BJU Int 2025; **136:** 473–483 doi:10.1111/bju.16795

BJUI
BJU International

Original Article

Magnetic resonance imaging-guided transurethral ultrasound ablation for benign prostatic obstruction: 1-year clinical outcomes of a phase II study

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Objectives

To evaluate the safety and efficacy of magnetic resonance imaging (MRI)-guided transurethral ultrasound ablation (TULSA) as a minimally invasive alternative for benign prostatic obstruction (BPO).

Patients and Methods

This prospective, single-centre, early phase II study (NCT03350529) included 30 men with BPO scheduled for primary transurethral resection of the prostate. Assessments over 12 months included uroflowmetry, prostate-specific antigen (PSA) levels, and validated questionnaires at baseline and 3-month intervals. MRI was performed at baseline and at 3 and 12 months. Medication use and adverse events (AEs) were recorded and graded using the Clavien–Dindo classification.

Results

The median patient age at treatment was 67 years. During the 12-month post-TULSA follow-up, prostate volume decreased from a median of 52 to 32 mL, and PSA levels from 3.1 to 1.5 μg/L. The maximum flow rate increased from 11.1 to 18.3 mL/s ($P < 0.001$), and the average flow rate from 4.2 to 9.1 mL/s ($P < 0.001$). Residual volume decreased from 71 to 40 mL, and voided volume increased from 211 to 301 mL. The International Prostate Symptom Score (IPSS) decreased from 17 to 4 ($P < 0.001$), and IPSS quality of life score improved from 4 to 1 ($P < 0.001$). The 26-item Expanded Prostate Cancer Index Composite urinary irritative/obstructive scores improved from 66 to 94 ($P < 0.001$), and urinary incontinence scores improved from 86 to 100 ($P = 0.008$). Sexual function remained stable or improved. A total of 13 AEs were recorded, including 11 Grade II events (urinary tract infections/retentions) and one Grade IIIb event (epididymitis requiring drainage under general anaesthesia). All AEs resolved during follow-up.

Conclusions

Transurethral ultrasound ablation appears to be a safe and effective experimental treatment for BPO, demonstrating clinically marked improvements in urinary function and quality of life at 12 months while preserving continence and sexual functions. However, it is not yet recommended by guidelines, and long-term outcomes and validation in larger cohorts remain essential.

Keywords

TULSA, ablation therapy, transurethral ultrasound ablation, benign prostatic hyperplasia, benign prostatic obstruction, LUTS

Introduction

Benign prostatic obstruction (BPO), commonly caused by BPH, affects many men with LUTS [1]. When conservative treatments fail or complications arise, surgical intervention is often necessary. The current 'gold standard' for surgical management is TURP, with endoscopic enucleation techniques such as holmium laser enucleation of the prostate (HoLEP) and simple prostatectomy recommended for larger prostates [2]. While TURP is effective, it carries risks of adverse events (AEs), including UTI, bleeding, urinary incontinence, and sexual dysfunction [3–5]. HoLEP offers comparable efficacy to TURP and provides additional benefits, including shorter catheterisation and hospitalisation times, lower re-intervention rates, and suitability for anticoagulated patients [3,5–8]. However, both procedures demand specialised surgical expertise, and HoLEP has a steep learning curve [3,5,6].

Several minimally invasive surgical treatments (MIST), such as transurethral needle ablation, transurethral microwave thermotherapy, prostatic urethral implants (e.g., prostatic urethral lift [Urolift] and temporary implanted nitinol device [iTIND]), water vapour therapy (Rezūm), water ablation (Aquablation), prostate artery embolisation (PAE) and transperineal laser ablation [9], have also been explored for BPO treatment. While these options can provide effective symptom relief, they generally lack the long-term durability and symptom resolution achieved with TURP and HoLEP [10–12].

The MRI-guided transurethral ultrasound ablation (TULSA) is an emerging minimally invasive technique for the treatment of prostate diseases, including BPO. TULSA employs a high-intensity linear ultrasound transducer within the prostatic urethra to deliver precise, localised thermal ablation. The procedure is tailored to individual anatomy using MRI and real-time thermal monitoring with MRI-thermometry [13,14]. While various transperineal and transrectal imaging-guided ablation techniques have also been investigated for BPO treatment, TULSA is currently the only transurethral ablation technology. It allows inside-out ablation of all prostate regions within a 3 cm radius from the urethra through a 50 mm long therapeutic window, offering the potential to address significantly enlarged transition zones.

We previously conducted a phase I study with 10 patients to evaluate the safety and feasibility of TULSA for BPO treatment. The results demonstrated substantial improvements in urinary symptoms, urinary flow rates, and prostate volume, with no severe AEs or negative impact on continence, sexual, erectile, or bowel functions [14]. Encouraged by these results, we expanded the study to include 30 patients. This paper reports the 1-year clinical follow-up outcomes for all 30 patients, providing a broader assessment of TULSA's safety and efficacy as a treatment for BPO.

Patients and Methods

Study Design

This investigator-initiated, prospective, non-randomised, single-centre, early phase II study was approved by the Ethics Committee and registered at clinicaltrials.gov (NCT03350529). Building on the promising 12-month results from our previous phase I TULSA study, the cohort was expanded to include 30 patients, incorporating the previously reported phase I participants (n = 10) to further evaluate safety and efficacy. Written informed consent was obtained from all participants before screening. The study adhered to the principles of the Declaration of Helsinki.

