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ROBOT-ASSISTED LAPAROSCOPIC SURGERY FOR HYSTERECTOMY: A SYSTEMATIC REVIEW OF RANDOMIZED CONTROLLED TRIALS

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ABSTRACT
Robot-assisted laparoscopic surgery (RALS) has emerged as an advancement in minimally invasive gynecology, particularly in hysterectomy for benign and oncologic indications. Compared with laparoscopy and laparotomy, RALS offers enhanced visualization, dexterity, and precision, though concerns remain regarding cost, operative time, and outcomes. This systematic review aimed to evaluate the efficacy and safety of RALS compared with conventional laparoscopy or laparotomy for hysterectomy, focusing on perioperative, oncologic, and patient-centered outcomes. Method: The review followed PRISMA 2020 guidelines. A database search of PubMed, ScienceDirect, and Taylor & Francis identified 752 records. After removal of duplicates and screening, 70 full-text articles were assessed, and 4 randomized controlled trials (RCTs) met the eligibility criteria and were included. Study selection involved independent screening by two reviewers, with disagreements resolved by consensus. Data extraction used a standardized template capturing study design, population characteristics, interventions, comparators, and outcomes. Given heterogeneity across studies, a narrative synthesis approach was applied. Four RCTs were included, encompassing benign hysterectomy, low-grade and high-risk endometrial cancer, and early-stage cervical cancer. RALS showed lower conversion rates and comparable complications. Operative times were longer, but perioperative outcomes were favorable. Long-term follow-up suggested improved survival in endometrial cancer, though findings remain inconsistent. Patient-reported outcomes were generally equivalent. RALS is a safe and effective alternative with selective advantages, though longer operative time and higher costs limit adoption. Further large-scale RCTs and cost-effectiveness studies are needed.

Keywords: gynecology; hysterectomy; randomized controlled trial; robot-assisted laparoscopic surgery; systematic review

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INTRODUCTION

The development of medical technology over the last decade has accelerated remarkably, particularly in the field of minimally invasive surgery. One of the most notable innovations is robot-assisted laparoscopic surgery (RALS), which is increasingly applied in obstetrics and gynecology (Obgyn). Whereas early minimally invasive techniques were limited to conventional laparoscopy with restricted instrument mobility and two-dimensional visualization, robotic systems have introduced significant advances. Features such as high-definition three-dimensional magnified vision, tremor-free control, and wrist-like articulation of instruments have enabled surgeons to manage technically complex cases with greater precision (Bankar and Keoliya, 2022).

In clinical practice, the use of RALS has shown promising results across various gynecological contexts. Recent studies have reported that, in cases of deep infiltrating endometriosis involving the bowel, although operative time tends to be longer, RALS is associated with shorter hospital stays and lower postoperative complication rates compared to conventional laparoscopy (Pavone et al., 2024). Similarly, reports on robotic sacrocolpopexy for apical prolapse indicate minimal blood loss (average 35 mL) and demonstrate a learning curve effect, with operative time decreasing after the initial adoption phase (Ferrier et al., 2022). In the context of myomectomy, particularly for patients

with large (≥8 cm) or multiple fibroids, RALS has also proven safe and feasible, with acceptable blood loss despite transfusion being necessary in a minority of cases (Zhao et al., 2025). These findings reinforce the potential of RALS as a valuable alternative in technically challenging gynecological procedures.

Nonetheless, non-technical aspects such as cost and facility availability remain significant concerns. RALS continues to be more expensive than conventional laparoscopy, both in terms of installation and maintenance, which limits its widespread adoption in many regions, particularly in Asia. However, factors such as patient satisfaction, postoperative quality of life, and reduced morbidity have prompted academic hospitals and referral centers to increasingly consider this technology (Chen et al., 2024). In the other side, the role of RALS in hysterectomy both for benign and oncologic indications has been investigated in several studies. The findings have demonstrated comparable safety outcomes between RALS and conventional laparoscopy, with advantages in specific scenarios such as reduced conversion rates, shorter hospital stays, and improved patient-reported outcomes. However, limitations such as longer operative times and certain postoperative complications, including trocar-site hernia, have also been reported. The evidence remains mixed across populations, ranging from women undergoing benign hysterectomy to those with high-risk endometrial or early-stage cervical cancer, underscoring the need for a systematic synthesis. Given these considerations, the present systematic review was conducted to critically evaluate the efficacy and safety of robot-assisted laparoscopic surgery compared with conventional laparoscopy or laparotomy for hysterectomy. By focusing exclusively on randomized controlled trials published between 2016 and 2025, this review aims to provide an updated and rigorous appraisal of perioperative, oncologic, and patient-centered outcomes associated with RALS in gynecological practice.

