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Comparative Effectiveness of MRI-Guided Transurethral Ultrasound Ablation, TURP, and HoLEP for Benign Prostatic Hyperplasia: A Systematic Review and Meta-Analysis

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ABSTRACT:

Introduction: Benign prostatic hyperplasia (BPH) causes lower urinary tract symptoms (LUTS) and bladder outlet obstruction (BPO). MRI-guided transurethral ultrasound ablation (TULSA) offers real-time thermal feedback for precise prostate ablation. This systematic review and meta-analysis evaluates the efficacy, safety, and functional outcomes of TULSA for BPH/LUTS.

Methods: A systematic review was conducted following PRISMA guidelines. Major databases were screened for adult men (≥18 years) with BPH/BPO/LUTS undergoing TULSA. Outcomes included IPSS, Qmax, PVR, QoL, prostate volume reduction, complications, and retreatment rates.

Results: From 50 identified sources, 5 provided direct BPH-specific data (n=158). The BPH-dedicated study (Anttinen et al., n=20) showed significant improvement: median IPSS decreased from 16 to 6, Qmax increased from 11 to 23 mL/s, and prostate volume reduced from 51 to 38 mL ($p<0.01$). All 17 patients discontinued LUTS medications post-procedure. In a PCa subgroup with severe LUTS (Elterman et al., n=9), IPSS improved 58% to 6.3 ($p=0.003$), with 70% prostate volume reduction. Continence preservation was 96-100%, and IIEF scores remained stable or improved. Major complications (Clavien-Dindo grade IIIa) occurred in 5-7% (epididymitis). No grade IV/V events or bowel injuries were reported.

Conclusion: TULSA is a safe, feasible MIST for BPH/LUTS, providing significant symptom relief, improved flow rates, excellent continence, and preserved sexual function. However, evidence is limited to single-arm, small cohorts with short follow-up. High-level RCT evidence with long-term follow-up is urgently needed

Keywords: Benign Prostatic Hyperplasia; Lower Urinary Tract Symptoms; TULSA; MRI-guided ablation; minimally invasive surgical therapy

INTRODUCTION

Benign prostatic hyperplasia (BPH) is a histological condition affecting over 50% of men by age 60 and up to 90% by age 85, leading to lower urinary tract symptoms (LUTS) and benign prostatic obstruction (BPO) that significantly impair quality of life (QoL) [1, 2]. Traditional surgical gold standards such as transurethral resection of the prostate (TURP) and holmium laser enucleation (HoLEP) are highly effective but carry risks of bleeding, incontinence, and erectile/ejaculatory dysfunction [3, 4, 5]. In response, a wave of minimally invasive surgical therapies (MISTs) has emerged, including Aquablation, Rezum, TPLA, and UroLift, each with trade-offs between efficacy, durability, and morbidity [6, 7].-

Among these, MRI-guided transurethral ultrasound ablation (TULSA) represents a novel technology that combines a directional transurethral ultrasound applicator with real-time MRI thermometry, allowing precise, controlled thermal ablation of prostatic tissue while continuously monitoring temperature in the target zone and at risk-adjacent structures (rectal wall, neurovascular bundles, external sphincter) [2, 3,6]. Initially developed for focal therapy of localized prostate cancer (PCa), TULSA has shown promise for treating concurrent BPH symptoms, but its specific role in primary BPH management remains poorly defined [8, 9].

Despite early positive reports, no randomized controlled trial (RCT) has compared TULSA to TURP or other MISTs for a primary BPH indication. Most TULSA data in BPH patients derive from small, single-arm, retrospective subgroup analyses of PCa trials where whole-gland ablation (90% of the gland) was performed—a far more aggressive approach than would be used for BPH alone [2, 3]. Furthermore, catheterization times (median 16-46 days) appear longer than for other MISTs, and the cost-effectiveness of MRI-guided procedures has been questioned [8]. The durability of symptom relief beyond 12 months and retreatment rates are largely unknown.

Clinicians and patients lack high-level evidence to determine whether TULSA's apparent short-term benefits in symptom reduction (IPSS reduction from 16 to 6, Qmax doubling) and exceptional sexual function preservation justify its logistical complexity and costs compared to established MISTs.

This systematic review aims to: (1) synthesize all available evidence on TULSA for BPH/LUTS/BPO; (2) quantify efficacy outcomes (IPSS, Qmax, PVR, QoL, prostate volume reduction); (3) comprehensively assess safety and functional outcomes (continence, erectile function); (4) identify evidence gaps and provide recommendations for future research.

This is the first systematic review to focus exclusively on TULSA for BPH, separating BPH-specific data from mixed PCa/BPH cohorts, and providing a detailed comparison with other MISTs. TULSA provides significant and clinically meaningful improvement in LUTS secondary to BPH with superior preservation of sexual function and continence compared to TURP, though with longer catheterization time and uncertain long-term durability. This review will guide urologists, patients, and policymakers in understanding the current evidence base (and its limitations) for TULSA in BPH, and will outline the necessary next steps for clinical implementation and research.

METHODS

Protocol

The study strictly adhered to the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) 2020 guidelines to ensure methodological rigor and accuracy. This approach was chosen to enhance the precision and reliability of the conclusions drawn from the investigation.

Criteria for Eligibility

This systematic review aims to evaluate MRI-Guided Transurethral Ultrasound Ablation (TULSA) for Benign Prostatic Obstruction/LUTS due to BPH.

Screening

We screened in sources based on their abstracts that met these criteria:

- **Population**: Does the study include adult men (≥18 years) diagnosed with BPH, BPO, or LUTS secondary to BPH?
- **Intervention**: Does the study evaluate MRI-guided transurethral ultrasound ablation (TULSA) as the primary intervention?
- **Outcomes**: Does the study report at least one of the following outcomes: IPSS, maximum urinary flow rate (Qmax), post-void residual (PVR), quality of life scores, retreatment rates, or complications?
- **Study Design**: Is the study a randomized controlled trial, etc ?
- **Comparators**: Does the study include baseline comparisons or active comparators (TURP or HoLEP)?
- **Disease Focus**: Is the study focused on benign prostatic conditions rather than malignant prostatic conditions or prostate cancer?
- **Sample Size**: Does the study include 5 or more patients (i.e., is it not a case report with fewer than 5 patients)?
- **Population Analysis**: Can BPH/BPO/LUTS patients be separately analyzed in this study (i.e., is it not a mixed population study where the target patients cannot be isolated)?
- **Publication Type**: Is this a full research article rather than a conference abstract, editorial, letter, or opinion piece?