Patients

Men with symptomatic BPO due to BPH who were scheduled for primary TURP were recruited. In our institution, patients with prostates >100 mL are typically considered for adenomectomy, effectively limiting our study population to prostates around or under 100 mL. Inclusion criteria required predominantly enlarged transition zones, as confirmed by TRUS, cystoscopy, and MRI; patients with enlarged middle lobes were included if the transition zones were predominantly enlarged. Exclusion criteria were suspicion of prostate cancer (PCa), calcifications or prostate cysts >1 cm in the anticipated treatment sector, MRI contraindications, hip prosthesis or other metal in the pelvic area, or any other condition deemed exclusionary by the treating physician. These criteria were consistent for both the initial 10 patients and the subsequent 20 patients.

Study Intervention

The treatments were performed using the TULSA-PRO system (Profound Medical Inc., Mississauga, Ontario, Canada), integrated with a 3.0-T MRI scanner (Ingenia 3.0 T; Philips Healthcare, Best, The Netherlands). Antibiotic prophylaxis with levofloxacin 500 mg was administered intravenously during anaesthesia induction, unless bacteria were detected in the preoperative urine sample, in which case an alternative antibiotic was selected based on urine culture and susceptibility testing. Each procedure was individually tailored to target adenomatous tissue within the transition zones, including the middle lobe when present. If undertreatment was suspected on MRI-thermometry, an additional sonication round was applied to ensure adequate ablation.

The treatments were conducted under general anaesthesia, with a urinary catheter placed during the procedure. The

choice of catheter type was influenced by factors such as the treatment extent, patient preference, and bladder emptying capability at baseline. A suprapubic catheter (SPC) was preferred if a longer duration of catheterisation was anticipated. Patients were discharged from the hospital with the catheter in place.

Patients were monitored overnight in the urological ward as per protocol. At discharge, they were prescribed paracetamol and NSAIDs for pain relief as needed. Further details of the intervention protocol are provided in Appendix S1.

Follow-Up

The frequency and severity of AEs were recorded and graded according to the Clavien–Dindo Classification for Surgical Complications [15]. Safety data were collected prospectively through chart reviews and face-to-face interviews conducted by clinical investigators at each follow-up visit. Severe genitourinary and gastrointestinal toxicities, defined as Clavien-Dindo Grade ≥III events or toxicity requiring hospitalisation, were specifically monitored.

Clinical outcomes were assessed at baseline and at 3, 6, 9, and 12 months following TULSA. These assessments included uroflowmetry, PSA levels, MRI-based prostate volume, and patient-reported outcomes collected via standardised questionnaires.

Uroflowmetry parameters included maximum flow rate (Q_{max}), average flow rate (Q_{ave}), voided volume, and post-void residual volume (PVR), assessed by ultrasonography. Patient-reported outcomes were collected using the 26-item Expanded Prostate Cancer Index Composite (EPIC-26) (Urinary incontinence domain minimal clinically important difference [MCID] ≥6; Urinary irritation/obstruction domain MCID ≥5; Bowel domain MCID ≥4; Hormonal domain MCID ≥4; Sexual domain MCID ≥10), IPSS (MCID ≥5; IPSS quality of life [QoL] MCID ≥1), and the five-item version of the International Index of Erectile Function (IIEF-5) [16,17]. Erectile function was further assessed using the IIEF-5 Question 2 (erection sufficient for penetration: score ≥3). Leak- and pad-free continence were evaluated using EPIC-26 Question 1 (leak-free: score ≥4, defined as leakage about once a week) and Question 3 (pad-free: score 0, defined as no pads required).

Prostate MRI took place immediately after treatment and at 3- and 12-months post-TULSA, with prostate volumes estimated using the ellipsoid method. Catheter removal visit, planned 2 weeks after TULSA, included voiding trial and PVR measurement to confirm adequate bladder emptying. Patients with a SPC also kept a residual diary for 3 days prior to removal to ensure reliable bladder function. The use of LUTS medications was documented both before and after treatment.

Additionally, outpatient flexible cystoscopy was performed at the 12-month follow-up to evaluate bladder and urethral integrity.

Sample Size Estimation, Clinical Phase Designation, and Endpoints

This study was designed as an early phase II trial to evaluate TULSA as a definitive treatment for BPO. Following promising safety and efficacy trends observed in our initial phase I study, we expanded the cohort to 30 patients to enable a more comprehensive assessment of treatment outcomes. The primary efficacy endpoints were improvements in IPSS and Q_{max} at 12 months, while the primary safety endpoint was the frequency and severity of AEs recorded over 12-month follow-up period.

Given the exploratory nature of this first-of-its-kind study, no formal power calculation was performed. Instead, the sample size was determined based on practical and ethical considerations, ensuring a sufficient dataset to inform future larger, controlled studies. Our study design aligns with established frameworks for transitioning from feasibility to early efficacy assessment in medical device trials [18,19].

Statistical Analysis

All statistical analyses and graphing were performed using R (version 4.2.2.; R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria). Descriptive statistics were used to summarise patient characteristics, treatment details, and follow-up data. Boxplots were used to visualise numerical variables. Data points located further than 1.5 times the interquartile range (IQR) from the box were considered as outliers and not visualised.

