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A comparative study of thulium fiber laser and holmium:YAG laser for prostate enucleation: a systematic review and meta-analysis

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Abstract

Introduction: Laser enucleation has become a preferred surgical treatment for benign prostatic hyperplasia (BPH), especially for large prostates and patients unable to discontinue anticoagulation. This systematic review and meta-analysis compared the efficacy and safety of Thulium Fiber Laser Enucleation of the Prostate (ThuFLEP) and Holmium Laser Enucleation of the Prostate (HoLEP).

Methods: We searched PubMed, Scopus, Embase, and the Cochrane Library for studies published up to February 2025. We included randomized controlled trials and observational studies comparing ThuFLEP and HoLEP in adult males with BPH. Outcomes included symptom scores (IPSS), urinary flow (Qmax), quality of life (QoL), post-void residual (PVR), enucleation time, operative time, enucleation efficiency, and complications. Risk of bias was assessed using the Cochrane RoB 2.0 tool for RCTs and the Newcastle-Ottawa Scale for cohort studies. Data were synthesized using random-effects meta-analysis models.

Results: Eleven studies were included. IPSS, QoL, PVR, total operative time, and complications showed no significant differences between groups. HoLEP showed a significantly greater Qmax improvement at 3 months (mean difference -1.25 mL/s; 95% CI -1.847 to -0.653) and shorter enucleation time (mean difference 7.654 min; 95% CI 0.362 to 14.947), though the clinical relevance was limited. No significant differences were observed in enucleation efficiency or urinary incontinence rates. Study limitations included heterogeneity in laser settings and surgical technique, limited RCTs, and a lack of long-term follow-up.

Conclusion: ThuFLEP and HoLEP are comparable in efficacy and safety for prostate enucleation in BPH patients. While HoLEP showed modest advantages in specific operative metrics, the clinical impact appears minimal. TFL represents a viable alternative in the surgical management of BPH.

Keywords: Prostatic hyperplasia, Laser surgery, Thulium fiber laser, Holmium:YAG laser, Endoscopic prostate enucleation

Introduction

The use of laser-based systems has taken on a growing role in modern urology, especially for managing conditions such as urinary stone disease and benign prostatic hyperplasia (BPH).[1] In contemporary practice, laser enucleation techniques have become a recommended option for individuals with markedly enlarged prostates (over 80 grams) or for patients who must continue anticoagulation, consistent with current guideline recommendations.[2] Among the various laser systems available, the Holmium:YAG (Ho:YAG) laser has remained the most widely used and well-established tool in urology, particularly for both lithotripsy and prostate enucleation. More recently, the thulium fiber laser (TFL) has been incorporated into urological procedures, and data from its use in lithotripsy indicate that its unique laser characteristics may offer advantages applicable to prostate enucleation.[3,4]

The TFL, which emits at 1940 nm, close to the maximal absorption range of water, interacts with tissue in a manner distinct from the holmium:YAG system. Its lower peak power and extended pulse durations confine energy delivery to more superficial tissue layers, producing finer incisions with narrower zones of coagulation, as well as smaller and more stable vapor bubbles that minimize mechanical disruption. Conversely, the Ho:YAG laser

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generates markedly higher peak power in shorter pulses, resulting in larger vapor bubble formation and deeper, broader incisions accompanied by less consistent coagulation effects. These fundamental physical contrasts imply that each laser system may offer specific strengths and limitations when applied to prostate enucleation.[5,6]

Thulium fiber laser enucleation of the prostate (ThuFLEP) has been shown to achieve outcomes similar to those of holmium laser enucleation (HoLEP) with respect to both safety and therapeutic effectiveness. Nonetheless, earlier meta-analyses were constrained by relatively small pooled populations and often failed to evaluate key procedural metrics, including enucleation efficiency[7]. With newer RCTs and larger observational studies now enriching the literature, the evidence base has become more substantial. Accordingly, we performed a systematic review and meta-analysis to provide an updated assessment of the comparative efficacy and safety of ThuFLEP and HoLEP.

Method

We conducted this meta-analysis under the 2020 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines for reporting interventions. The protocol was registered in the International Prospective Register of Systematic Reviews (PROSPERO) (registration number: CRD42024585981, available from https://www.crd.york.ac.uk/PROSPERO/view/CRD42024585981). No amendments were made to the original protocol.

Search Strategy

A systematic search of four major databases—PubMed, Scopus, Embase, and the Cochrane Library—was performed, covering all publications available up to February 2025. The specific search strategies used for each database are detailed as follows. *Scopus and PubMed*: (“Thulium Fiber Laser” OR TFL OR ThuFLEP) AND (“Holmium laser” OR Holmium OR MoLEP OR “Ho:YAG” OR HoLEP) AND (Prostate OR Enucleation OR EEP OR AEEP) OR (HoLEP AND ThuFLEP). *Embase*: (‘thulium fiber laser’/exp OR ‘TFL’:ab,ti OR ‘ThuFLEP’:ab,ti) AND (‘holmium laser’/exp OR ‘holmium’/exp OR ‘MoLEP’:ab,ti OR ‘Ho:YAG’:ab,ti OR ‘HoLEP’:ab,ti) AND (‘prostate’/exp OR ‘enucleation’/exp OR ‘EEP’:ab,ti OR ‘AEEP’:ab,ti) OR (‘HoLEP’:ab,ti AND ‘ThuFLEP’:ab,ti). *Cochrane Library*: (“Thulium Fiber Laser” OR TFL OR ThuFLEP) AND (“Holmium Laser” OR Holmium OR MoLEP OR “Ho:YAG” OR HoLEP) AND (Prostate OR Enucleation OR EEP OR AEEP) OR (HoLEP AND ThuFLEP)

Eligibility Criteria

Eligible studies were randomized controlled trials or observational designs that directly compared ThuFLEP with HoLEP, enrolled adult men with benign prostatic hyperplasia (BPH), and reported outcomes assessing efficacy or safety. Only full-text articles available in English were considered. Studies were excluded if they were review articles, editorials, or case reports, or if they did not directly compare ThuFLEP and HoLEP.

