

Review article

Comparative outcomes of laparoscopic versus robotic-assisted laparoscopic techniques in the surgical staging of endometrial cancer: A systematic review and meta-analysis

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ARTICLE INFO

Keywords:

Conventional laparoscopic surgery
Robotic-assisted laparoscopic surgery
Endometrial cancer
Complications

ABSTRACT

Background: Endometrial cancer (EC) is a prevalent gynecologic malignancy associated with escalating mortality rates. Surgical interventions continue to be the primary treatment modality for EC, with a growing utilization of minimally invasive surgeries (MIS) such as robotic-assisted laparoscopic surgery (RALS) and conventional laparoscopic surgery (CLS). Given the technical advantages of RALS, this study aimed to compare the surgical outcomes of RALS and CLS in the management of EC.

Methods: A systematic search was conducted on three electronic databases, namely PubMed, Scopus, and ISI Web of Science, up to June 2024 with no date restriction. Randomized controlled trials and cohort studies that compared surgical outcomes, intraoperative parameters, and short-term postoperative outcomes between RALS and CLS in women with EC were included in the analysis. Data on age, body mass index (BMI) kg/m², dissected lymph nodes, operative time, estimated blood loss, intraoperative complications (conversion rate to laparotomy and injuries), and short-term postoperative outcomes (length of hospital stay and complications) in both groups were collected and analyzed using R software (version 4.2.3). Weighted mean and standardized mean differences (SMDs) with 95 % confidence intervals (CIs) were used for continuous outcomes, while binary outcomes were analyzed using pooled odds ratios (ORs) with 95 % CIs using random-effects models. The risk of bias in the included studies was assessed.

Results: Sixteen studies with 2,725 patients were included. RALS was associated with longer operative time (170.0 vs. 152.6 min; SMD = 0.5) but lower blood loss (109.1 vs. 180.1 mL; SMD = -0.66), fewer conversions to laparotomy (OR = 0.29), reduced intraoperative injuries (OR = 0.32), and shorter hospital stay (2.91 vs. 3.36 days; SMD = -0.4) compared to CLS. However, postoperative complications were more frequent with RALS (OR = 1.8). Most studies had methodological limitations, with over 70 % rated as "poor," and substantial heterogeneity was observed.

Conclusion: RALS provides specific advantages over CLS, including reduced blood loss, fewer conversions, and shorter hospitalization, but it is associated with longer operative time and higher postoperative complication rates. Results may primarily reflect outcomes from high-volume or experienced surgeons, limiting generalizability. Further high-quality prospective studies, including detailed patient-level and surgeon experience data, are needed to clarify the relative benefits, cost-effectiveness, and long-term outcomes of RALS versus CLS.

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<https://doi.org/10.1016/j.gore.2025.101980>

Received 17 September 2025; Received in revised form 19 October 2025; Accepted 24 October 2025

Available online 7 November 2025

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1. Introduction

The most prevalent gynecologic cancer is endometrial cancer (EC), which has a mortality rate of 5.1 % per 100,000 women in 2019 and is increasing by almost 2 % per year. Obesity, physical inactivity, and excess body weight are associated with more than 70 % of the cases (Eakin et al., 2023). Globally, there were 91,641 fatalities and 417,000 new cases of EC in 2020 (Mazidimoradi et al., 2024; Kivekäs et al., 2024). Patients with stage IVA and IVB have significantly worse outcomes, with five-year survival rates of only 17 % and 15 %, respectively (Mazidimoradi et al., 2024; Makker et al., 2021).

The primary treatment for early-stage EC typically involves surgical procedures such as total hysterectomy, bilateral salpingo-oophorectomy (BSO), and pelvic and/or para-aortic lymph node dissection (Wright et al., 2012; Abu-Rustum et al., 2023). Significant improvements in surgical methods for treating EC have been made during the last three decades. For EC staging procedures, a number of studies have shown that the laparoscopic approach has emerged as the preferred technique and is frequently considered as the gold standard. Compared to the conventional laparotomic approach, laparoscopy (LPS) has several advantages, such as less intraoperative blood loss, fewer postoperative complications, and shorter hospital stays. Notably, laparoscopy has been demonstrated to have comparable oncological results to laparotomy, confirming its efficacy in the treatment of EC (Mäenpää et al., 2016; Johansson and Chan, 2020; Fu et al., 2023; Bergstrom et al., 2018; Casarin et al., 2018; Mourits et al., 2010).

Since 2005, robotic-assisted laparoscopic surgery (RALS), an advanced development of conventional laparoscopic surgeries (CLS), has been used in gynecological procedures to treat benign and malignant conditions (Xie et al., 2024 6). The primary robotic surgical system used in gynecological robot-assisted surgery is the Da Vinci® Surgical System, which was created by Sunnyvale, California-based Intuitive Surgical (Chandrakar et al., 2022). Surgeons can control robotic arms with this system's "master/slave" setup from a console that is located far away. Enhanced three-dimensional visualization, precise control of robotic arms with increased mobility, fatigue resistance, tremor reduction, improved surgeon ergonomics, and a relatively short learning curve are just a few of the noteworthy technical benefits that RALS offers. Its widespread use in a variety of thoracoabdominal surgical specialties has been made possible by these advantages (Moss et al., 2017 14; Lim et al., 2023). Given the increasing trend towards the use of RALS, our study aims to perform a comparative analysis of RALS and CLS in the management of EC, in order to better understand their relative efficacy, safety, and potential benefits for guiding future clinical decision-making.

2. Materials and methods

2.1. Protocol and guideline

This systematic review and meta-analysis was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021) and Assessing the Methodological Quality of Systematic Reviews (AMSTAR) guidelines (Shea et al., 2017), and has been registered with the International Prospective Register of Systematic Reviews (PROSPERO number: CRD42024552197). Formal ethical approval was not necessary for this study.

2.2. Inclusion criteria

This study included all randomized controlled trials (RCTs) and cohort studies of women with EC, as defined by the International Classification of Diseases (ICD)-11 code 2C76 and confirmed through histological analysis, and compared surgical outcomes, intraoperative complications, and short-term postoperative complications of between

RALS using the Da Vinci® Surgical System and CLS, both involving hysterectomy, BSO, and pelvic lymph node dissection (PLND), with or without para-aortic lymph node dissection (PaLND).

2.3. Exclusion criteria

The following types of publications were excluded from the analysis: case reports, case series, commentaries, studies published in languages other than English, editorials, letters, and articles lacking full-text availability. Additionally, studies that didn't report the primary outcome (estimated blood loss or the duration of operation) or did not compare these outcomes between the RALS group and a control group of CLS were excluded. Furthermore, studies involving patients with gynecological indications other than the focus of the study were also excluded from the analysis.

2.4. Outcomes

The primary outcomes of this study were: (a) operative time, defined as the time (in minutes) from the initial incision to skin closure; and (b) estimated blood loss (EBL), measured in milliliter (ml) and recorded in the anesthesiology notes.

Additionally, the secondary outcomes included: (c) intraoperative complications: included conversion to laparotomy, urinary tract injury, gastrointestinal tract injury, nerve injury, and vascular injury; (d) short-term postoperative outcomes, included the length of hospital stay, the incidence of urinary tract infections (UTIs), wound infections, the need for blood transfusions, hernias, lymphoceles, vaginal cuff dehiscence, and thromboembolic events.

2.5. Search strategy

A computerized literature search was conducted using three electronic databases, PubMed, Scopus, and ISI Web of Science. The search used the keywords "Robotic Surgical Procedure", "Endometrial Cancers" and "Laparoscopic Surgical Procedure" and encompassed studies published until June 2024. To optimize the search results, we employed MeSH keywords and Boolean operators (such as AND, OR). The reference lists of relevant papers were reviewed manually by one reviewer (A.K). For transparency and reproducibility, the search strategy and a comprehensive list of search terms can be found in Appendix 1.

2.6. Study selection

Following the elimination of duplicate articles, the eligibility screening process was conducted in two phases. First, H. Gh and A. KA evaluated the articles based on their titles and abstracts to determine their relevance to the research topic. Next, L. A. and A. K. carried out a comprehensive review of the full texts to further assess the articles' appropriateness for inclusion in the study. In instances of disagreement, a consensus was achieved through discussion. Each identified article was assessed using a standardized evaluation format that included criteria such as study design, methodologies, participant demographics, intervention specifics, and reported outcomes. To elucidate our selection process, we employed a PRISMA flowchart (Fig. 1), providing a visual representation of how studies were screened and included in our review.

2.7. Data synthesis and extraction

The two reviewers (A. K and H. Gh) conducted an independent data collection process from the selected studies utilizing a tailored data extraction table created in Microsoft Excel 2016. The gathered data encompassed several essential components, systematically arranged to enhance understanding and facilitate comparisons. These components included demographic details (such as the study title, the name of the first author, publication date, country of origin, study design, surgical

techniques (RALs versus CLS), type of the surgery (hysterectomy, BSO, and PLND, with or without PaLND), sample characteristics (including sample size, age (year), body mass index (BMI) (kg/m^2), and past medical history), study-specific parameters (such as FIGO staging system, grading (well differentiated, moderately differentiated, poorly differentiated, unspecified), pathology findings (endometrioid serous, clear cell, carcinosarcoma, adenosquamous, mucinous, sarcoma, mixed, unclassified), prior neoadjuvant treatments, and the number of lymph nodes dissected, and *para*-aortic and plevic lymph nodes dissected), as well as measured outcomes which covered operative time, estimated blood loss, and intra- and post operative complications. This data was organized and presented in tables, effectively summarizing both the characteristics of the studies and the extracted data.

