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REVIEW PAPER

Dual energy single probe lithotripsy versus laser lithotripsy in percutaneous nephrolithotomy: A systematic review and meta-analysis

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Introduction Advances in laser technology have rendered laser lithotripsy an attractive option for lithotripsy during percutaneous nephrolithotomy (PCNL). However, limitations such as lower ablation rates and significant stone retropulsion have been noted, particularly in larger or harder stones. Trilogy is an emerging lithotrite that combines electromagnetic ballistic and ultrasonic energy with integrated suction in a single probe. This design offers theoretical advantages in stone fragmentation speed and debris clearance. This systematic review and meta-analysis aims to evaluate the safety and efficacy of Trilogy versus laser lithotripsy in PCNL.

Material and methods A comprehensive literature search was conducted in PubMed, Scopus, Web of Science, and the Cochrane Library. Studies that compared the efficacy and safety of the Trilogy lithotripsy system to laser-based lithotripsy in adult patients undergoing percutaneous nephrolithotomy were included.

Results Four studies including 260 patients were included. Trilogy lithotripsy demonstrated a statistically significant higher stone-free rate (RR = 1.24, 95% CI: 1.06–1.44; p = 0.005) and higher lithotripsy rate (MD = 33.23 mm³/min 95% CI: 13.55–52.91; p = 0.0009) compared to laser-based lithotripsy. No statistically significant difference was found between Trilogy and laser lithotripsy regarding operative time (MD = 3.75 minutes, 95% CI: from –5.39 to 12.88; p = 0.42) and risk of perioperative complications (RR = 1.44, 95% CI: 0.53–3.91; p = 0.47)

Conclusions Despite technological advances in laser lithotripsy, dual energy lithotripsy probes with suction provide more efficient stone disintegration and superior stone-free rates in PCNL compared to laser lithotripsy without compromising safety or operative time. The combination of ultrasonic, ballistic, and suction capabilities in dual energy probes facilitates stone fragmentation and simultaneous fragment removal while reducing stone retropulsion and lowering the intra-renal pressure, contributing to improved visibility and lower risk of infectious complications.

Key Words: Trilogy ‹› laser ‹› lithotripsy ‹› PCNL ‹› stones

INTRODUCTION

Effective stone fragmentation is a crucial component of successful percutaneous nephrolithotomy (PCNL), alongside other key factors such as proper access, tract dilation, and complete stone clearance [1]. Traditional intracorporeal lithotripsy modalities include pneumatic, ultrasonic, and laser-based technologies. Advances in laser technology have rendered laser lithotripsy as an attractive option for lithotripsy during PCNL, particularly with mini-PCNL [2]. Holmium:YAG laser is the preferred lithotripsy modality for mini-PCNL owing to its flexible and smaller fiber size [3]. However, relatively low ablation rates and significant stone retropulsion are known limitations, particularly in larger or harder stones [4]. The development of the thulium fiber laser (TFL) has addressed some of these concerns, offering faster ablation with reduced retropulsion [5].

The Swiss LithoClast Trilogy is an emerging lithotripsy technology that combines electromagnetic ballistic and ultrasonic energies with integrated suction in a single probe. This design offers theoretical advantages in stone fragmentation speed, debris clearance, and ergonomics [6]. A multicenter prospective study involving 157 PCNL procedures demonstrated a median stone clearance rate of 65.55 mm^2/min and an 83% stone-free rate (SFR) confirmed by fluoroscopy at the end of the procedure [7].

The available literature shows mixed results regarding the effectiveness of Trilogy for PCNL compared to laser lithotripsy. Some studies have reported significantly faster stone fragmentation with Trilogy compared to TFL, while maintaining similar stone-free and complication rates [8, 9]. Other studies have reported better stone clearance with laser lithotripsy, especially for hard and large stones [3, 10]. Therefore, it remains unclear whether either of the two modalities provides a relative advantage for lithotripsy during PCNL.

We conducted this systematic review and meta-analysis to evaluate the stone fragmentation efficiency, stone-free rate and safety profiles of Trilogy versus laser lithotripsy in PCNL, to help clinical decision-making in the selection of optimal lithotripsy technology.