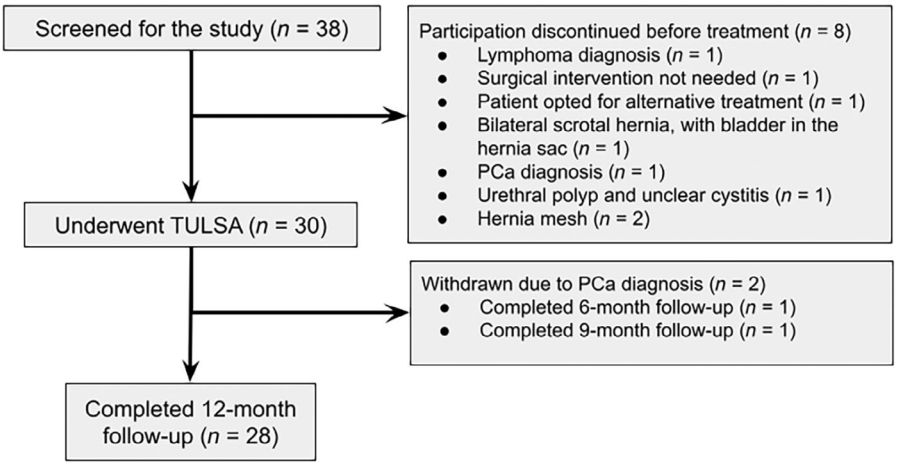
Statistical significance was evaluated using the two-sided Wilcoxon paired test for comparisons between baseline and 3 months, baseline and 12 months, and between 3 and 12 months. Correlations between prostate volume, ablation time and catheterisation duration were evaluated using Pearson's correlation coefficient r, with 95% CIs reported. A $P < 0.05$ was considered statistically significant. Missing data were not imputed.

Results

Patient Characteristics

The study recruitment is outlined in the flowchart (Fig. 1). Of the 38 patients screened, 30 underwent treatment, and 28 completed the 12-month follow-up. Two patients were withdrawn after PCa diagnoses at 6 and 9 months. Figure 1 details the reasons for patient exclusions during screening.

Fig. 1 Study flowchart. Men with symptomatic BPO due to BPH who were scheduled for primary TURP at the Turku University Hospital were enrolled. One patient with a single subcapsular peripheral zone Prostate Imaging-Reporting and Data System (PI-RADS) 4 lesion suspicious for PCa was included in the study after negative systematic and targeted biopsy findings. The TULSA ablation plan for this patient specifically excluded the PI-RADS 4 lesion. However, due to the persistence of the PI-RADS 4 lesion on follow-up MRI, this patient underwent a re-biopsy, which confirmed a PCa diagnosis. In another case, a new PIRADS 4 lesion was detected in the follow-up MRI. Subsequent biopsy confirmed a PCa diagnosis.



Baseline characteristics of the patient population are summarised in Table 1. The median (IQR) age was 67 (64–72) years, with a BMI of 26 (20–25) kg/m^2, prostate volume of 52 (48–65; range: 29–107) mL, and PSA levels of 3.1 (2.3–6.3) μg/L. Charlson's Comorbidity Index scores were distributed as follows: four patients scored 1, 12 scored 2, 11 scored 3, and three scored 4.

Before treatment, 28 of 30 patients (93%) were using medication for BPO, including α-blockers, 5α-reductase inhibitors (5-ARI), or combinations of these. The remaining two patients were not using α-blockers or 5-ARI due to intolerable side effects. Despite widespread medication use, 90% of patients reported moderate or severe urinary symptoms, with a median (IQR) Q_{max} of 11.1 (7.9–14.6) mL/s. The median IPSS QoL score was 4, reflecting dissatisfaction with urinary symptoms.

In all, 12 patients (40%) had a history of BPO-related complications, including urinary retention (five patients), UTI (five), and macrohaematuria (two). Three patients were catheter-dependent due to urinary retention before undergoing TULSA treatment. One patient was diagnosed with Peyronie's disease during screening and had severe erectile dysfunction.

Five patients (17%) were on anticoagulant or antithrombotic medication (warfarin, rivaroxaban, or acetylsalicylic acid), none of whom discontinued medication before TULSA. Phosphodiesterase type 5 inhibitors (PDE5 inhibitors) were used by six patients (20%) to improve erectile function. Three patients (10%) were receiving testosterone replacement therapy, which was continued after the TULSA procedure.

At baseline, 86% of patients were leak-free, 100% were pad-free, and 64% reported erections sufficient for penetration, with or without medication (Table 1).

Procedural Outcomes and Follow-Up

The TULSA procedure was technically successful in 29 out of 30 treatments, with a median (IQR) ablation time of 39 (24–55) min. A moderate correlation was demonstrated between prostate volume and ablation time (r = 0.57, 95% CI 0.25–0.77; P = 0.001), regardless of whether patients received one (20 patients) or two sonications (nine) (Fig. S1). In one patient, only a quarter of a transducer round could be performed due to device malfunction, leaving the ablation incomplete.

Following the procedure, patients were hospitalised for 12–24 h, except one patient who remained hospitalised for 48 h due to logistical reasons. A SPC was placed in 28 patients, while an indwelling transurethral catheter was used in two. The median (IQR) catheterisation duration was 17 (15–23) days. No significant correlation was observed between prostate volume and catheterisation duration or between ablation time and catheterisation duration (Fig. S2).

Of the 28 patients using BPO medication prior to TULSA, 27 discontinued it after the procedure. For two patients, BPO medication was resumed briefly during the first few months following the procedure and then discontinued. During follow-up, nine patients (30%) were prescribed mirabegron for urinary urgency or frequency, most of them within the first 3 months after TULSA. One of these patients had also used mirabegron before TULSA. In eight of the nine patients

Table 1 Patients' characteristics at baseline.