2.8. Assessment of risk bias

In this study, we used the Cochrane Risk of Bias Tool (RoB 2) to assess the risk of bias in randomized controlled trials. RoB does not have specific predefined cutoffs but rather assesses the risk of bias in various domains of a study. For each domain, the RoB provides options to assign a judgment of “low risk,” “high risk,” or “some concerns” of bias (Sterne et al., 2019).

Newcastle–Ottawa Scale (NOS) for cohort studies. The quality of

each study was rated using the following scoring algorithms: ≥ 7 points were considered as “good”, 2 to 6 points were considered as “fair”, and ≤ 1 point was considered as “poor” quality (Stang, 2010).

2.9. Statistical analysis

Statistical analysis was conducted using R (version 4.2.3). Data were pooled using a *meta*-analysis focusing on the efficacy of RALs versus CLS both involving hysterectomy, BSO, and PLND, with or without PaLND in women with EC. A random effects *meta*-analysis was calculated due to expected heterogeneity was examined using the standardized mean difference (SMD) 95 % confidence interval [CI]), where SMD values of <0.2 , >0.2 and <0.8 , or >0.8 indicated small, moderate, or large effects, respectively (Cohen, 2013). Binary outcomes, such as the conversion to laparotomy or intraoperative complication were analyzed using pooled odds ratios (OR) and 95 % CIs. Between-study variability was compared with within-study variability (i.e., heterogeneity of effect size) using both the chi-squared (Q) test of heterogeneity and the I^2 statistic, which measures the percentage of variation due to heterogeneity. An I^2 value <25 % indicated low heterogeneity, whereas values between 35 and 50 % denoted moderate heterogeneity, and those above 50 % denoted high heterogeneity (Higgins, 2003). A forest plot was generated to visually present the data from the included studies.

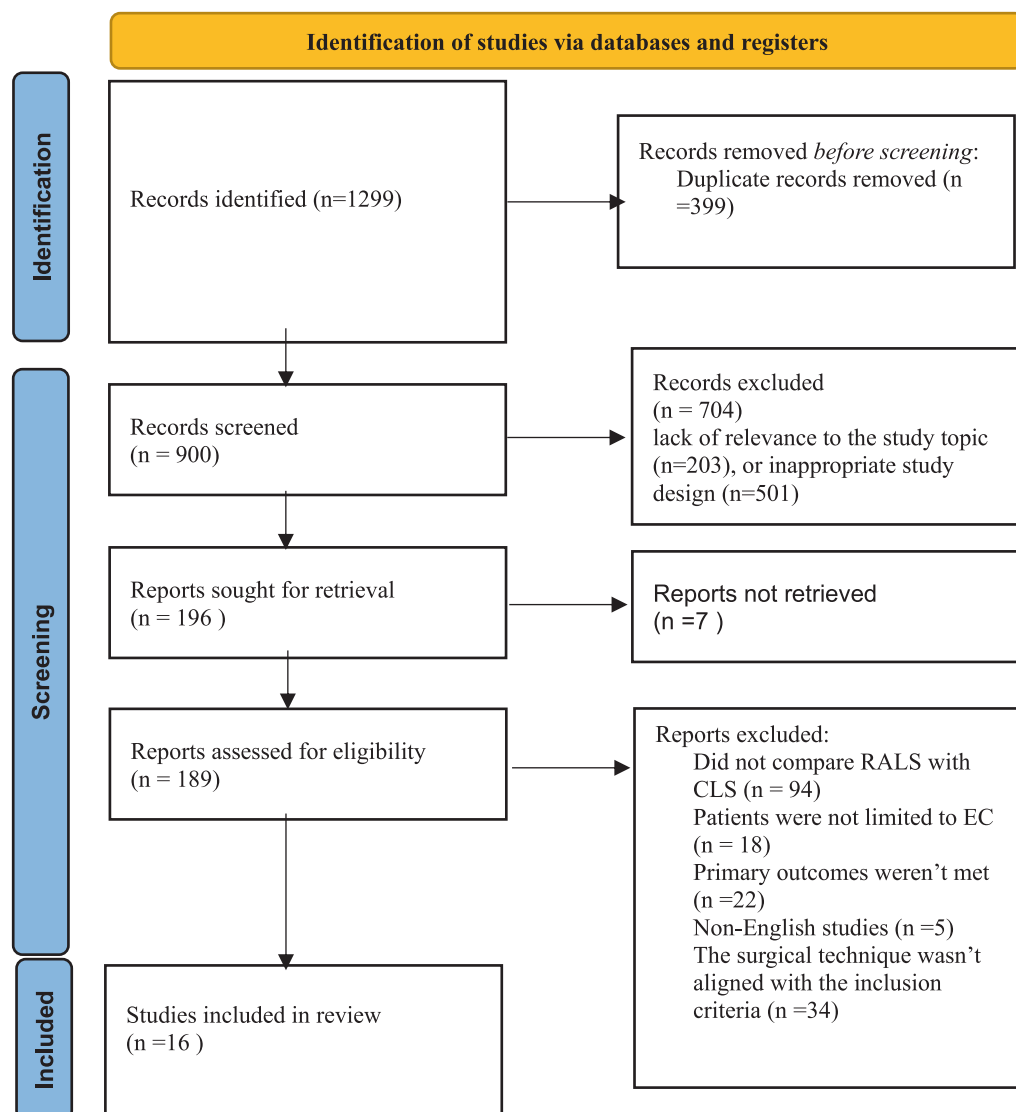


Fig. 1. The study selection process.

For parameters such as age, BMI, and number of dissected pelvic and para-aortic lymph nodes, weighted mean was calculated. The mean values for each group were multiplied by their respective sample sizes and then divided by the total sample size. The pooled standard deviation (SD) for each group was calculated by combining the within-group variances, adjusting for the sample size, and accounting for the differences in means within each group. This method provided an estimate of the overall variability within each group, which was used to assess the spread and consistency of the data.

Possible publication bias was examined through visual inspection of funnel plots for all studies in all meta-analyses combined with the regression-based Egger test (Egger et al., 1997). All two-way statistical tests were considered with $\alpha = 0.05$.

3. Results

3.1. Search results

In initial searches, 1299 publications across all the databases were found. 399 of which were duplicates. 704 publications were eliminated after a thorough screening of abstracts and titles based on factors like improper study design or lack of relevance to the research topic. Seven of the 196 articles that were originally identified for retrieval did not have full texts available. 22 studies failed to report the primary outcomes of interest after a thorough review of the remaining 189 articles, 94 studies were ruled out as they used study groups other than robotic versus conventional laparoscopy, 18 studies were eliminated since they included participants with conditions outside the purview of EC, and 22 studies failed to report the primary outcomes of interest (estimated blood loss or operative time). Furthermore, the surgical methods used in 34 studies did not meet the established inclusion criteria. At the end, 16 articles were included in the systematic review and meta-analysis (Mäenpää et al., 2016; Johansson and Chan, 2020; Chiou et al., 2015; Aiko et al., 2020; Romano et al., 2016; Hayashi et al., 2024; Gueli Alletti et al., 2016; Johnson et al., 2017; Mendivil et al., 2015; Cardenas-Goicoechea et al., 2012; Cardenas-Goicoechea et al., 2010; Lim et al., 2011; Jung et al., 2010; Lim et al., 2010; Sun et al., 2021; Estape et al., 2012).

3.2. Synthesis of results

This systematic review encompasses a total of 16 studies involving 1343 patients in the RAL group and 1382 in the CLS group, from the years 2010 to 2023 (Mäenpää et al., 2016; Johansson and Chan, 2020; Chiou et al., 2015; Aiko et al., 2020; Romano et al., 2016; Hayashi et al., 2024; Gueli Alletti et al., 2016; Johnson et al., 2017; Mendivil et al., 2015; Cardenas-Goicoechea et al., 2012; Cardenas-Goicoechea et al., 2010; Lim et al., 2011; Jung et al., 2010; Lim et al., 2010; Sun et al., 2021; Estape et al., 2012). Seven articles described patients who underwent hysterectomy, BSO, and PLND (Mäenpää et al., 2016; Johansson and Chan, 2020; Mendivil et al., 2015; Aiko et al., 2020; Romano et al., 2016; Hayashi et al., 2024; Gueli Alletti et al., 2016), while five outlined women who had hysterectomy, BSO, PLND, and PaLND (Cardenas-Goicoechea et al., 2012; Cardenas-Goicoechea et al., 2010; Lim et al., 2011; Jung et al., 2010; Lim et al., 2010). The study by Johnson et al. (2016, USA) included two subgroups based on surgical procedures: one group underwent hysterectomy, BSO, PLND and PaLND, while the other group underwent hysterectomy, BSO, PLND without PaLND (Johnson et al., 2017). In the study by Estape et al., patients in the RAL group underwent hysterectomy, BSO, and PLND, whereas patients in the CLS group had hysterectomy, BSO, PLND, and possibly PaLND (Estape et al., 2012). Similarly, patients in the Sun et al. and Chiou et al. study were treated with PLND, BSO, and hysterectomy with or without PaLND (Chiou et al., 2015; Sun et al., 2021) Table 1 lists the features of the studies that were included in this review.