Data Extraction and Management

Screening was performed independently by two reviewers (P.L. and K.H.). Initial eligibility was assessed based on titles and abstracts, followed by a full-text review using the inclusion criteria. Agreement between reviewers was measured using Cohen’s kappa. Any discrepancies were discussed, and unresolved disagreements were finalized through a vote involving a third reviewer (G.S.). Data were extracted using a standardized form, documenting study characteristics, patient demographics, and procedural information. The reported outcomes collected were the International Prostate Symptom Score (IPSS), maximum urinary flow rate (Qmax), Quality of Life (QoL), Postvoid residual urine (PVR), enucleation time, enucleation efficiency, total operative time, and complications. Outcomes at 3 and 6 months were selected as these were the most consistently reported follow-up intervals across studies. Outcomes at 12–24 months were not analyzed because no RCT reported data at these time points, and only two cohort studies provided such follow-up, which precluded meaningful synthesis. Studies that employed the Moses Laser Enucleation of the Prostate (MoLEP) technique were analyzed within the HoLEP group, as MoLEP represents a modification of the Ho:YAG laser system rather than a distinct laser platform.

Risk of Bias Assessment

Risk of bias was assessed using tools appropriate to each study design. For randomized controlled trials, the Cochrane RoB 2.0 framework was used, as it evaluates key domains such as randomization, deviations from intended interventions, missing data, outcome assessment, and selective reporting. The Newcastle–Ottawa Scale was used for cohort studies because it is widely validated for assessing selection, comparability, and outcome ascertainment in observational research. We assessed publication bias using a funnel plot and Egger’s regression test.

Data Synthesis and Statistical Analysis

The primary outcome measures included efficacy, measured by changes in the IPSS and QoL, and safety, assessed by the incidence of complications. Random-effects models were applied for the meta-analyses in order to address the variability among the included studies. For continuous outcomes (IPSS, Qmax, QoL, PVR, Enucleation Time, Total Operative Time, Enucleation Efficiency), the effect measure was the Mean Difference (MD). For categorical outcomes (Complications), the effect measure was the Relative Risk (RR). We evaluated statistical heterogeneity using the I^2 statistic. Values of this statistic were categorized as low, moderate, or high if they were approximately 25%, 50%, or 75%, respectively. Sensitivity analyses were performed, particularly when high heterogeneity was observed, to investigate potential sources of heterogeneity and assess the reliability of the findings, primarily by conducting subgroup analysis based on study design. All statistical analyses were conducted using Comprehensive Meta-Analysis software, version 2.0 (Biostat, Englewood, NJ, USA; www.meta-analysis.com).

Results

Database searches from 4 databases resulted in 549 studies, 87 of which were found to be duplicates, resulting in a total of 462 studies screened for eligibility. From the abstract review, 431 studies were deemed irrelevant, leaving 31 studies for retrieval, all of which were successfully retrieved. During the eligibility assessment, 20 studies were excluded due to reasons such as being a poster (16 studies), having the wrong intervention (2 studies), or having the wrong study design (2 studies). A total of 11 studies met all criteria and were included in the final analysis. (Figure 1) Inter-rater reliability was high, with a Cohen's kappa of 0.81 for title and abstract screening and 1.0 for the full-text review.

Characteristics of the Studies

Among these studies comparing ThuFLEP with HoLEP, four are randomized controlled trials (RCTs) conducted by Kosiba[8], Enikeev (2022)[9], Enikeev (2018)[10], and

