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MODERN SURGICAL TECHNIQUES FOR THE TREATMENT OF BENIGN PROSTATIC HYPERPLASIA: A SYSTEMATIC REVIEW

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ABSTRACT

Aims: To systematically review randomized evidence on modern minimally invasive and endoscopic techniques for treating lower urinary tract symptoms (LUTS) due to benign prostatic hyperplasia (BPH), focusing on clinical efficacy, safety, perioperative outcomes, preservation of sexual/ejaculatory function, and durability compared with TURP or sham.
Methods: We conducted a systematic PubMed search (2020–2025) using predefined terms for BPH surgery and randomized controlled trials. Main findings from eligible articles were summarized.
Results: The review identified 41 randomized controlled trials evaluating nine modern techniques (endoscopic enucleation, laser vaporization, Aquablation, Rezūm water vapor thermal therapy, prostatic urethral lift/PUL, transperineal laser ablation/TPLA, temporary nitinol device/iTind, drug-coated balloon/Optilume, and prostatic artery embolisation/PAE), comprising thousands of men with moderate-to-severe LUTS. Endoscopic enucleation and Aquablation showed durable, TURP-like or superior improvements in IPSS, QoL, Qmax, and PVR, particularly in large prostates (>80 mL), with better perioperative outcomes. Minimally invasive surgical therapies (MISTs) provided meaningful symptom relief and excellent preservation of sexual/ejaculatory function, while PAE had lower objective efficacy and higher reintervention rates. Serious complications were uncommon across all techniques.
Conclusions: Current evidence supports these modern techniques as valuable alternatives to TURP, enabling individualized treatment based on prostate volume and patient priorities for sexual function, recovery, and durability. However, heterogeneity in follow-up duration, variable prostate-size criteria, and the limited number of large head-to-head trials restrict definitive conclusions. Further adequately powered, long-term randomized studies are needed to better define the optimal role of each modality in clinical practice.

KEYWORDS

Benign Prostate Hyperplasia, Lower Urinary Tract Symptoms, Minimally Invasive Surgical Therapies, Endoscopic Surgery, Systematic Review

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Introduction

Global Burden of Disease (GBD) 2019 estimates indicate that benign prostatic hyperplasia affected approximately 94 million people worldwide (≈1.2% of the global population) [42]. In a real-world cohort of men aged 35–64 years with a first diagnosis of BPH and prescribed oral medication for LUTS, the 5-year risk of BPH surgery was 10.2% [43]. According to EAU guidelines, surgery is indicated when symptoms are refractory to conservative or pharmacological therapy, with bipolar or monopolar TURP as the standard procedure for prostates 30–80 mL [45]. In a U.S. database analysis, the number of BPH procedures increased from 82,086 (2011–2014) to 86,528 (2015–2018) and 106,194 (2019–2022) [44]. The growing demand for surgical treatment is driving the development of new procedures, which are the focus of this article.

Aim of the Publication

This systematic review provides an overview of randomized evidence on modern minimally invasive techniques for treating LUTS due to benign prostatic hyperplasia, focusing on clinical efficacy, safety, functional outcomes (including sexual/ejaculatory function), and durability.

Research objectives

1. To identify and critically appraise randomized controlled trials evaluating modern surgical and minimally invasive interventions for BPH compared with TURP or other comparators.
2. To analyze changes in key efficacy outcomes, including symptom severity, quality of life (IPSS, IPSS-QoL), and objective voiding parameters (Qmax, PVR).
3. To summarize perioperative and recovery outcomes, such as operative time, hemoglobin drop or transfusion, postoperative irrigation, catheterization duration, and length of hospital stay.
4. To review safety profiles and complication rates, including overall adverse events and clinically relevant events such as urinary retention, UTIs, bleeding complications, urethral stricture or bladder neck contracture, and incontinence.
5. To evaluate postoperative sexual and ejaculatory function, where such data are available in the included articles.
6. To assess the durability of treatment by summarizing retreatment or reintervention rates and long-term maintenance of symptoms and flow.

Methods

We searched PubMed database from 2020 to 2025 with words: ("Prostatic Hyperplasia"[Mesh] OR BPH[tiab] OR "benign prostatic hyperplasia"[tiab] OR "benign prostatic enlargement"[tiab]) AND (“surgery”[tiab] OR “surgical”[tiab] OR “operative”[tiab] OR "minimally invasive"[tiab] OR “MIST”[tiab] OR “endoscopic”[tiab]) AND (“randomized controlled trial”[pt] OR “comparative study”[pt] OR “multicenter study”[pt]) NOT ("Prostatic Neoplasms"[Mesh] OR "prostate cancer"[tiab]) NOT (animals[mh] NOT humans[mh]).

Following the PRISMA 2020 guidelines, we identified 282 articles. Two independent researchers screened titles and abstracts. We excluded 244 articles for the following reasons: not RCT/comparative (n=93), no BPH data (n=61), non-surgical (n=30), no modern technique (n=21), review/meta-analysis (n=20), non-English (n=18), or no clinical outcomes (n=1). The PRISMA flow diagram of the study selection process is presented in Figure 1.

