342	1.37	[0.86; 2.19]	6.3%
Francesco Ferrara 2015	1	58	0	42	2.18	[0.09; 52.21]	0.8%
Random effects model		**60898**		**8061**	**0.92**	**[0.34; 2.48]**	**13.2%**
Heterogeneity: $I^2 = 50.7\%$, $\tau^2 = 0.3059$, $p = 0.1075$							
Random effects model		**246317**		**33406**	**0.76**	**[0.61; 0.96]**	**100.0%**
Heterogeneity: $I^2 = 98.5\%$, $\tau^2 = 0.2993$, $p = 0$							
Test for subgroup differences: $\chi^2_4 = 2.84$, df = 4 ($p = 0.5851$)							

Egger's Test p-value: 0.131

Figure 4: Comparison between postoperative complications of Laparoscopic versus robotic surgery for colorectal cancer

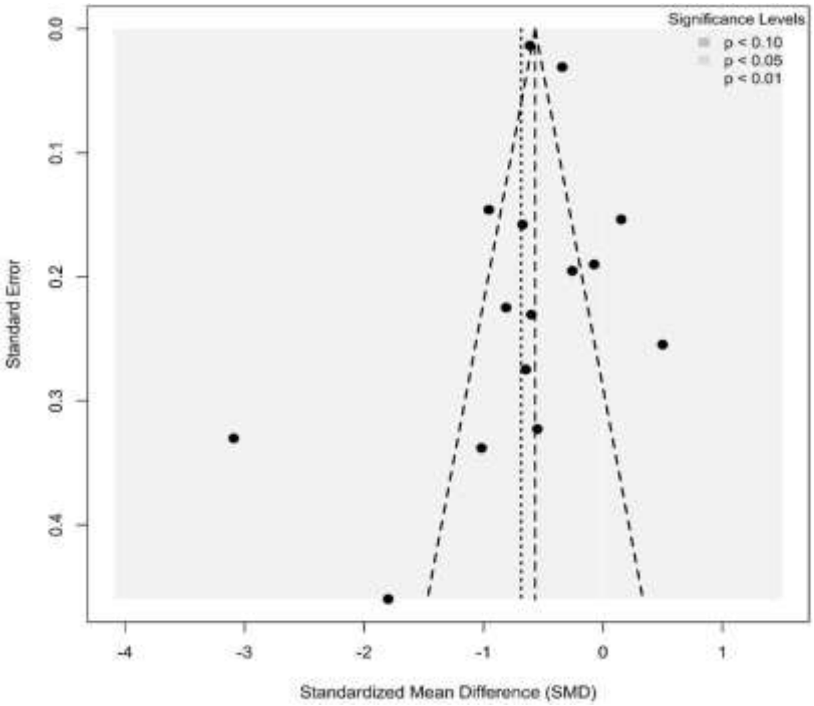


Figure 5: Publication bias in operative time outcome

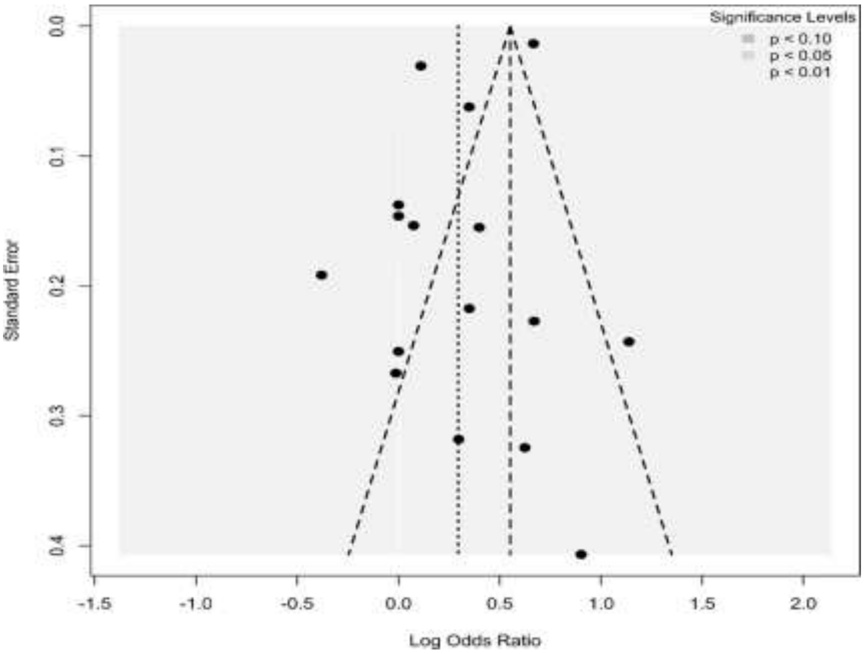


Figure 6: Publication bias in length of hospital stay outcome

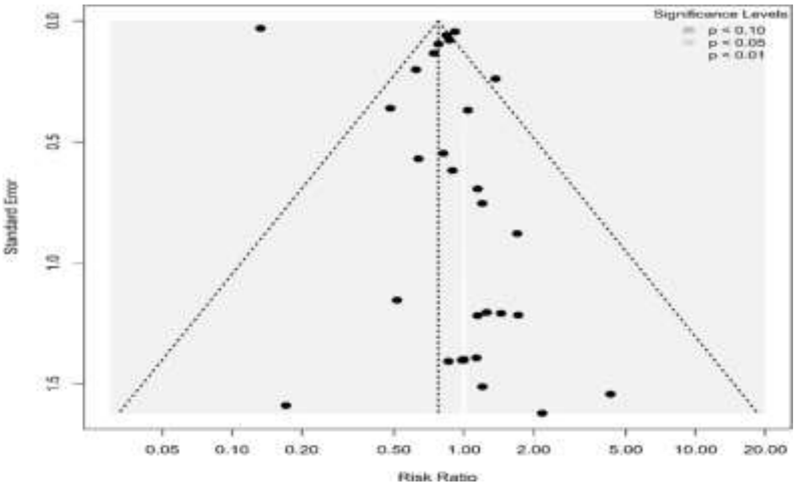


Figure 7: Publication bias in post-operative complications outcome

DISCUSSION

This systematic review and meta-analysis synthesized data from 14 studies with a variety of patient groups and surgical settings to compare the short-term outcomes of robotic-assisted colorectal surgery (RACS) and laparoscopic (LCS) for colorectal cancer. According to our research, both minimally invasive procedures are safe and effective in managing CRC, but they also have unique benefits and drawbacks that should be carefully considered in clinical settings.

Our data verified that RACS takes longer operation times than LCS, which is consistent with previous literature and is graphically demonstrated in Figure 2, where the pooled standardized mean difference was -0.67 (95% CI: -1.10 to -0.23). A prior meta-analysis comparing robotic-assisted and laparoscopic surgery for colon cancer indicated that robotic methods had longer operative times but had advantages in precision and lymph node retrieval [35]. However, the increased duration does not necessarily translate to worse outcomes. Another study on robot-assisted abdominopelvic surgery revealed that robotic operations had longer operative periods compared to laparoscopic surgery [36]. Despite this, robotic surgery showed benefits in decreased open conversion rates and shorter hospital stays. A systematic review and meta-analysis of studies published between 2020 and 2024 found that