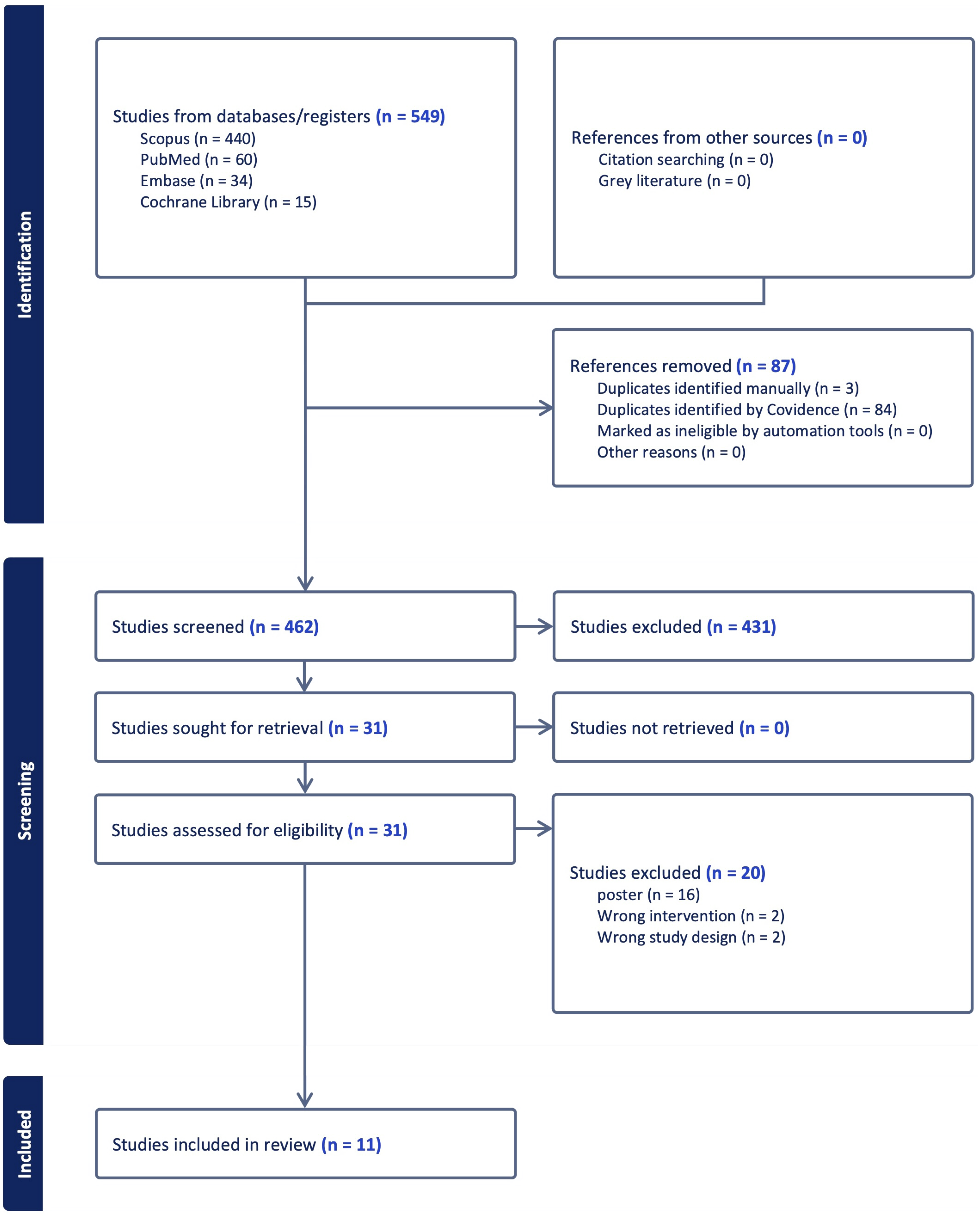

Figure 1. PRISMA flow diagram.
Abbreviation: PRISMA = Preferred Reporting Items for Systematic Reviews and Meta-analyses

Otero,[11] while the remaining seven are cohort studies by Gauhar,[12] Lim,[13] Castellani,[14] Elmansy,[15] Morozov,[16] Aybal (2024),[17] and Aybal (2025).[18] The studies span various periods, with the earliest starting in 2013 and the latest concluding in 2024. The baseline characteristics across studies show a similar patient demographic. The average age of participants ranges from approximately 64 to 74 years. Prostate-specific antigen (PSA) levels and prostate volumes are also reported, with PSA levels ranging from 3.6 to 5.27 ng/mL and prostate volumes varying widely across studies. The IPSS and Qmax are used to assess urinary symptoms, with IPSS scores generally ranging between 20 and 30 and Qmax ranging from 7 to 10 mL/s. QoL scores and PVR are also reported. (Table 1) Various laser manufacturers, powers, fiber sizes, and settings were used across studies. (Table 2)

It is worth noting that among the included cohort studies, six studies (Gauhar 2024[12], Castellani 2023[14], Morozov 2020[16], Lim 2024[13], Aybal 2024[17] Aybal 2025[18]) contain some overlapping authors and possible overlapping centers of data collection in similar periods. This has led to our concerns about possible duplication of patient data, and we, therefore, decided to analyze data from the most recent and largest cohort study for each overlapping group.

Risk of Bias

We assessed the risk of bias using the Newcastle–Ottawa Scale for observational studies and the RoB 2.0 framework for randomized trials. Most of the included studies are of moderate to high quality, with only a few studies presenting serious concerns regarding bias (Supplementary data)

Surgical Outcomes

IPSS

Six studies, including four RCTs and two cohort studies, reported IPSS outcomes at 3 months post-op. Meta-analysis showed that ThuFLEP reduced IPSS similarly to HoLEP, with a mean difference of -0.451 (95% CI -1.012 to 0.109), favoring HoLEP. However, this difference was not statistically significant ($P = 0.114$) (Figure 2). The heterogeneity among studies was low, with an I^2 value of 16.8%, indicating consistency in the results across different studies. Egger's test ($P = 0.69$) suggested no significant publication bias. At 6 months post-op, a similar outcome was observed with a mean difference of -1.015 (95% CI -2.885 to 0.854) without statistical significance.

Qmax

Four studies, two randomized controlled trials and two cohort studies, reported maximum urinary flow rate (Qmax) outcomes at 3 months post-op. The pooled analysis revealed that ThuFLEP improved Qmax less than HoLEP, with a mean difference of -1.250 ml/s (95% CI -1.847, -0.653), favoring HoLEP. This difference was statistically significant ($P < 0.001$) (Figure 2). The heterogeneity among studies was very low, with an I^2 value of 0%, indicating high consistency in the results across different studies. Egger's test ($P = 0.69$) suggested no significant publication bias.