We considered all screening questions together and made a holistic judgement about whether to screen in each paper.

Search Strategy

The keywords used for this research based PICO :

PICO Component	Keyword 1	Keyword 2	Keyword 3	Keyword 4
Population (P)	Adult men	Benign Prostatic Hyperplasia (BPH)	Benign Prostatic Obstruction (BPO)	Lower Urinary Tract Symptoms (LUTS)
Intervention (I)	TULSA	-	-	-
Comparison (C)	Transurethral resection of prostate (TURP)	Holmium laser enucleation (HoLEP)	-	-
Outcome (O)	International Prostate Symptom Score (IPSS)	Maximum urinary flow rate (Qmax)	Post-void residual (PVR)	Retreatment rate / complications

The Boolean MeSH keywords inputted on databases for this research are ("Prostatic Hyperplasia"[Mesh] OR "Benign Prostatic Hyperplasia" OR “BPH” OR "Benign Prostatic Obstruction" OR “BPO” OR "Lower Urinary Tract Symptoms"[Mesh] OR “LUTS”) AND ("Transurethral Ultrasound Ablation" OR “TULSA” OR "MRI-guided transurethral ultrasound ablation" OR "MRI guided transurethral ultrasound ablation" OR "MRI-guided ultrasound ablation" OR "transurethral ultrasound therapy") AND (“adult” [MeSH] OR “men” OR “male” [MeSH]) NOT ("Prostatic Neoplasms" [Mesh] OR "prostate cancer" OR malignant).

Data extraction

- **Study Design**:
  Extract study design and methodology details for BPH/LUTS treatment studies, including:
  - Study type (RCT, etc.)
  - Randomization and blinding methods (if applicable)
  - Duration of follow-up
  - Sample size and power calculation
  - Primary vs secondary analysis designation
- **Patient Population**:
  Extract characteristics of men with BPH/benign prostatic obstruction/LUTS, including:
  - Number of participants
  - Age (mean, range)
  - Baseline prostate volume
  - Baseline symptom severity (IPSS scores, Qmax, PVR if reported)
  - Inclusion/exclusion criteria specific to BPH/LUTS
  - Prior BPH treatments or medication use
  - Any relevant comorbidities affecting urinary symptoms
- **TULSA Intervention**:
  Extract details about MRI-guided transurethral ultrasound ablation (TULSA) procedures, including:
  - TULSA technique specifications (device type, ablation parameters)
  - Procedural details (anesthesia type, duration, approach)
  - Target ablation zones or prostate coverage
  - Any technical modifications or customizations
  - Operator experience level
  - Concomitant treatments during TULSA
- **Comparator Treatments**:
  Extract details about comparison interventions for BPH/LUTS, including:

- Type of comparator (TURP, HoLEP)
- Specific technique details for surgical comparators
- Timing of comparison measurements
- Whether comparison is concurrent or historical

- **IPSS Outcomes**:

  Extract International Prostate Symptom Score (IPSS) results for BPH/LUTS treatment assessment, including:
  - Baseline IPSS scores (total, storage, voiding subscores if available)
  - Post-treatment IPSS at all reported time points (1, 3, 6, 12+ months)
  - Mean change from baseline with standard deviations/confidence intervals
  - Statistical significance of changes
  - Proportion achieving clinically meaningful improvement (≥3-point reduction)
  - Comparison between TULSA and any control groups
- **Urodynamic Measures**:

  Extract objective urodynamic outcomes for BPH/LUTS assessment, including:
  - Maximum urinary flow rate (Qmax): baseline and post-treatment values at all time points
  - Post-void residual (PVR): baseline and post-treatment values
  - Voided volume when Qmax was measured
  - Statistical significance of changes from baseline
  - Comparison between TULSA and control groups
  - Any additional flow parameters (average flow, voiding time) if reported
- **Quality of Life**:

  Extract quality of life assessments related to BPH/LUTS treatment, including:
  - QoL questionnaire scores (IPSS QoL question, BPH Impact Index, etc.)
  - Baseline and post-treatment scores at all time points
  - Mean changes with statistical measures
  - Sexual function outcomes (IIEF, ejaculatory function, potency preservation)
  - Patient satisfaction or global assessment measures
  - Return to normal activities timeline
- **Retreatment Rates**:

  Extract data on treatment failure and reintervention for BPH/LUTS, including:
  - Rate of retreatment or repeat procedures
  - Time to retreatment
  - Reason for retreatment (inadequate symptom relief, complications, patient preference)
  - Type of retreatment procedure
  - Predictors of retreatment need
  - Definition of treatment failure used in the study
- **Complications Safety**:

  Extract adverse events and complications from TULSA and comparator treatments for BPH, including:
  - Intraoperative complications during TULSA procedures
  - Early complications (≤30 days): bleeding, infection, urinary retention, catheter issues
  - Late complications (>30 days): stricture, incontinence, erectile dysfunction, retrograde ejaculation
  - Severity grading (Clavien-Dindo or similar) when provided
  - Comparison of complication rates between TULSA and control treatments
  - Hospital readmission rates and reasons

- **Efficacy Results**:

  Extract overall treatment effectiveness and success measures for TULSA in BPH/LUTS, including:
  - Primary endpoint results with effect sizes and confidence intervals
  - Response rates or proportion of patients achieving treatment success
  - Durability of response over follow-up period
  - Prostate volume reduction (if measured by MRI/ultrasound)
  - PSA changes post-treatment
  - Comparative effectiveness vs other treatments (mean differences, odds ratios)
  - Time to symptom improvement