Characteristic	Value
Age, years, median (IQR)	67 (64–72)
BMI, kg/m^2, median (IQR)	26 (25–30)
PSA level, μg/L, median (IQR)	3.1 (2.3–6.3)
Creatinine level, μmol/L, median (IQR)	83 (73–93)
Prostate volume*, mL, median (IQR)	52 (48–65)
Charlson Comorbidity index, *n* (%)	
1	4 (13)
2	12 (40)
3	11 (37)
4	3 (10)
Anticoagulative/antithrombotic medication, *n* (%)	5 (17)
Acetylsalicylic acid	3 (10)
Rivaroxaban	1 (3)
Warfarin	1 (3)
BPO medication, *n* (%)	28 (93)
α-blocker	6 (20)
α-blocker + 5α-reductase inhibitor	21 (70)
5α-reductase inhibitor	1 (3)
Erection medication (PDE5 inhibitors), *n* (%)	6 (20)
Testosterone replacement therapy, *n* (%)	3 (10)
History of urinary retention before TULSA, *n* (%)	5 (17)
History of urinary infection before TULSA, *n* (%)	5 (17)
History of macroscopic haematuria before TULSA, *n* (%)	2 (7)
Uroflowmetry parameters, median (IQR)	
Q_{max}, mL/s	11 (8–14)
Average flow, mL/s	4 (3–7)
Residual volume, mL	71 (42–235)
Voided volume, mL	211 (149–328)
IPSS symptoms score, points	17 (12–22)
Mildly symptomatic (0–7 points), *n* (%)	1 (3)
Moderately symptomatic (8–19 points), *n* (%)	16 (53)
Severely symptomatic (20–35 points), *n* (%)	11 (37)
IPSS QoL score, median (IQR)	4 (3–4)
Leak free continence (EPIC-26 Question 1 ≥4), *n/N* (%)	25/29 (86)†
Pad free continence (EPIC-26 Question 3 =0), *n/N* (%)	29/29 (100)†
Erection sufficient for penetration (IIEF-5 Question 2 ≥3), *n/N* (%)	18/28 (64)‡

**MRI-based measurement using the ellipsoid method. †One patient had a Foley catheter at the baseline. ‡Two patients had not answered the question.*

mirabegron was discontinued after a few months due to either lack of efficacy or spontaneous resolution of storage symptoms over time. For the patient whose treatment was incomplete, BPO medication and mirabegron were used throughout the follow-up. Eventually, a second-line treatment was pursued due to insufficient clinical outcomes.

During the 12-month follow-up, 13 of 30 patients (43%) were prescribed PDE5 inhibitors on an as-needed basis after a 3-month follow-up visit, including six patients who had been using PDE5 inhibitors prior to TULSA. Newly prescribed PDE5 inhibitors during recovery were initiated for patients who reported unchanged erectile function after TULSA, indicating an unmet need for treatment that had not been addressed prior to the intervention. For the patient with Peyronie's disease, TULSA did not impact the severity of the condition or the quality of erections. The disease was managed with PDE5 inhibitors and alprostadil during follow-up.

Cystoscopy performed at 12 months revealed no urethral or bladder neck strictures in any patients.

Safety Outcomes

A total of 13 AEs were reported in 11 patients (Table 2). Notably, no intraoperative complications, including bleeding, occurred, and early postoperative recovery was uneventful. No additional analgesics beyond paracetamol and NSAIDs were required at discharge. One patient, who was on acetylsalicylic acid, experienced Grade I haematuria without clotting on the treatment day, but no patients required an irrigation catheter, as there were no cases of gross haematuria. Additionally, no antibiotics were required for infection during the immediate postoperative period.

Epididymitis occurred in three patients: one progressed to an abscess requiring drainage under general anaesthesia (Grade IIIb), one was treated with intravenous antibiotics (Grade II), and one with oral antibiotics (Grade II). Urinary retention (Grade II) was reported in four patients, two of whom had concomitant UTIs. Overall, eight patients experienced UTIs; one required hospitalisation, and the others were managed on an outpatient basis.

Most AEs occurred and resolved by the 3-month follow-up visit, except for one UTI that developed around the 6-month time point. Severe genitourinary toxicity (Clavien-Dindo ≥III or toxicity requiring hospitalisation) was observed in three of

Table 2 The AEs associated with the MRI-guided TULSA for BPO.

Characteristic	*n/N* (%)
Overall number of patients with any AE	11
Overall number of AEs	13
Overall number of AEs within 90 days	12
Grade I	1/12 (8)
Grade II	10/12 (83)
Grade IIIb	1/12 (8)
Types of AEs within 90 days	
Haematuria	1/12 (8)
UTI	4/12 (33)
UTI and urinary retention	2/12 (17)
UTI and epididymitis	1/12 (8)
Urinary retention	2/12 (17)
Epididymitis	2/12 (17)
Overall number of AEs after 90 days	1
Grade II	1/1
Types of AEs after 90 days	
UTI	1/1

The AEs were recorded at each follow-up visit using the Clavien–Dindo classification for surgical complications. Continuation of catheterisation following an unsuccessful catheter removal trial was not classified as an AE. However, urinary retention requiring re-catheterisation after an initially successful catheter removal was classified as a Grade II AE.

the 30 patients (10%). No gastrointestinal toxicity occurred in any patients throughout the study.