A sensitivity analysis was conducted to assess whether the findings were consistent when restricted to randomized controlled trials. The results demonstrated similarly that HoLEP provided a statistically higher increase in Qmax over ThuFLEP, with a mean difference of -1.45 ml/s ($P = 0.021$).

At 6 months post-op, there were 3 studies that reported this outcome, including 1 RCT and 2 cohort studies. The pooled analysis result, however, demonstrated that the mean difference of Qmax improvement was 1.73 ml/s, slightly favoring ThuFLEP. However, this result was not statistically significant ($P = 0.129$).

Quality of Life

QoL refers to the final item in the IPSS questionnaire. Six studies, including four RCTs and two cohort studies, reported QoL outcomes at 3 months. Our combined synthesis indicated that ThuFLEP and HoLEP had similar effects on the reduction of QoL scores, with a mean difference of -0.136 (95% CI -0.563 to 0.292), slightly favoring favoring HoLEP. (Figure 2) However, this difference was not statistically significant ($P = 0.533$). The heterogeneity among studies was relatively high, with an I^2 value of 93.1% ($P < 0.001$), indicating substantial variability in the results across the different studies. Egger's test ($P = 0.85$) suggested no significant publication bias. To address this heterogeneity, we performed a sensitivity analysis excluding the two cohort studies. This analysis showed a statistically significant mean difference of -0.388 (95% CI -0.564 to -0.212; $P < 0.001$) in favor of HoLEP, with heterogeneity reduced to a moderate level ($I^2 = 46.6\%$). At 6 months, the mean difference in QoL was -0.116, but without statistical significance.

PVR

Five studies—three randomized trials and two cohort studies—reported data on post-void residual urine volume (PVR). Combined results demonstrated that ThuFLEP and HoLEP had similar effects on PVR reduction, with a mean difference of -6.686 ml (95%CI -17.111 to 3.738), slightly favoring HoLEP. However, this difference was not statistically significant ($P = 0.209$). The heterogeneity among studies was moderate, with an I^2 value of 84% ($P < 0.001$), indicating significant variability in the results across different studies. Egger's regression test ($P = 0.608$) indicated that there was no evidence of publication bias.

To explore the source of heterogeneity, a sensitivity analysis restricted to RCTs was performed. The results remained unchanged, and heterogeneity persisted at a high level ($I^2 = 91.65$).

Table 1 Baseline characteristics of the studies included

Study	Study design	Study period	Arm	Baseline Characteristics							
				N	Age	PSA	Prostate Volume	IPSS	Qmax	PVR	QoL
Kosiba[8]	RCT	2021-2022	ThuFLEP	74	69.33 ± 6.8	4.93 ± 3.3	77.67 ± 25	21.67 ± 6.8	9.87 ± 5	100 ± 75.6	4.4 ± 1
			HoLEP	76	69.33 ± 6.8	5.23 ± 4.4	84 ± 31.7	20.33 ± 6.8	9.27 ± 3.9	113.33 ± 120.9	4.17 ± 1.1
Enikeev[9]	RCT	2020-2021	ThuFLEP	86	64.3 ± 6.2	3.8 ± 3.8	66.2 ± 18.9	23.3 ± 6	8.7 ± 3.2	76.5 ± 70.2	5.1 ± 0.8
			HoLEP	77	65 ± 7	4.2 ± 4.1	64.7 ± 17.5	24.3 ± 5.1	8.6 ± 2.6	75.5 ± 77.3	5 ± 1
Enikeev[10]	RCT	2016-2018	ThuFLEP	30	67.8 ± 6.8	4.5 ± 2.8	59.5 ± 11.7	22.8 ± 1.8	7.0 ± 2.3	96.0 ± 43.1	3.2 ± 0.8
			HoLEP	30	66.8 ± 7.4	3.6 ± 1.8	56.72 ± 14.16	23.1 ± 2.3	7.5 ± 2.4	85.3 ± 32.1	2.9 ± 1
Otero[11]	RCT	2021-2022	ThuFLEP	100	68.7 ± 7.9	5.22 ± 5.8	84.06 ± 41.57	22.07 ± 7.68	10.46 ± 6.31	146 ± 155.43	4.53 ± 1.37
			HoLEP	100	69.61 ± 8.38	4.24 ± 3.57	73.55 ± 29.44	23.14 ± 6.8	10.51 ± 4.71	73 ± 75.08	4.85 ± 0.89
Gauhar[12]	Cohort	2020-2022	ThuFLEP	563	66.83 ± 7.8	5.07 ± 3.6	76.67 ± 22.3	22.3 ± 2.2	7.3 ± 2.2	70 ± 29.7	4 ± 1.5
			HoLEP	563	67.33 ± 8.2	4.57 ± 2.7	74.33 ± 29	22.7 ± 2.2	7.47 ± 2.8	73.33 ± 37.2	4.67 ± 0.7
Lim[13]	Cohort	2019-2023	ThuFLEP	247	67.83 ± 8.6	NR	NR	23.33 ± 3.7	8.83 ± 3	75 ± 33.6	4 ± 1.5
			HoLEP	247	67.5 ± 7.8	NR	NR	24 ± 3	9 ± 3	72 ± 24.6	4.67 ± 0.7
Castellani[14]	Cohort	2020-2022	ThuFLEP	118	69.33 ± 9	4.52 ± 3.4	83.33 ± 22.5	23 ± 3	9.63 ± 3.2	NR	4.33 ± 0.8
			HoLEP	118	68.67 ± 6.8	6.08 ± 4.8	80.33 ± 31.5	23.33 ± 0.8	7.97 ± 5.6	NR	4.33 ± 0.8
Elmansy[15]	Cohort	2020-2021	ThuFLEP	20	74.2 ± 13.1	4.83 ± 1	104.08 ± 21.7	25.77 ± 4.1	8.45 ± 3.7	257.83 ± 271.7	5.08 ± 1.4
			HoLEP	62	72 ± 11.8	5.27 ± 2.9	106 ± 26.6	25 ± 4.6	8 ± 3.7	225.33 ± 146.5	4.75 ± 0.9
Morozov[16]	Cohort	2013-2018	ThuFLEP	812	67 ± 7.6	5.2 ± 5	86 ± 40	23.1 ± 1.8	10 ± 2.7	74 ± 20.7	4.03 ± 0.83
			HoLEP	509	66.5 ± 7.7	4.5 ± 3.1	91 ± 44	22 ± 1.2	7.7 ± 1.8	70.8 ± 28.8	4.05 ± 0.88
Aybal[17]	Cohort	2015 - 2023	ThuFLEP	193	66.5 ± 7.7	4.3 ± 4.7	131.9 ± 41.2	28.8 ± 4.8	9.2 ± 3.7	164.5 ± 124.1	4.6 ± 0.5
			HoLEP	193	65.6 ± 8.5	4.1 ± 3.6	127 ± 45.6	25.9 ± 6.5	9.8 ± 4.1	213.5 ± 214	4.9 ± 1
Aybal[18]	Cohort	2015 - 2024	ThuFLEP	85	68.1 + 7.1	4.8 + 2.8	210.1 + 38.5	29.8 + 4.9	9.0 + 3.9	189.0 + 167.6	4.1 + 0.8
			HoLEP	72	66.8 + 7.3	4.6 + 3.8	204.6 + 38.3	30.2 + 4.4	9.3 + 3.1	186.7 + 198.1	4.38 + 0.7