MATERIAL AND METHODS

This systematic review and meta-analysis was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [11]. The protocol was prospectively registered in PROSPERO (CRD420251069480).

Search strategy

A comprehensive search was conducted using the following electronic databases: PubMed, Scopus, Web of Science and Cochrane Library. The search included studies from inception to the present and was restricted to articles published in English.

The search strategy combined MeSH terms and free-text keywords including: “Trilogy lithotripsy,” “holmium:YAG laser,” “thulium fiber laser,” “percutaneous nephrolithotomy,” “PCNL,” “mini-PCNL,” and “renal calculi.” Reference lists of included studies and relevant reviews were manually screened to identify additional eligible studies.

Two independent reviewers screened the search results to ensure all eligible studies were included in the systematic review and meta-analysis.

Eligibility criteria

We included studies that compared the efficacy and safety of the Trilogy lithotripsy system to laser-based lithotripsy (holmium:YAG or thulium fiber laser (TFL)) in adult patients (≥18 years) undergoing PCNL, including both standard and mini-PCNL approaches. Eligible study designs comprised randomized controlled trials (RCTs), prospective comparative studies, and retrospective cohort studies. Studies were required to report at least one of the following outcomes: SFR, lithotripsy rate (stone volume clearance), operative time, stone lithotripsy time, perioperative complications, or device-related issues. We excluded case reports, case series, editorials, conference abstracts without full data, narrative reviews, systematic reviews, and meta-analyses.

Screening and study selection

All retrieved results were screened blindly using Rayyan software [12] for any selection bias. Two reviewers (H.M. and M.R) independently screened titles and abstracts for relevance, followed by full-text reviewing of potentially eligible studies. Discrepancies were resolved through discussion or consultation with a third reviewer (A.A).

Data extraction and quality assessment

Data were independently extracted by two reviewers. Extracted data included study characteristics (author, year, country, study design), patient demographics, stone characteristics (size, number, density), intervention and comparator details (type of lithotripsy device and settings), and all reported outcomes. We extracted numerical data for SFR, lithotripsy rate (mm³/min), stone lithotripsy time (minutes), and operative time (minutes). For dichotomous outcomes, such as post-operative complications, event counts and sample sizes were collected. For continuous outcomes, means and standard deviations were extracted. When medians and interquartile ranges (IQRs) were reported, Meta-analysis Accelerator [13] was used to convert the values to means and standard deviations (SDs) using the methods of Wan et al. [14] and Walter and Yao [15]. The Newcastle-Ottawa Scale was used as a quality assessment tool for observational studies [16] and the Cochrane Risk of Bias tool was used for randomized trials [17].

