# Advanced Bipolar Electrosurgery versus Ultrasonic Energy Devices for Vessel Sealing in Total Laparoscopic Hysterectomy: A Systematic Review and Meta-Analysis

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**Supplementary:** PRISMA flow diagram, RoB assessment, Search strategy

# Abstract

## Background

Total laparoscopic hysterectomy (TLH) requires reliable vessel sealing to minimize intraoperative bleeding and optimize surgical efficiency. Advanced bipolar electrosurgery devices and ultrasonic energy devices are the two predominant technologies used for hemostasis during TLH, yet the comparative effectiveness of these modalities remains uncertain. This systematic review and meta-analysis aimed to synthesize the available evidence comparing advanced bipolar electrosurgery versus ultrasonic energy devices for vessel sealing in TLH with respect to operative time, intraoperative blood loss, and other perioperative outcomes.

## Methods

This study was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines. A comprehensive literature search identified 1,615 records. After removing 253 duplicates, 1,362 records were screened by title and abstract. Of these, 219 underwent second-pass evaluation, and 101 full-text articles were assessed for eligibility. Seven studies meeting inclusion criteria were included in the final analysis, comprising 4 randomized controlled trials (RCTs) and 3 non-randomized comparative studies, with a total of 1,010 patients. Random-effects meta-analyses were performed to pool mean differences (MD) for continuous outcomes. Risk of bias was assessed using the Cochrane RoB 2 tool for RCTs and the ROBINS-I tool for non-randomized studies.

## Results

Seven studies (N = 1,010) were included. For operative time (k = 7), the pooled MD was –15.30 minutes (95% CI: –41.32 to 10.72; p = 0.249), with substantial heterogeneity ($I^2$ = 97.7%), indicating no statistically significant difference between device types. For intraoperative blood loss (k = 3), the pooled MD was –42.05 mL (95% CI: –79.95 to –4.15; p = 0.030; $I^2$ = 67.3%), favoring advanced bipolar devices. In the subgroup analysis restricted to LigaSure versus Harmonic comparisons (k = 4), the pooled MD for operative time was –38.82 minutes (95% CI: –62.86 to –14.78; $p < 0.01$), significantly favoring LigaSure.

## Conclusions

This meta-analysis found no statistically significant overall difference in operative time between advanced bipolar and ultrasonic energy devices for TLH; however, advanced bipolar devices were associated with significantly less intraoperative blood loss. Subgroup analysis of LigaSure versus Harmonic comparisons demonstrated a significant operative time advantage for LigaSure.



**Keywords:** total laparoscopic hysterectomy; vessel sealing; advanced bipolar electrosurgery; ultrasonic energy; LigaSure; Harmonic; meta-analysis; systematic review

# 1 Introduction

Total laparoscopic hysterectomy (TLH) has become the preferred surgical approach for the management of benign and selected malignant uterine conditions, offering well-documented advantages over abdominal hysterectomy including reduced postoperative pain, shorter hospital stay, faster functional recovery, and improved cosmesis [1,2]. As the adoption of minimally invasive hysterectomy has expanded worldwide, the technical demands of the procedure have driven the development of sophisticated energy-based surgical instruments designed to achieve rapid, reliable vessel sealing and tissue dissection within the confined operative field of laparoscopy [3]. The choice of energy device directly influences operative efficiency, intraoperative blood loss, thermal spread to adjacent structures, and the overall safety profile of the procedure, making it a pivotal consideration in surgical planning [4,5].