3.3. Patients characteristics

The meta-analysis included 11 studies reporting the mean age and BMI of the participants (Johansson and Chan, 2020; Estape et al., 2012; Chiou et al., 2015; Aiko et al., 2020; Romano et al., 2016; Hayashi et al., 2024; Cardenas-Goicoechea et al., 2012; Cardenas-Goicoechea et al., 2010; Lim et al., 2011; Jung et al., 2010; Lim et al., 2010). The weighted mean age ($\pm$ pooled SD) was 59.76 (11.22) years in the RALS group and 58.73 (12.08) years in the CLS group with no statistically significant difference ($p = 0.54$). The weighted mean BMI was slightly higher in RALS group (29.32 ± 8.50) compared to the CLS group (28.99 ± 8.34), although this difference was also not statistically significant ($p = 0.49$ and $p = 0.63$, respectively).

The meta-analysis included studies that reported the mean collected lymph node in participants (Chiou et al., 2015; Aiko et al., 2020; Hayashi et al., 2024; Lim et al., 2010; Estape et al., 2012; Cardenas-Goicoechea et al., 2012; Cardenas-Goicoechea et al., 2010; Lim et al., 2011; Jung et al., 2010; Lim et al., 2010). The weighted mean ($\pm$ pooled SD) of collected lymph nodes patients in RALS group was 24.21 (14.05), while in CLS group it was 25.47 (18.21), with no statistically significant difference between the groups ($p = 0.66$). Six studies reported the number of para-aortic lymph nodes collected (Johnson et al., 2017; Cardenas-Goicoechea et al., 2012; Cardenas-Goicoechea et al., 2010; Lim et al., 2011; Jung et al., 2010; Lim et al., 2010). The weighted mean ($\pm$ pooled SD) of para-aortic lymph in the RALS group was 8.64 (6.97) compared to 10.45 (9.17) in the CLS group, with no statistically significant difference between the groups ($p = 0.68$). Six studies also reported the number of pelvic lymph nodes collected (Johnson et al., 2017; Cardenas-Goicoechea et al., 2012; Cardenas-Goicoechea et al., 2010; Lim et al., 2011; Jung et al., 2010; Lim et al., 2010). The weighted mean ($\pm$ pooled SD) of pelvic lymph of patients in the RALS group was 21.09 (13.99), while in the CLS group it was 21.27 (14.11), with no statistically significant difference observed between the groups ($p = 0.85$) (Chiou et al., 2015; Aiko et al., 2020; Hayashi et al., 2024; Cardenas-Goicoechea et al., 2012; Cardenas-Goicoechea et al., 2010; Lim et al., 2011; Jung et al., 2010; Lim et al., 2010).

3.4. Comparison of intraoperative outcomes of RALS and conventional CLS

The primary outcome of this systematic review was to compare operative time and estimated blood loss in two groups.

3.4.1. Comparison of operative time of RALS and CLS

A total of 2483 participants from 12 studies were included in the meta-analysis, comprising 1225 patients in the RALS group and 1258 in the CLS group (Johansson and Chan, 2020; Chiou et al., 2015; Aiko et al., 2020; Hayashi et al., 2024; Johnson et al., 2017; Estape et al., 2012; Cardenas-Goicoechea et al., 2012; Cardenas-Goicoechea et al., 2010; Lim et al., 2011; Jung et al., 2010; Lim et al., 2010). In the study by Johnson et al. (Johnson et al., 2017), operative times were reported separately based on the surgical approach, which led to the inclusion of two arms: (1) hysterectomy, BSO, PLND; and (2) hysterectomy, BSO, PLND with and without PaLND. The mean operative time was 170.04 min for the RALS group and 152.55 min for the CLS group. The data on operative time for both RALS and CLS are presented in detail in Table 2. The random-effects meta-analysis revealed a statistically significant SMD of 0.5 (95 % CI: 0.06 to 1.01; $p = 0.0281$), indicating that RALS was associated with a moderately longer operative time compared to CLS. However, substantial heterogeneity was detected among the included studies ($I^2 = 96.8\%$, $\tau^2 = 0.6727$), suggesting considerable variability in effect sizes across studies, possibly due to differences in study design, patient populations, or surgical techniques (Fig. 2). The publication bias of the studies included in the operative time analysis is shown. While the bias estimate (-6.2059) suggests some degree of funnel plot asymmetry, the lack of statistical significance indicates that there is no strong

Table 1

Characteristics of studies between conventional laparoscopic surgery and robotic-assisted laparoscopic surgery: study characteristics stratified by surgical approach (hysterectomy, BSO, PLND, and with or without PaLND).

Study, Date, and Country	Sample Size (n)	CLS vs. RALS	Grade (n, %)	Stage (n, %)	Pathology findings (n, %)	Age (year) (Mean, SD)	BMI (kg/m ²) (Mean, SD)	Lymph node dissected (Mean, SD)	Quality of the Article
<i>Hysterectomy + BSO + PLND</i>									
Mendivil et al., 2015, USA (Mendivil et al., 2015)	13	16	I = 9 (69.2 %) vs. 6 (37.5 %) II = 3 (23.1 %) vs. 9 (56.3 %) III = 1 (7.7 %) vs. 1 (6.3 %)	I = 13 (100.0 %) vs. 15 (93.8 %) II = 0 (0.0 %) vs. 1 (6.3 %)	Endometrioid = 9 (69.2 %) vs. 12 (75.0 %) Serous = 1 (7.7 %) vs. 0 (0.0 %) Mixed = 2 (15.4 %) vs. 4 (25.0 %)	Media 54 vs. 59	Median: 51.2 vs. 47.9	N/A	Poor
Alletti et al., 2015, Italy (Gueli Alletti et al., 2016)	15	15	N/A	N/A	N/A	N/A	N/A	Median: 15 vs. 18	Poor
Cucinella et al., 2015, Italy (Romano et al., 2016)	18	26	N/A	I = 18 (100.0 %) vs. 26 (100.0 %)	N/A	52.4 vs. 55	28.5 vs. 29.1	N/A	Poor
Johnson et al., 2016, USA (Johnson et al., 2017)	234	143	N/A	N/A	N/A	N/A	N/A	N/A	Poor
Mäenpää et al., 2016, Finland (Mäenpää et al., 2016)	50	49	I = 34 (68.0 %) vs. 31 (63.3 %) II = 10 (20.0 %) vs. 14 (28.6 %) III = 3 (6.0 %) vs. 0 (0.0 %) IV = 3 (6.0 %) vs. 4 (8.2 %)	I = 43 (86.0 %) vs. 41 (83.7 %) II = 0 (0.0 %) vs. 3 (6.1 %) III = 5 (10.0 %) vs. 5 (10.2 %) IV = 0 (0.0 %) vs. 5 (10.2 %)	N/A	Median: 67 vs. 70	Median: 29 vs. 29	Median: 25 vs. 23	Low risk
Aiko et al., 2020, Japan (Aiko et al., 2020)	121	102	I = 42 (34.7 %) vs. 49 (48.0 %) II = 49 (40.5 %) vs. 35 (34.3 %) III = 16 (13.2 %) vs. 7 (6.9 %)	I = 119 (98.3 %) vs. 101 (99.0 %) II = 2 (1.7 %) vs. 1 (1.0 %)	Endometrioid = 106 (87.6 %) vs. 83 (81.4 %) Serous = 5 (4.1 %) vs. 4 (3.9 %) Clear cell = 2 (1.7 %) vs. 2 (2.0 %) Carcinosarcoma = 5 (4.1 %) vs. 2 (2.0 %) Mucinous = 0 (0.0 %) vs. 2 (2.0 %) Sarcoma = 1 (0.8 %) vs. 0 (0.0 %) Mixed = 2 (1.7 %) vs. 1 (1.0 %)	56 (11) vs. 58 (11)	25.2 (5.9) vs. 24.0 (3.8)	41 (16) vs. 42 (174)	Poor
Johansson at al., 2020, Australia (Johansson and Chan, 2020)	39	41	I = 23 (59.0 %) vs. 27 (65.9 %) II = 6 (15.4 %) vs. 7 (17.1 %) III = 6 (15.4 %) vs. 6 (14.6 %) IV = 4 (10.3 %) vs. 1 (2.4 %)	I = 33 (84.6 %) vs. 35 (85.4 %) II = 3 (7.7 %) vs. 0 (0.0 %) III = 3 (7.7 %) vs. 6 (14.6 %) IV = 0 (0.0 %) vs. 6 (14.6 %)	Endometrioid = 34 (87.2 %) vs. 38 (92.7 %) Serous = 1 (2.6 %) vs. 2 (4.9 %) Clear cell = 1 (2.6 %) vs. 0 (0.0 %) Carcinosarcoma = 3 (7.7 %) vs. 1 (2.4 %)	64.6 (10.43) vs. 63.7 (10.12)	37.6 (10.63) vs. 33.8 (9.96)	Median: 6 vs. 7	Fair
Hayashi et al., 2023, Japan (Hayashi et al., 2024)	99	77	N/A	I = 93 (93.9 %) vs. 74 (96.1 %) II = 0 (0.0 %) vs. 1 (1.3 %) III = 6 (6.1 %) vs. 2 (2.6 %) IV = 0 (0.0 %) vs. 0 (0.0 %)	Endometrioid = 93 (93.9 %) vs. 70 (90.9 %) Serous = 2 (2.0 %) vs. 1 (1.3 %) Clear cell = 1 (1.0 %) vs. 0 (0.0 %) Mucinous = 1 (1.0 %) vs. 1 (1.3 %) Mixed = 4 (4.0 %) vs. 5 (6.5 %) Unclassified = 0 (0.0 %) vs. 0 (0.0 %)	54.2 (11.5) vs. 55.1 (11.1)	23 (6.7) vs. 21 (5.4)	20 (13) vs. 16 (10.9)	Fair
<i>Hysterectomy + BSO + PLND + PaLND</i>									
Cardenas-Goicoechea et al., 2010, USA (Cardenas-Goicoechea et al., 2010)	102	173	I = 51 (50.0 %) vs. 106 (61.3 %) II = 24 (23.5 %) vs. 43 (24.9 %) III = 27 (26.5 %) vs. 24 (13.9 %)	I = 82 (80.4 %) vs. 152 (87.9 %) II = 3 (2.9 %) vs. 9 (5.2 %) III = 16 (15.7 %) vs. 11 (6.4 %) IV = 1 (1.0 %) vs. 1 (0.6 %)	Endometrioid = 85 (83.3 %) vs. 157 (90.8 %) Serous = 7 (6.9 %) vs. 8 (4.6 %) Clear cell = 1 (1.0 %) vs. 0 (0.0 %) MMMT = 4 (3.9 %) vs. 7 (4.0 %) Mixed = 5 (4.9 %) vs. 1 (0.6 %)	62 (8.7) vs. 59.6 (9.75)	32.32 (8.13) vs. 32.7 (9.5)	Pelvic: 13 (6.8) vs. 16.1 (8.88) Para-aortic: 9 (6.1) vs. 7.18 (6.01) Total: 22 (10.3) vs. 23 (12.2)	Poor
Lim et al., 2010, USA (Lim et al., 2011)	122	122	N/A	N/A	N/A	62.1 (8.4) vs. 61.6 (11.8)	31.0 (8.8) vs. 29.9 (7.0)	Pelvic: 19.2 (9) vs. 24.7 (11.9) Para-aortic:	Poor