If no TURP-comparator RCT was retrieved for a procedure found in the primary search, we conducted a targeted PubMed search combining procedure-specific terms with TURP-related keywords: (("Prostatic Hyperplasia"[Mesh] OR "benign prostatic hyperplasia"[tiab] OR BPH[tiab] OR "benign prostatic enlargement"[tiab] OR "benign prostatic obstruction"[tiab] OR BPO[tiab]) AND (“TURP”[tiab] OR "transurethral resection"[tiab] OR "transurethral resection of the prostate"[tiab] OR "bipolar TURP"[tiab] OR "plasmakinetic TURP"[tiab] OR “PK-TURP”[tiab] OR "button TURP"[tiab]) AND (iTind[tiab] OR i-Tind[tiab] OR TIND[tiab] OR "temporarily implanted nitinol device"[tiab] OR "temporary implantable nitinol device"[tiab] OR Optilume[tiab] OR "Optilume BPH"[tiab] OR "drug-coated balloon"[tiab] OR DCB[tiab] OR paclitaxel[tiab] OR enucleat*[tiab] OR "endoscopic enucleation"[tiab] OR HoLEP[tiab] OR "holmium laser enucleation"[tiab] OR ThuLEP[tiab] OR "thulium laser enucleation"[tiab] OR "thulium:YAG"[tiab] OR ThuFLEP[tiab] OR "thulium fiber"[tiab] OR "thulium fiber laser"[tiab] OR TFL[tiab] OR BipoLEP[tiab] OR "bipolar enucleation"[tiab] OR PKEP[tiab] OR "plasmakinetic enucleation"[tiab] OR DiLEP[tiab] OR "diode laser enucleation"[tiab] OR GreenLEP[tiab] OR PSEP[tiab] OR "photoselective sharp enucleation"[tiab] OR "GreenLight enucleation"[tiab] OR vapor*[tiab] OR "photoselective vaporization"[tiab] OR PVP[tiab] OR GreenLight[tiab] OR "diode laser vaporization"[tiab] OR "thulium laser vaporization"[tiab] OR "holmium laser vaporization"[tiab] OR HoLAP[tiab] OR BPVP[tiab] OR "bipolar button"[tiab] OR "button plasma vaporization"[tiab] OR "plasma vaporization"[tiab]) AND (randomized controlled trial[pt] OR random*[tiab] OR randomised[tiab] OR randomized[tiab]) NOT ("Prostatic Neoplasms"[Mesh] OR "prostate cancer"[tiab]) NOT (animals[mh] NOT humans[mh])).

We identified 95 articles. After removing duplicates (n=19), 2 independent researchers screened titles and abstracts using the same criteria. Articles were excluded for the following reasons: review/meta-analysis (n=49), not RCT/comparative (n=15), no BPH data (n=2), non-English (n=2), or not surgical (n=1). Eligible 7 articles were added to the title list.

To maintain focus on comparative effectiveness among different BPH procedures, we excluded randomized trials evaluating technical modifications or equipment settings within the same procedure (n=11). Only RCTs directly comparing different surgical procedures were included in the main synthesis.

We then reviewed the full texts of the remaining 34 articles. For each included trial, we searched for companion publications to capture all reported outcomes and avoid incomplete data extraction (n=7). Main findings are synthesized and presented below.

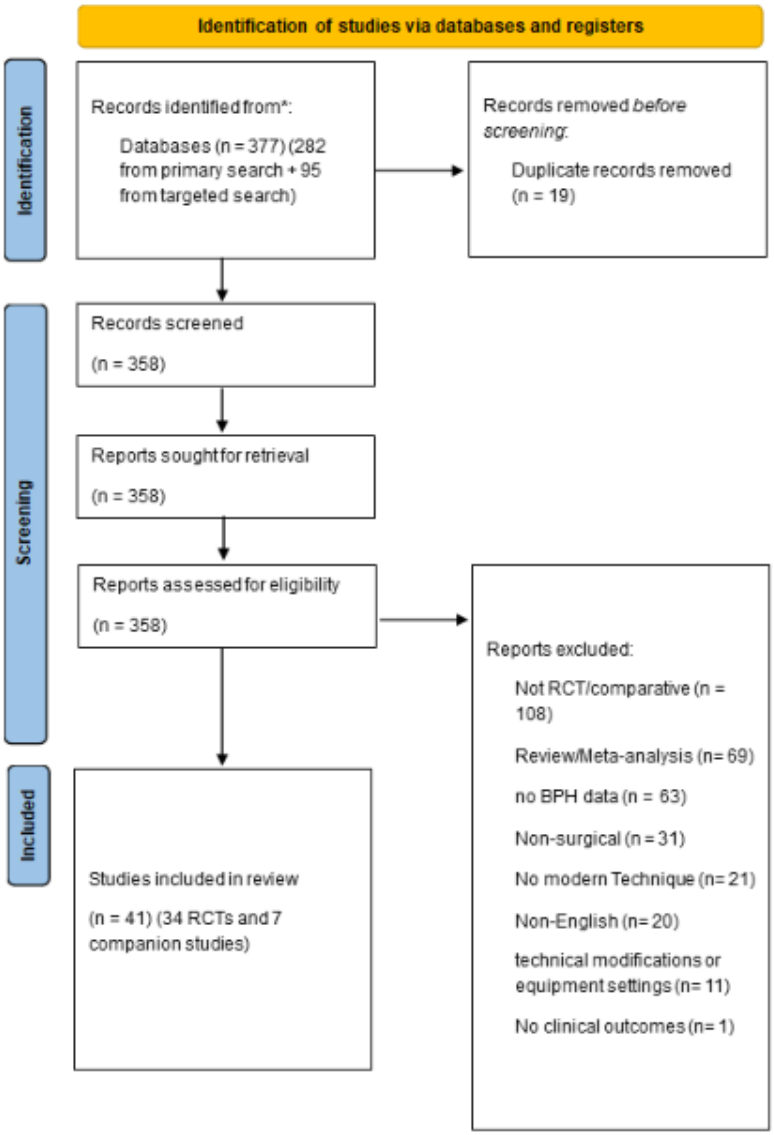

Fig. 1. *PRISMA 2020 flow diagram of the study selection process*

The surgical techniques and included article titles are presented in the table below.