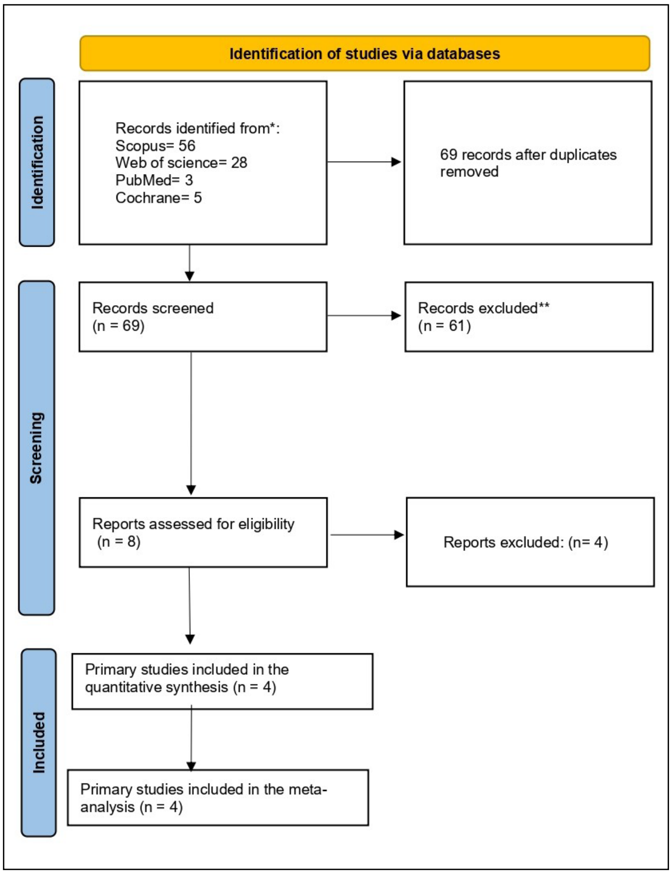

Figure 1. *PRISMA flow chart of the meta-analysis.*

Statistical analysis

Statistical analysis was conducted using the Review Manager software (The Cochrane Collaboration, Oxford, UK). Homogeneity between the included studies was evaluated using visual inspection of the forest plots, I^2, and χ^2 statistics. If the I^2 value >50%, the data were considered significantly heterogeneous. A random effect model was applied in cases of heterogeneous data, while the fixed-effect model was applied among homogeneous data. Sensitivity analysis was also applied to address heterogeneity if present.

RESULTS

The PRISMA flow chart is shown in Figure 1. Four studies met the eligibility criteria and were included in this review, including 260 adult patients undergoing PCNL using either the Trilogy lithotripsy system or laser-based lithotripsy. Table 1 shows the characteristics of included studies. Patient characteristics and stone metrics are summarized in Table 2. The results of risk of bias assessment for randomized studies are shown in Figure 2, while those for cohort studies are shown in Figure 3.

Stone-free rate

SFR was consistently defined across studies as the absence of residual stone fragments following percutaneous nephrolithotomy, confirmed either intraoperatively or through postoperative imaging. Trilogy lithotripsy demonstrated a statistically significant advantage in achieving stone-free status compared to laser-based lithotripsy (risk ratio = 1.24, 95% CI: 1.06–1.44; p = 0.005). Sensitivity analysis was performed by excluding Ejaz (2023) to resolve heterogeneity (I^2 = 0%; Figure 4).

Figure 2. *Forest plot of risk of bias assessment of RCTs.*

Lithotripsy rate

A quantitative meta-analysis of lithotripsy efficiency was not conducted due to significant methodological differences in how the stone removal rate was measured across the three included studies. Despite these definitional differences, a qualitative review revealed a consistent trend favoring the Trilogy device. Timm et al. [10] (2020), who measured overall procedural efficiency, found the Trilogy (70.4 mm^3/min) to be more effective than the 30 W Ho:YAG laser (37.6 mm^3/min). Similarly, Manzo et al. [9] (2025), focusing on task-specific duration, reported a higher rate for Trilogy (212 mm^3/min) compared to the 100W Ho:YAG laser (179 mm^3/min). Finally, Patil et al. [5] evaluated peak device performance, and found a superior fragmentation rate for Trilogy (5.98 mm^3/s) over TFL (3.95 mm^3/s). Since these studies measured different concepts, including overall efficiency, task duration, and peak performance, pooling their results would be misleading, but each comparison consistently favored the Trilogy lithotripter.

Stone area clearance time

Stone area clearance time (SCT), defined as the area of stone cleared per minute (mm^2/min), was reported in only one study Timm et al. [10]. In this study, Trilogy lithotripsy showed a higher mean clearance rate (4.7 ±1.8 mm^2/min) compared to laser lithotripsy (3.4 ±0.7 mm^2/min). However, no meta-analysis was conducted due to limited data.