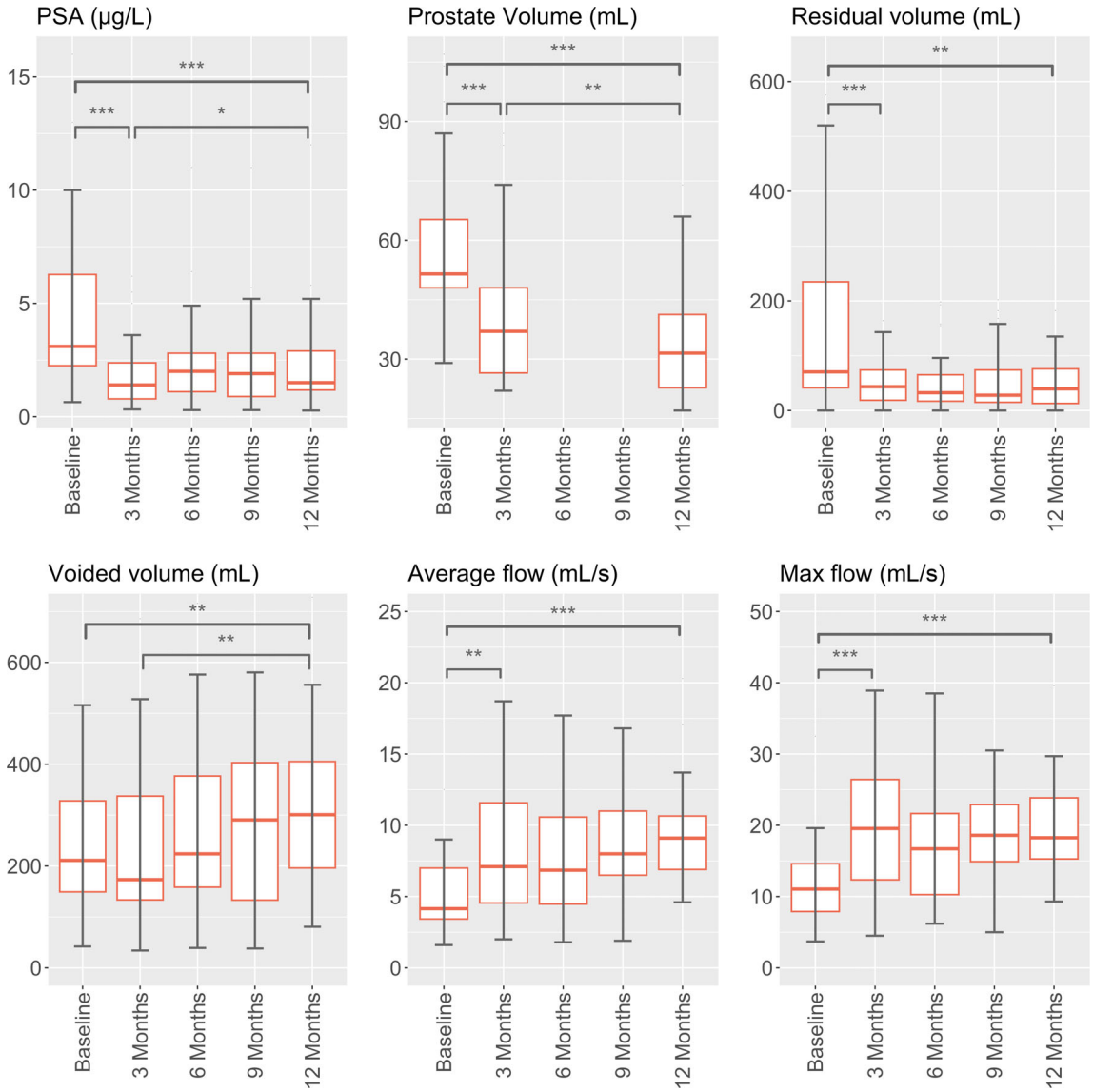
Prostate Volume and PSA

Significant reductions were observed in median prostate volume and PSA levels (Fig. 2). Between baseline and 12 months, the median (IQR) prostate volume decreased from 52 (48–65) to 32 (23–41) mL ($P < 0.001$), and the PSA levels dropped from 3.1 (2.3–6.3) to 1.5 (1.2–2.9) μg/L ($P < 0.001$). The most pronounced reductions in both parameters occurred within the first 3 months.

Uroflowmetry Outcomes

Clinically marked improvements were observed in all uroflowmetry parameters during the follow-up (Fig. 2). Between baseline and 12 months, the median (IQR) Q_{max} improved from 11.1 (7.9–14.6) to 18.3 (15.3–23.9) mL/s ($P < 0.001$), Q_{ave} from 4.2 (3.4–7) to 9.1 (6.9–10.7) mL/s ($P < 0.001$), PVR from 71 (42–235) to 40 (13–76) mL ($P = 0.006$), and voided volume from 211 (149–328) to 301 (196–405) mL ($P = 0.005$).

Fig. 2 Prostate volume, PSA, and uroflowmetry outcomes at baseline, 3, 6, 9, and 12 months. Boxplot: median and IQR values. Whiskers: minimum and maximum values (outliers omitted). Explanation for annotations: *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.



Quality of Life Outcomes

Figure 3 summarises outcomes from the patient-reported functional status and QoL questionnaires. Substantial improvements were observed in all measured outcomes except for the IIEF-5, which showed no overall significant change.

The median (IQR) IPSS improved from 17 (12–22) at baseline to 4 (2–7) at 12 months ($P < 0.001$), having already decreased to 3 at 6 months. The number of mildly (IPSS 0–7), moderately (IPSS 8–19), and severely symptomatic (IPSS 20–35) patients shifted from one, 16, and 11 at baseline to 22, 5, and one at 12 months, respectively. The remaining severely symptomatic patient at 12 months was the same individual in whom only a quarter of the planned sonication round could be performed due to technical issues.

The median (IQR) IPSS QoL scores improved markedly from 4 (3–4) at baseline to 1 (0–2) at 12 months ($P < 0.001$). Similarly, significant improvements were observed in EPIC-26 domains: urinary irritative/obstructive scores increased from 66 (56–75) to 94 (88–100) ($P < 0.001$), urinary incontinence from 86 (73–100) to 100 (86–100) ($P = 0.008$), sexual from 54 (21–67) to 62 (28–83) ($P < 0.001$), bowel from 88 (79–96) to 100 (92–100) ($P = 0.001$), and hormonal from 95 (85–100) to 100 (95–100) ($P = 0.050$).