(continued on next page)

Table 1 (continued)

Study, Date, and Country	Sample Size (n) CLS vs. RALS		Grade (n, %)	Stage (n, %)	Pathology findings (n, %)	Age (year) (Mean, SD)	BMI (kg/ m ²) (Mean, SD)	Lymph node dissected (Mean, SD)	Quality of the Article
								5.8 (7.8) vs. 18.4 (9.7) Total: 25.1 (12.7) vs. 43.1 (17.8)	
Jung et al., 2010, Korea (Jung et al., 2010)	28	25	N/A	I = 28 (100.0 %) vs. 25 (100.0 %)	Endometrioid = 28 (100.0 %) vs. 24 (96.0 %) Serous = 0 (0.0 %) vs. 0 (0.0 %)Clear cell = 0 (0.0 %) vs. 1 (4.0 %)	52.89 (11.91) vs. 49.88 (10.75)	23.38 (3.08) vs. 25.17 (5.11)	Pelvic: 21.14 (9.28) vs. 18.36 (7.25) Para-aortic: 7.71 (7.32) vs. 4.41 (3.26)	Poor
Lim at al., 2010, USA (Lim et al., 2010)	56	56	N/A	N/A	N/A	62.5 (8.4) vs. 61.4 (11.7)	30.4 (8.8) vs. 28.2 (6.7)	Pelvic: 19.2 (7.9) vs. 24.1 (11.8) Para-aortic: 12.9 (7.6) vs. 20.9 (12.1) Total: 26.7 (12.8) vs. 45.1 (20.9)	Poor
Cardenas- Goicoechea et al., 2012, USA (Cardenas- Goicoechea et al., 2012)	187	245	I = 93 (49.7 %) vs. 136 (55.5 %) II = 44 (23.5 %) vs. 67 (27.3 %) III = 50 (26.7 %) vs. 42 (17.1 %)IV = 1 (0.5 %) vs. 4 (1.6 %)	I = 157 (84.0 %) vs. 201 (82.0 %) II = 5 (2.7 %) vs. 13 (5.3 %) III = 24 (12.8 %) vs. 27 (11.0 %)IV = 1 (0.5 %) vs. 4 (1.6 %)	Endometrioid = 155 (82.9 %) vs. 219 (89.4 %) Serous = 10 (5.3 %) vs. 12 (4.9 %) Clear cell = 4 (2.1 %) vs. 1 (0.4 %) Carcinosarcoma = 8 (4.3 %) vs. 7 (2.9 %) MMMT = 0 (0.0 %) vs. 3 (1.2 %) Mixed = 10 (5.3 %) vs. 3 (1.2 %)	62.1 (9.4) vs. 61.2 (10.5)	31.8 (7.95) vs. 31.8 (8.89)	Pelvic: 12.5 (6.36) vs. 14.6 (8.32) Para-aortic: 8.92 (5.44) vs. 7.57 (5.79) Total: 18.9 (10.4) vs. 20 (12.1) Para-aortic: 9.56 (7.96) vs. 3.75 (3.39)	Poor
Johnson et al., 2016, USA, (Johnson et al., 2017)	49	20	N/A	N/A	N/A	N/A	N/A		Poor
<i>Hysterectomy + BSO + PLND ± PaLND</i>									
Estape at al., 2012, USA (Estape et al., 2012)	102	104	I = 24 (23.5 %) vs. 36 (34.6 %) II = 52 (51.0 %) vs. 51 (49.0 %)III = 26 (25.5 %) vs. 17 (16.3 %)	I = 90 (88.2 %) vs. 94 (90.4 %) II = 6 (5.9 %) vs. 5 (4.8 %) III = 3 (2.9 %) vs. 5 (4.8 %) IV = 2 (2.0 %) vs. 0 (0.0 %)	Endometrioid = 89 (87.3 %) vs. 92 (88.5 %) Serous = 2 (2.0 %) vs. 3 (2.9 %) Adenosquamous = 1 (1.0 %) vs. 0 (0.0 %)Unclassified = 10 (9.8 %) vs. 9 (8.7 %)	64 (14.5) vs. 60.8 (13.2)	31.5 (8.3) vs. 30.3 (6.9)	16 (8.2) vs. 5 (4.6)	Fair
Chiou et al., 2014, Taiwan (Chiou et al., 2015)	86	150	N/A	I = 72 (83.7 %) vs. 121 (80.7 %) II = 2 (2.3 %) vs. 9 (6.0 %) III = 12 (14.0 %) vs. 20 (13.3 %)	Endometrioid = 74 (86.0 %) vs. 127 (84.7 %) Serous = 2 (2.3 %) vs. 1 (0.7 %) Clear cell = 0 (0.0 %) vs. 3 (2.0 %) Carcinosarcoma = 0 (0.0 %) vs. 0 (0.0 %) Adenosquamous = 0 (0.0 %) vs. 0 (0.0 %) Mucinous = 0 (0.0 %) vs. 2 (1.3 %) MMMT = 0 (0.0 %) vs. 0 (0.0 %) Sarcoma = 0 (0.0 %) vs. 0 (0.0 %) Mixed = 10 (11.6 %) vs. 16 (10.7 %) Unclassified = 0 (0.0 %) vs. 1 (0.7 %)	53.6 (11.1) vs. 51.4 (14.2)	26.0 (5.2) vs. 25.6 (5.6)	26.5 (10.7) vs. 23.4 (14.2)	Poor
Sun et al., 2021, China (Sun et al., 2021)	22	18	N/A	I = 22 (100.0 %) vs. 18 (100.0 %)	Endometrioid = 22 (100.0 %) vs. 18 (100.0 %)	Media56 vs. 55.5	Median: 25 vs. 24.5	N/A	Poor

Abbreviation: BMI: Body mass index, BSO: Bilateral salpingo-oophorectomy, CLS: conventional laparoscopic surgery, MMT: Malignant mixed müllerian tumors, N/A: Not available, n: number, PLND: Pelvic lymph node dissection, PaLND: Para-aortic lymph node dissection, RALS: Robotic-assisted laparoscopic surgery.

* Numbers represent CLS vs. RALS groups, respectively.

Table 2
Comparison of surgical and intra-operative complications between conventional laparoscopic surgery and robotic-assisted laparoscopic surgery: study characteristics stratified by surgical approach (hysterectomy, BSO, PLND, and with or without PaLND).