Table 1. *Characteristics of included studies*

ID	Study design	Population	Intervention	Comparator	Outcomes	Key findings
Ejaz et al. 2023 [3]	Randomized controlled study	90 patients (>18 years) with renal stones >2 cm undergoing PCNL) Group A (30 patients): pneumatic lithotripsy; Group B (30 patients) laser lithotripsy; Group C (30 patients) Trilogy lithotripsy	Group C: combined electromagnetic with ultrasonic lithotripsy (Trilogy), 30 patients	Group B: Holmium laser lithotripsy, 30 patients	• Operative time, post-operative pain, complications (fever, UTI, hematuria), and stone clearance • Follow-up: inpatient period only	• Operative time: no difference • Hematuria: lower in laser • Complete stone clearance: higher in laser (86.7%) vs Trilogy (60%) • Fever or UTI: no difference
Manzo et al. 2025 [9]	Double-blind, randomized, single center-controlled trial	83 patients with Guy's grade 1–2 kidney stones undergoing mini-PCNL	Mini-percutaneous nephrolithotomy (mini-PCNL) using 1.5 mm EMS Lithoclast Trilogy with suction, 43 patients	Mini-PCNL using 100 W Ho-YAG laser, 40 patients	• Stone fragmentation rate, SLT, SLR, treatment time, stone-free rate at 48 hours and 1 month, hemoglobin drop, postoperative complications (Clavien–Dindo) • Follow-up: 3 months	• SFR: higher in Trilogy (88.4% vs 70%) • SLT and SLR: no difference • Operative time: no difference • Complication rates: no difference
Patil et al. 2022 [5]	Prospective comparative study	60 adults (≥18 years) with renal stones >1.5 cm on CT urography; normal upper tract anatomy; no untreated UTI or solitary kidney	Mini-PCNL using EMS Lithoclast Trilogy (1.9 mm probe) with suction, 30 patients	Thulium fiber laser (TFL), 30 patients	• Stone size, stone volume, stone Hounsfield unit (HU), lasing time (TFL arm), probe activation time (Trilogy arm), stone fragmentation rate, treatment time, intra-operative stone clearance, post-operative stone clearance at 48 hours, post-operative stone clearance at one month • Follow-up: 1 month	• Fragmentation rate: higher in Trilogy (5.98 mm^3/s vs 3.95 mm^3/s) • Higher immediate SFR: higher in Trilogy (96.6% vs 76.6%) • Complications: (3 UTI requiring antibiotics in the Trilogy arm vs 2 in TFL arm)
Timm et al. 2021 [10]	Retrospective comparative cohort study	27 patients undergoing mini-PCNL) with 1.5 mm Trilogy probe or with 30 W holmium:YAG laser	Mini-PCNL using 1.5 mm Swiss LithoClast Trilogy probe (ballistic/ultrasonic lithotripter), 11 patients	Mini-PCNL using 30 W holmium:YAG (Ho:YAG) laser with 550 µm fiber, 16 patients	• SCT in mm^2/min and mm^3/min), SFR, operative time, device-related complications, complications • Follow-up: 3 months	• Efficacy for hard stones (>1,000 HU): no difference • Efficacy for soft stones (<1,000 HU): higher in Trilogy (8.9 vs 3.6 mm2/minutes) • SFR: no difference • Volume clearance time: higher in Trilogy (70.4 mm^3/min vs 37.6 mm^3/min) • No device-related complications in either group

CT – computed tomography; PCNL – percutaneous nephrolithotomy; SCT – stone clearance time; SFR – stone-free rate; SLR – lithotripsy rate; SLT – stone lithotripsy time; UTI – urinary tract infection

Operative time

Operative time was defined across studies as the total duration of the PCNL procedure. Most studies measured operative time from cystoscopy or patient positioning to removal of the access sheath. One study [5] defined it from kidney puncture to the end of the procedure and was therefore excluded from the pooled analysis but discussed narratively.

Pooled data from three studies (Ejaz et al. 2023 [3], Manzo et al. 2025 [9], Timm et al. 2020 [10]; n = 170) demonstrated no statistically significant difference in operative time between Trilogy and laser lithotripsy (mean difference = 3.75 minutes, 95% CI: from –5.39 to 12.88; p = 0.42). No significant heterogeneity was observed (p = 0.12, I^2 = 48%). Patil et al. 2021 [5], while not included in the meta-analysis, reported slightly longer operative times in the Trilogy arm, although the difference was not statistically significant (32.48 ±15.39 minutes vs 28.63 ±18.56 minutes) (p = 0.38; Figure 5).