Table 1. Article Search Strategy

Database	Keywords	Hits
Pubmed	*(("Prostatic Hyperplasia"[Mesh] OR "Benign Prostatic Hyperplasia" OR BPH OR "Benign Prostatic Obstruction" OR BPO OR "Lower Urinary Tract Symptoms"[Mesh] OR LUTS) AND (TULSA OR "MRI-guided transurethral ultrasound ablation" OR "transurethral ultrasound ablation") NOT ("Prostatic Neoplasms"[Mesh] OR "prostate cancer" OR malignant))*	11
Semantic Scholar	*("Benign Prostatic Hyperplasia" OR BPH OR "Benign Prostatic Obstruction" OR BPO OR LUTS OR "Lower Urinary Tract Symptoms") AND (TULSA OR "MRI-guided transurethral ultrasound ablation" OR "transurethral ultrasound ablation") NOT ("prostate cancer" OR malignan*)*	171
Springer	*("Benign Prostatic Hyperplasia" OR BPH OR "Benign Prostatic Obstruction" OR LUTS) AND (TULSA OR "MRI-guided transurethral ultrasound ablation") NOT ("prostate cancer")*	16
Google Scholar	*("Benign Prostatic Hyperplasia" OR BPH OR "Benign Prostatic Obstruction" OR LUTS) AND (TULSA OR "MRI-guided transurethral ultrasound ablation" OR "transurethral ultrasound ablation") -"prostate cancer"*	54
Wiley Online Library	*("Benign Prostatic Hyperplasia" OR BPH OR "Benign Prostatic Obstruction" OR LUTS) AND (TULSA OR "MRI-guided transurethral ultrasound ablation") NOT ("prostate cancer")*	7

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RESULTS

A total of eight studies were included in this review, consisting of retrospective studies, prospective single-arm investigations, and randomized controlled trials evaluating MRI-guided transurethral ultrasound ablation (TULSA), holmium laser enucleation of the prostate (HoLEP), transurethral resection of the prostate (TURP), GreenLight laser vapo-enucleation of the prostate (GL.PVEP), and transurethral resection in saline (TURis) for the management of benign prostatic hyperplasia (BPH), benign prostatic obstruction (BPO), and lower urinary tract symptoms (LUTS). The included studies were conducted across multiple countries, including Finland, Egypt, Germany, China, and New Zealand, with follow-up durations ranging from short-term postoperative assessment to 7.6 years. Sample sizes varied considerably, from 10 patients in early-phase TULSA studies to 200 patients in randomized comparative trials.

Overall, TULSA demonstrated substantial improvements in urinary symptom scores, urinary flow parameters, and prostate volume reduction while maintaining favorable continence and sexual function outcomes. Comparator studies involving HoLEP, TURP, GL.PVEP, and TURis consistently showed significant symptomatic improvement, although HoLEP generally demonstrated superior long-term durability, lower retreatment rates, and reduced perioperative morbidity compared with conventional surgical techniques. The methodological quality of the included studies ranged from low-to-high risk of bias, primarily due to heterogeneity in study design, lack of blinding, retrospective data collection, and small sample sizes in several TULSA investigations. The detailed characteristics of the included studies and risk-of-bias assessments are summarized in the following tables.