Table 1. Surgical techniques with included articles title

No.	Procedure	Titles
1	Endoscopic enucleation (EEP/AEEP)	1. Safety and efficacy of transurethral holmium laser enucleation of the prostate versus bipolar transurethral resection of the prostate in the treatment of benign prostatic hyperplasia: a prospective randomized controlled trial. [1] 2. B-TURP versus HoLEP: Peri-Operative Outcomes and Complications in Frail Elderly (>75 y.o.) Patients: A Prospective Randomized Study. [2] 3. 1470 nm diode laser enucleation versus bipolar transurethral resection of the prostate for the surgical management of benign prostatic hyperplasia: a randomized comparison. [3] 4. Holmium laser enucleation of the prostate versus thulium laser enucleation of the prostate for the treatment of large-volume prostates > 80 ml: 18-month follow-up results. [4] 5. A prospective multicenter randomized comparison between Holmium Laser Enucleation of the Prostate (HoLEP) and Thulium Laser Enucleation of the Prostate (ThuLEP). [5] 6. A randomized trial of holmium laser vs thulium laser vs bipolar enucleation of large prostate glands. [6] 7. Prospective randomized multicenter study to evaluate holmium vs. new thulium fiber laser for prostate enucleation. [7] 8. Randomized prospective trial of the severity of irritative symptoms after HoLEP vs ThuFLEP. [8] 9. Thulium: YAG vs continuous-wave thulium fiber laser enucleation of the prostate: do potential advantages of thulium fiber lasers translate into relevant clinical differences?. [9] 10. Comparison of Holmium Laser Enucleation of the Prostate with Bipolar Plasmakinetic Enucleation of the Prostate: A Randomized, Prospective Controlled Trial at Midterm Follow-Up. [10] 11. Plasma Kinetic Enucleation *vs* Holmium Laser Enucleation for Treating Benign Prostatic Hyperplasia: A Randomized Controlled Trial with a 3-Year Follow-Up. [11] 12. Holmium Laser Enucleation *vs* Bipolar Plasmakinetic Enucleation of a Large Volume Benign Prostatic Hyperplasia: A Randomized Controlled Trial. [12] 13. Comparing surgical techniques: ThuLEP and transurethral BPEP for prostate over 80 grams. Intraoperative and postoperative results. A prospective randomized trial. [13] 14. Functional outcomes of transurethral thulium laser enucleation versus bipolar transurethral resection for benign prostatic hyperplasia over a period of 12 months: A prospective randomized study. [18]
2	Laser Vaporization	1. Thulium laser transurethral vaporesection of the prostate versus transurethral resection of the prostate for men with lower urinary tract symptoms or urinary retention (UNBLOCS): a randomised controlled trial [14] 2. A randomised controlled trial to determine the clinical and cost effectiveness of thulium laser transurethral vaporesection of the prostate (ThuVARP) versus transurethral resection of the prostate (TURP) in the National Health Service (NHS) - the UNBLOCS trial: a study protocol for a randomised controlled trial. [15] 3. Thulium laser transurethral vaporesection versus transurethral resection of the prostate for benign prostatic obstruction: the UNBLOCS RCT. [16] 4. Outcomes of thulium prostatectomy with "Oyster technique" versus transurethral prostatectomy (TURP): a randomized control trial. [17] 5. A prospective, single-center, randomized clinical trial to evaluate the efficacy of three types of laser vaporization surgeries using a 180-W GreenLight XPS laser, a 300-W diode laser, and a 200-W thulium laser for the treatment of benign prostatic hyperplasia. [19] 6. GreenLight HPS laser 120 W vs diode laser 300 W vaporization of the prostate for the treatment of benign prostatic hyperplasia in Japanese patients: A prospective, single-center, randomized clinical trial. [20] 7. Ejaculatory Hood-Sparing Photoselective Vaporization of the Prostate *vs* Bipolar Button Plasma Vaporization of the Prostate in the Surgical Management of Benign Prostatic Hyperplasia. [21] 8. Holmium Laser Xpeeda Vaporization *vs* GreenLight XPS Vaporization of the Prostate for Benign Prostatic Obstruction: 1-Year Results from a Randomized Controlled Clinical Study. [22]