METHOD

This systematic review was designed to evaluate the efficacy and safety of robot-assisted laparoscopic surgery (RALS) compared with conventional laparotomy or laparoscopy for hysterectomy. The study was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Page et al., 2021).

Eligibility Criteria

Studies were considered eligible if they met the following inclusion criteria: randomized controlled trials (RCTs), including non-inferiority and equivalence trials; populations of women undergoing hysterectomy for benign or oncologic indications; interventions involving robot-assisted laparoscopy; comparators including conventional laparoscopy and/or laparotomy (open surgery); and studies reporting at least one extractable clinical outcome or complication. Outcomes of interest included 30-day overall or major complications, intraoperative complications, conversion to open procedures, estimated blood loss, operative time, length of hospital stay, transfusion, readmission, reoperation, and quality of life. Eligible studies were limited to those published between 2016 and 2025, in English, and available as free full-text articles. Exclusion criteria were non-randomized study designs, studies not involving hysterectomy populations or without separable data for hysterectomy, articles without free full-text access, studies involving non-human or pediatric populations, and studies including mixed populations without separable adult data.

Search Strategy

A systematic search was conducted in PubMed, ScienceDirect (Elsevier), and Taylor & Francis from database inception to September 30, 2025. The following search terms were applied in various combinations keyword with Boolean operator AND and OR : *(robot OR "robot-assisted" OR "robotic-assisted" OR "da Vinci" OR RALS) AND gynaecology AND (hysterectomy OR TLH OR LAVH) AND (laparoscopy OR laparotomy OR open) AND ("outcome" OR "complication")*.

Study Selection and Data Extraction

All identified records were deduplicated and screened in a two-stage process. Title and abstract screening was followed by full-text review, both performed independently by two reviewers according to prespecified eligibility criteria. Disagreements were resolved by discussion and consensus. Reasons for exclusion at the full-text stage were documented, and the overall selection process was summarized in a PRISMA flow diagram in figure 1. Data were extracted from the included studies using a standardized template, capturing study characteristics (country, centers, recruitment period), baseline participant characteristics (age, body mass index, comorbidities, prior surgery), intervention and comparator details, outcome definitions, follow-up duration, and reported complications.

Risk of Bias Assessment

The risk of bias of each included RCT was evaluated using the Cochrane Risk of Bias 2 (RoB-2) tool across five domains. Two reviewers performed the assessments independently, and any discrepancies were resolved through consensus.

Data Synthesis

Given the heterogeneity of surgical procedures, outcome definitions, and reporting methods, a narrative synthesis approach was adopted without quantitative meta-analysis. Studies were grouped according to comparator (RALS vs. laparoscopy and RALS vs. laparotomy) and indication (benign vs. oncologic hysterectomy). For each outcome, we summarized the direction and magnitude of the effect as reported by the study authors. Findings are presented in narrative form and in summary tables.