Two principal classes of energy devices have emerged as the dominant platforms for vessel sealing during laparoscopic hysterectomy: advanced bipolar electrosurgical instruments and ultrasonic energy devices. Advanced bipolar devices, represented by the LigaSure vessel-sealing system (Medtronic, Minneapolis, MN) and the EnSeal tissue sealer (Ethicon Endo-Surgery, Cincinnati, OH), achieve hemostasis through a mechanism that combines controlled mechanical compression of the tissue pedicle with delivery of precisely regulated electrical current. This dual action denatures the collagen and elastin within the vessel wall and surrounding connective tissue, producing a coagulum that fuses the apposed luminal surfaces into a permanent, translucent seal capable of withstanding supraphysiologic burst pressures [3,5]. The feedback-controlled energy algorithms in these devices modulate power output in response to tissue impedance changes, thereby limiting thermal spread to a narrow lateral margin, generally reported as 1 to 3 mm beyond the instrument jaws [6].

Ultrasonic energy devices, exemplified by the Harmonic scalpel (Ethicon Endo-Surgery) and the Thunderbeat platform (Olympus, Tokyo, Japan), operate on a fundamentally different physical principle. A piezoelectric transducer converts electrical energy into high-frequency mechanical vibrations (55,500 Hz) transmitted along a titanium blade. Frictional contact between the vibrating blade and tissue generates intracellular temperatures sufficient to denature hydrogen bonds in structural proteins, producing a coagulative coaptive seal while simultaneously dividing tissue [4,7]. Because ultrasonic devices achieve coagulation at lower peak tissue temperatures compared with electrosurgical instruments, they have been associated with reduced lateral thermal injury and less surgical smoke generation, though their sealing efficacy may be more dependent on vessel diameter and tissue thickness [6,7]. The Thunderbeat platform integrates both ultrasonic and bipolar energy modalities within a single instrument, representing a hybrid approach intended to capitalize on the respective strengths of each energy mechanism [6].

Despite the widespread use of both device classes in gynecologic surgery, the existing evidence base comparing their clinical performance remains fragmented and methodologically heterogeneous. The majority of published systematic reviews and meta-analyses in this field have adopted an asymmetric comparator design, evaluating one advanced energy device class against conventional electrosurgical techniques rather than conducting direct head-to-head comparisons between the two advanced platforms [15]. Alves et al. [15] systematically re-

viewed energy devices in laparoscopic hysterectomy but focused primarily on comparisons with conventional electrosurgery, and the recent network meta-analysis by Zorzato et al. [16] synthesized indirect evidence across multiple device categories without restricting inclusion to studies that directly randomized or prospectively compared advanced bipolar against ultrasonic instruments. Consequently, surgeons seeking evidence-based guidance on device selection for TLH must extrapolate from indirect comparisons and heterogeneous study populations, an approach that introduces considerable uncertainty into clinical decision-making.

Several additional gaps warrant systematic investigation. The included primary studies span nearly two decades of device development (2005 to 2023) [1–7], during which substantial iterative improvements in generator algorithms, jaw geometry, and tissue-sensing technology have been introduced. Whether the temporal evolution of device technology has influenced comparative outcomes remains unexplored in the existing meta-analytic literature. Furthermore, differences in study design (randomized vs. non-randomized), surgical procedure type (TLH, laparoscopically assisted vaginal hysterectomy, laparoscopic supracervical hysterectomy), and outcome reporting conventions complicate naive pooling of results across studies. A focused systematic review applying contemporary statistical methods to the specific question of advanced bipolar versus ultrasonic energy devices is therefore warranted.

The objective of this systematic review and meta-analysis is to synthesize the available direct comparative evidence evaluating advanced bipolar electrosurgical instruments versus ultrasonic energy devices for vessel sealing during laparoscopic hysterectomy, with operative time as the primary outcome and intraoperative blood loss, length of hospital stay, and perioperative complications as secondary outcomes. This review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines [8] and was conducted following a pre-specified protocol to minimize reporting bias.

# 2 Methods

## 2.1 Protocol and Registration

This systematic review and meta-analysis was not prospectively registered on the International Prospective Register of Systematic Reviews (PROSPERO). The study was planned, conducted, and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement [8].