3	Aquablation (waterjet)	1. Five-year outcomes for Aquablation therapy compared to TURP: results from a double-blind, randomized trial in men with LUTS due to BPH. [23] 2. Three-year outcomes after Aquablation therapy compared to TURP: results from a blinded randomized trial. [24] 3. Two-Year Outcomes After Aquablation Compared to TURP: Efficacy and Ejaculatory Improvements Sustained. [25] 4. Aquablation versus TURP: 5-year outcomes of the WATER randomized clinical trial for prostate volumes 50-80 mL. [26]
4	Rezūm / water vapor thermal therapy (WVTT)	1. Final 5-Year Outcomes of the Multicenter Randomized Sham-Controlled Trial of a Water Vapor Thermal Therapy for Treatment of Moderate to Severe Lower Urinary Tract Symptoms Secondary to Benign Prostatic Hyperplasia. [27] 2. Convective Thermal Therapy: Durable 2-Year Results of Randomized Controlled and Prospective Crossover Studies for Treatment of Lower Urinary Tract Symptoms Due to Benign Prostatic Hyperplasia. [28] 3. Erectile and Ejaculatory Function Preserved With Convective Water Vapor Energy Treatment of Lower Urinary Tract Symptoms Secondary to Benign Prostatic Hyperplasia: Randomized Controlled Study. [29] 4. Minimally Invasive Prostate Convective Water Vapor Energy Ablation: A Multicenter, Randomized, Controlled Study for the Treatment of Lower Urinary Tract Symptoms Secondary to Benign Prostatic Hyperplasia. [30] 5. Preserving erectile and ejaculatory function in patients undergoing minimally invasive techniques: the first randomized clinical trial comparing convective water vapor ablation and transperineal laser ablation. [31] 6. Two-year follow-up comparing Rezūm therapy versus bipolar transurethral resection of the prostate for treating benign prostatic hyperplasia. A prospective randomized study. [32]
5	PUL / UroLift (prostatic urethral lift)	1. Randomised controlled trial comparing safety and efficacy of UroLift to monopolar TURP. [33]
6	TPLA (transperineal laser ablation)	1. Ejaculatory function following transperineal laser ablation vs TURP for benign prostatic obstruction: a randomized trial. [34]
7	iTind/TIND (temporary nitinol device)	1. An Evaluation of Sexual Function in the Treatment of Lower Urinary Tract Symptoms Secondary to Benign Prostatic Hyperplasia in Men Treated with the Temporarily Implanted Nitinol Device. [35] 2. The iTind Temporarily Implanted Nitinol Device for the Treatment of Lower Urinary Tract Symptoms Secondary to Benign Prostatic Hyperplasia: A Multicenter, Randomized, Controlled Trial. [36]
8	Optilume (drug-coated balloon)	1. The PINNACLE Study: A Double-blind, Randomized, Sham-controlled Study Evaluating the Optilume BPH Catheter System for the Treatment of Lower Urinary Tract Symptoms Secondary to Benign Prostatic Hyperplasia. [37] 2. Two-year long-term follow-up of treatment with the Optilume BPH catheter system in a randomized controlled trial for benign prostatic hyperplasia (The PINNACLE Study). [38] 3. Preservation of sexual function with Optilume-a novel treatment for lower urinary tract symptoms secondary to benign prostatic hyperplasia. [39]
9	PAE (prostatic artery embolization)	1. Prostatic Artery Embolisation Versus Transurethral Resection of the Prostate for Benign Prostatic Hyperplasia: 2-yr Outcomes of a Randomised, Open-label, Single-centre Trial. [40] 2. Prostatic Artery Embolisation Versus Transurethral Resection of the Prostate for Benign Prostatic Obstruction: 5-year Outcomes of a Randomised, Open-label, Noninferiority Trial. [41]

Results

Endoscopic enucleation (EEP/LEP)

Holmium laser enucleation of the prostate (HoLEP) is a transurethral, laser-based enucleation technique in which adenomatous tissue is dissected along the surgical capsule and subsequently morcellated, typically under general or spinal-epidural anesthesia. In a key prospective, randomized, single-center trial enrolling men aged ≥60 years with refractory BPH, participants were randomized to HoLEP (n=110) or bipolar TURP (B-TURP)(n=110)(total n=220). According to functional outcomes, both procedures improved objective parameters (PVR decreased at 1 and 6 months without meaningful differences between groups; Qmax at 1 month was similar: 17.33 vs 17.27 mL/s), but HoLEP achieved more pronounced short-term symptom improvement, with lower postoperative IPSS at 1 month (8.80 vs 11.12 points; P<0.001) and comparable QoL scores (2.16 points in both groups). Perioperatively, HoLEP demonstrated fewer intraoperative bleeding than B-TURP (31.32 vs 52.55 mL; p<0.001) and faster postoperative recovery markers, including shorter bladder irrigation (30.57 vs 40.96 h; p=0.002), catheterization (90.82 vs 133.52 h;p<0.001), and hospitalization time (11.45 vs 14.25 days; p=0.002), alongside lower post-catheter voiding pain scores (VAS 2.15 vs 3.91 points; p<0.001). Early complications were numerically lower with HoLEP (3.63% vs 9.18%), although this difference was not statistically significant (P=0.153) [1]. Better intra and perioperative outcomes were confirmed in elderly patients (>75 y.o.) [2].

In a randomized comparison of DiLEP (1470-nm diode laser enucleation) versus bipolar TURP, DiLEP demonstrated comparable 12-month improvements in IPSS, QoL, Qmax, and PVR, while offering greater surgical efficiency (0.7 (DiLEP) vs. 0.5 (B-TURP) g/min; P=0.001) and better perioperative outcomes (shorter operative time, higher retrieval efficiency, smaller hemoglobin drop) with shorter postoperative irrigation and catheterization times, and numerically fewer complications [3].

In RCTs comparing bipolar/plasmakinetic enucleation (PKEP/BPEP/B-TUEP) with HoLEP, both procedures provided durable improvements regarding symptoms and flow with results maintained for at least 3-5 years, but HoLEP was often faster (operative time (30.91 *vs* 41.63 min; p<0.05) with less hemoglobin drop (0.46 *vs* 0.87 g/dL; p<0.01) [10], better symptoms relief in patients with glands larger than 120 mL (IPSS improvement; p=0.01) [6] and, in some studies, shorter irrigation/catheterization/hospital stay, whereas bipolar techniques avoid laser-related costs [11,12]

In a randomized trial in large prostates (>80 mL), ThuLEP (thulium laser enucleation) demonstrated comparable functional outcomes to HoLEP (IPSS, QoL, Qmax, PVR) through 18 months, while operative and enucleation times were slightly shorter with ThuLEP (78.4 (HoLEP) vs 71.4 (ThuLEP) min; p<0.001) and enucleation time (61.2 (HoLEP) vs. 56.4 (ThuLEP) min; p<0.001) [4]. In subsequent trial ThuLEP was associated with lower hemoglobin loss and fewer postoperative incidences of stress incontinence and urinary retention [5]. Compared with bipolar TURP, ThuLEP showed greater early symptom improvement at 1 month (IPSS, p=0.027; QoL, p=0.041; PVR, p=0.040; OABSS, p<0.0001), with no significant between-group differences at 12 months. ThuLEP also yielded better perioperative outcomes (smaller hemoglobin decrease and shorter catheterization time) and a higher rate of erectile function recovery (IIEF-5: 44% vs 17%; p=0.009). [18]. ThuLEP was associated with better perioperative outcomes (enucleation, hospitalization, and catheterization time) compared with BPEP [13]. Other articles support these data [6].