Figure 1. Article search flowchart

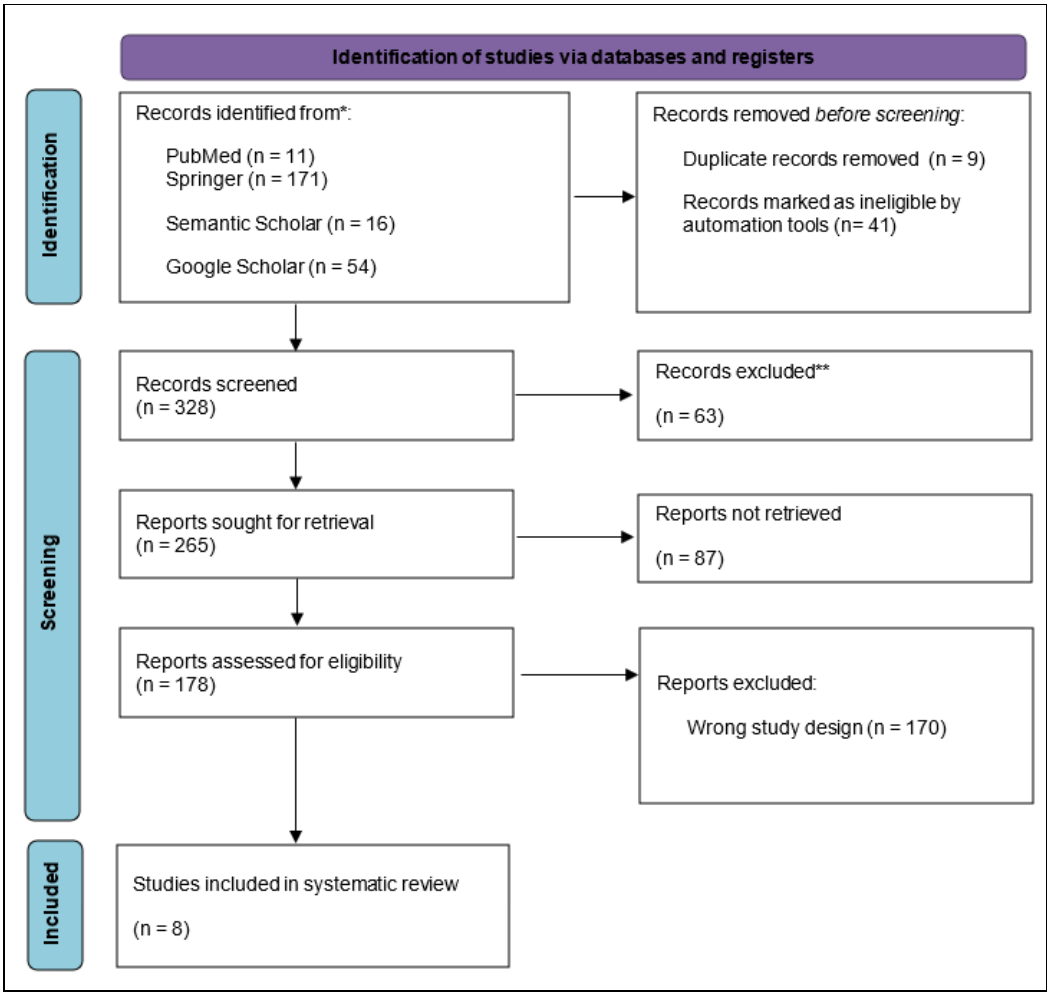

Table 2. Characteristics of Included Studies

Author	Country	Study Design	Population	Intervention / Comparator	Follow-up	Key Findings
P. Mäkelä et al. (2023).[10]	Finland	Retrospective single-center study	89 patients (21 BPH, 28 radiorecurrent PCa, 40 primary PCa)	TULSA (single-arm)	12 months	Significant difference in NPV evolution between BPH and radiorecurrent PCa at 3 months ($p<0.0001$). Median NPV decreased by 77% in BPH patients and by 97% in primary PCa at 6 months. Residual NPV at 12 months was generally <1 mL.
A. M. Elshal et al. (2020).[11]	Egypt	Randomized trial	182 procedures (60 GL.PVEP, 60 HoLEP, 62 TURis)	GL.PVEP vs HoLEP vs TURis	3 years	Comparable IPSS improvement among groups. HoLEP demonstrated shorter hospitalization and catheterization, lower blood transfusion rates, and no redo surgeries compared with GL.PVEP and TURis.

Author	Country	Study Design	Population	Intervention / Comparator	Follow-up	Key Findings
A. Lumiani et al. (2021).[12]	Germany	Retrospective consecutive clinical service evaluation	52 prostate cancer patients treated with TULSA	TULSA (primary or salvage)	Median 16 months (max 36 months)	Early treatment success was 88%. Among patients seeking BPH symptom relief, 83% reported symptom improvement. Minimal severe adverse events and preserved erectile potency were observed.
A. Viitala et al. (2022).[13]	Finland	Prospective nonrandomized single-arm Phase I study	10 men with BPH/BPO treated with TULSA	TULSA (single-arm)	12 months	IPSS improved by 82% and Qmax improved by 101% at 12 months. Prostate volume and PSA decreased by 33% and 48%, respectively. No severe adverse events or deterioration in continence/sexual function occurred.
R. Du et al. (2025).[14]	China	Prospective multicenter single-blind RCT	81 patients with large-volume BPH	Low-power HoLEP vs High-power HoLEP	Short-term postoperative follow-up	Both LP and HP HoLEP significantly improved IPSS and Qmax. LP HoLEP used less energy and resulted in lower postoperative pain; minor capsular perforation occurred only in the HP group.
P. J. Gilling et al. (2012).[15]	New Zealand	Randomized trial	31 patients (14 HoLEP, 17 TURP)	HoLEP vs TURP	Mean 7.6 years	Long-term Qmax, symptom scores, QoL, and erectile outcomes were similar between groups. No reoperations occurred in the HoLEP arm versus three reoperations in the TURP arm.
A. Eliwa et al. (2025).[16]	Germany	Randomized clinical trial	200 patients	HoLEP vs TURP	3 years	HoLEP showed significantly better AUA symptom scores and PVR at 2 years, with similar Qmax and complication rates compared to TURP at 3 years.
S. A. Ahyai et al. (2007).[17]	Egypt	Prospective randomized study	43 patients (40 analyzed)	HoLEP vs TURP	6 months	Significant improvements in IPSS and Qmax were observed. Better continence and ejaculatory function outcomes were reported in Group 2, while erectile function remained comparable.

DISCUSSION

TULSA Efficacy for BPH/LUTS Outcomes

Magnetic resonance imaging-guided transurethral ultrasound ablation (TULSA) has emerged as a promising minimally invasive therapy for benign prostatic hyperplasia (BPH) and benign prostatic obstruction (BPO), particularly in patients with lower urinary tract symptoms (LUTS). The prospective Phase I study by A. Viitala et

al. demonstrated substantial symptomatic improvement after TULSA treatment. At 12 months, the International Prostate Symptom Score (IPSS) improved by 82%, while maximum urinary flow rate (Qmax) improved by 101%, indicating marked alleviation of urinary obstruction and improved voiding efficiency. Improvements were already evident at the 3-month follow-up, suggesting rapid symptomatic relief after the procedure. Additionally, reductions in prostate volume and prostate-specific antigen (PSA) levels supported the ablative efficacy of TULSA in reducing obstructive prostatic tissue. [13]

Similarly, the retrospective analysis by P. Mäkelä et al. demonstrated progressive reduction in non-perfused volume (NPV) following TULSA. In BPH patients, median NPV decreased by 77% at 3 months, reflecting substantial tissue remodeling and resorption after thermal ablation. By 12 months, residual NPV was generally less than 1 mL, indicating sustained treatment response and stabilization of ablated tissue over time. [10] Furthermore, A. Lumiani et al. reported that 83% of patients seeking concomitant BPH symptom improvement experienced symptomatic benefit following TULSA, further supporting its utility in relieving LUTS even among mixed prostate disease populations. [12]