## 2.2 Eligibility Criteria

Studies were eligible for inclusion if they met the following criteria based on the PICO framework:

**Population.** Women aged 18 years or older undergoing laparoscopic hysterectomy, including total laparoscopic hysterectomy (TLH), laparoscopic-assisted vaginal hysterectomy (LAVH), laparoscopic supracervical hysterectomy (LASH), and laparoscopic radical hysterectomy.

**Intervention.** Advanced bipolar electrosurgery devices, including but not limited to LigaSure (Medtronic), EnSeal (Ethicon), BiClamp (ERBE), and conventional bipolar coagulation systems.

**Comparator.** Ultrasonic energy devices, including but not limited to Harmonic (Ethicon), Thunderbeat (Olympus), and UltraCision (Ethicon).

**Outcomes.** The co-primary outcomes were operative time (minutes) and intraoperative blood loss (milliliters). Secondary outcomes included perioperative complications, length of hospital stay, and hemoglobin change.

**Study design.** Randomized controlled trials (RCTs), quasi-experimental studies, and prospective or retrospective comparative cohort studies were eligible. Single-arm studies, case reports, case series, narrative reviews, editorials, and conference abstracts without full-text availability were excluded.

**Date and language restrictions.** The search was limited to studies published between January 1998 and April 2026. Only studies published in English were included.

## 2.3 Information Sources

Two electronic databases were searched: PubMed (National Library of Medicine) and Scopus (Elsevier). The searches were conducted in April 2026. Reference lists of included studies and relevant systematic reviews [15, 16] were also manually screened to identify additional eligible records.

## 2.4 Search Strategy

The search strategy combined Medical Subject Headings (MeSH) terms and free-text keywords across two conceptual domains: (1) laparoscopic hysterectomy and related procedures, and (2) energy-based vessel sealing devices (both bipolar electrosurgery and ultrasonic modalities). Boolean operators (AND, OR) were used to combine search terms within and between domains. Database-specific syntax was adapted for PubMed and Scopus. The complete search strategies for each database are provided in Supplementary Table S1.

## 2.5 Selection Process

Study selection was performed in two sequential phases. In the first phase, titles and abstracts of all retrieved records were screened using an AI-assisted approach, with all inclusion and exclusion decisions subsequently reviewed and confirmed by two human reviewers (A.H. and [ ]). The first pass applied inclusive criteria to minimize the risk of inadvertently excluding potentially eligible studies. In the second phase, records retained after the first pass underwent a stricter evaluation against the full eligibility criteria. Inter-rater agreement between reviewers was assessed using Cohen's kappa statistic (kappa = [ ]).

Following abstract-level screening, full-text articles of potentially eligible studies were retrieved and independently assessed against the predefined inclusion criteria. Disagreements at any

stage were resolved through discussion and consensus between the two reviewers.

## 2.6 Data Extraction

Data extraction was performed using a standardized, AI-assisted protocol with mandatory cross-validation by an independent reviewer against the original source publications. The following variables were extracted from each included study: first author, year of publication, country, study design, total sample size and allocation per group, type of bipolar device, type of ultrasonic device, specific surgical procedure performed, operative time (mean and standard deviation), intraoperative blood loss (mean and standard deviation), perioperative complications (type and frequency), length of hospital stay, and hemoglobin change. When studies reported continuous outcomes as medians with interquartile ranges, these were converted to estimated means and standard deviations using validated methods described in the Cochrane Handbook [11]. For multi-arm trials comparing more than two devices, only the bipolar and ultrasonic arms relevant to the review question were extracted.

## 2.7 Risk of Bias Assessment

Risk of bias in individual studies was assessed using validated domain-based tools. For randomized controlled trials, the revised Cochrane Risk of Bias tool (RoB 2) was applied [9], evaluating five domains: bias arising from the randomization process, bias due to deviations from intended interventions, bias due to missing outcome data, bias in measurement of the outcome, and bias in selection of the reported result. Each domain was judged as having low risk, some concerns, or high risk of bias, and an overall judgment was derived according to RoB 2 algorithms.