Randomized comparisons of ThuFLEP (thulium fiber laser enucleation) vs HoLEP show no clinically relevant differences in early efficacy (IPSS/QoL/Qmax/PVR) and similar complication profiles up to 6 months, with low and comparable rates of postoperative stress urinary incontinence and urethral stenosis/stricture [7,8]. A direct comparison of ThuFLEP and ThuLEP showed that the more superficial depth of penetration achieved by fiber does not translate into differences in perioperative or clinical outcomes at 3 months of follow-up [9].

Endoscopic Vaporization

Thulium laser transurethral vaporesection of the prostate (ThuVARP) is a transurethral, endoscopic laser technique that combines tissue vaporization and resection in a TURP-like fashion using a thulium laser, intending to relieve benign prostatic obstruction while sustaining good haemostasis. In the UNBLOCS, multicentre, single-blind RCT enrolling men with bothersome LUTS or urinary retention secondary to benign prostatic obstruction, were randomised to ThuVARP (n=205) or standard TURP (n=205; total n=410; centres used their usual monopolar or bipolar TURP). At 12 months, symptom outcomes were equivalent between techniques (IPSS 6.43 vs 6.26; 95% CI −0.92 to 1.49), whereas TURP achieved a higher flow rate (Qmax 20.16 vs 23.24 mL/s; 95% CI −5.79 to −0.45). Perioperative and postoperative safety signals were broadly similar: median hospital stay was 48 h in both groups, transfusion rates were low and comparable (2% vs 2%), postoperative catheter time was similar (median 2 days in both groups), and the proportion experiencing ≥1

postoperative complication over 12 months was comparable (47% (ThuVARP) vs 45% (TURP). Repeat TURP by 12 months occurred infrequently (3 (ThuVARP) vs 2 (TURP) patients). Overall, anticipated advantages of ThuVARP in reducing length of stay or complications were not observed, with equivalence in symptom improvement but inferior Qmax versus TURP at 12 months [14-16]. However, other RCT using "oyster technique" suggest potentially better perioperative outcomes (shorter operative, hospitalization, and catheterization times) with comparable clinical efficacy (IPSS and Qmax reductions) [17].

Compared with ThuVARP, other vaporization lasers, such as Holmium, Bipolar plasma button, Diode, and Greenlight, exhibit similar perioperative and clinical outcomes [19-22]. Some data suggest a lower rate of postoperative complications with Holmium Laser Xpeeda [22].

Aquablation

Aquablation therapy is a minimally invasive, transurethral, robot-assisted, heat-free tissue resection performed under real-time transrectal ultrasound (TRUS) guidance, most commonly under general (or spinal) anesthesia. The procedure involves automated, high-velocity waterjet ablation that removes adenomatous tissue according to a pre-planned contour while preserving critical structures responsible for ejaculatory function. In the pivotal, prospective, multicenter, double-blind randomized study, men aged 45–80 years with moderate-to-severe LUTS (IPSS ≥12, Qmax <15 mL/s, prostate volume 30–80 mL) were randomized to Aquablation (treated n=116) or TURP (treated n=65; 181 treated of 184 randomized). The primary efficacy endpoint (IPSS change at 6 months) showed substantial symptom progress in both groups, with Aquablation meeting non-inferiority versus TURP (IPSS 16.9 (Aquablation) vs 15.1 (TURP) points; p<0.0001 for noninferiority and p=0.1346 for superiority), and these effects remained durable through longer follow-up: at 2 years IPSS improved by 14.7 vs 14.9 points, at 3 years by 14.4 vs 13.9 points, and at 5 years by 15.1 vs 13.2 points (between-group differences generally not statistically significant overall, while men with larger prostates (≥50 mL) showed greater symptom reduction with Aquablation across follow-up; p=0.0125). Objective outcomes also improved and were maintained over time, with marked increases in Qmax in both arms (11.2 vs 8.6 mL/s at 2 years; p = 0.1880; and maintained improvements at 5 years, reported as ~125% vs 89% improvement from baseline for Aquablation vs TURP; p=0.1880). Safety favored Aquablation early, as the main safety endpoint at 3 months (procedure-related persistent grade 1 or grade ≥2 Clavien–Dindo events) occurred less frequently than with TURP (26% vs 42%;p=0.0149 for superiority), and ejaculatory outcomes were consistently better preserved with Aquablation (lower rates of anejaculation/ejaculatory dysfunction vs TURP) [23-25]. In a subsequent 5-year trial enrolling men with larger glands (50-80 mL), the effectiveness of Aquablation in symptom relief was confirmed (change in IPSS: 14.1 (Aquablation) vs 10.8 (TURP) points; p=0.02), with similar bleeding risk [26]. Aquablation provides TURP-like, durable symptom and flow improvements through 5 years, with fewer early complications and better preservation of ejaculatory function, and may offer a relative advantage in larger prostates (≥50 mL).