Study, Date, and Country	Sample Size (n) CLS vs. RALS		Operative time (min) (Mean, SD)	Estimated blood loss (ml) (Mean, SD)	Conversion to laparotomy (n, %)	Urinary tract injury (n, %)	GI tract injury (n, %)	Nerve injury (n, %)	Vascular injury (n, %)
<i>Hysterectomy + BSO + PLND</i>									
Mendivil et al., 2015, USA (Mendivil et al., 2015)	13	16	Median (range) 166.8 (85.2–265.2) vs. 109.2 (66–235)	Median (range) 100 (50–150) vs. 175 (25–700)	1 (7.7 %) vs. 1 (6.3 %)	N/A	N/A	N/A	N/A
Alletti et al., 2015, Italy (Gueli Alletti et al., 2016)	15	15	Median (range) 193 (129–290) vs. 104 (36–106)	Median (range) 60 (0–200) vs. 84 (20–200)	2 (13.3 %) vs. 0 (0.0 %)	N/A	N/A	N/A	N/A
Cucinella et al., 2015, Italy (Romano et al., 2016)	18	26	102.5 vs. 95.7	50 vs. 150	0 (0.0 %) vs. 0 (0.0 %)	0 (0.0 %) vs. 0 (0.0 %)	0 (0.0 %) vs. 0 (0.0 %)	0 (0.0 %) vs. 0 (0.0 %)	0 (0.0 %) vs. 0 (0.0 %)
Johnson et al., 2016, USA (Johnson et al., 2017)	234	143	125.6 (32.8) vs. 75.8 (29.3)	N/A	N/A	N/A	N/A	N/A	N/A
Mäenpää et al., 2016, Finland (Mäenpää et al., 2016)	50	49	Median (range) 139 (86–197) vs. 170 (126–259)	Median (range) 50 (5–500) Vs. 50 (20–1200)	0 (0.0 %) vs. 5 (10.2 %)	0 (0.0 %) vs. 1 (2.0 %)	0 (0.0 %) vs. 1 (2.0 %)	0 (0.0 %) vs. 1 (2.0 %)	0 (0.0 %) vs. 1 (2.0 %)
Aiko et al., 2020, Japan (Aiko et al., 2020)	121	102	178 (41) vs. 133 (28)	237 (146) vs. 196 (153)	1 (0.8 %) vs. 0 (0.0 %)	1 (0.8 %) vs. 1 (1.0 %)	0 (0.0 %) vs. 1 (1.0 %)	0 (0.0 %) vs. 0 (0.0 %)	0 (0.0 %) vs. 0 (0.0 %)
Johansson at al., 2020, Australia (Johansson and Chan, 2020)	39	41	132.9 (32.3) vs. 107.1 (24.4)	22.3 vs. 77.7	0 (0.0 %) vs. 0 (0.0 %)	N/A	N/A	N/A	N/A
Hayashi et al., 2023, Japan (Hayashi et al., 2024)	99	77	226 (69.2) vs. 234 (60.0)	10 (78.2) vs. 50 (279.6)	0 (0.0 %) vs. 1 (1.3 %)	1 (1.0 %) vs. 0 (0.0 %)	N/A	0 (0.0 %) vs. 2 (2.6 %)	0 (0.0 %) vs. 1 (1.3 %)
<i>Hysterectomy + BSO + PLND + PaLND</i>									
Cardenas-Goicoechea et al., 2010, USA (Cardenas-Goicoechea et al., 2010)	102	173	237 (57) vs. 178 (58.9)	109 (83.3) vs. 187 (187)	1 (1.0 %) vs. 9 (5.2 %)	0 (0.0 %) vs. 6 (3.5 %)	2 (2.0 %) vs. 0 (0.0 %)	1 (1.0 %) vs. 9 (5.2 %)	N/A
Lim et al., 2010, USA (Lim et al., 2011)	122	122	147.2 (48.2) vs. 186.8 (59.8)	81.1 (45.9) vs. 207.4 (109.4)	1 (0.8 %) vs. 8 (6.6 %)	0 (0.0 %) vs. 2 (1.6 %)	1 (0.8 %) vs. 1 (0.8 %)	0 (0.0 %) vs. 3 (2.5 %)	0 (0.0 %) vs. 1 (0.8 %)
Jung et al., 2010, Korea (Jung et al., 2010)	28	25	193.18 (60.42) vs. 165.2 (43.39)	N/A	N/A	N/A	N/A	N/A	N/A
Lim at al., 2010, USA (Lim et al., 2010)	56	56	162.5 (53.0) vs. 192.3 (55.5)	89.3 (45.4) vs. 209.1 (91.8)	1 (1.8 %) vs. 4 (7.1 %)	0 (0.0 %) vs. 2 (3.6 %)	0 (0.0 %) vs. 1 (1.8 %)	0 (0.0 %) vs. 3 (5.4 %)	0 (0.0 %) vs. 1 (1.8 %)
Cardenas-Goicoechea et al., 2012, USA (Cardenas-Goicoechea et al., 2012)	187	245	218 (58.8) vs. 161 (58.9)	110 (82.9) Vs. 187 (169)	1 (0.5 %) vs. 10 (4.1 %)	0 (0.0 %) vs. 7 (2.9 %)	3 (1.6 %) vs. 0 (0.0 %)	N/A	0 (0.0 %) vs. 1 (0.4 %)
Johnson et al., 2016, USA (Johnson et al., 2017)	49	20	162.1 (34.0) vs. 106.1 (24.5)	N/	N/A	N/A	N/A	N/A	N/A
<i>Hysterectomy + BSO + PLND ± PaLND</i>									
Estape at al., 2012, USA (Estape et al., 2012)	102	104	108.7 (37.5) vs. 79.4 (121.7)	108.4 (94.1) vs. 193.7 (110.2)	0 (0.0 %) vs. 1 (1.0 %)	0 (0.0 %) vs. 1 (1.0 %)	N/A	N/A	N/A
Chiou et al., 2014, Taiwan (Chiou et al., 2015)	86	150	155.6(45.7) vs. 178.6(58.7)	94.8 (78.6) vs. 174.2 (229.6)	N/A	N/A	N/A	N/A	N/A
Sun et al., 2021, China (Sun et al., 2021)	22	18	Median (range) 95 (85–150) vs. 125 (95–150)	Median (range) 50 (30–100) vs. 85 (50–120)	0 (0.0 %) vs. 0 (0.0 %)	0 (0.0 %) vs. 0 (0.0 %)	0 (0.0 %) vs. 0 (0.0 %)	0 (0.0 %) vs. 0 (0.0 %)	0 (0.0 %) vs. 0 (0.0 %)

Abbreviations: BSO: Bilateral salpingo-oophorectomy, GI: Gastrointestinal, ML: Milliliter, Min: Minutes, N/A: Not available, n: Number, PLND: Pelvic lymph node dissection, PaLND: Para-aortic lymph node dissection, SD: Standard deviation
* Numbers represent CLS vs. RALS groups, respectively.

evidence of publication bias or small-study effects in the *meta*-analysis (Supplementary Fig. 1a).

3.4.2. Estimated blood loss of RALS and CLS

With 875 observations in the RALS group and 1029 in the CLS group, the *meta*-analysis consists of 8 studies encompassing 1904 observations (24,25,27,31–33,35,37). The mean estimated blood loss was 109.10 mL for the RALS group and 180.07 mL for the CLS group. Table 2 presents the estimated blood loss and study characteristics by individual study. The pooled SMD was −0.7 (95 % CI: −1.1 to −0.2; p = 0.0029), indicating a statistically significant reduction in blood loss in the RALS group compared to the CLS group. This moderate-to-large effect size

suggests a clinically meaningful advantage for RALS. However, the ^I2 value of 93.9 % reflects substantial heterogeneity across studies, indicating considerable variability in effect estimates. The Q-test for heterogeneity was also significant (Q = 114.52, df = 7, p < 0.0001), supporting the presence of substantial inter-study differences (Fig. 3). The publication bias of the studies included in the estimated blood loss analysis shows that the bias estimate (6.2431) is positive, indicating a potential asymmetry in the funnel plot. However, because of the small number of studies (k = 8) and the high standard error, the evidence remains weak and inconclusive (Supplementary Fig. 1b).

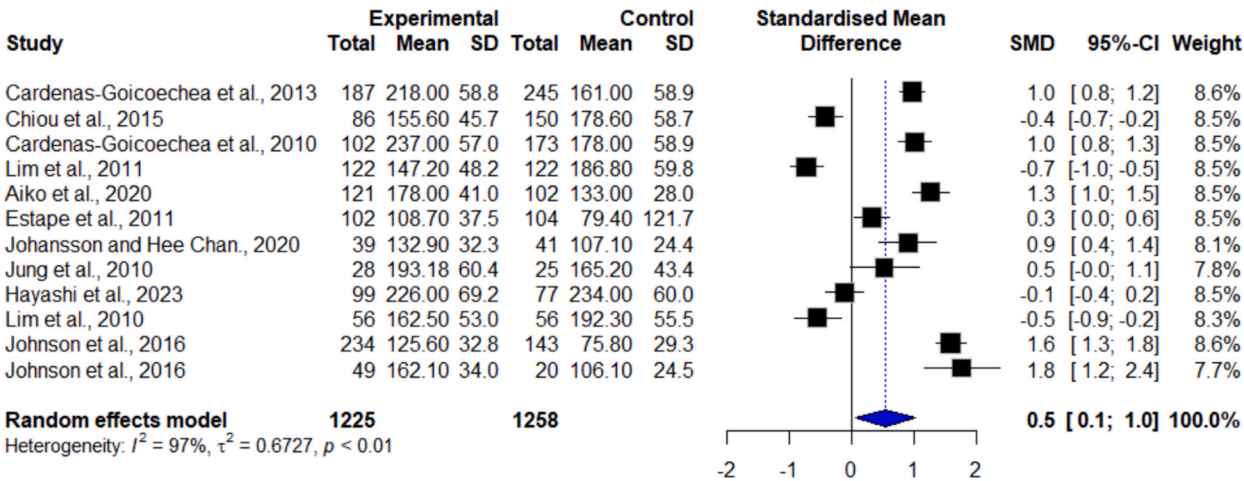


Fig. 2. Forest plot of random effects standardized mean difference (SMD) between control and treatment means for procedural time. The solid diamonds represent individual studies and their weighting by the inverse of their respective variances. The horizontal lines represent the 95 % confidence interval for the study. The open diamond represents the overall SMD and its width represents the associated 95 % confidence interval. The solid line is the line depicting no intervention effect.