Post-operative complications

Postoperative complications were defined as any adverse clinical events following PCNL and included events such as fever, urinary tract infection (UTI), hematuria, and complications classified using the Clavien–Dindo system. Pooled analysis of four studies including 230 patients showed no statistically significant difference in the risk of postoperative complications between Trilogy and laser lithotripsy (RR = 1.44, 95% CI: 0.53–3.91; p = 0.47) without heterogeneity among the studies (p = 0.2, I^2 = 36%; Figure 6).

DISCUSSION

Mini-percutaneous nephrolithotomy (mini-PCNL), defined by the use of access tracts smaller than 22 F, has gained global acceptance as a standard approach for renal stone management [18]. Although the Ho:YAG laser remains the principal modality

Table 2. *Patient characteristics and stone metrics*

	Group	Ejaz et al. 2023 [3]	Manzo et al. 2025 [9]	Patil et al. 2022 [5]	Timm et al. 2021 [10]
Sample size	Trilogy	30	43	30	11
	Laser	30	40	30	16
Age (years)	Trilogy	49.90 (8.8)	45.3 (12.2)	44.6 (15.40)	59.5
	Laser	49.73 (9.17)	46.4 (13.7)	44.5 (14.40)	58.7
Number of males n (%)	Trilogy	12 (40)	–	23 (76.6)	9 (81.8)
	Laser	23 (76.7)	–	27 (90)	9 (56.2)
Stone volume (mm³)	Trilogy	–	1,642 (1,558.5)	3,718.92 (3,938.72)	5,936.5 (2,814.1)
	Laser	–	1,761 (1,423.3)	3,425.91 (3,096.11)	3,724.0 (1,318.3)
Stone density (HU)	Trilogy	–	978.8 (373.4)	1,172.97 (313.52)	1,193.4 (283.3)
	Laser	–	1,011.6 (292.5)	1,308.93 (333.97)	1,049.3 (206.0)
Stone size (mm) **Ejaz et al. [3] 2023: n (%)*	Trilogy	10–20 = 12 (40) 20–30 = 6 (20) 30–40 = 5 (16.7) >40 = 7 (23.3)	20.8 (7.6)	27.6 (10.17)	26.7 (4.0)
	Laser	10–20 = 16 (53.3) 20–30 = 14 (46.7) 30–40 = 0 >40 = 0	20.1 (5.8)	22.04 (9.69)	(5.1)

* Mean (SD)