Rezūm (water vapor thermal therapy)

Rezūm water vapor thermal therapy (WVTT; convective water vapor ablation) is a minimally invasive transurethral endoscopic procedure that can be performed under local anesthesia and uses radiofrequency energy to generate sterile water vapor, which is delivered via needle injections into the prostatic tissue, causing targeted thermal ablation and subsequent tissue resorption with volume reduction. In the pivotal, randomized, multicenter, sham-controlled trial enrolling men aged >50 years with moderate-to-severe LUTS due to BPH (prostate volume 30-80 cm3, IPSS ≥13, Qmax <15 mL/s), participants were randomized to WVTT (n=136) or sham (n=61; total N=197). After 3 months, Rezūm achieved an over 125% reduction in IPSS vs sham (p<0.0001) and was supported by an IPSS QoL reduction vs baseline (4.4 vs 2.3 points). Also, at this time point, participants were unblinded, and those in the control group could undergo WVTT if they met the initial inclusion criteria. 53/61 requalified and underwent WVTT. Both treatment and crossover groups were followed for 5 years. During this period, there was a BPH Impact index (BPHII) reduction (up to 51% at a 6-month time frame) and Qmax improvement (9.9 vs 15.5 mL/s at a 1-year time frame). Those findings were sustained at the 5-year time point, showing a reduction in IPSS (48% from baseline), IPSS QoL (4.4 vs 2.2 points, or 45%), BPHII (45%), and improvement in Qmax (9.9 vs 14 mL/s, or 49%). Going further, 61% of participants in the treatment group required no additional intervention and achieved a ≥30% reduction in IPSS from baseline at 5-year follow-up. Adverse events were generally transient; the most common included dysuria, gross hematuria, hematospermia, urinary frequency, acute urinary retention, suspected UTI, and decreased ejaculatory volume [27]. WVTT was associated with a 7.1% improvement in IIEF scores and a 50% reduction in PVR at 2-year follow-up. However, a subsequent randomized, open-label, two-center trial comparing Rezūm (WVTT) with TURP demonstrated greater improvements with TURP, particularly for urinary flow and

longer-term outcomes (Qmax 14.1 vs 20.1 mL/s at 24 months; p<0.001). TURP was also superior at 6 months for symptom burden and functional measures (IPSS 18.5 vs 12.0 points; p<0.001; PVR 83 vs 43.5 mL; p<0.001; QoL 2.9 vs 2.3; p<0.001). In contrast, erectile function scores favored WVTT (IIEF 12.7 vs 7.42 at 6 months; p<0.001). TURP was associated with higher rates of postoperative complications, including erectile dysfunction (p=0.002) and hematuria (p=0.0025) [32]. Other studies support these outcomes [28-31]. Overall, Rezūm/WVTT provides rapid and durable symptom relief with meaningful improvements in flow and quality of life and a low retreatment rate, while largely preserving sexual function—making it a strong MIST option for appropriately selected men with 30–80 cm³ prostates and moderate-to-severe LUTS.

Prostatic Urethral Lift (PUL / UroLift)

Prostatic Urethral Lift (PUL; UroLift) is a minimally invasive transurethral endoscopic procedure that can be performed under local anesthesia. It works by mechanically retracting the obstructing lateral lobes using permanent implants, thereby widening the prostatic urethra without tissue resection or thermal injury. In an open-label, single-center randomized trial including men aged >50 years with LUTS due to BPH, participants were randomized to UroLift (n=100) or TURP (n=100) (total N=200). At 6 months, PUL was associated with a significant reduction in IPSS from baseline (46%; p=0.032), although the effect decreased over time. TURP was superior in improving IPSS, reducing reoperation rates (5% for TURP vs 40% for PUL at 4 years; p<0.05), and improving uroflowmetry outcomes (p<0.001 at 2 years). However, compared with TURP, UroLift was associated with a significantly lower need for postoperative catheterization (42.9% vs 100%; p<0.001), a lower rate of retrograde ejaculation (0% vs 90% at 6 months; p<0.001), and a shorter hospital stay (0.1 vs 1.3 days; p<0.001). Intraoperative hemorrhage was numerically lower with PUL (0% vs 13.3%), although the difference was not statistically significant [33]. Overall, PUL provides meaningful symptom improvement with a favorable perioperative and sexual-function profile, but with less durable symptom relief and higher retreatment rates in comparison with TURP.

TPLA (transperineal laser ablation)

TPLA (transperineal laser ablation) is a minimally invasive, percutaneous, transperineal, image-guided procedure that can be performed under local anesthesia. Through transperineal introducer needles placed into the prostate, laser optical fibers are inserted, and energy is delivered to induce localized thermal coagulative necrosis, followed by gradual tissue resorption and volume reduction. In an open-label, single-center, randomized trial enrolling surgically eligible men aged 18–75 years with symptomatic BPH (IPSS ≥10, Qmax <15 mL/s), prostate volume <100 mL, and preserved antegrade ejaculation, patients were randomized to TPLA (n=26) or TURP (n=25) (total n=51). The primary endpoint was ejaculatory function at 1 month (EJ-MSHQ), which remained unchanged after TPLA but decreased significantly after TURP; absence of antegrade ejaculation was reported in 1 patient after TPLA versus 18 after TURP. Both treatments improved symptom scores from baseline, whereas TURP achieved a significantly greater postoperative Qmax than TPLA (15.2 vs 26.0 mL/s; p<0.001). Patient satisfaction (EPIC question 32) favored TURP (80% vs 50%; p=0.02), while hospital stay was slightly longer after TURP (3 vs 2 days; p=0.008). In this small, randomized trial, TPLA was ejaculation-sparing and provided clinically meaningful symptom relief, but TURP delivered substantially greater improvement in urinary flow (Qmax) and higher patient-reported satisfaction, at the cost of markedly worse ejaculatory effects and a slightly longer hospital stay [34].