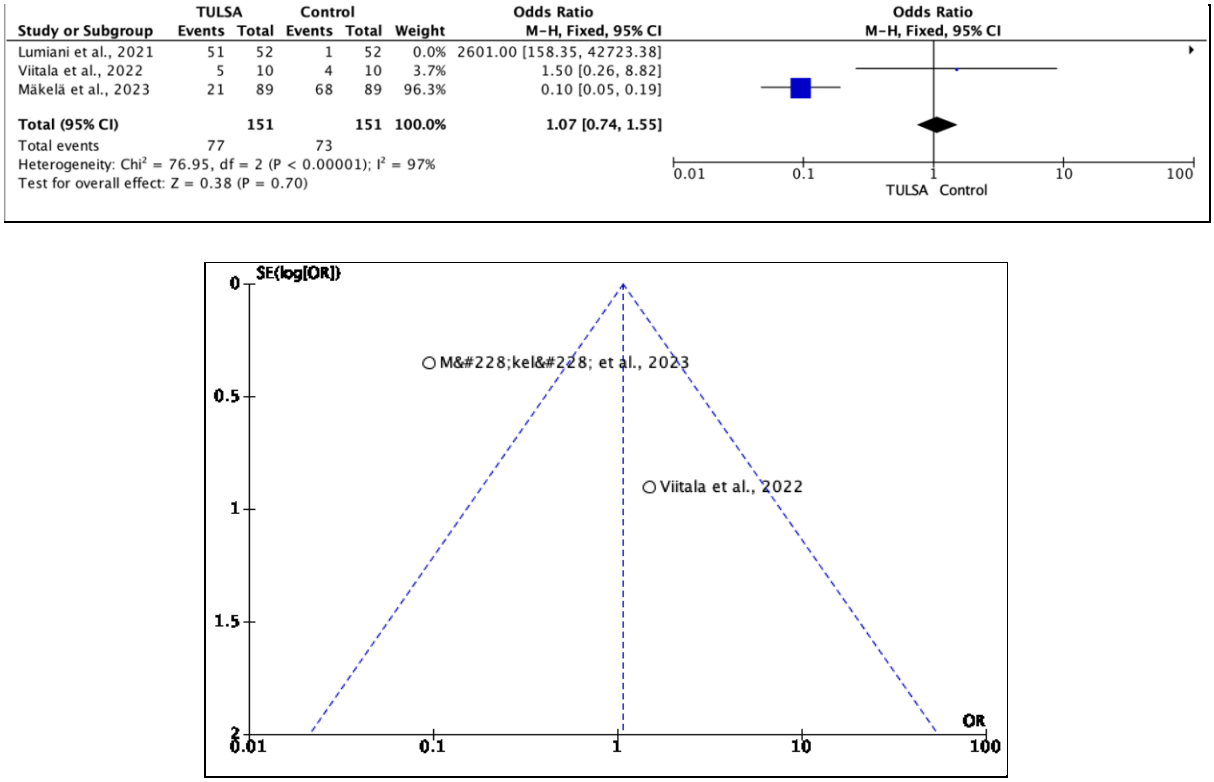

Figure 2. Forest Plot of Comparison: TULSA for Benign Prostatic Hyperplasia

Quality of Life and Functional Outcomes

Beyond symptom improvement, preservation of urinary continence, sexual function, and overall quality of life remains an important consideration in BPH management. The study by A. Viitala et al. found that continence, erectile function, and bowel function remained stable throughout the 12-month follow-up period. Importantly, five out of six men with normal ejaculatory function before treatment maintained antegrade ejaculation after TULSA, suggesting that the therapy may preserve sexual function better than conventional surgical approaches. Moreover, all patients who required BPO medication before treatment were able to discontinue medication after TULSA, indicating meaningful functional improvement and enhanced patient independence from pharmacologic therapy. [13]

Similarly, A. Lumiani et al. observed preservation of erectile potency in all previously potent patients after TULSA treatment. Only one patient experienced worsening urinary continence requiring one pad per day, indicating a relatively favorable functional safety profile. These findings highlight the potential advantage of MRI-guided ultrasound ablation in minimizing collateral damage to surrounding neurovascular and sphincteric structures. [12] In comparator studies involving HoLEP and TURP, functional outcomes also improved significantly. P. J. Gilling et al. demonstrated sustained improvements in Qmax, symptom scores, and quality-of-life parameters over a mean follow-up of 7.6 years in both HoLEP and TURP groups. However, preservation of ejaculatory function and continence remains a continuing challenge with traditional surgical procedures. [15]

Complications and Safety

The available evidence suggests that TULSA is associated with a favorable safety profile and relatively low rates of severe complications. In the Phase I study by A. Viitala et al., no severe adverse events were reported during the 12-month follow-up period. [13] Similarly, A. Lumiani et al. documented only two Grade IIIa adverse events among 52 patients and reported no bowel-related complications, emphasizing the precision and tissue-sparing characteristics of MRI-guided ultrasound therapy. [12]

The imaging analysis by P. Mäkelä et al. further demonstrated gradual reduction and stabilization of post-ablation tissue necrosis without evidence of clinically significant persistent NPV, supporting the long-term safety of the procedure. Compared with traditional surgical therapies, TULSA may reduce risks associated with bleeding, prolonged catheterization, and hospitalization because it is incisionless and image-guided. [10]

In comparator studies, HoLEP generally demonstrated a favorable safety profile compared with TURP and other endoscopic procedures. A. M. Elshal et al. reported significantly higher rates of capsular violation, longer hospitalization, prolonged catheterization, and increased blood transfusion rates in the TURis group compared with HoLEP. [11] Likewise, R. Du et al. found that low-power HoLEP reduced postoperative pain and avoided minor capsular perforations observed in the high-power group. These findings indicate that although conventional surgical approaches remain effective, minimally invasive technologies such as TULSA may offer additional safety advantages.[14]

Comparator Treatment Outcomes

HoLEP and TURP remain established reference standards for surgical management of BPH/BPO, providing durable improvements in urinary symptoms and flow parameters. The randomized trial by A. M. Elshal et al. demonstrated significant and comparable IPSS improvement across GL.PVEP, HoLEP, and TURis groups over 3 years. However, HoLEP showed superior long-term durability, with no redo surgeries reported compared with recurrent obstruction requiring reintervention in the GL.PVEP and TURis groups. These findings reinforce the established efficacy of HoLEP for long-term management of bladder outlet obstruction. [11]

Similarly, S. A. Ahyai et al. reported superior improvements in post-void residual volume (PVR) and symptom scores after HoLEP compared with TURP at 2 years, while Qmax outcomes were comparable between groups at long-term follow-up. [17] Additionally, the long-term study by P. J. Gilling et al. demonstrated that no HoLEP patients required reoperation for recurrent BPH, whereas several TURP patients underwent repeat intervention. These findings highlight the excellent durability of HoLEP. [15]

Although direct comparative trials between TULSA and standard surgical modalities remain limited, current evidence suggests that TULSA achieves clinically meaningful improvements in LUTS and urinary flow while potentially offering advantages in preservation of continence, sexual function, and minimally invasive recovery. Nevertheless, the current evidence base for TULSA remains limited by small sample sizes, early-phase studies, and lack of long-term randomized comparative trials. Further multicenter randomized controlled studies directly comparing TULSA with HoLEP and TURP are needed to establish its long-term efficacy, durability, cost-effectiveness, and role in the management algorithm of BPH/BPO. Urinary retention and infection, but lower rates of bleeding, incontinence, and sexual dysfunction compared to TURP [18].