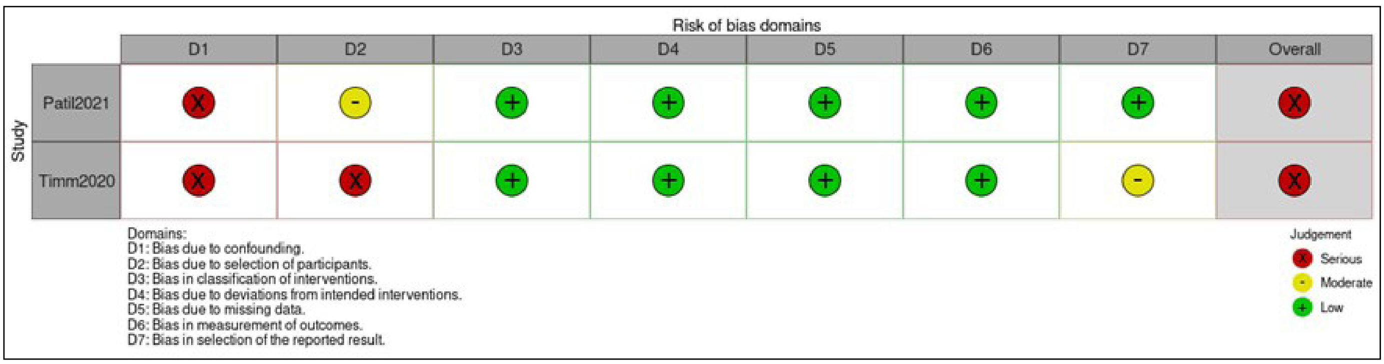

Figure 3. *Forest plot of risk of bias assessment of cohort studies.*

for stone fragmentation in mini-PCNL, recent technological developments have expanded the array of available tools, including dual-function single-probe lithotripters [19]. Lithotripters that combine pneumatic and ultrasonic energy have demonstrated superior stone clearance efficiency compared to single-energy systems [20]. Integrating a suction mechanism into the lithotripsy probe facilitates concurrent evacuation of stone fragments, thereby enhancing both fragment clearance and endoscopic visibility during the procedure [21]. The Trilogy lithotripsy system has shown efficiency in stone clearance time and procedural reliability compared to other lithotripsy devices [22]. This meta-analysis aimed to evaluate and compare the outcomes of percutaneous nephrolithotomy (PCNL) with either the Trilogy system or laser-based lithotripsy. The findings of this systematic review and meta-analysis suggest that Trilogy lithotripsy offers advantages in stone clearance while maintaining comparable operative safety. Trilogy lithotripsy demonstrated superior efficacy in achieving stone-free status compared to laser lithotripsy. The consistency across studies, with insignificant heterogeneity, strengthens the reliability of this finding. These results suggest that Trilogy provides more efficient stone disintegration and may enhance complete stone removal, both of which are critical determinants of PCNL success. The pooled analysis confirmed these advantages, without significant heterogeneity among the included studies. This suggests that Trilogy can potentially improve procedural efficiency. Even in studies not included in this meta-analysis, Trilogy showed a faster rate of stone disintegration [8]. Limited data on stone