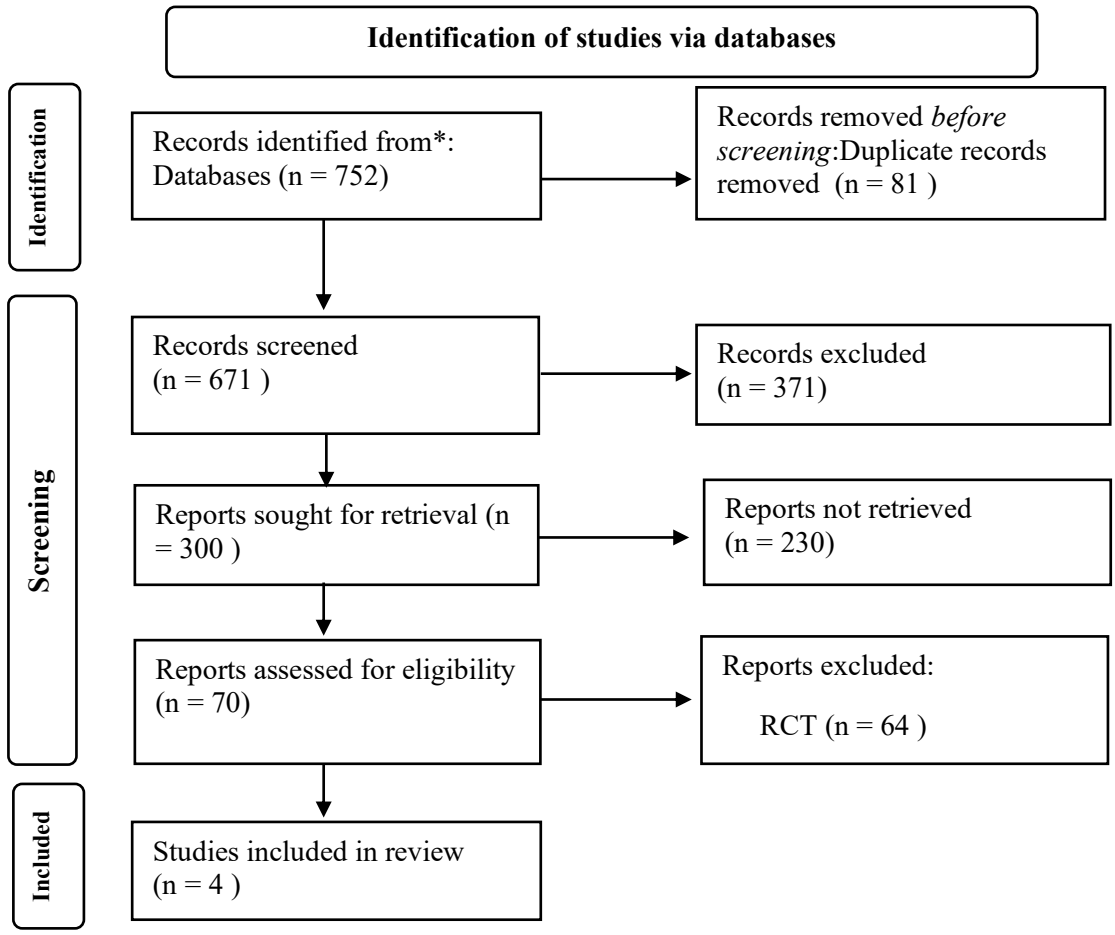

Figure 1. Identification of studies via databases

RESULT

Patient Characteristics

In the Finnish RCT, baseline age and BMI were closely matched between groups: the conventional laparoscopy arm had a mean age of 67.9 ± 8.3 years and BMI 29.7 ± 5.6 kg/m², while the robotic arm had 66.7 ± 8.9 years and 29.5 ± 6.3 kg/m², respectively (Kivekäs et al., 2025). Comorbidity burden (Charlson Comorbidity Index) was also well balanced: CCI 0 in 73.5% (36/49) vs 77.1% (37/48), CCI 1 in 18.4% (9/49) vs 16.7% (8/48), and CCI ≥2 in 8.2% (4/49) vs 6.3% (3/48) for conventional and robotic groups, respectively; prior surgery was not reported in the baseline table (Kivekäs et al., 2025).

In the updated Deimling benign-hysterectomy RCT, 144 women were randomised (72 per arm). Mean age and BMI were similar between groups (42.3 ± 8.0 vs 43.2 ± 8.5 years; 30.6 ± 7.8 vs 32.1 ± 9.3 kg/m², robotic vs standard laparoscopy). Several baseline factors were reported as follows (robotic vs standard laparascopy): white ethnicity 88% (63/72) vs 82% (59/72); current smoker 31% (22/72) vs 36% (26/72); history of caesarean delivery 24% (17/72) vs 44% (32/72); prior laparotomy 4% (3/72) vs 6% (4/72); and prior laparoscopy 21% (15/72) vs 28% (20/72). Indications at baseline were balanced: pelvic pain 24% vs 24%, endometriosis 33% vs 35%, abnormal uterine bleeding 40% vs 28%, fibroids 33% vs 40%, and previous failed ablation 11% vs 11% (Deimling et al., 2016).