Improvements in IPSS, IPSS QoL, and EPIC-26 urinary irritative/obstructive scores were observed by 3 months, whereas improvements in EPIC-26 incontinence, bowel, sexual and hormonal domains developed more gradually over 12 months (Fig. 3).

At 12 months, all patients (28/28) had leak-free continence, and 96% (27/28) reported pad-free continence, with one patient requiring 1 pad/day. Erections sufficient for penetration were reported by 64% (18/28) of patients at baseline and 70% (19/27) at 12 months. Among patients with sufficient erections at baseline, 94% (17/18) retained erectile function at 12 months.

Discussion

Our study is the first prospective investigation to evaluate TULSA as a first-line treatment for BPO. Clinical outcomes in this cohort of 30 men were excellent, reinforcing findings from our initial study of 10 patients.

The treatment resulted in significant reductions in median prostate volume (38%) and PSA levels (52%), with marked improvements in uroflowmetry parameters: Q_{max} increased by 64%, Q_{ave} by 117%, voided volume by 43%, and PVR decreased by 44%. Notably, 27 of the 28 patients who discontinued BPO medication maintained these improvements, underscoring the effectiveness of TULSA in alleviating urinary symptoms and improving QoL.

As TULSA is performed under general anaesthesia, it is most appropriately compared with conventional surgical therapies rather than with MISTs performed under local anaesthesia. Systematic reviews indicate that while procedures such as TURP and HoLEP offer excellent symptomatic relief, their resective nature is associated with significant intra- and perioperative complications [20,21]. For example, HoLEP has been associated with complications such as incomplete morcellation (2.3%), capsular perforation (2.2%), and bladder injuries (2.4%), as well as with perioperative bleeding-related complications [20]. In contrast, our findings indicate that TULSA, through its targeted thermal ablation, achieves comparable improvements in urinary parameters while minimising intra- and perioperative complications. Although TULSA is less invasive—being incision-free and relying on thermal ablation rather than tissue resection—some may still classify it as a minimally invasive procedure.

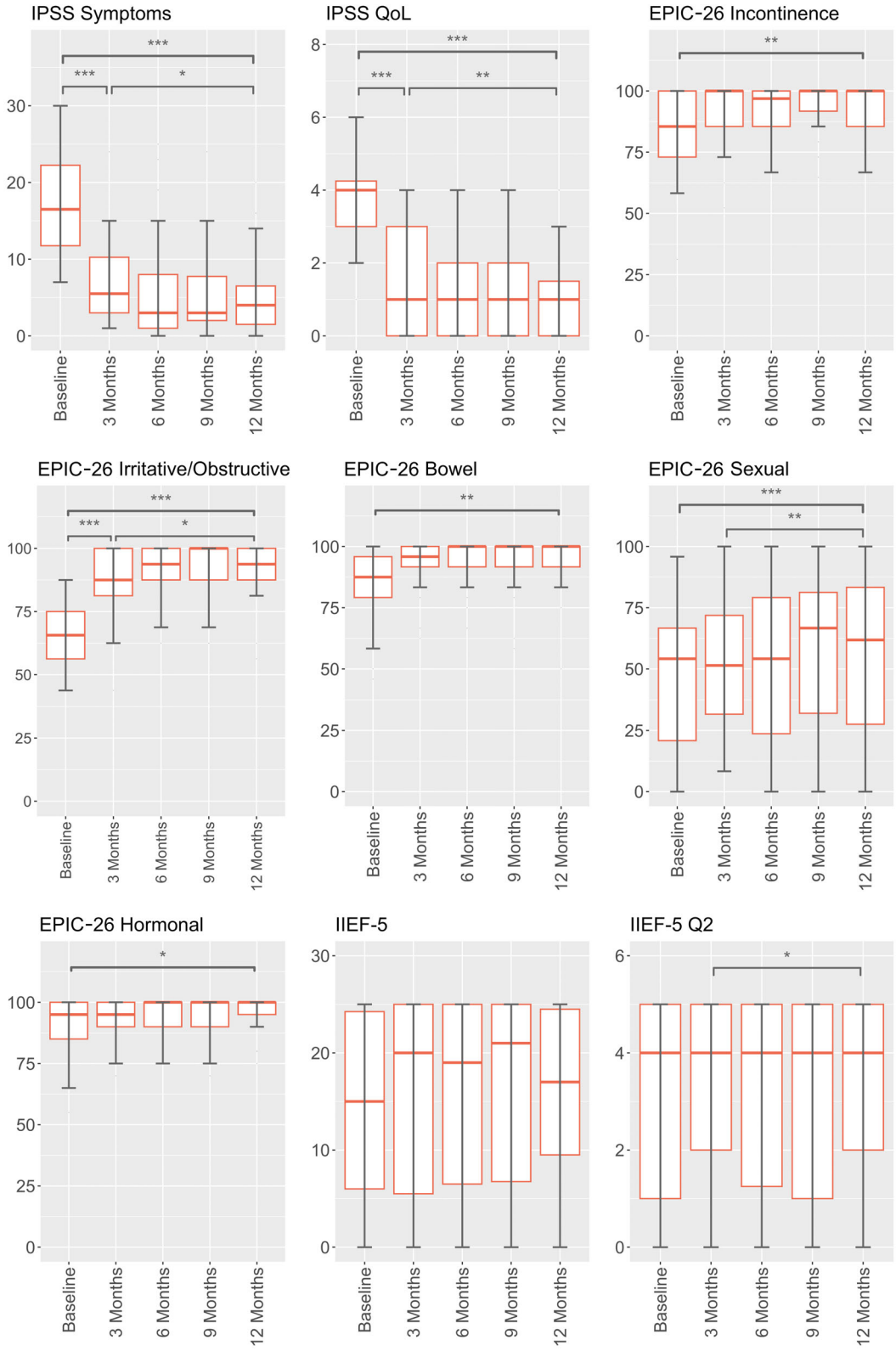
In a recent meta-analysis, pooled mean improvements for alternative MISTs (including Urolift, Rezūm, iTIND, and PAE) at 12 months were as follows: IPSS decreased by 13.1 points, IPSS QoL improved by 2.5 points, Q_{max} increased by 4.1 mL/s, and PVR decreased by 10.1 mL [22]. In our study, by 12 months, the median IPSS decreased by 13 points, IPSS QoL improved by 3 points, Q_{max} increased by 7.1 mL/s, and PVR decreased by 31 mL. While comparisons between studies are inherently limited due to variations in patient populations, methodologies, and reporting, these findings suggest that TULSA achieves outcomes comparable to or exceeding those reported for other MISTs, with substantial improvements in urinary function and symptom relief.