robotic-assisted surgery for colon cancer was associated with comparable oncologic outcomes to laparoscopic surgery, while offering advantages such as reduced conversion rates to open procedures and improved short-term recovery metrics, albeit at the cost of longer operative times [37]. This is probably because of the complexity of robotic system setup and surgeon learning curves. But in some investigations, especially for technically difficult situations like low rectal resections, robotics showed lower conversion rates to open surgery [26, 32]. Although precise dissection in confined anatomical places may be made easier by robotic systems' improved dexterity and 3D imaging, this hasn't always resulted in fewer complications.

RACS was associated with a slight reduction in hospital stays, although this benefit varied from study to study, as indicated by the high heterogeneity ($I^2 = 96.1\%$) shown in the length-of-stay analysis, and might be due to institutional procedures rather than the intrinsic benefits of robotics. Remarkably, LCS had a much lower overall rate of complications, including as readmissions and anastomotic leaks. The safety of both strategies is supported by the lack of variation in surgical site infections or mortality. Evidence from a study on robotic total gastrectomy for advanced gastric cancer demonstrated that this approach achieved favorable long-term oncologic outcomes, with survival rates comparable to conventional techniques and without an increase in postoperative complications [38]. This shows that patient-specific characteristics, such as preoperative muscle health, may play a substantial influence in determining LOS. Research on robot-assisted radical prostatectomy found that patient comorbidities were the strongest predictor of LOS rather than the surgical method itself [39]. While robotic surgery may shorten LOS in some circumstances, underlying health issues can still extend hospitalization. A large-scale study examining 4,495,582 patients indicated that surgical complications significantly increased LOS, with some challenges prolonged hospitalization by up to 20 days [40]. This confirms the foundation that while robotic surgery may reduce LOS, the occurrence of complications can counterbalance this benefit.