Abbreviations: ThuFLEP, Thulium Fiber Laser Enucleation of the Prostate; HoLEP, Holmium Laser Enucleation of the Prostate; PSA, prostate-specific antigen; IPSS, International Prostate Symptoms Score; Qmax, maximum urinary flow rate; PVR, post-void residual urine volume; QoL, Quality of life score; W, watt.

Enucleation Time

Seven studies, including four RCTs and three cohort studies, reported enucleation time outcomes. Pooled analysis showed that enucleation time was significantly longer with ThuFLEP than with HoLEP, with a mean difference of 7.654 minutes (95% CI 0.362–14.947). This difference was statistically significant ($P = 0.04$) (Figure 3). However, the heterogeneity among studies was also relatively high, with an I^2 value of 93.612% ($P < 0.001$), indicating substantial variability in the results across different studies. Egger's test ($P = 0.98$) suggested no significant publication bias.

A sensitivity analysis excluding data from cohort studies was performed to assess the robustness of the result. The mean difference from this analysis was 3.919 minutes (95%CI 1.719 to 6.118) with a p-value < 0.001, favoring HoLEP. Heterogeneity also decreased to 0% in this sensitivity analysis.

Total Operative Time

Six studies were included for the total operative time outcome, including 4 RCTs and 2 cohort studies. The pooled analysis revealed that ThuFLEP and HoLEP had similar total operative time, with a mean difference of 0.301 minutes (95%CI -3.534 to 4.135), slightly favoring HoLEP. However, this difference was not statistically significant ($P = 0.878$). (Figure 3) Heterogeneity was moderate among included studies with an I^2 value of 47.53% and Egger's test ($P = 0.082$), indicating no significant publication bias. A sensitivity analysis excluding data from cohort studies was also performed with similar results.

Enucleation Efficiency

Enucleation efficiency was calculated by dividing the

Table 2 Laser parameters of the included studies

Study	ThuFLEP		HoLEP	
	Manufacturer	**Settings**	**Manufacturer**	**Settings**
Kosiba[8]	Soltive™ SuperPulsed TFL	40 Hz, 1.5J	MOSES™ Pulse 120H	50 Hz, 1.4J
Enikeev[9]	Urolase 120W	60W	VersaPulse 100W	60W
Enikeev[10]	NTO IRE-Polus 120W	NR	VersaPulse 100W	NR
Otero[11]	Soltive Premium	60 J, 1 Hz	VersaPulse 100W	50 J, 2 Hz
Gauhar[12]	TFL U3 or super pulse TFL IPG photonics	NR	HP-Ho laser	NR
Lim[13]	60W IPG or Quanta	NR	>100 Watt Holmium laser	NR
Castellani[14]	TFL U3, IRE-Polus OR super pulse TFL IPG photonics	NR	VersaPulse 120W	NR
Elmansy[15]	Soltive Premium	NR	Lumenis	NR
Morozov[16]	NTO IRE-Polus 120W	NR	VersaPulse 100W	NR
Aybal[17]	FiberDust, Quanta	1.5J, 40Hz	120W VersaPulse, Lumenis	100W
Aybal[18]	FiberDust, Quanta	1.5J, 40Hz	120W VersaPulse, Lumenis	100W

Abbreviations: ThuFLEP, Thulium Fiber Laser Enucleation of the Prostate; HoLEP, Holmium Laser Enucleation of the Prostate; W, watt; NR, not reported.