Continence outcomes were favourable, with significant improvements in EPIC-26 urinary incontinence scores. By 12 months, all patients achieved leak-free continence, and 96% were pad-free. These results highlight the potential of TULSA to preserve continence after treatment.

Sexual health outcomes were similarly promising. EPIC-26 sexual domain scores improved significantly, while IIEF-5 scores remained unchanged. However, one additional patient reported erections sufficient for penetration at 12 months compared to baseline. These findings suggest that TULSA preserves erectile function. Meanwhile the cessation of 5-ARI medications, which are known to adversely affect sexual health, likely contributed to the improvement of sexual function. Importantly, newly prescribed PDE5 inhibitors during recovery addressed pre-existing concerns identified during structured follow-up rather than TULSA-induced changes.

A favourable safety profile was demonstrated for TULSA, with one Grade IIIb event – a single epididymal abscess requiring drainage under general anaesthesia. Severe genitourinary toxicity occurred in two additional patients: one

Fig. 3 The QoL outcomes at baseline, 3, 6, 9, and 12 months. Boxplot: median and IQR values. Whiskers: minimum and maximum values (outliers omitted). Explanation for annotations: *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$. In the IIEF-5 Question 2, although the median value remained the same in all time points, there was a statistically significant improvement ($P < 0.01$) between 3 and 12 months in the paired Wilcoxon test; the score increased in seven patients and decreased only in one patient.



with epididymitis and another with a UTI, both requiring hospitalisation. All other AEs were mild, anticipated, and resolved during follow-up. While the rate of infectious complications was notable, including some requiring hospitalisation, the overall safety profile of TULSA remains comparable to MISTs [22]. The absence of complications such as bleeding, continuous bladder irrigation, and re-interventions for haematuria, commonly seen with TURP, highlights the potential of TULSA as a safer alternative regarding perioperative bleeding risks. This is particularly noteworthy given that anticoagulant and antithrombotic medications used by five patients were not discontinued before the procedure [3–5].

Most AEs and toxicity, including urinary retention, UTIs, and LUTS, occurred during catheterisation or shortly after catheter removal. These issues were likely due to transient oedema, tissue healing, catheter-related irritation, and sloughing of necrotic tissue in the urine, which can obstruct urinary flow. Mirabegron was prescribed briefly during the early post-TULSA period to manage irritative symptoms but was discontinued as symptoms resolved spontaneously. Clinical improvements occurred mostly by 3 months, with additional gains up to 12 months. However, the improvement in voided volume on uroflowmetry was delayed beyond 3 months and became clinically relevant by 12 months, likely due to the resolution of storage symptoms contributing to increased bladder capacity.

Catheter management remains challenging following TULSA. Both early removal and prolonged use carry risks of urinary retention and UTIs. In this study, a 2-week catheterisation protocol was adopted, resulting in a median catheterisation duration of 17 days. SPCs were preferred over transurethral catheters for easier monitoring of bladder emptying. Unlike transurethral catheters, which must be removed to assess spontaneous voiding, SPCs enable ongoing assessment without catheter re-insertion, reducing the risks of complications. Both patients who had transurethral catheters experienced urinary retention and UTI shortly after catheter removal, highlighting the challenges associated with this approach. Occasionally, replacing a transurethral catheter after removal can be technically challenging after TULSA, likely due to the catheter's propagation under the bladder neck during insertion.

Future research should investigate optimal catheterisation protocols, including the potential use of thermo-expandable urethral stents, such as Memokath [23,24,25], to ensure spontaneous voiding, maintain bladder emptying, and improve patient comfort during the transient oedema phase and sloughing of necrotic tissue. Additionally, it remains to be studied whether catheterisation could be avoided in select patients undergoing ablation of smaller prostates.

Non-circumferential ablation may also reduce oedema-related obstruction, although further research is needed to confirm these hypotheses.

The TULSA's MRI-guided precision enables tailored treatment, sparing of critical structures and preserving continence and erectile function. Unlike many MISTs, TULSA has no significant size limitations. In this study, seven patients had prostate volumes of ≥80 mL, including two exceeding 100 mL. However, treating larger prostates requires longer ablation times. The resolution of larger necrotic tissue volumes associated with larger prostates may contribute to prolonged recovery periods. Nevertheless, no associations were observed between prostate volume or ablation time and catheterisation duration in our study.