In the Swedish RASHEC trial of high-risk, early-stage endometrial cancer, women randomised to laparotomy (n = 57) or robotic surgery (n = 56) were comparable at baseline for age and BMI (mean 66 ± 6 vs 64 ± 9 years; mean 28 ± 6 kg/m² in both arms) and for performance status (ECOG 0 97% vs 95%). Reported comorbidities were evenly distributed: diabetes 5% (3/57) vs 7% (4/56), hypertension 43% (24/57) vs 40% (23/56), cardiovascular disease 9% (5/57) vs 9% (5/56), asthma 7% (4/57) vs 7% (4/56), and previous malignancy 11% (6/57) vs 16% (9/56) (laparotomy vs robotic). Prior abdominal/pelvic surgery was not found (Salehi et al., 2018).

Population, Indication, and Diagnosis

The study populations reflected different gynecological indications. Kivekäs et al. (2025) recruited women with low-grade endometrial cancer undergoing minimally invasive surgical staging. Deimling et al. (2016) studied women undergoing benign hysterectomy in a high-volume centre. In contrast, Salehi et al. (2018) focused on women with stage I–II high-risk endometrial cancer requiring comprehensive staging. The RACC trial was designed for women with early-stage cervical cancer (FIGO stages IB1, IB2, and IIA1) undergoing radical hysterectomy (Falconer et al., 2019).

Intervention Strategy

In the Finnish RCT by Kivekäs et al. (2025), women with low-grade endometrial cancer were randomized to robotic-assisted laparoscopic surgery (n = 48) or conventional laparoscopy (n = 49), with all intended to undergo total laparoscopic hysterectomy, bilateral salpingo-oophorectomy, and pelvic lymphadenectomy. Robotic procedures were successfully completed in all patients. In the U.S. trial by Deimling et al. (2016), 144 women scheduled for benign hysterectomy were randomized equally to robotic-assisted or standard laparoscopic hysterectomy. The robotic arm was performed without a uterine manipulator, and all patients received routine salpingectomy and cystoscopy. In the Swedish RASHEC trial (Salehi et al., 2018), 120 women with high-risk, early-stage endometrial cancer were randomized to robotic-assisted comprehensive staging (n = 56) or open staging by laparotomy (n = 57), including hysterectomy, bilateral salpingo-oophorectomy, and both pelvic and infrarenal para-aortic lymphadenectomy.

Outcomes and Complications

In the Finnish RCT, Kivekäs et al. (2025) reported long-term oncologic outcomes after robotic-assisted versus conventional laparoscopic staging for low-grade endometrial cancer. With a mean

follow-up of over ten years, overall survival was significantly better in the robotic group, while progression-free survival remained similar. Importantly, no conversions occurred in the robotic arm, compared with five conversions (10.2%) in the conventional laparoscopy group. Complication profiles were largely comparable, although trocar-site hernia was more frequent following robotic surgery (18.2% versus 4.1%). Rates of lymphocele and lymphedema were similar between arms.

In the U.S. trial of benign hysterectomy, Deimling et al. (2016) assessed operative outcomes and short-term safety. The primary endpoint operative time was non-inferior between robotic and standard laparoscopy (73.9 versus 74.9 minutes, respectively). Secondary outcomes, including estimated blood loss, postoperative pain, and length of stay, showed no clinically meaningful differences. No conversions were required in either group, and overall complication rates were low. The only major intraoperative event was a single ureteric injury (1.4%) in the robotic group, which was successfully repaired during the procedure.

In the Swedish RASHEC trial, Salehi et al. (2018) examined both perioperative safety and long-term quality of life in high-risk, early-stage endometrial cancer patients. Operative time was significantly longer in the robotic group (229 versus 183 minutes), but there were no conversions to laparotomy. Thirty-day serious adverse events occurred at similar rates in both groups, estimated around 10–12%. At twelve months, health-related quality-of-life scores were comparable between robotic and open arms on EORTC QLQ-C30 and EN24 scales, although patients in the laparotomy arm more often reported mobility problems on the EQ-5D instrument

DISCUSSION

The findings of this review indicate that robot-assisted laparoscopic surgery (RALS) for hysterectomy demonstrates comparable or superior outcomes relative to conventional laparoscopy or laparotomy across several domains, albeit with notable limitations. In both benign and oncologic settings, RALS was consistently associated with reduced conversion rates, comparable complication profiles, and in some instances improved long-term oncologic outcomes (Deimling et al., 2016; Kivekäs et al., 2025; Salehi et al., 2018). These results align with the broader literature on robotic gynecological surgery, which highlights advantages in surgical precision and postoperative recovery (Pavone et al., 2024; Zhao et al., 2025).