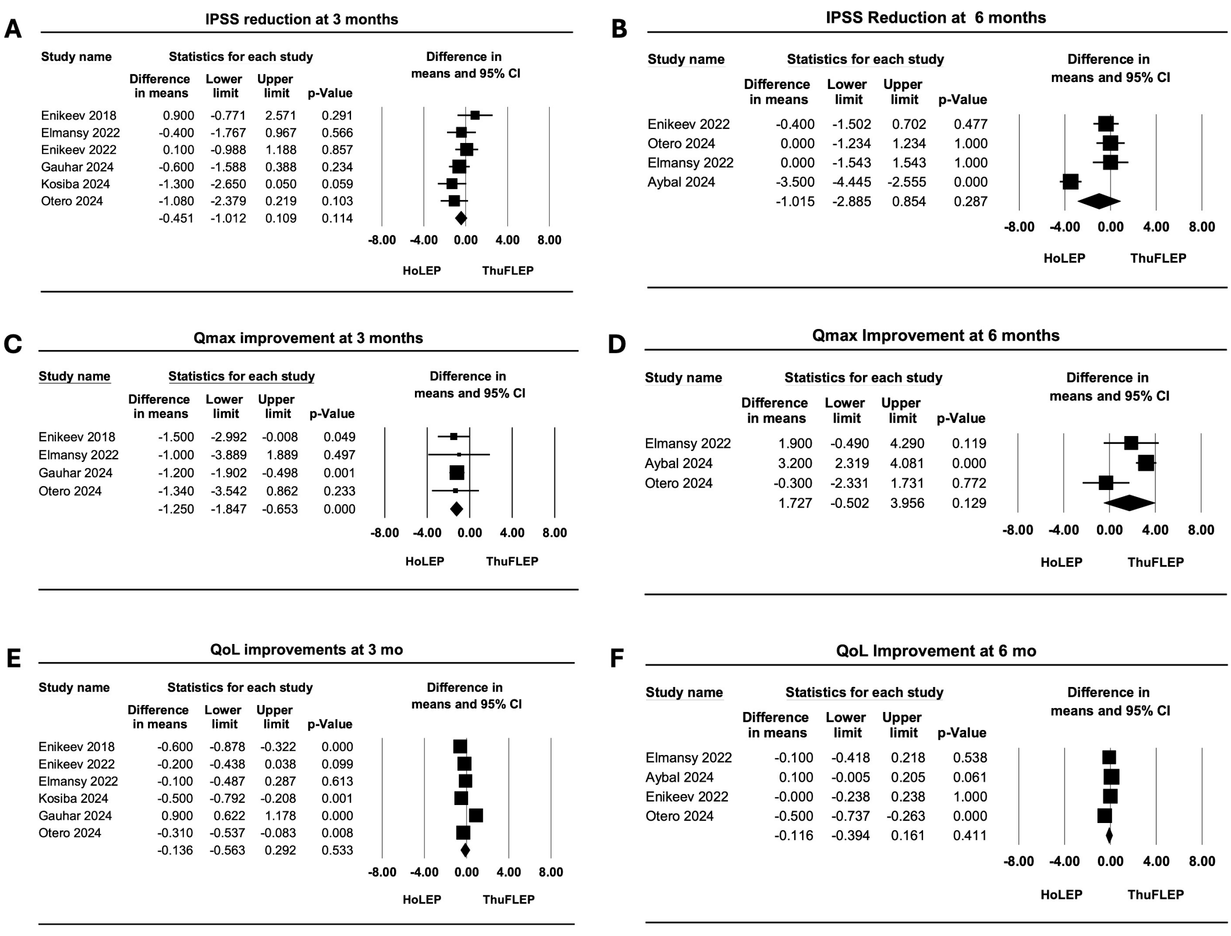

Figure 2. Forest plot of IPSS reduction at 3 months (A), IPSS reduction at 6 months (B), Qmax improvement at 3 months (C), Qmax improvement at 6 months (D), QoL improvement at 3 months (E), and QoL improvement at 6 months (F).
Abbreviations: IPSS, International Prostate Symptom Score; Qmax, maximum urinary flow rate; QoL, Quality of life score; ThuFLEP, Thulium Fiber Laser Enucleation of the Prostate; HoLEP, Holmium Laser Enucleation of the Prostate; CI, confidence interval

weight of removed prostatic tissue (g) by the enucleation time (min). Four studies, including two RCTs and two cohort studies, reported enucleation efficiency outcomes. The combined analysis demonstrated that ThuFLEP and HoLEP had similar enucleation efficiency, with a mean difference of -0.079 g/min (95%CI -0.363 to 0.205), slightly favoring HoLEP. However, this difference was not statistically significant ($P = 0.586$) (Figure 3). The