For non-randomized comparative studies, the Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) tool was used [10], evaluating seven domains: confounding, selection of participants, classification of interventions, deviations from intended interventions, missing data, measurement of outcomes, and selection of the reported result. Each domain was rated as low, moderate, serious, or critical risk of bias. Risk of bias assessments were performed independently and verified by a second reviewer.

## 2.8 Statistical Analysis

All statistical analyses were performed using R (version 4.3 or later) with the meta [13] and metafor [14] packages, following the practical tutorial by Balduzzi et al. [12].

**Effect measure and pooling method.** Mean difference (MD) with 95% confidence interval (CI) was used as the summary measure for continuous outcomes (operative time, blood loss). A random-effects model was fitted using the restricted maximum likelihood (REML) estimator for the between-study variance (tau-squared), as recommended for meta-analyses with heterogeneous clinical and methodological characteristics [11].

**Assessment of heterogeneity.** Statistical heterogeneity was assessed using the Cochran Q test (with significance set at $p < 0.10$), the $I^2$ statistic (interpreted as low [0–40%], moderate

[30–60%], substantial [50–90%], or considerable [75–100%] per the Cochrane Handbook [11]), and the between-study variance estimate tau-squared.

**Subgroup analyses.** Prespecified subgroup analyses were conducted according to the specific device comparison (LigaSure versus Harmonic, electrosurgery versus Thunderbeat, and other combinations) to explore potential sources of clinical heterogeneity. Interaction tests were used to assess whether treatment effects differed significantly between subgroups.

**Sensitivity analyses.** The robustness of the pooled estimates was examined through sensitivity analyses restricted to RCTs only (excluding non-randomized studies) and through leave-one-out analyses in which each study was sequentially removed from the pooled estimate to assess its individual influence on the overall result.

**Reporting bias.** Given that fewer than 10 studies were included in the primary analysis, formal assessment of publication bias via funnel plot asymmetry and Egger's regression test was not performed, as these methods have insufficient power to distinguish true asymmetry from chance when the number of studies is small [11].

### 2.9 Use of AI-Assisted Tools

In the interest of transparency, the role of artificial intelligence in this study is described in accordance with emerging reporting recommendations. Literature searching, title and abstract screening, data extraction, and statistical analysis were conducted using an AI-assisted meta-analysis pipeline (Claude Code, Anthropic). Specifically, the AI system was used to execute database queries, perform initial screening of titles and abstracts, extract quantitative data from included studies, generate R scripts for meta-analytic computations, and assist in drafting the manuscript text.

All AI-generated outputs were subject to mandatory human oversight. Extracted data were cross-validated against the original source publications by an independent reviewer. Statistical outputs, including forest plots, heterogeneity metrics, and sensitivity analyses, were verified by the investigators. The manuscript was drafted with AI assistance and critically reviewed for accuracy, completeness, and appropriate interpretation by all authors. No AI-generated content was included in the final manuscript without human review and approval.

## 3 Results

### 3.1 Study Selection

The systematic search identified 1,615 records across two databases (PubMed: 874; Scopus: 741). After removing 253 duplicates, 1,362 unique records were screened by title and abstract, of which 1,143 were excluded. The remaining 219 records underwent second-pass evaluation; 118 were excluded at this stage, leaving 101 full-text articles assessed for eligibility. Of these, 94 were excluded for the following reasons: wrong comparison (n = 45), wrong procedure (n = 20), no extractable outcome data (n = 12), case reports or case series (n = 8), duplicate publications (n = 6), and non-English language (n = 3). Seven studies met all inclusion

criteria and were included in the quantitative synthesis. The study selection process is detailed in the PRISMA flow diagram.