iTind/TIND (Temporary Implantable Nitinol Device)

iTind/TIND (Temporary Implantable Nitinol Device) is a minimally invasive transurethral endoscopic procedure that can be performed under local anesthesia. The device, consisting of three interconnected nitinol struts, is deployed into the prostatic urethra under endoscopic guidance (typically with a rigid cystoscope). Over 5–7 days, iTind expands and exerts radial force, producing controlled pressure effects at the bladder's neck and prostatic urethra, followed by tissue remodeling; the device is then removed. In a single-blinded, multicenter, randomized, sham-controlled trial, men aged ≥50 years with symptomatic BPH (IPSS ≥10, Qmax ≤12 mL/s, prostate volume 25–75 mL) were randomized to iTind (n=118) or sham (n=57) (total n=175). The primary endpoint—an IPSS improvement of ≥3 points at 3 months—was achieved in 78.6% of patients vs 60.0% (p=0.029), with durability to 12 months (p=0.009). However, at the blinded 3-month assessment, iTind did not demonstrate statistically significant between-group improvements versus sham in mean IPSS change (9.0 vs 6.6 points; p=0.063), QoL (4.6→2.7 vs 4.9→3.4; p=0.264), peak flow rate (8.7→13.1 vs 8.5→11.4 mL/s; p=0.230), or PVR (60.78→59.44 vs 61.9→66.9 mL; p=0.781). After unblinding at 3 months, follow-up continued to 12 months in the treated cohort, presenting significant improvements versus baseline in IPSS (22.64→12.69; p<0.0001), QoL (4.51→2.45; p<0.0001), and peak flow rate (8.42→11.93 mL/s; p<0.0001) [36]. In a sub-analysis assessing sexual function, there was no significant difference in total IIEF score between

iTind and sham at 3 months (41.47 vs 39.31; p=0.645) [35]. The iTind arm had higher rates of adverse events (38.1% vs 17.5%) and serious adverse events (urinary retention n=2, UTI n=2, sepsis n=1) compared with none reported in the control group [36]. iTind increased the 3-month responder rate versus sham, but did not show significant improvement in mean LUTS/uroflow outcomes at the blinded time point; post-unblinding data suggest sustained within-group improvement through 12 months, with sexual function appearing preserved, but adverse events—including SAEs—were more frequent than with sham.

Optilume BPH (drug-coated balloon)

Optilume BPH (drug-coated balloon, DCB) is a minimally invasive transurethral endoscopic procedure that can be performed under local anesthesia. Under cystoscopic guidance, the drug-coated balloon is positioned within the prostatic urethra and inflated for approximately 5 minutes to mechanically dilate the channel (including opening at the anterior commissure) while locally delivering paclitaxel; the device is then removed. In a key double-blind, multicenter, randomized, sham-controlled trial enrolling men aged 50–80 years with moderate-to-severe LUTS due to BPH (IPSS ≥13, Qmax 5–12 mL/s, prostate volume 20–80 g, and prostatic urethral length 32–55 mm), participants were randomized to Optilume BPH (n=100) or a sham procedure (n=48) (total n=148). The primary endpoint—change in IPSS from baseline to 12 months in the Optilume group compared with change from baseline to 3 months in the sham group—favored Optilume (11.5 vs 8.0 points; p=0.008). Among secondary comparative endpoints, Optilume was superior in improving Qmax (9.7 mL/s at 12 months vs 5.5 mL/s at 3 months in the sham group; p=0.009). At 12 months, Optilume also significantly improved QoL (4.6→2.2; p<0.0001), BPH Impact Index (BPH-II) (6.8→2.3; p<0.0001), and reduced PVR (83.2→58.0 mL; p=0.006), while sexual function remained largely stable (IIEF-EF 15.6→17.1; EjD 7.6→8.4) [37]. In the Optilume arm, five serious adverse events were reported (four episodes of hematuria requiring cystoscopic management and one urethral false passage), and 98 adverse events—typically mild to moderate—were reported, most resolving within 1 month [38]. The results were supported by additional publication [39]. Optilume BPH demonstrated clinically meaningful improvements regarding symptoms and flow versus sham, with generally preserved sexual/ejaculatory function, and while overall safety was acceptable, cystoscopy-requiring hematuria and rare access-related complications occurred.

Prostatic Artery Embolization (PAE)

Prostatic artery embolization (PAE) is an endovascular procedure, typically performed under local anesthesia, in which the prostatic arteries are catheterized and embolized using embolic particles to reduce prostatic perfusion. In the randomized, open-label, single-center trial enrolling men aged ≥40 years with TURP-eligible refractory LUTS (prostate volume 25–80 mL, IPSS ≥8, QoL ≥3, and Qmax <12 mL/s or urinary retention), PAE was compared with TURP (N=103). At 2 years, TURP achieved a significantly greater reduction in IPSS than PAE (−12.09 vs −9.21; p=0.047) and was superior in objective outcomes, including improvement in Qmax (10.23 vs 3.9 mL/s; p<0.001), reduction in postvoid residual volume (PVR) (204.0 vs 62.1 mL; p=0.005), and reduction in prostate volume (30.20 vs 10.66 mL; p=0.005), while adverse events were less frequent after PAE (43 vs 78 events; p=0.005) [40]. At 60 months of follow-up, TURP maintains superiority in IPSS reduction, which remained numerically smaller after PAE than after TURP (−7.78 vs −11.57; p=0.092), as well as in objective parameters, including improvement in Qmax (9.30 vs 3.59 mL/s; p=0.027) and reduction in PVR (219.97 vs 27.81 mL; p=0.001). The only exception was the International Index of Erectile Function (IIEF), which showed numerical improvement in the PAE group, but not reaching statistical significance (1.06 vs −1.50 points; p=0.053). In a group of 48 patients who underwent PAE, 20 of them (41.7%) required secondary intervention (TURP) due to unsatisfactory clinical outcomes [41]. Overall, PAE can provide durable symptom improvement in selected men prioritizing minimal invasiveness, but it is less effective than TURP and carries a substantial reintervention rate, despite a more favorable adverse-event profile.