3.4.3. Comparison of intraoperative complications and short term post-operative outcomes of RALS and CLS

Intraoperative complications and short-term postoperative outcomes were evaluated as secondary outcomes in this study. The results of secondary outcomes are presented in [Table 2](#).

3.4.3.1. Intraoperative complications RALS and CLS. Intraoperative complications including conversion to laparotomy and injuries (urinary, gastrointestinal, nerve, and vascular).

3.4.3.1.1. Comparison of conversion to laparotomy of RALS and CLS. Although 13 studies with a total of 2043 observations (974 in the RALS group and 1069 in the CLS) were considered for this variable ([Mäenpää et al., 2016](#); [Johansson and Chan, 2020](#); [Aiko et al., 2020](#); [Romano et al., 2016](#); [Hayashi et al., 2024](#); [Gueli Alletti et al., 2016](#); [Mendivil et al., 2015](#); [Cardenas-Goicoechea et al., 2012](#); [Cardenas-Goicoechea et al., 2010](#); [Lim et al., 2011](#); [Jung et al., 2010](#); [Lim et al., 2010](#); [Sun et al., 2021](#); [Estape et al., 2012](#)), only 10 studies were included in the meta-analysis because, in the remaining studies, no events were reported in either arm ([Chiou et al., 2015](#); [Johnson et al., 2017](#); [Jung et al., 2010](#)). Nevertheless, these studies are included in the plot for transparency and to reflect their contribution to the overall sample structure. Across these studies, 47 events were reported. The pooled OR from the random effects model is 0.29 (95 % CI: 0.13–0.65), indicating that the RALS group had a statistically significant 71 % reduction in the odds of the event compared to the CLS group ($z = -3.01$, $p = 0.0026$). ([Fig. 4](#)).

Heterogeneity among the included studies was low, as indicated by an I^2 of 0.0 % and a non-significant Q-test ($Q = 8.59$, $df = 9$, $p = 0.48$), suggesting consistent results across studies. The between-study variance (τ^2) was near zero, further supporting minimal variability in effect sizes. The significant result of the Egger’s test ($p = 0.0494$) suggests potential funnel plot asymmetry, possibly indicating publication bias or small-study effects, with a bias estimate of 3.0801 (SE = 1.3311) and moderate heterogeneity ($\tau^2 = 0.6432$) (Supplementary [Fig. 1c](#)).

3.4.3.1.2. Comparison of intraoperative injuries of RALS and CLS. Although the forest plot displays all 11 studies comprising 1984 observations (946 in the RALS group and 1038 in the CLS group) ([Mäenpää et al., 2016](#); [Johansson and Chan, 2020](#); [Aiko et al., 2020](#); [Romano et al., 2016](#); [Hayashi et al., 2024](#); [Cardenas-Goicoechea et al., 2012](#); [Cardenas-Goicoechea et al., 2010](#); [Lim et al., 2011](#); [Jung et al., 2010](#); [Lim et al., 2010](#); [Sun et al., 2021](#); [Estape et al., 2012](#)), only eight studies contributed to the pooled effect estimate, as other studies reported no events in either the RALS or CLS groups ([Chiou et al., 2015](#); [Johnson et al., 2017](#); [Jung et al., 2010](#)). Nevertheless, all twelve studies are displayed in the forest plot for transparency and to acknowledge their contribution to the overall sample size. A total of 46 intraoperative complications were reported, including gastrointestinal, vascular, nerve, and urinary injuries. A single pooled OR was calculated for these grouped complications, indicating that RALS is associated with a 69 % lower risk of intraoperative injuries compared to CLS (pooled OR: 0.31). With a p-value of 0.0019, this finding is statistically significant and suggests a

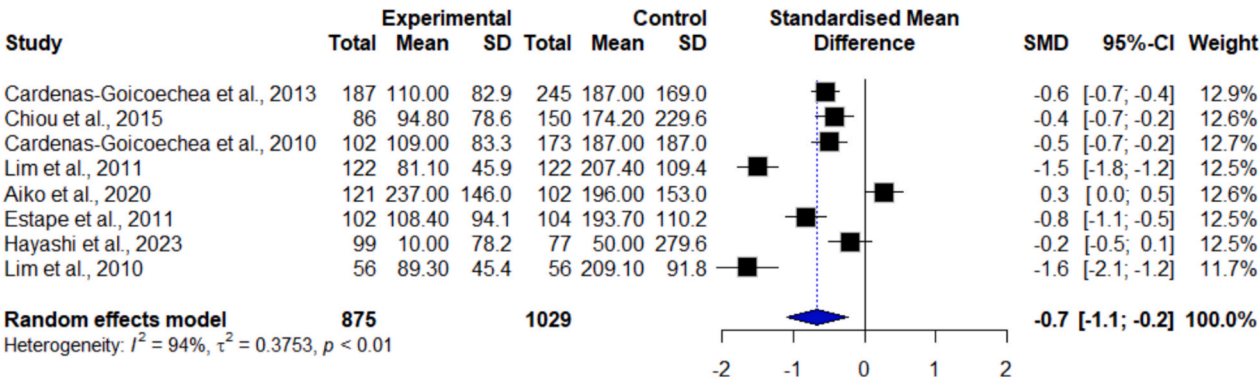


Fig. 3. Forest plot of random effects standardized mean difference (SMD) between control and treatment means for estimated blood loss. The solid diamonds represent individual studies and their weighting by the inverse of their respective variances. The horizontal lines represent the 95 % confidence interval for the study. The open diamond represents the overall SMD and its width represents the associated 95 % confidence interval. The solid line is the line depicting no intervention effect.

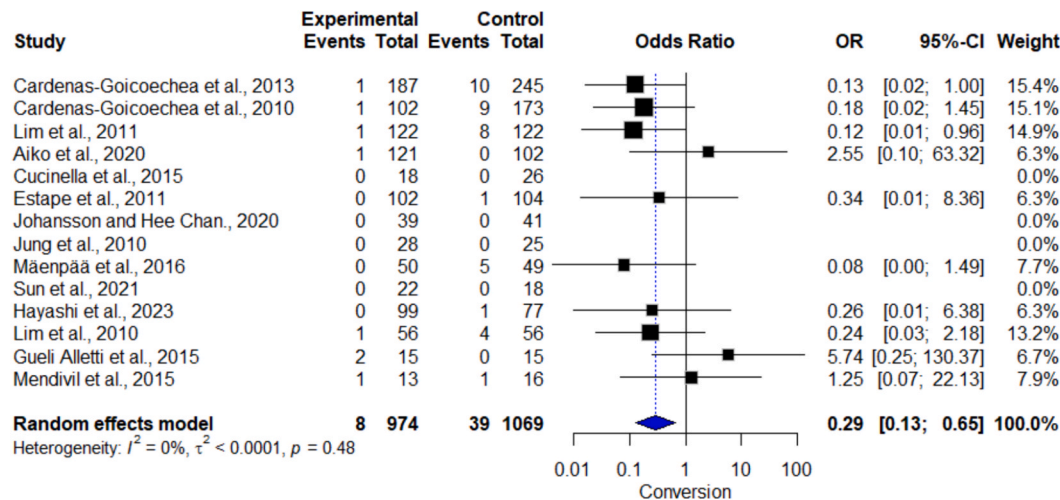


Fig. 4. Forest plot effect of robotic-assisted laparoscopy on conversion. The odds ratio and 95 % confidence interval are plotted for each study. The pooled odds ratio (diamond apex) and 95 % confidence interval (diamond width) is calculated using a random effects model.

strong association (Fig. 5). An I^2 value of 0 % and a non-significant Q-test ($p = 0.84$) indicate minimal heterogeneity across the studies. The τ^2 value is also 0, further confirming the lack of between-study variability. These results collectively support a consistent protective effect of the intervention across the included studies. The Egger's test showed no significant evidence of funnel plot asymmetry ($p = 0.3964$), but the small number of studies ($k = 8$) and missing data limit the reliability of the results (Supplementary Fig. 1d).

3.4.3.2. Comparison of short-term postoperative outcomes between RALS and CLS. Short-term postoperative outcomes included hospital length of stay and complications such as urinary tract infections (UTIs), wound infections, blood transfusions, hernias, lymphoceles, vaginal cuff dehiscence, and thromboembolic events.

3.4.3.2.1. Comparison of length of hospital stay of RALS and CLS. The meta-analysis includes 7 studies with a total of 1728 observations, with 776 in the RALS group and 952 in the CLS group (Chiou et al., 2015; Aiko et al., 2020; Lim et al., 2010; Estape et al., 2012; Cardenas-Goicoechea et al., 2012; Cardenas-Goicoechea et al., 2010; Lim et al., 2011). On average, the hospital stay was 2.91 days in the RALS group and 3.36 days in the CLS group, demonstrating a clinically meaningful benefit of RALS in reducing recovery time (Table 3). The pooled SMD was -0.44 (95 % CI: -0.77 to -0.11), indicating a moderate but statistically significant reduction in hospital stay for patients undergoing

RALS compared to CLS ($p = 0.0091$) (Fig. 6). However, there is considerable heterogeneity among the studies, as indicated by an I^2 of 88.3 %, which means there is significant variability in the effect sizes. The Q-test ($p < 0.0001$) confirms the presence of high heterogeneity. The Egger's test showed no significant evidence of funnel plot asymmetry ($p = 0.2113$), with a bias estimate of -7.5779 (SE = 5.2879), but the small number of studies ($k = 7$) limits the reliability of these findings (Supplementary Fig. 1e).