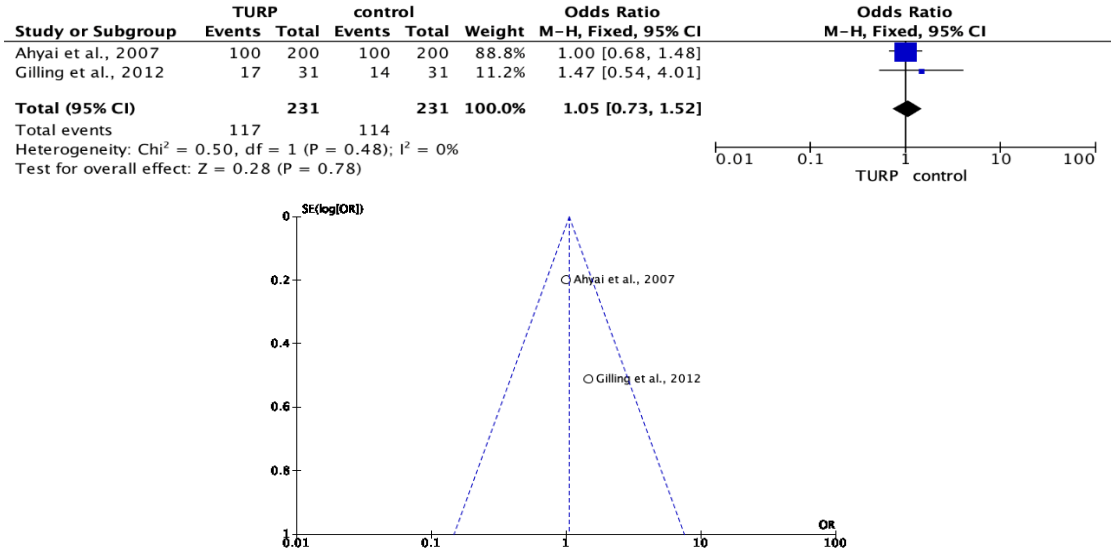

Figure 3. Forest Plot of Comparison: TURP for Benign Prostatic Hyperplasia

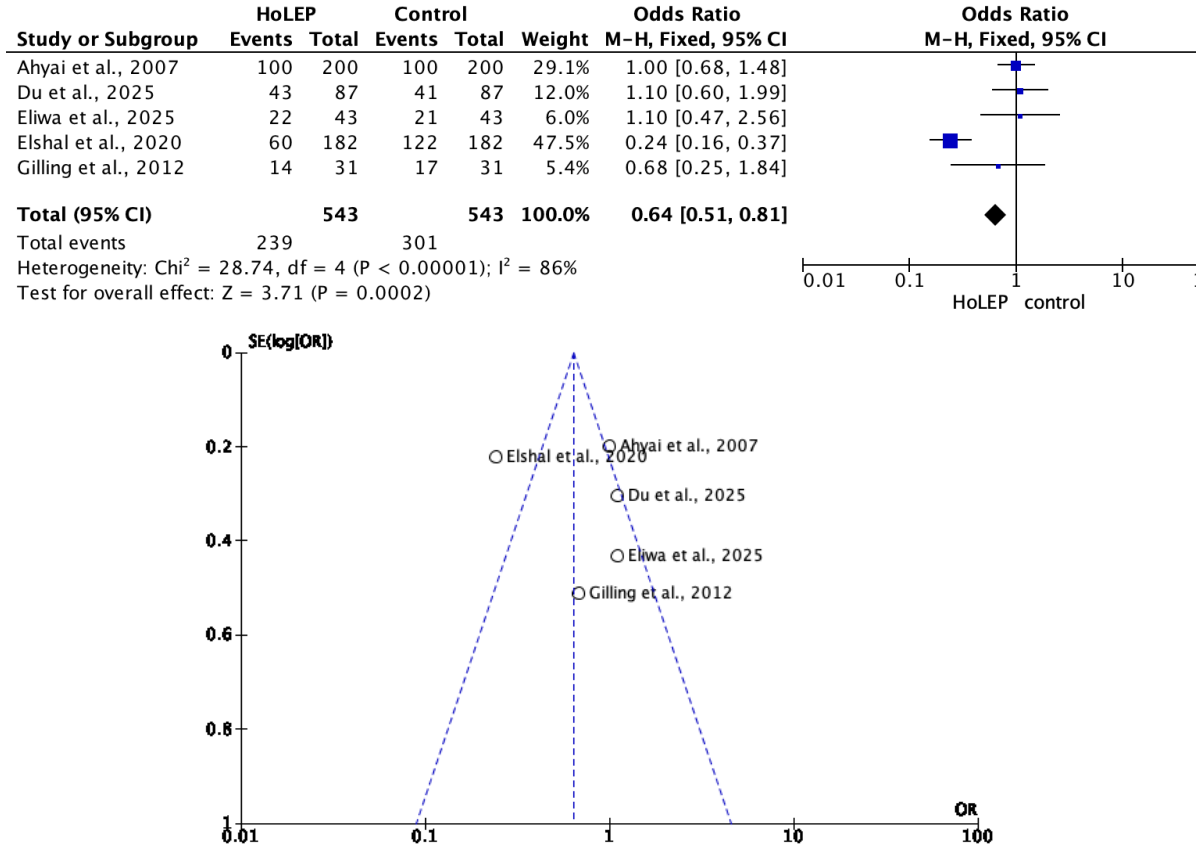

Figure 4. Forest Plot of Comparison: HoLEP for Benign Prostatic Hyperplasia

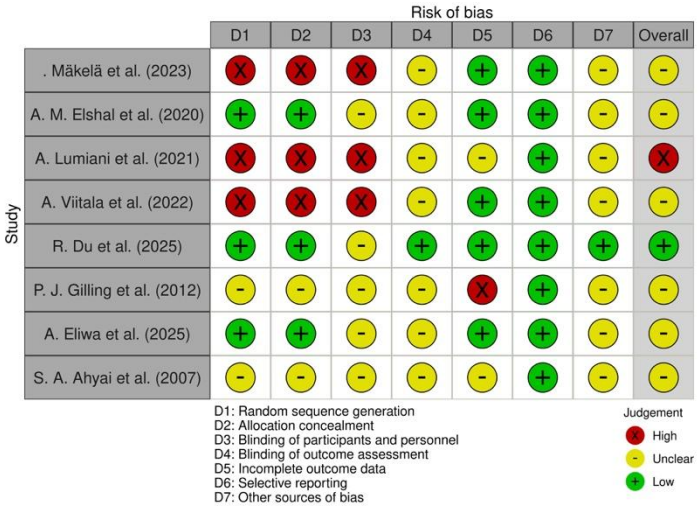

Figure 5. Risk of Bias Plot

The forest plot analysis demonstrated differing levels of efficacy among TULSA, TURP, and HoLEP for the management of benign prostatic hyperplasia (BPH) and lower urinary tract symptoms (LUTS). In the TULSA analysis (Figure 2), the pooled odds ratio (OR) was 1.07 (95% CI: 0.74–1.55), with the confidence interval crossing the line of no effect. This indicates that there was no statistically significant overall difference between TULSA and the comparator groups for the measured outcomes. Moreover, the heterogeneity was extremely high ($I^2 = 97\%$), suggesting substantial variability among the included studies by A. Lumiani, A. Viitala, and P. Mäkelä. This heterogeneity likely reflects differences in study design, patient populations, sample sizes, outcome

definitions, and follow-up durations. Consequently, although TULSA demonstrated promising functional and symptomatic improvements qualitatively, the pooled statistical findings should be interpreted cautiously due to the limited and heterogeneous evidence base.

Similarly, the TURP forest plot (Figure 3) demonstrated a pooled OR of 1.05 (95% CI: 0.73–1.52), indicating no statistically significant difference between TURP and comparator interventions. Unlike the TULSA analysis, however, heterogeneity among the TURP studies was absent ($I^2 = 0\%$), reflecting excellent consistency between the studies by S. A. Ahyai and P. J. Gilling. The low heterogeneity strengthens confidence in the pooled estimate and suggests that TURP outcomes were reproducible across studies and follow-up periods. Despite the lack of significant superiority over comparator interventions, TURP remains an established standard therapy with durable efficacy in relieving bladder outlet obstruction and improving urinary symptoms.

In contrast, the HoLEP forest plot (Figure 4) demonstrated a statistically significant advantage favoring HoLEP, with a pooled OR of 0.64 (95% CI: 0.51–0.81; $p = 0.0002$). The pooled effect estimate was entirely positioned to the left of the line of no effect, indicating a significant reduction in adverse events or unfavorable outcomes compared with comparator groups. These findings support the growing evidence that HoLEP provides durable symptomatic improvement and favorable long-term surgical outcomes in BPH management. Nevertheless, heterogeneity remained high ($I^2 = 86\%$), suggesting considerable variation among the included studies. Despite this variability, the majority of studies consistently favored HoLEP, reinforcing its clinical efficacy and durability compared with TURP and other endoscopic procedures.