One important contribution from the Finnish RCT was the demonstration of improved overall survival following RALS in patients with low-grade endometrial cancer, despite no significant difference in progression-free survival (Kivekäs et al., 2025). This finding raises questions regarding possible indirect benefits of robotic technology, such as reduced perioperative morbidity enabling faster initiation of adjuvant therapy. However, this contrasts with a large multicenter retrospective cohort from the United States, which found no significant survival benefit of RALS over standard minimally invasive approaches in endometrial cancer staging (Marchand et al., 2023). The discrepancy suggests that long-term outcomes may be influenced by center experience, surgical volume, and patient selection.

The results of the Swedish RASHEC trial also underscore a persistent limitation of robotic surgery, longer operative times compared to laparotomy (Salehi et al., 2018). Longer duration has been consistently reported in other RCTs and observational studies, especially during the early adoption phase (Bankar and Keoliya, 2022; Ferrier et al., 2022). Yet, with increasing surgeon experience, operative efficiency improves and may offset the initial learning curve. Moreover, despite longer procedure times, robotic approaches frequently reduce estimated blood loss and length of hospital stay, which are clinically meaningful advantages (Takmaz and Güngör, 2020).

In benign hysterectomy, Deimling et al. (2016) demonstrated non-inferiority of RALS compared with standard laparoscopy in operative time and complications. This is consistent with the randomized trial by Paraiso et al. (2013), which similarly found no significant differences in major

perioperative outcomes but confirmed higher procedural costs in the robotic group. Cost-effectiveness remains a central barrier to wider adoption of robotic technology, particularly in low- and middle-income regions where healthcare resources are constrained (Chen et al., 2024). Thus, while RALS is feasible and safe, its broader implementation will depend on economic considerations and institutional investment.

Importantly, patient-centered outcomes such as quality of life and satisfaction were similar across treatment arms in the included RCTs (Deimling et al., 2016; Salehi et al., 2018). These findings are in line with systematic reviews suggesting that robotic surgery of obgyn case in general does not confer significant long-term quality-of-life advantages over conventional laparoscopy (Weinberg et al., 2011). Nevertheless, specific subgroups such as women with obesity, complex surgical histories, or high-risk oncologic conditions may particularly benefit from the enhanced dexterity and visualization offered by robotic platforms (Falconer et al., 2019; Zhao et al., 2025).

Overall, the evidence supports the role of RALS as a safe and effective alternative to conventional techniques for hysterectomy, particularly in complex or high-risk cases. However, the higher cost, longer operative time, and mixed evidence regarding long-term outcomes emphasize the need for further well-designed RCTs with standardized outcome measures. Future research should also address cost-effectiveness, surgeon learning curves, and subgroup analyses to clarify which patient populations derive the greatest benefit

CONCLUSION

This systematic review demonstrates that robot-assisted laparoscopic surgery (RALS) is a safe and effective alternative to conventional laparoscopy and laparotomy for hysterectomy, both in benign and oncologic indications. Across the included randomized controlled trials, RALS was consistently associated with reduced conversion rates and comparable complication profiles, with selective advantages in perioperative outcomes such as blood loss and hospital stay. In oncologic settings, evidence from long-term follow-up suggests potential survival benefits, though findings remain inconsistent across studies. Patient-centered outcomes, including quality of life, were generally equivalent between groups. Nonetheless, RALS was frequently associated with longer operative times and higher procedural costs, which continue to limit its widespread adoption. These findings suggest that while RALS holds particular value in complex or high-risk cases where enhanced precision is critical, its broader integration into clinical practice requires further validation through cost-effectiveness analyses and large-scale RCTs. Future research should also clarify patient subgroups that may benefit most from robotic platforms, thereby enabling more tailored and sustainable implementation of this evolving surgical technology.

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