A study comparing laparoscopic and open colorectal surgery indicated that laparoscopic operations had decreased incidence of anastomotic leakage and readmissions, similar to the current study findings [41]. However, the study also showed a small increase in operative time for laparoscopic surgery. Another research assessing robotic vs. laparoscopic rectal cancer surgery revealed no significant differences in surgical site infections, perioperative mortality, or incisional hernias, consistent with the current results [42]. However, robotic surgery exhibited reduced conversion rates to open surgery. A meta-analysis comparing laparoscopic vertical sleeve gastrectomy (LVSG) with laparoscopic Roux-en-Y gastric bypass (LRYGB) indicated that LVSG had fewer early significant complications, corroborating the trend that laparoscopic methods generally result in lower complication rates [43].

RACS and LCS had similar lymph node yields and R0 resection rates, indicating equivalent oncologic outcomes. According to long-term data, there are no changes in survival [31]. RACS's significantly increased costs, which are mostly caused by equipment, maintenance, and extended operation hours, cast doubt on its cost-effectiveness, especially in healthcare systems with limited resources [18, 24].

There are certain limitations regarding our investigation. First, as surgeons might save robotics for more complicated situations, the prevalence of non-randomized studies raises the possibility of selection bias. Second, cross-study comparisons are made more difficult by variations in surgical methods and outcome classifications, as reflected in the substantial statistical heterogeneity observed in our meta-analyses. Third, evaluation of long-term survival or functional outcomes was not possible due to the emphasis on short-term results. However, our analysis is one of the most comprehensive assessments to date and is supported by a strict methodology that includes bias evaluations and sensitivity analyses.

CONCLUSION

This systematic review and meta-analysis comparing laparoscopic (LCS) and robotic-assisted colorectal surgery (RACS) for colorectal cancer indicated that both approaches are safe and effective, with neither approach exhibiting clear superiority across all evaluated outcomes. The data demonstrated considerable variations in operative efficiency, with laparoscopic surgery consistently requiring lower operative times compared to robotic procedures. While robotic surgery may provide technical advantages in challenging instances such as pelvic dissections, these improvements do not reliably translate to reduced complication rates or improved patient outcomes.

When analyzing short-term outcomes, the study suggests that robotic surgery may offer a slight reduction in hospital length of stay, although this finding varies greatly between studies. More importantly, laparoscopic surgery was associated with fewer overall postoperative complications, including decreased rates of clinically relevant outcomes such as anastomotic leaks and hospital readmissions.

Based on these data, the study suggests laparoscopic surgery as the standard minimally invasive technique for most colorectal cancer cases, given its proven efficacy, reduced costs, and faster operative times. Robotic surgery may find its most optimal use in select patients requiring difficult rectal resections or complex anatomical conditions such as narrow pelvises. However, the decision between procedures should ultimately be guided by surgeon experience, unique patient characteristics, and institutional cost considerations. The findings underscore the need for more randomized controlled trials with long-term follow-up to better characterize the role of robotic surgery in colorectal cancer management.

Supplementary Materials

The following supporting information can be downloaded at:……., Table S1: Identify the report as a systematic review, Figure S.2.1: Risk of bias Graph by Robins I Quality assessment Tool; Figure S.2.2: Risk of bias Summary by Robins I Quality assessment Tool; Figure S.2.3: Risk of bias Graph by JBI Quality assessment Tool; Figure S.2.4: Risk of bias Summary by JBI Quality assessment Tool

Author Contributions

Conceptualization, S.A. and K.A.; methodology, S.A., K.A..; software, S.A..; writing—original draft preparation, S.A.; writing— review and editing, K.A. All authors have read and agreed to the published version of the manuscript

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Abbreviations:

ACS-NSQIP	American College of Surgeons National Surgical Quality Improvement Program
AJCC	American Joint Committee on Cancer
ASA	American Society of Anesthesiologists
BMI	Body Mass Index
CEA	Carcinoembryonic Antigen
CI	Confidence Interval
CRC	Colorectal Cancer
CT	Computed Tomography
FAP	Familial Adenomatous Polyposis
I^2	I-squared Statistic
LC	Laparoscopic Colectomy
LCO	Laparoscopic Colorectal Operation
LCR	Laparoscopic Colorectal Resection
LCS	Laparoscopic Colorectal Surgery
LOS	Length of Stay
MMR	Mismatch Repair
MSQC	Michigan Surgical Quality Collaborative
NR	Not Reported
OC	Open Colectomy
OCO	Open Colorectal Operation
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
R0	Resection Margin Negative
RACS	Robotic-Assisted Colorectal Surgery
RC	Robotic Colectomy
RCO	Robotic Colorectal Operation
RCR	Robotic Colorectal Resection
RCT	Randomized Controlled Trial
RR	Risk Ratio
SMD	Standardized Mean Difference
TME	Total Mesorectal Excision

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