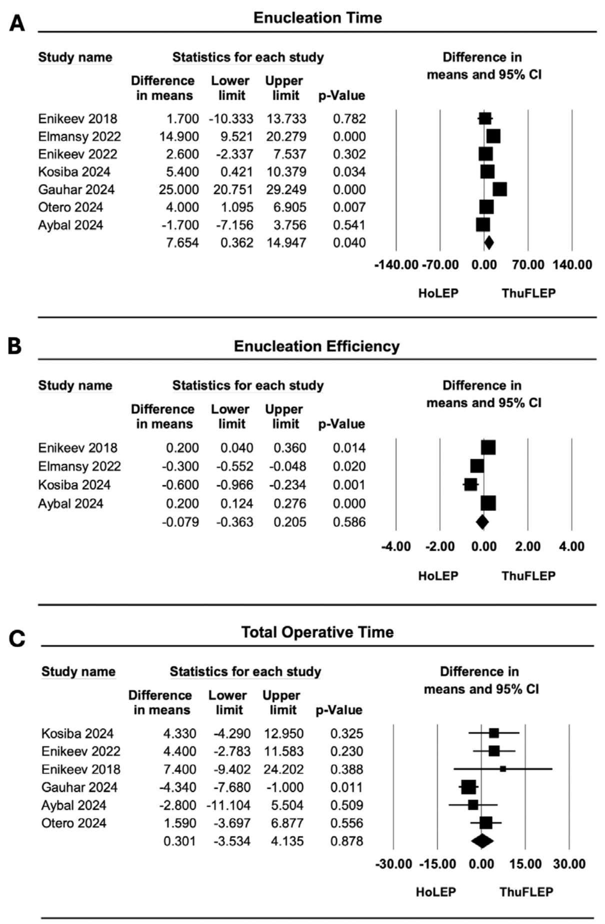

Figure 3. Forest plot of enucleation time (A), enucleation efficiency (B), and total operative time outcomes(C).
Abbreviations: ThuFLEP, Thulium Fiber Laser Enucleation of the Prostate; HoLEP, Holmium Laser Enucleation of the Prostate; CI, confidence interval

heterogeneity among studies was very high, with an I^2 value of 90.11% ($P<0.001$), indicating substantial variability in the results across different studies. Egger's test ($P=0.108$) suggested no significant publication bias. We then performed a sensitivity analysis excluding cohort studies; the results remained unchanged, and the heterogeneity was persistently high ($I^2=93.50$).

Complications

Reported complications across studies included, but were not limited to, blood loss, clot retention, urinary tract infections, and urinary incontinence. However, these were presented in varying formats and categorizations, which made a unified pooled analysis of all individual complications infeasible. Therefore, only studies that reported complications according to the modified Clavien–Dindo classification were included in the quantitative synthesis. Complications were analyzed in two categories: grades lower than IIIb (minor) and grades IIIb or higher (major). Five studies, including three RCTs and two cohort studies, reported the outcomes of complications.

For complications lower than grade 3b, the analysis revealed a similar risk between ThuFLEP and HoLEP, with a relative risk ratio of 0.720 (95% CI 0.497 to 1.041), favoring ThuFLEP, but this was not statistically significant ($P=0.081$) (Figure 4). The heterogeneity among studies was moderate, with an I^2 value of 49.11% ($P=0.097$). Egger's test ($P=0.83$) suggested no significant publication bias.

For complications grade 3b or higher, the analysis also showed a similar risk between the two procedures, with a relative risk ratio of 1.130 (95% CI 0.381 to 3.348), slightly favoring HoLEP, but again not statistically significant ($P=0.826$) (Figure 4). The heterogeneity was very low, with an I^2 value of 0% ($P=0.561$). Egger's test ($P=0.87$) indicated no significant publication bias for this outcome as well. It is also worth noting that 1 RCT (Enikeev 2018) and 1 cohort (Morozov 2020) studies reported zero events of complication grade 3b or higher.

Urinary incontinence represents one of the most important long-term adverse outcomes following prostate enucleation. However, discrepancies in data reporting systems among the included studies (e.g., definition and type of incontinence) have rendered the pool analysis inappropriate. Nevertheless, data from most of the included studies point in the same direction that there was no difference in the incontinence rate between HoLEP and ThuFLEP. The reported overall incontinence rate ranged from 1.3-3.9% at 3 months and tended to decrease at 6 months.

Discussion

In this systematic review and meta-analysis, we compared the efficacy and safety profiles of ThuFLEP with those of HoLEP. Across multiple outcome domains, our findings suggest that both techniques offer comparable clinical effectiveness. In terms of IPSS, no statistically significant differences were observed between the two modalities at both 3 and 6 months postoperatively. Similarly, other outcomes such as PVR, total operative time, and complication rates—both minor (grade < 3b) and major (grade ≥ 3b)—did not differ significantly. Interestingly, HoLEP showed a statistically significant advantage in Qmax and QoL at 3 months and a slightly shorter enucleation time.

The observed mean difference in Qmax improvement at 3 months was 1.25 mL/s in favor of HoLEP, which was statistically significant. Sensitivity analysis for the QoL outcome reduced heterogeneity (I^2 from 93.1% to 46.6%), and the mean difference for QoL score reduction became statistically significant. However, these findings are less likely to be clinically meaningful, as postoperative Qmax typically ranges from 15 to 30 mL/s, and the widely accepted minimal clinically important difference (MCID) is 2 mL/s for Qmax and 0.5 for the QoL score.[19] Notably, these differences were not sustained at 6 months