Discussion

This systematic review addressed the predefined research objectives by critically synthesising randomised controlled trial evidence on nine modern minimally invasive and endoscopic techniques for the surgical treatment of lower urinary tract symptoms (LUTS) caused by benign prostatic hyperplasia (BPH), with a primary focus on clinical efficacy, safety, perioperative outcomes, sexual/ejaculatory function preservation, and durability compared with the reference standard (TURP) or sham procedures.

Regarding efficacy and functional outcomes, endoscopic enucleation techniques (HoLEP, ThuLEP, ThuFLEP, DiLEP, and bipolar/plasmakinetic enucleation) consistently presented non-inferior or superior improvements in IPSS, QoL, Qmax, and PVR to TURP, with particularly strong and durable performance in large-volume prostates (>80 mL). Laser vaporization methods (ThuVARP, GreenLight, diode, holmium Xpeeda) obtained comparable IPSS relief to TURP, although Qmax gains were occasionally inferior in the

largest trial. Aquablation met non-inferiority criteria versus TURP with sustained symptom and flow improvements through 5 years, showing a relative advantage in glands ≥50 mL. Among minimally invasive surgical therapies (MIST), Rezūm (water vapor thermal therapy) and Optilume provided clinically meaningful reductions in IPSS and QoL versus sham, while PUL/UroLift, TPLA, and iTind offered moderate symptom relief, with the key advantage of local anaesthesia. Prostatic artery embolisation (PAE) was consistently less effective than TURP in both subjective and objective parameters at 2–5 years.

Safety profiles and perioperative outcomes strongly favoured the novel techniques over TURP. Endoscopic enucleation and Aquablation showed significantly less intraoperative bleeding, shorter bladder irrigation and catheterisation times, and shorter hospital stays. The truly minimally invasive procedures (Rezūm, PUL, TPLA, iTind, Optilume) were associated with minimal perioperative morbidity and could often be performed in an office setting without general anaesthesia. PAE demonstrated the most favourable adverse-event profile overall. Overall complication rates were generally low across all modalities, although iTind reported higher rates of urinary retention and early adverse events compared with sham.

A major advantage of many newer techniques is the preservation of sexual and ejaculatory function. Aquablation, Rezūm, PUL, TPLA, iTind, and Optilume all demonstrated significantly better maintenance of antegrade ejaculation and erectile function than TURP. In contrast, enucleation and vaporization techniques carried retrograde-ejaculation rates similar to TURP.

Durability of treatment effect varied substantially. Endoscopic enucleation and Aquablation showed excellent long-term maintenance of symptom and flow improvements, with retreatment rates comparable to those of TURP. Rezūm demonstrated sustained benefit up to 5 years with acceptable reintervention rates. However, PUL, iTind, and especially PAE were associated with considerably higher reintervention rates (up to 40 % for PUL and 42 % for PAE), showing the trade-off between minimal invasiveness and long-term durability.

To summarize, modern techniques have substantially expanded the therapeutic options for BPH, allowing individualised treatment selection based on prostate volume, comorbidities, and patient priorities regarding sexual function versus maximal efficacy and durability. Endoscopic enucleation remains the preferred option for large prostates, while Aquablation, Rezūm, and selected MIST procedures offer an excellent balance for patients concerned about sexual side effects.

Limitations of this review include heterogeneity in follow-up duration, variable inclusion criteria for prostate size, and the fact that several MISTs have been evaluated primarily against sham rather than active surgical comparators. Further head-to-head RCTs with longer-term follow-up are needed to define better the precise role of each modality in contemporary clinical practice.

Conclusions

The available evidence from randomised controlled trials indicates that modern minimally invasive and endoscopic techniques for the treatment of lower urinary tract symptoms due to benign prostatic hyperplasia provide effective alternatives to conventional TURP, each with distinct advantages in clinical efficacy, perioperative recovery, safety, and preservation of sexual function.

These effects are consistently found across multiple RCTs comparing the nine evaluated procedures (endoscopic enucleation, laser vaporization, Aquablation, Rezūm/WVTT, PUL/UroLift, TPLA, iTind, Optilume, and PAE) to TURP or sham controls. Endoscopic enucleation techniques and Aquablation demonstrate durable, TURP-comparable or superior improvements in IPSS, QoL, Qmax, and PVR, particularly in large-volume prostates (>80 mL). Office-based MISTs (Rezūm, PUL, TPLA, iTind, Optilume) achieve clinically meaningful symptom relief and excellent preservation of ejaculatory and erectile function, while PAE offers moderate benefits but with lower objective efficacy.

Perioperative advantages, including reduced bleeding, shorter catheterisation time and hospital stay, as well as the possibility of local anaesthesia and outpatient treatment, are evident for the majority of novel techniques. Serious device- or procedure-related complications remain uncommon across all modalities.

The durability of treatment effect is well established for up to 5 years with endoscopic enucleation and Aquablation, whereas retreatment rates are higher with PUL, iTind, and especially PAE compared with TURP.

Taken together, the current evidence supports these modern techniques as valuable additions to the therapeutic armamentarium for BPH, allowing individualised treatment selection according to prostate volume, patient comorbidities, and priorities regarding sexual function, recovery time, and long-term durability. At the same time, the heterogeneity of follow-up durations, variable prostate-size inclusion criteria, and the limited number of large-scale head-to-head trials demonstrate the need for further adequately powered, long-term randomised studies to more precisely define the optimal role of each modality in contemporary clinical practice.

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