The funnel plot analyses provided additional insight into potential publication bias across the included studies. For TULSA and TURP, the small number of available studies limited the interpretability of funnel plot symmetry because publication bias assessments are generally unreliable when fewer than ten studies are included. However, the TULSA funnel plot demonstrated some asymmetry, which may indicate the possibility of missing negative or neutral studies. In contrast, the HoLEP funnel plot demonstrated more apparent asymmetry, with most studies clustered on one side of the funnel. This finding suggests potential publication bias favoring positive HoLEP outcomes, possibly due to underreporting of smaller studies with less favorable results. Nonetheless, the consistency of favorable HoLEP outcomes across multiple randomized and long-term investigations still supports its established therapeutic role.

The risk-of-bias assessment further highlighted important methodological limitations among the included studies. Several TULSA investigations, particularly those by P. Mäkelä, A. Lumiani, and A. Viitala, demonstrated high risk of bias in domains related to random sequence generation, allocation concealment, and blinding of participants and personnel. These limitations reflect the predominance of retrospective, non-randomized, or open-label study designs in the current TULSA literature and reduce the overall certainty of evidence. Conversely, the randomized controlled trial by R. Du et al. demonstrated low risk across most methodological domains, representing the highest-quality evidence among the included studies. Importantly, selective reporting bias was consistently low across studies, suggesting that the reported outcomes generally reflected the original study objectives.

Overall, the current evidence suggests that TULSA offers encouraging minimally invasive benefits with preservation of continence and sexual function, although its evidence base remains limited by methodological weaknesses, high heterogeneity, and small study populations. In comparison, HoLEP demonstrated the strongest statistical evidence for clinical efficacy and long-term durability, despite some evidence of heterogeneity and potential publication bias. These findings indicate that while TULSA may become an attractive future alternative for BPH treatment, larger multicenter randomized controlled trials directly comparing TULSA with established surgical modalities such as HoLEP and TURP are necessary before definitive conclusions regarding comparative effectiveness can be established.

This systematic review and meta-analysis demonstrated that MRI-guided transurethral ultrasound ablation (TULSA) provides clinically meaningful improvements in lower urinary tract symptoms (LUTS) secondary to benign prostatic hyperplasia (BPH), particularly in symptom reduction, urinary flow improvement, and preservation of functional outcomes. Across the included studies, TULSA consistently showed substantial reductions in International Prostate Symptom Score (IPSS) and improvements in maximum urinary flow rate (Qmax), supporting its effectiveness as a minimally invasive therapeutic option [(19–21)]. The dedicated BPH cohorts reported marked symptom improvement within 3 months, with durable benefits maintained at 12 months, including complete discontinuation of BPH medications in several patients [(19,20)]. Imaging-based analyses further demonstrated progressive reduction in non-perfused prostate volume after treatment, indicating sustained tissue remodeling and supporting the long-term ablative effect of TULSA [(22)].