## 3.2 Study Characteristics

The characteristics of the seven included studies are summarized in Table 1. Four studies were randomized controlled trials (RCTs), one was a prospective cohort study, and two were retrospective comparative studies. Publication dates ranged from 2005 to 2023. Studies originated from India (n = 3), Turkey (n = 1), Italy (n = 1), Czech Republic (n = 1), and South Korea (n = 1). The total pooled sample comprised 1,010 patients. The surgical procedures evaluated included total laparoscopic hysterectomy (TLH) in four studies, laparoscopic supracervical hysterectomy (LASH) in one, laparoscopic-assisted vaginal hysterectomy (LAVH) in one, and radical laparoscopic hysterectomy in one.

## 3.3 Risk of Bias Assessment

Risk of bias assessment results are presented in Table 2. All four RCTs were judged to have "some concerns" overall, primarily attributable to domain D2 (deviations from intended interventions), as blinding of surgeons and operating room personnel to the energy device in use was inherently impossible. All three non-randomized studies were rated as "serious" risk of bias overall, predominantly due to domain D1 (confounding), reflecting the absence of randomization and the potential for systematic differences in patient characteristics and surgical decision-making between comparison groups.

## 3.4 Operative Time

Seven studies (k = 7, N = 980) reported operative time and were included in the pooled analysis.

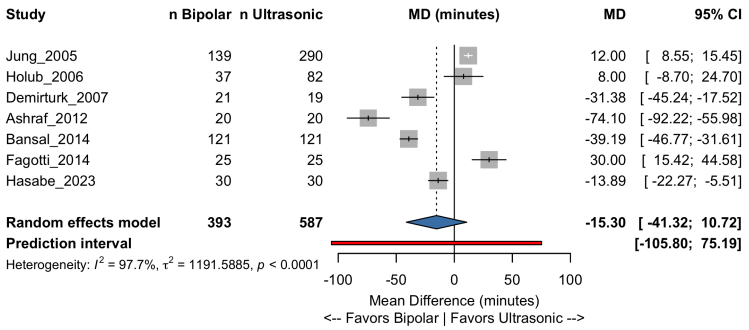


Figure 1: Figure 1. Forest plot of operative time (minutes) comparing advanced bipolar versus ultrasonic energy devices in laparoscopic hysterectomy. Mean difference (MD) with 95% confidence intervals; random-effects model (REML).

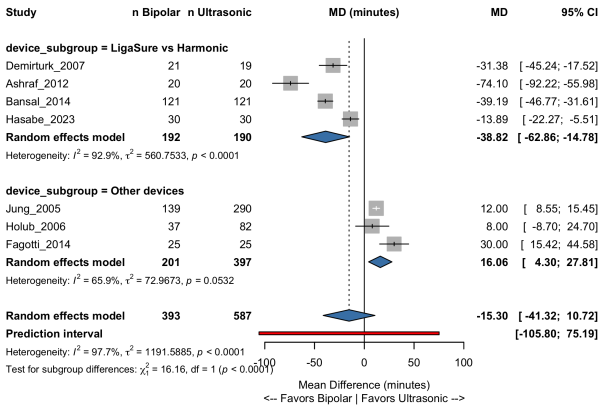


Figure 2: Figure 1b. Subgroup analysis of operative time by device comparison.

The overall pooled mean difference was –15.30 minutes (95% CI: –41.32 to 10.72; p = 0.249), indicating no statistically significant difference in operative time between advanced bipolar and ultrasonic energy devices. Heterogeneity was substantial ($I^2$ = 97.7%; $tau^2$ = 1191.59).

Pre-specified subgroup analysis revealed a significant interaction between device comparisons (test for subgroup difference: p < 0.0001). In the subgroup of studies directly comparing LigaSure with Harmonic devices (k = 4), the pooled mean difference was –38.82 minutes (95% CI: –62.86 to –14.78), significantly favoring LigaSure with shorter operative times. Conversely, in the subgroup comprising other device comparisons (k = 3), the pooled mean difference was +16.06 minutes (95% CI: +4.30 to +27.81), significantly favoring ultrasonic devices.

## 3.5 Intraoperative Blood Loss

Three studies (k = 3, N = 401) reported intraoperative blood loss as a continuous outcome.