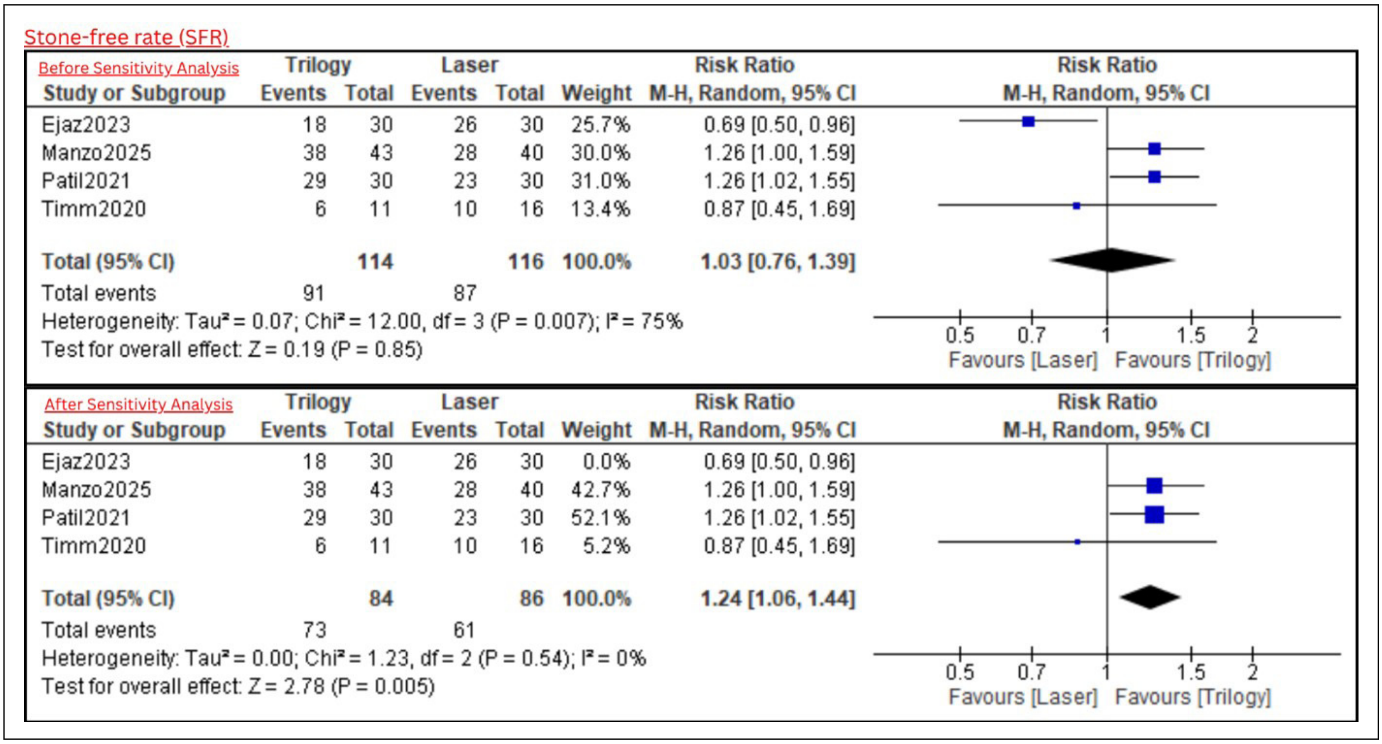

Figure 4. *Forest plot of SFR.*

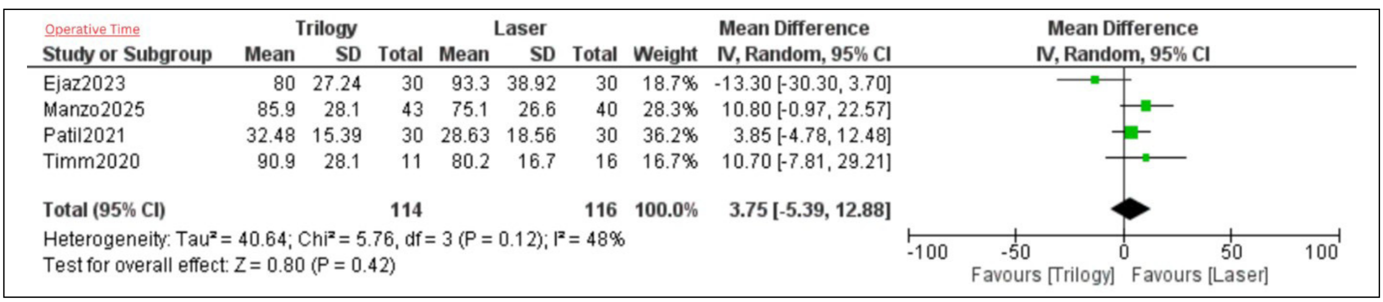

Figure 5. *Forest plot of operative time.*

area clearance time suggested better performance with Trilogy, although only one study reported this outcome [10]. Further research is needed to validate these findings. Neither lithotripsy method significantly influenced operative duration. The absence of a significant difference suggests that steps beyond lithotripsy, such as patient positioning, establishing access, and closure, may contribute more to the total surgical time than lithotripsy alone. Both Trilogy and laser lithotripsy showed similar safety profiles, with no significant difference in complication rates. This implies that Trilogy does not increase procedural risk despite its superior stone clearance.

SFR with Trilogy suggests a significant reduction in residual fragments, which lowers the need for secondary procedures, reduces the risk of recurrent symptoms, and improves long-term outcomes. In addition, the higher fragmentation rate (33.23 mm^3/min) may translate to faster stone clearance intraoperatively, potentially reducing anesthesia time and surgical costs. However, the increased fragmentation efficiency did not translate to shorter operative time, possibly due to other procedural steps dominating the timeline. The comparable operative times between the two technologies can be attributed to Trilogy's efficient fragmentation-suction mechanism, potentially offsetting the delays from device setup.

Table 3. *Quality assessment of non-randomized controlled trials*

Study	Selection	Comparability	Outcome	Quality score
Ejaz et al. 2023 [3]	★★★★	★	★★★	8
Timm et al. 2021 [10]	★★★	★	★★★	7
Patil et al. 2022 [5]	★★★★	★★	★★★	9

Good quality: 3 or 4 stars (★) in selection domain AND 1 or 2 stars in comparability domain AND 2 or 3 stars in outcome domain. Fair quality: 2 stars in selection domain AND 1 or 2 stars in comparability domain AND 2 or 3 stars in outcome/exposure domain. Poor quality: 0 or 1 star in selection domain OR 0 stars in comparability domain OR 0 or 1 star in outcome/exposure domain.

It may also be due to procedural steps such as cleaning the suction tube or re-screwing the probe, which could offset faster fragmentation rates. No significant difference was found between the two groups in terms of complications.