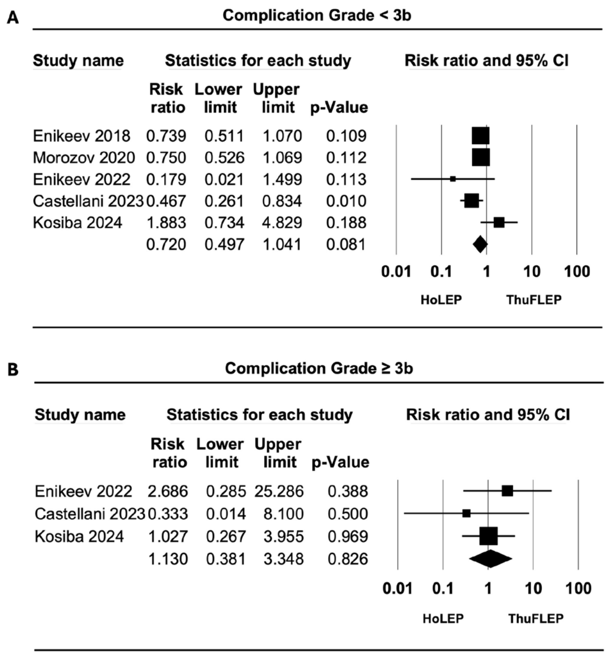

Figure 4. Forest plot of post-operative complications outcome classified by Clavien-Dindo classification grade lower than 3b (A) and grade 3b or higher (B)
Abbreviations: ThuFLEP, Thulium Fiber Laser Enucleation of the Prostate; HoLEP, Holmium Laser Enucleation of the Prostate; CI, confidence interval

postoperatively.

In terms of enucleation time, ThuFLEP required a significantly longer duration compared to HoLEP, a finding which may be primarily attributed to the distinct physical characteristics and operative mechanisms of the two laser systems. The Ho:YAG laser operates with high peak power and short pulse durations, which generate a large, explosive vapor bubble.[20] This bubble formation creates a powerful mechanical force that facilitates the separation and creation of the surgical plane. Conversely, the TFL utilizes a low peak power and a long pulse duration. This unique pulse profile minimizes the mechanical effect, resulting in a cleaner incisional cut rather than mechanical dissection; however, it may also lead to increased superficial tissue carbonization. This difference may necessitate a more precise, slower, and meticulous application of laser energy in ThuFLEP to define the capsule boundary, which may contribute to the longer enucleation time observed, potentially compounded by variations in the standardized surgical techniques employed across study groups. Despite requiring more time during the enucleation phase, the two techniques demonstrated similar overall enucleation efficiency. Furthermore, the longer enucleation time with ThuFLEP did not translate into an increase in the total operative time. One plausible explanation for this crucial observation is that the superior hemostatic properties of the thulium fiber laser may effectively offset its slightly prolonged enucleation phase by reducing the time needed for subsequent bleeding control.

A recent study by Aybal et al. (2025)[18] focused on prostates > 175 mL but was not included in our pooled analysis due to likely overlap with their earlier cohort (Aybal et al. 2024)[17]. The study found that although ThuFLEP and HoLEP had similar functional outcomes, ThuFLEP offered shorter enucleation time, greater enucleation efficiency, and reduced overall operative time. These results contrast with our meta-analysis, where HoLEP had shorter enucleation time. Further research specifically on very large prostates is needed to clarify this discrepancy.

Taken together, our analysis suggests that ThuFLEP performs similarly to HoLEP in terms of both efficacy and safety. Unlike the earlier meta-analysis by Uleri et al.[7], which included only five studies, our review incorporated a broader and more up-to-date body of evidence with a greater number of RCTs. Although Uleri et al.[7] reported comparable outcomes for Qmax, IPSS, and complication rates, our analysis offers more granular detail by evaluating enucleation efficiency and total operative time, and by incorporating sensitivity analyses to assess the stability of these findings.

Our study shows several strengths, including a comprehensive analysis of all clinically relevant aspects of prostate enucleation and the use of sensitivity analyses to manage heterogeneity and assess the impact of study design. However, several limitations must be acknowledged. This review does not include non-English publications and unpublished data. The number of available randomized controlled trials remains limited, and cohort studies were included to ensure sufficient data, which may introduce bias. Furthermore, several studies had to be excluded due to potential overlap in patient data. Finally, we encountered high heterogeneity in several outcomes, particularly QoL, PVR, and enucleation efficiency. Sensitivity analysis excluding cohort studies reduced the I^2 for QoL, but heterogeneity for PVR and enucleation efficiency remained high. This variability may be explained by differences in laser settings, fiber types, surgical techniques, patient demographics, and prostate volumes across studies. In particular, device heterogeneity and the lack of standardized laser parameters could have affected the comparability of results and limited the generalizability of our findings. Long-term implications of these findings are also limited due to the fact that most studies did not report outcomes beyond 6 months postoperatively; therefore, we were unable to incorporate long-term results in the analysis. Additional studies with larger cohorts and extended follow-up are required to more clearly delineate the differences between the two procedures.

Conclusion

In conclusion, current evidence from this review suggests that both procedures are effective and safe options for prostate enucleation in patients with BPH. While HoLEP may offer a slight advantage in terms of enucleation time and Qmax improvement at 3 months, the clinical significance of these differences is limited. Given the distinct advantages of TFL in lithotripsy, the comparable outcomes observed in prostate enucleation support TFL as a viable and versatile option. Nevertheless, the limited number of randomized controlled trials warrants caution in drawing definitive conclusions. Outcomes are importantly determined by device availability, patient-specific factors, and surgical technique. Future research should include long-term follow-up and adopt standardized reporting of laser parameters to validate these results. Data supporting this work can be obtained from the corresponding author upon reasonable request.

Authors' Contribution

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Competing Interests

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