3.4.3.2.2. Post operative complications of RALS and CLS. Although the forest plot displays all 11 studies with a total of 2100 observations—971 in the RALS and 1129 in the CLS—with 169 events reported (7.24–27.31–35.37), for the purpose of calculating the pooled effect estimate, only 10 studies were considered because one study had no events in either the RALS or CLS groups (Sun et al., 2021). Despite this, the forest plot includes all studies to maintain transparency and acknowledge their role in the total sample size. The pooled OR is 1.8, suggesting that the of RALS increases the odds of the complications by approximately 77 % compared to the CLS. This result is statistically significant, with a p-value of 0.0008, indicating a reliable effect (Fig. 7). Heterogeneity across studies is negligible, as shown by an I^2 of 0.0 % and a non-significant Q-test ($p = 0.8805$), indicating consistency in the effect size among the studies. The τ^2 value is also 0, reinforcing the lack of variability in the findings. These results suggest a robust and consistent association between the intervention or exposure and the

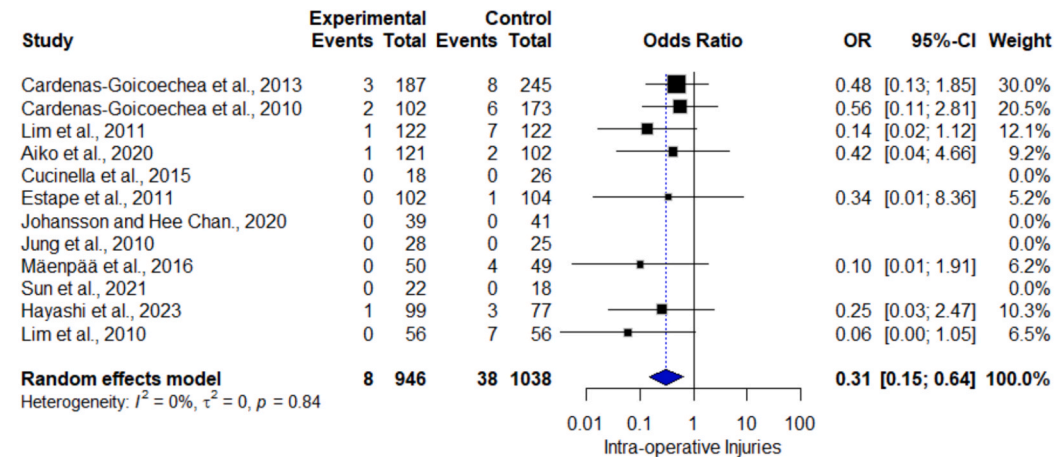


Fig. 5. Forest plot effect of robotic-assisted laparoscopy on intra-operative complications. The odds ratio and 95 % confidence interval are plotted for each study. The pooled odds ratio (diamond apex) and 95 % confidence interval (diamond width) is calculated using a random effects model.

Table 3
Length of hospital stay and short-term post operative complications in conventional laparoscopic surgery and robotic-assisted laparoscopic surgery.

Study, Date, and Country	Sample size (n) CLS vs. RALS	Length of Hospital stay (days) (mean, SD)	UTI (n, %)	Thromboembolic event (n, %)	Vaginal cuff dehiscence (n, %)	Uterovaginal fistula (n, %)	Hernia (n, %)	Cellulitis (n, %)	Lymphocele (n, %)	Blood transfusion (n, %)	Re admission (n, %)	Reoperation (n, %)
Cardenas-Goicoechea et al., 2010, USA (Cardenas-Goicoechea et al., 2010)	102 vs. 173	1.88 (1.67) vs. 2.31 (2.21)	2 (2.0 %) vs. 1 (0.6 %)	1 (1.0 %) vs. 0 (0.0 %)	1 (1.0 %) vs. 0 (0.0 %)	N/A	1 (1.0 %) vs. 0 (0.0 %)	0 (0.0 %) vs. 2 (1.2 %)	1 (1.0 %) vs. 3 (1.7 %)	3 (2.9 %) vs. 3 (1.7 %)	5 (4.9 %) vs. 3 (1.7 %)	2 (2.0 %) vs. 2 (1.2 %)
Lim et al., 2010, USA (Lim et al., 2011)	122 vs. 122	1.5 (0.9) vs. 3.2 (2.3)	6 (4.9 %) vs. 1 (0.8 %)	2 (1.6 %) vs. 0 (0.0 %)	N/A	0 (0.0 %) vs. 1 (0.8 %)	0 (0.0 %) vs. 1 (0.8 %)	0 (0.0 %) vs. 1 (0.8 %)	N/A	0 (0.0 %) vs. 3 (2.5 %)	10 (8.2 %) vs. 4 (3.3 %)	N/A
Jung et al., 2010, Korea (Jung et al., 2010)	28 vs. 25	Median: 7.92 vs. 7.67	N/A	N/A	N/A	N/A	0 (0.0 %) vs. 0 (0.0 %)	N/A	0 (0.0 %) vs. 0 (0.0 %)	4 (14.3 %) vs. 4 (16.0 %)	N/A	N/A
Lim et al., 2010, USA (Lim et al., 2010)	56 vs. 56	1.6 (0.7) vs. 2.6 (0.9)	4 vs. 1	2 (3.6 %) vs. 1 (1.8 %)	N/A	0 (0.0 %) vs. 1 (1.8 %)	N/A	0 (0.0 %) vs. 1 (1.8 %)	N/A	N/A	6 (10.7 %) vs. 3 (5.4 %)	N/A
Cardenas-Goicoechea et al., 2012, USA (Cardenas-Goicoechea et al., 2012)	187 vs. 245	1.96 (2.01) vs. 2.45 (2.08)	2 (1.1 %) vs. 2 (0.8 %)	1 (0.5 %) vs. 0 (0.0 %)	3 (1.6 %) vs. 2 (0.8 %)	N/A	1 (0.5 %) vs. 2 (0.8 %)	0 (0.0 %) vs. 2 (0.8 %)	1 (0.5 %) vs. 4 (1.6 %)	5 (2.7 %) vs. 5 (2.0 %)	7 (3.7 %) vs. 5 (2.0 %)	7 (3.7 %) vs. 5 (2.0 %)
Estape et al., 2012, USA (Estape et al., 2012)	102 vs. 104	1.9 (1.5) vs. 1.8 (1.1)	N/A	N/A	1 (1.0 %) vs. 0 (0.0 %)	N/A	N/A	N/A	N/A	6 (5.9 %) vs. 4 (3.8 %)	2 (2.0 %) vs. 0 (0.0 %)	N/A
Chiou et al., 2014, Taiwan (Chiou et al., 2015)	86 vs. 150	3.1 (1.1) vs. 3.7 (2.2)	N/A	N/A	1 (1.2 %) vs. 0 (0.0 %)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cucinella et. al., 2015, Italy (Romano et al., 2016)	18 vs. 26	2.3 vs. 2.3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0 vs.0	0 vs. 0	N/A
Alletti et al., 2015, Italy (Gueli Alletti et al., 2016)	15 vs. 15	Median: 2 vs. 2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Mendivil et al., 2015, USA (Mendivil et al., 2015)	13 vs. 16	Median: 2 vs. 2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Mäenpää et al., 2016, Finland (Mäenpää et al., 2016)	50 vs. 49	Median: 1 vs. 2	1 vs. 1	N/A	N/A	N/A	N/A	0 (0.0 %) vs. 0 (0.0 %)	N/A	6 (12.0 %) vs. 2 (4.1 %)	N/A	1 vs.0
Aiko et al., 2020, Japan (Aiko et al., 2020)	121 vs. 102	8 (3) vs. 9 (4)	N/A	1 (0.8 %) vs. 0 (0.0 %)	N/A	1 (0.8 %) vs. 0 (0.0 %)	N/A	N/A	1 (0.8 %) vs. 0 (0.0 %)	0 vs.0	N/A	N/A
Johansson et al., 2020, Australia (Johansson and Chan, 2020)	39 vs. 41	1.26 vs. 1.78	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Sun et al., 2021, China (Sun et al., 2021)	22 vs. 18	Median: 2 vs. 3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hayashi et al., 2023, Japan (Hayashi et al., 2024)	99 vs. 77	N/A	N/A	1 (1.1 %) vs. 0 (0.0 %)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Abbreviations: N/A: not available, UTI: Urinary tract infections.
Numbers represent CLS vs. RALS groups, respectively.

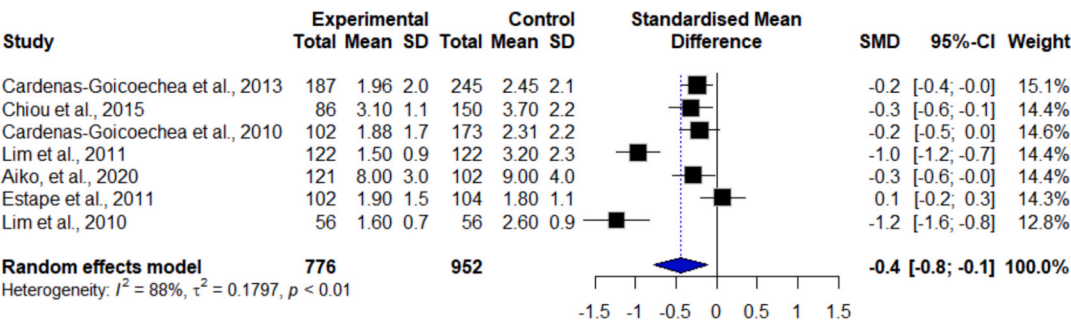


Fig. 6. Forest plot of random effects standardized mean difference (SMD) between control and treatment means for length of hospital stay. The solid diamonds represent individual studies and their weighting by the inverse of their respective variances. The horizontal lines represent the 95 % confidence interval for the study. The open diamond represents the overall SMD and its width represents the associated 95 % confidence interval. The solid line is the line depicting no intervention effect.

outcome across the included studies. The Egger’s test showed no significant evidence of funnel plot asymmetry ($p = 0.0914$), with a bias estimate of 0.7231 ($SE = 0.3770$), while moderate heterogeneity ($\tau^2 = 0.3222$) indicates some variability between studies; however, one study was excluded due to missing data, which may affect the analysis (Supplementary Fig. 1f).