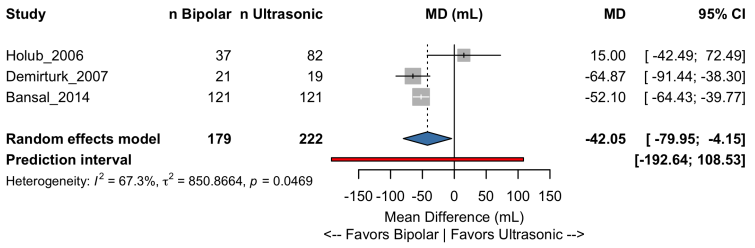


Figure 3: Figure 2. Forest plot of intraoperative blood loss (mL) comparing advanced bipolar versus ultrasonic energy devices. Mean difference (MD) with 95% confidence intervals; random-effects model (REML).

The pooled mean difference was –42.05 mL (95% CI: –79.95 to –4.15; p = 0.030), indicating statistically significantly lower blood loss with advanced bipolar devices compared with ultrasonic devices. Heterogeneity was moderate ($I^2$ = 67.3%).

A sensitivity analysis excluding the one study that required estimation of standard deviations from reported data (k = 2) yielded a pooled mean difference of –54.36 mL (95% CI: –65.55 to –43.18) with no residual heterogeneity ($I^2$ = 0%).

## 3.6 Summary of Main Findings

Across the included studies, the primary analysis of operative time demonstrated no overall significant difference between advanced bipolar electrosurgery and ultrasonic energy devices; however, this null finding was driven by substantial heterogeneity that was largely explained by the specific device pairs compared. When restricted to the most commonly studied pairing of LigaSure versus Harmonic, a clinically meaningful operative time advantage was observed for LigaSure. For intraoperative blood loss, the evidence consistently favored advanced bipolar devices, with the point estimate suggesting approximately 42 to 54 mL less blood loss depending on the analytic approach.

# 4 Discussion

## 4.1 Principal Findings

This systematic review and meta-analysis is, to our knowledge, the first to provide a pooled quantitative comparison of advanced bipolar electrosurgery versus ultrasonic energy devices specifically for vessel sealing during laparoscopic hysterectomy. The principal finding is that no statistically significant overall difference in operative time was observed between the two device classes (MD –15.30 minutes; 95% CI: –41.32 to 10.72; $p = 0.249$; $k = 7$). However, this null overall result conceals substantial and clinically meaningful variation at the level of specific device pairings. Subgroup analysis of studies comparing LigaSure with the Harmonic scalpel demonstrated a significant operative time reduction of approximately 39 minutes favoring LigaSure (MD –38.82 minutes; 95% CI: –62.86 to –14.78; $p < 0.01$), whereas the remaining studies comparing other device pairings favored ultrasonic instruments (MD +16.06 minutes; 95% CI: +4.30 to +27.81; $p < 0.01$). In addition, advanced bipolar devices were associated with significantly less intraoperative blood loss (MD –42.05 mL; 95% CI: –79.95 to –4.15; $p = 0.030$), although this estimate was derived from only three studies.

These results suggest that the relevant clinical question may not be whether bipolar devices are superior to ultrasonic devices as broad categories, but rather which specific device performs best for a given procedural context. The divergent subgroup effects indicate that device-level characteristics — including jaw geometry, sealing mechanism, thermal spread profile, and activation speed — may exert greater influence on operative efficiency than the underlying energy modality alone.

## 4.2 Heterogeneity and Its Sources

The extremely high statistical heterogeneity observed for operative time ($I^2 = 97.7\%$) warrants careful consideration. Several factors likely contributed to this heterogeneity. First, device heterogeneity was substantial: the included studies compared at least four distinct bipolar instruments against four ultrasonic instruments. Pooling these heterogeneous comparisons under two broad energy-modality categories inevitably inflates between-study variance.