Transurethral ultrasound ablation is among the few technologies investigated for both PCa and BPH [26–29], with the potential to treat both conditions in a single session. Studies have also demonstrated its repeatability, adding to its versatility [30,31]. These advantages suggest potential clinical benefits and resource efficiencies, particularly for healthcare systems managing BPH, PCa, or a combination of both.

Despite its promise, TULSA has limitations. The procedure requires prolonged MRI-suite occupation and general anaesthesia with MRI-compatible equipment, contributing to logistical and financial challenges. Widespread adoption will not only depend on clinical outcomes but also on logistical feasibility, resource allocation, and cost considerations. Furthermore, the integration of TULSA into clinical practice may impact the roles of urologists and radiologists, as MRI-guided procedures require interdisciplinary collaboration. While TULSA remains a urologist-led intervention, radiology expertise is essential for procedural planning and execution. In our initial experience, the overall procedure duration was extended by the learning curve and workflow constraints; in our institution, we are currently able to treat two patients with BPH per normal 8-h workday. The technical complexity of TULSA underscores the need for specialised training and expertise, which may further influence its accessibility and implementation in routine practice.

However, TULSA offers advantages in postoperative care. Patients experience minimal pain, do not require irrigation catheters, and are typically discharged the day after the procedure, compared to TURP patients who are usually discharged on postoperative Day 2 [22]. In our study, five patients were discharged on the same day as the procedure. All others were discharged on the first postoperative day, except for one patient who was discharged on the second postoperative day due to logistical reasons. We believe that same-day discharge is feasible for more patients with proper

preoperative counselling and guidance on SPC use, representing an area for improvement in TULSA protocols.

This study is limited by its non-randomised, single-arm, single-centre design, the absence of a control group, and its relatively small sample size. In general, multiple statistical testing increases the risk of false positive findings; however, in our study, improvements across all key outcome measures were both clinically and statistically significant, strengthening the robustness of our findings. Nonetheless, randomised controlled trials are essential to fully assess the benefits and risks of TULSA compared to established treatments such as TURP and HoLEP. Furthermore, only the ablation time was recorded rather than the overall procedural time, and systematic assessment of ejaculatory function was not conducted in the subsequent 20 patients. Notably, in our previously published phase I cohort [14], five out of six men with normal pre-TULSA ejaculatory function preserved antegrade ejaculation at 12 months. While the EPIC-26 sexual domain provides an overall measure of patient satisfaction with sexual function, it does not specifically assess ejaculatory function. These limitations should be addressed in future studies to better delineate procedural efficiency and sexual outcomes associated with TULSA.

Conclusions

This prospective early phase II study demonstrates that TULSA is a safe and effective treatment for BPO, offering significant improvements in urinary symptoms, QoL, and sexual function. These findings position TULSA as a promising alternative to traditional surgical treatments, particularly for patients seeking minimally invasive, function-preserving options. However, further research, including randomised controlled trials and long-term follow-up, is essential to validate these results, assess their durability, and address the logistical and financial challenges associated with the procedure. Until then, TULSA remains an experimental technique without guideline recommendations.

Acknowledgements

We thank all the patients and referring physicians who made this study project possible. We also want to thank the staff team of the urological outpatient clinic at Turku University Hospital for their contribution to the project. Open access publishing facilitated by Turun yliopisto, as part of the Wiley - FinELib agreement.

Funding

Although the trial was investigator-initiated, the funding for therapies reported here was provided by the device manufacturer, Profound Medical Corp. Our study was planned and implemented solely by the clinical authors.

Disclosure of Interests

Antti Viitala reports grants from TYKS Foundation, the Finnish Radiological Society, and University of Turku. Mikael Anttinen reports grants and honorariums from Profound Medical Inc, TYKS Foundation, Ida Montini Foundation, Emil Aaltonen Foundation, the Finnish Urological Research Foundation and the Finnish Urological Association. Pietari Mäkelä reports grants and honorariums from the Finnish Radiological Society and the Cancer Foundation Finland. Pekka Taimen reports grants from the Cancer Foundation Finland and personal fees from Roche and AstraZeneca. Peter J. Boström reports grants from the Cancer Foundation Finland, personal fees from Profound Medical Inc and Janssen-Cilag Company. The other authors declare that there is no conflict of interest regarding the publication of this article.

Data Availability Statement

De-identified data can be made available upon a reasonable request for a period of 5 years after the publication of the article. Proposals for access to the data should be directed to mikael.hogerman@varha.fi. Requesters will need to sign a data access agreement.

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Abbreviations: 5-ARI, 5α-reductase inhibitors; AE, adverse event; BPO, benign prostatic obstruction; EPIC-26, 26-item Expanded Prostate Cancer Index Composite; HoLEP, holmium laser enucleation of the prostate; IIEF-5, five-item version of the International Index of Erectile Function; IQR, interquartile range; iTIND, temporary implanted nitinol device; MCID, minimal clinically important difference; MIST, minimally invasive surgical treatment; PAE, prostate artery embolisation; PCa, prostate cancer; PDE5 inhibitor, phosphodiesterase type 5 inhibitor; PI-RADS, Prostate Imaging-Reporting and Data System; PVR, post-void residual; Q_{ave}, average flow rate; Q_{max}, maximum flow rate; QoL, quality of life; SPC, suprapubic catheter; TULSA, transurethral ultrasound ablation.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Fig. S1. Correlation between the prostate volume and ablation time.

Fig. S2. Upper image: sonication time and catheterisation time. No significant correlation between the parameters was detected. Pearson's correlation coefficient, 95% CIs and *P* value shown in the image. Lower image: prostate volume and catheterisation time. No significant correlation between the parameters was detected. Pearson's correlation coefficient, 95% CIs and *P* value shown in the image.

Appendix S1. Description of the TULSA procedure.