Our results align with several previous studies. Sabnis et al. and Thakare et al. reported superior stone clearance rates with Trilogy, attributing this to its dual-energy and suction capabilities [7, 22]. Similarly, Patil et al. [5] noted higher fragmentation rates with Trilogy compared to thulium fiber laser (TFL), supporting our findings. However, Timm et al. [10] found no significant difference in stone clearance times between Trilogy and laser for hard stones (>1,000 HU), contradicting our pooled results [10]. This discrepancy may stem from differences in study design, such as smaller sample sizes or variations in stone composition.

Strengths of this meta-analysis include the comprehensive analysis of both randomized and comparative cohort studies, providing a broader clinical perspective. The consistent definition of key outcomes such as stone-free rate and the absence of heterogeneity in major outcomes reinforce the reliability of our conclusions. It is worth mentioning that all of our included studies used the mini-PCNL technique except one study by Ejaz et al. [3], who did not provide data on dilatation. We conducted a sensitivity analysis by excluding this study to address this heterogeneity.

Limitations include the moderate to high risk of bias in included studies, mainly due to confounding and selective reporting. The relatively small sample sizes and limited number of trials restrict the generalizability of the results. Various laser modalities of different powers were used in the included studies, which could limit the ability to compare the outcomes. Additionally, variations in operative techniques and outcome definitions across studies could have resulted in inconsistency. Data regarding surgeon experience were not reported across studies

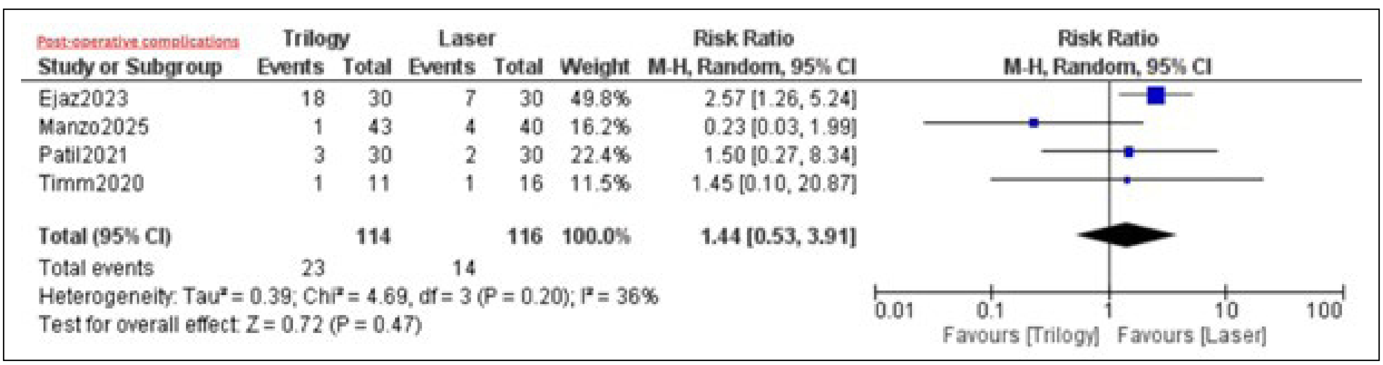

Figure 6. *Forest plot of complications.*

and could not be fully analyzed. Variability in operator experience among included studies may have influenced procedural efficiency and outcomes. Finally, most included studies did not report standardized stone complexity scores (e.g., Guy's Stone Score), which is a major limitation that needs to be considered in future studies.

CONCLUSIONS

Despite technological advances in laser lithotripsy, dual energy lithotripsy probes with suction provide more efficient stone disintegration and superior stone-free rates in PCNL compared to laser lithotripsy without compromising safety or operative time. The use of laser lithotripsy during PCNL should be reserved for select cases. The combination of ultrasonic, ballistic, and suction capabilities in dual energy probes facilitates stone fragmentation and simultaneous fragment removal while reducing stone retropulsion and lowering the intra-renal pressure, contributing to improved visibility and lower risk of infectious complications.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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ETHICS APPROVAL STATEMENT

The ethical approval was not required.

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