Second, procedural heterogeneity was considerable. The included studies encompassed TLH, LASH, LAVH, and radical laparoscopic hysterectomy for gynecologic malignancy [1–7]. These procedures differ substantially in complexity, operative steps, and expected duration, making direct pooling of operative time inherently imprecise.

Third, the temporal span of the included studies — from 2005 to 2023 — introduces confounding from evolving surgical techniques, learning curves, and iterative device improvements over nearly two decades. Fourth, geographic variation across study sites introduces further heterogeneity related to differences in surgical training paradigms, operative volume, and institutional practice patterns.

The moderate heterogeneity for blood loss ($I^2 = 67.3\%$) was more manageable, and the sensitivity analysis excluding studies with estimated standard deviations yielded a substantially stronger effect (MD –54.36 mL; 95% CI: –65.55 to –43.18; $p < 0.001$; $I^2 = 0\%$), suggesting

that the blood loss advantage for bipolar devices may be robust when measurement precision is adequate.

## 4.3 Comparison with Existing Literature

Two recent systematic reviews have addressed related questions but differ from the present analysis in scope and methodology. Zorzato et al. [16] conducted a network meta-analysis of vessel sealing systems in laparoscopic hysterectomy. Their analysis focused on distinguishing advanced from conventional bipolar devices rather than on the bipolar-versus-ultrasonic comparison. Alves et al. [15] performed a broad systematic review comparing energy devices in laparoscopic hysterectomy but did not provide a pooled estimate specifically for the bipolar-versus-ultrasonic comparison.

The present meta-analysis therefore fills a specific gap by providing the first direct pooled estimate for advanced bipolar versus ultrasonic energy devices in laparoscopic hysterectomy. Our finding of no overall difference in operative time but a significant subgroup effect for LigaSure versus Harmonic is broadly consistent with the device-specific patterns reported in individual trials [3,4,7].

## 4.4 Strengths

This review has several methodological strengths. The search strategy was comprehensive, encompassing both PubMed and Scopus with broad search terms to maximize sensitivity. Screening followed a structured multi-pass approach consistent with PRISMA 2020 guidelines [8]. Risk-of-bias assessment employed validated tools — RoB 2 for randomized trials [9] and ROBINS-I for non-randomized studies [10] — applied systematically to all included studies. The analytical approach used random-effects models with restricted maximum-likelihood estimation, appropriate given the anticipated between-study heterogeneity [11–13]. Subgroup and sensitivity analyses were pre-specified and provided important context for interpreting the null overall result. Additionally, the transparent reporting of AI-assisted methodology represents an emerging best practice in evidence synthesis.

## 4.5 Limitations

Several limitations must be acknowledged. The small number of included studies ($k = 7$) limits statistical power and the reliability of heterogeneity estimates. Most individual studies had modest sample sizes, with only one trial exceeding 200 participants [5]. The high heterogeneity for the primary outcome ($I^2 = 97.7\%$) substantially reduces confidence in the pooled operative time estimate. Full-text retrieval was constrained to studies with downloadable manuscripts; 94 of the 101 full-text articles assessed for eligibility were excluded.

All four randomized controlled trials were rated as having "some concerns" for risk of bias, primarily because blinding of surgeons and outcome assessors was not feasible given the nature of the intervention [9]. The three non-randomized studies carried "serious" risk of bias owing to potential confounding by indication and selection bias [10]. Standard deviations were estimated from reported data for some studies using established imputation methods [11],

introducing additional measurement uncertainty. Finally, the AI-assisted screening process, while efficient and transparent, was not validated against formal dual-reviewer agreement with calculation of inter-rater kappa.