3.5. Risk of bias assessment

Among the 16 studies for which risk of bias was assessed, 12 studies (70.6 %) were assessed as ‘poor’, indicating significant methodological weaknesses. Three studies (17.6 %) were classified as ‘fair’, indicating moderate quality and significant potential for bias, and only one study (5.9 %) was classified as ‘low risk of bias’, indicating high methodological rigor and rigor. These results indicate that the majority of studies (over 70 %) have significant limitations and only a small proportion are of better quality. The results of the risk of bias assessment of the studies are presented in Table 1.

4. Discussion

This systematic review and meta-analysis was performed to compare RALS and CLS in terms of surgical outcomes, intraoperative and short-term postoperative complications. Our results showed that RALS was linked to fewer intraoperative complications, lower conversion rates, reduced blood loss, and a longer operating time. Nonetheless, it was observed that the RALS group experienced a higher rate of postoperative complications.

Since its introduction in 1992, the use of MIS for EC has grown in popularity. Research has demonstrated that MIS procedures show fewer

postoperative complications and offer comparable oncological outcomes to open surgery (Corrado et al., 2015; Boggess et al., 2008). With its three-dimensional view, wristed instruments, and scaled movement capabilities, RALS is responsible for more than half of MIS procedures (Aiko et al., 2020). Robotic systems provide a stable platform that eliminates the challenges of manually maintaining instrument and camera positions, particularly in larger patients. Since receiving FDA approval for gynecologic surgery in 2005, these advantages have encouraged widespread adoption of robotic technology by gynecologic oncologists (Bell et al., 2008). Therefore; there has been a significant increase in the use of robotic technology, while CLS has seen a decline (Seror et al., 2014).

Limited randomized controlled trials have been performed to compare RALS with CLS for the treatment of EC. In a randomized controlled trial conducted by Corrado et al. (Corrado et al., 2015) which compared open surgery, laparoscopy, and robotic-assisted laparoscopy for EC, it was found that MIS outperformed abdominal surgery in terms of surgical outcomes. Within MIS, RALS demonstrated advantages over CLS in terms of intra- and post-operative complications, conversion rates, length of hospital stay, and re-interventions. However, RALS was associated with longer operative times, which runs counter to the results of Mäenpää et al.’s randomized controlled trial (Mäenpää et al., 2016). In their study involving patients with EC, it was observed that RALS was actually quicker to perform compared to CLS. Conversely, several retrospective studies indicate that surgery typically takes longer in RALS compared to CLS for EC (Boggess et al., 2008; Bell et al., 2008; Seror et al., 2014).When directly comparing RALS and CLS, Ind et al. found that the former had fewer conversions, shorter hospital stays, less blood loss, and fewer overall surgical complications than the latter (Ind et al., 2017). These results were consistent with a network meta-analysis and

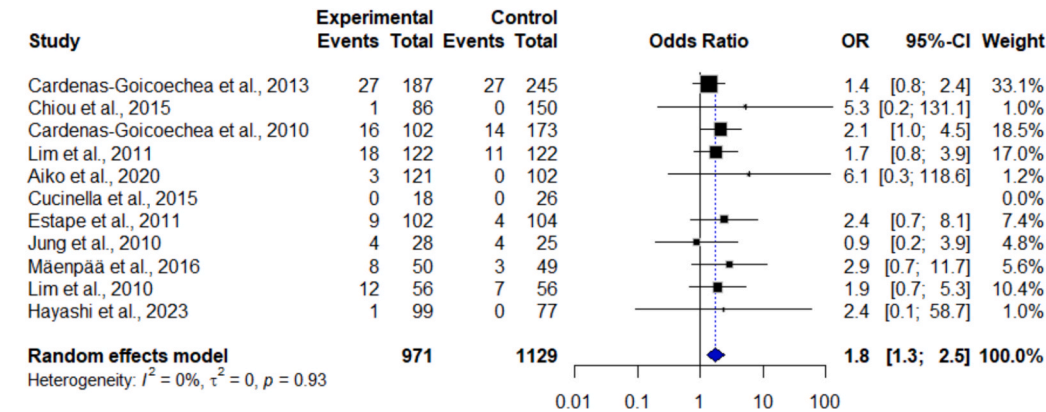


Fig. 7. Forest plot of post-operative complication. The odds ratio and 95 % confidence interval are plotted for each study. The pooled odds ratio (diamond apex) and 95 % confidence interval (diamond width) is calculated using a random effects model.

systematic review by Natarajaan et al., which included 99 studies involving 181,716 women and assessed 14 outcomes (Natarajan et al., 2024).

It is important to note that previous studies in the literature have often pooled outcomes from heterogeneous surgical procedures; for instance, combining hysterectomies performed with or without BSO, and with or without lymphadenectomy. Each of these variations can independently influence surgical outcomes, thereby introducing confounding factors (Barrie et al., 2016). To minimize such variability, our systematic review and meta-analysis specifically included studies in which patients underwent a uniform surgical approach consisting of hysterectomy with BSO and PLND, with or without PaLND. This allowed for a more precise assessment of the relative effects of RALS versus CLS without the confounding influence of differing surgical scopes or procedures. The surgical methods reviewed in this analysis are consistent with the previous accepted standard of care. It should be acknowledged that current practice has shifted toward the use of sentinel lymph node biopsy (SLNB) as the preferred staging method, as recommended by recent ESGO and NCCN guidelines, due to its lower morbidity and shorter operative time. However, the body of literature available for inclusion in this analysis contained insufficient studies employing SLNB to enable a meaningful comparison. Consequently, we focused on the traditional comprehensive staging approach (hysterectomy + BSO ± PLND/PaLND) to ensure methodological consistency and comparability across studies. As a result, our pooled estimates for operative time, blood loss, and complications may be higher than what would be expected with contemporary SLNB-based surgical protocols.

However, our study has several limitations. Firstly, the choice between CLS and RALS may have been influenced by patient characteristics like advanced disease stage, surgeon skill, and institutional resources, which could cause selection bias or affect case allocation. These biases could affect the pooled data. For instance, despite fewer intraoperative injuries and conversions, our study showed that the robotic group demonstrated a higher pooled postoperative complication rate. This finding may be partly attributable to the biases mentioned above. Furthermore, the retrospective nature of most included studies may have introduced recall bias in reporting self-limiting complications and documentation bias in recording postoperative events, potentially inflating the observed complication rate in the robotic cohort.

Temporal heterogeneity among studies [2010–2023] represents another limitation. Earlier studies often used first-generation robotic systems and pre-ERAS perioperative pathways, whereas later studies reflect modern instrumentation and enhanced recovery protocols. These differences likely influenced operative times and surgical outcomes. Now a days, robotic-assisted procedures are increasingly performed on an outpatient basis in some centers, the pooled mean length of stay of approximately 2–3 days in our review likely reflects variability in institutional discharge protocols, patient comorbidities, and the inclusion of comprehensive staging procedures. In addition, many studies were conducted before the widespread adoption of enhanced-recovery-after-surgery (ERAS) pathways, which today permit earlier discharge for suitable patients (Altman et al., 2019).

Significant heterogeneity in outcomes, such as operative time ($I^2 = 96.8\%$) and estimated blood loss ($I^2 = 93.9\%$), as well as a high risk of bias—more than 70 % of the included studies were rated as “poor” in methodological quality—are among the study’s limitations. Given the variability across studies, the overall result should be interpreted with caution, as different studies may yield different outcomes.

Because most available data are retrospective and based on earlier robotic platforms, further high-quality prospective evidence is needed. A large RCT directly comparing modern robotic and conventional laparoscopic systems would provide the most definitive evidence, but such a study may be challenging to implement given surgeon expertise, equipment availability, and ethical considerations once proficiency is established. Alternatively, prospective multicenter registries and pragmatic comparative-effectiveness studies could yield timely, real-world

insights into outcomes, costs, and patient-reported recovery. Furthermore, additional studies with more comprehensive patient-level data—including age, prior surgical history, and lymphadenectomy details and surgeon experience—are warranted.

5. Conclusion

Because RALS provides improved visualization without sacrificing oncological results, its use as an extension of MIS has been increasing in the field of gynecological oncology. According to the results of our study, RALS is linked to fewer intraoperative complications. Additionally, our findings indicate that RALS procedures typically require more time. To get a more complete picture of the real comparison between RALS and CLS, future research should try to address potential confounding factors like the type of surgery.

6. Patient consent

N/A.

7. Provenance and peer review

Not commissioned, externally peer-reviewed.

Data availability statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethics statement

N/A (This is a review article).

CRediT authorship contribution statement

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Funding

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.gore.2025.101980>.

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