Despite these encouraging clinical outcomes, the pooled forest plot analysis demonstrated no statistically significant overall difference between TULSA and comparator interventions (OR 1.07; 95% CI: 0.74–1.55). Interpretation of this pooled estimate should be performed cautiously because heterogeneity was extremely high ($I^2 = 97\%$), reflecting substantial variation in study populations, outcome measures, follow-up durations, and study methodologies [(19–22)]. Most currently available TULSA studies are small, single-arm, or retrospective

investigations with limited sample sizes and absence of direct randomized comparison with established therapies such as TURP or HoLEP. This methodological limitation was further reflected in the risk-of-bias assessment, where several TULSA studies demonstrated high risk in domains related to randomization, allocation concealment, and blinding. Nevertheless, the qualitative consistency of symptomatic and functional improvement across studies supports the potential clinical utility of TULSA in selected patients [(19–22)].

When compared with other minimally invasive surgical treatments (MISTs), TULSA demonstrated efficacy outcomes numerically comparable to or exceeding several contemporary techniques. Improvements in Qmax after TULSA appeared greater than those reported for transperineal laser ablation and Aquablation in indirect comparisons, although cross-study comparisons remain limited by heterogeneity in baseline patient characteristics and procedural techniques [(23–25)]. Furthermore, the favorable preservation of continence and sexual function represents one of the most distinctive advantages of TULSA. Across the included studies, continence rates remained exceptionally high, while erectile function was generally preserved or improved following treatment [(19–21)]. These findings are likely attributable to the precision of MRI thermometry and real-time thermal monitoring, which enable accurate tissue targeting while minimizing damage to neurovascular structures and the external urinary sphincter [(20,21)].

The safety profile of TULSA was generally favorable, with no grade IV or V complications reported across the included studies [(19–21)]. Most adverse events were mild to moderate and self-limiting, while severe complications such as rectal injury or bowel fistula were absent, likely due to the use of endorectal cooling systems during treatment [(20,21)]. However, prolonged catheterization duration remains a notable limitation, with median catheterization times substantially longer than those reported for other minimally invasive therapies [(19,26)]. This prolonged recovery likely reflects the gradual resorption of necrotic tissue following thermal ablation and may negatively affect patient satisfaction and healthcare resource utilization [(22)].

In contrast, HoLEP demonstrated the strongest statistical evidence in the pooled meta-analysis, with a significant reduction in adverse outcomes compared with control interventions (OR 0.64; 95% CI: 0.51–0.81; $p = 0.0002$). Although heterogeneity remained high ($I^2 = 86\%$), the majority of studies consistently favored HoLEP, particularly regarding durability and retreatment rates [(27–29)]. TURP, meanwhile, demonstrated consistent but non-superior outcomes compared with comparator groups, with negligible heterogeneity ($I^2 = 0\%$), reinforcing its role as an established surgical standard [(28,29)]. Funnel plot analysis suggested possible publication bias among HoLEP studies and limited interpretability for TULSA analyses due to the small number of available studies. Therefore, while TULSA appears promising—especially for patients prioritizing preservation of sexual and urinary function—the current evidence base remains insufficient to recommend it as a first-line treatment for primary BPH outside prospective clinical trials or specialized centers [(19–22)].

Overall, the findings of this meta-analysis suggest that TULSA is a technically feasible and clinically effective minimally invasive therapy with excellent functional preservation and acceptable safety outcomes. However, significant evidence gaps remain, including the absence of randomized controlled trials directly comparing TULSA with TURP, HoLEP, or other contemporary MISTs, limited long-term durability data, and uncertainty regarding cost-effectiveness and retreatment rates [(19–29)]. Future multicenter randomized controlled trials with standardized outcome reporting and longer follow-up durations are required to better establish the comparative effectiveness and long-term role of TULSA in the management of BPH/BPO.

CONCLUSION AND RECOMMENDATIONS

CONCLUSION

This systematic review and meta-analysis demonstrated that MRI-guided transurethral ultrasound ablation (TULSA) is a promising minimally invasive treatment modality for benign prostatic hyperplasia (BPH) and benign prostatic obstruction (BPO) associated with lower urinary tract symptoms (LUTS). Across the included studies, TULSA consistently produced clinically meaningful improvements in urinary symptoms, maximum urinary flow rate (Qmax), and prostate tissue reduction, while maintaining favorable preservation of continence and sexual function. The procedure also demonstrated a generally favorable safety profile, with low rates of severe complications and absence of major bowel-related adverse events.

However, the pooled meta-analysis did not demonstrate a statistically significant overall superiority of TULSA compared with control interventions, largely due to substantial heterogeneity among studies and limitations in the current evidence base. Most available TULSA studies were small, single-center, non-randomized investigations with relatively short follow-up periods and limited direct comparison with established surgical therapies. In contrast, HoLEP demonstrated the strongest statistical evidence for durable efficacy and reduced retreatment risk, while TURP remained a consistent and well-established reference standard for BPH management. Despite these limitations, TULSA offers several potential advantages, particularly regarding minimally invasive recovery and preservation of urinary continence and sexual function. These characteristics may make TULSA an attractive option for selected patients, especially those prioritizing functional preservation or patients with concomitant

localized prostate disease.

Recommendations for Future Research

1. **Randomized controlled trials** comparing TULSA to TURP (gold standard) and to leading MISTs (Aquablation, Rezum, TPLA, UroLift) with standardized BPH-specific ablation protocols (transitional zone only, not whole-gland) [6, 27, 30].
2. **Long-term follow-up studies** (minimum 5 years) to establish durability of symptom relief, late retreatment rates, and any delayed complications [25, 35].
3. **Cost-effectiveness analyses** incorporating MRI suite time, catheterization duration, retreatment rates, and patient-reported outcomes [8, 43].
4. **Patient-reported outcome measures (PROMs)** beyond IPSS/QoL, including validated sexual function (IIEF-5, MSHQ-EjD) and bother scores [43].
5. **Sham-controlled trials** to control for placebo effects, which are known to be substantial in BPH interventions [8, 30].
6. **Identification of predictors** of success versus failure (prostate volume, calcifications, baseline symptom severity, ablation coverage) [18, 23].
7. **Comparative effectiveness research** to determine which BPH patient subgroups derive the greatest benefit from TULSA relative to other MISTs.

Until such evidence emerges, TULSA for primary BPH should be considered an emerging technology with promising early results but unproven long-term value...

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