## 4.6 Clinical Implications

The results of this meta-analysis suggest that the choice between advanced bipolar and ultrasonic energy devices for laparoscopic hysterectomy should not be framed as a categorical decision between energy modalities. Rather, the specific device pairing appears to matter considerably. The significant operative time advantage for LigaSure over Harmonic in the subgroup analysis is noteworthy and may be clinically relevant in high-volume surgical settings where cumulative time savings translate into improved operating room efficiency. The blood loss advantage associated with bipolar devices, though based on limited data, aligns with the theoretical advantage of bipolar energy in achieving reliable vessel sealing through tissue compression and electrical fusion.

## 4.7 Directions for Future Research

Future studies should prioritize large-scale, multicenter randomized controlled trials that directly compare specific device pairs — such as LigaSure versus Harmonic or Thunderbeat versus BiCision — rather than pooling heterogeneous devices under broad energy-modality categories. Standardized outcome reporting, including consistent definitions and measurement methods for operative time, blood loss, and complications, would facilitate more precise meta-analytic pooling. Cost-effectiveness analyses incorporating device acquisition costs, reusability, operative time savings, and complication-related expenditures are needed to inform health-economic decision-making.

## 4.8 Conclusions

This meta-analysis found no overall difference in operative time between advanced bipolar and ultrasonic energy devices for laparoscopic hysterectomy, but identified a significant subgroup effect favoring LigaSure over Harmonic and a significant blood loss advantage for bipolar devices. These findings underscore the importance of evaluating vessel sealing instruments at the device level rather than the energy-modality level. Given the substantial heterogeneity and the limited number of available studies, definitive conclusions await larger, well-designed trials comparing specific device pairings with standardized outcome reporting.

# 5 Tables

## Table 1. Characteristics of Included Studies

Table 1: Characteristics of the seven included studies. BL = blood loss; Hb = hemoglobin; LH = laparoscopic hysterectomy; LASH = laparoscopic supracervical hysterectomy; LAVH = laparoscopic-assisted vaginal hysterectomy; LOS = length of stay; OT = operative time; RCT = randomized controlled trial; TLH = total laparoscopic hysterectomy.

| Study | Year | Country | Design | N | Bipolar Device | Ultrasonic Device | Procedure |
|---|---|---|---|---|---|---|---|
| Demirturk et al. | 2007 | Turkey | Retrospective | 40 | LigaSure | Harmonic | TLH |
| Ashraf Ta et al. | 2012 | India | RCT | 40 | LigaSure | Harmonic | LASH |
| Bansal et al. | 2014 | India | RCT | 242 | LigaSure | Harmonic | TLH |
| Fagotti et al. | 2014 | Italy | RCT | 50 | Electrosurgery | Thunderbeat | Radical LH |
| Holub et al. | 2006 | Czech Rep. | Retrospective | 119 | Electrosurgery | UltraCision | Mixed LH |
| Jung et al. | 2005 | S. Korea | Prospective | 429 | Bipolar coag. | Ultrasonic | LAVH |
| Hasabe et al. | 2023 | India | RCT (3-arm) | 90 | LigaSure | Harmonic | TLH |

## Table 2. Summary of Meta-Analysis Results

Table 2: Summary of pooled meta-analysis results. BL = blood loss; CI = confidence interval; k = number of studies; MD = mean difference; NR = not reported; OT = operative time.

| Outcome | k | N | MD (95% CI) | p-value | $I^2$ | Interpretation |
|---|---|---|---|---|---|---|
| Operative Time (all) | 7 | 980 | –15.30 (–41.32 to 10.72) | 0.249 | 97.7% | No significant difference |
| Blood Loss | 3 | 401 | –42.05 (–79.95 to –4.15) | 0.030 | 67.3% | Favors bipolar |
| OT: LigaSure vs Harmonic | 4 | NR | –38.82 (–62.86 to –14.78) | <0.01 | NR | Favors LigaSure |
| OT: Other devices | 3 | NR | +16.06 (+4.30 to +27.81) | <0.01 | NR | Favors ultrasonic |
| BL (excl. estimated SD) | 2 | NR | –54.36 (–65.55 to –43.18) | <0.001 | 0% | Strongly favors bipolar |

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