# Aquablation therapy for symptomatic benign prostatic hyperplasia: a single-centre experience in 47 patients

Mihir M. Desai*, Abhishek Singh†, Shashank Abhishek†, Abhishek Laddha†, Harshad Pandya†, Akbar N. Ashrafi*, Arvind P. Ganpule†, Claus G. Roehrborn‡, Andrew J. Thomas§, Mahesh Desai† and Ravindra B. Sabnis†

*USC Institute of Urology, University of Southern California, Los Angeles, CA, USA, †Department of Urology, Muljibhai Patel Urological Hospital, Nadiad, India, ‡Department of Urology, UT Southwestern Medical Center, Dallas, TX, USA, and §Department of Urology, Princess of Wales Hospital, Bridgend, UK

## Objective

To report procedure process improvements and confirm the preserved safety and short-term effectiveness of a second-generation Aquablation device for the treatment of lower urinary tract symptoms (LUTS) attributable to benign prostatic hyperplasia (BPH) in 47 consecutive patients at a single institution.

## Patients and Methods

Aquablation was performed in 47 patients with symptomatic BPH at a single institution. Baseline, peri-operative and 3-month urinary function data were collected.

## Results

The mean (range) patient age was 66 (50–79) years, and transrectal ultrasonography-measured prostate volume was 48 (20–118) mL. A median lobe was present in 25 patients (53%) and eight patients had catheter-dependent urinary retention. The mean (range) total procedure time was 35 (13–128) min and the tissue resection time was 4 (1–10) min.

Five Clavien–Dindo grade I/II and five Clavien–Dindo grade III complications were recorded in eight patients. The mean (range) hospital stay was 3.1 (1–8) days and the mean (range) duration of urethral catheterization was 1.9 (1–11) days. The mean International Prostate Symptom Score (IPSS) decreased from 24.4 at baseline to 5 at 3 months; IPSS quality-of-life score decreased from 4.5 to 0.3 points; peak urinary flow rate increased from 7.1 to 16.5 mL/s and post-void residual urine volume decreased from 119 to 43 mL (all $P < 0.01$).

## Conclusions

This study confirmed procedure process improvements resulting from system enhancements, with preservation of safety and effectiveness during use of a second-generation device for the treatment of LUTS attibutable to BPH in the largest single-institution study conducted to date.

## Keywords

aquablation, benign prostatic hyperplasia, prospective study, robotics, surgical resection, waterjet

## Introduction

Ablative techniques using various lasers and electrical energy sources have emerged as alternatives to TURP for the surgical treatment of symptomatic BPH. These techniques generally use heat to vaporize or resect prostate tissue and are best suited for small and medium-sized prostates. With increasing adenoma size, the efficiency of heat-based ablation decreases, resulting in longer operating times or reduced efficacy, with resultant higher retreatment rates over time [1].

Aquablation is a novel minimally invasive surgical therapy for BPH delivered by the AQUABEAM® System (PROCEPT BioRobotics, Redwood Shores, CA, USA), a robotic surgical system that uses a high-velocity waterjet under surgeon control and robotic execution to mechanically remove prostatic adenoma. The robotically driven waterjet cutting depth follows the contour plan specified by the surgeon using real-time intraprocedural ultrasonography. The physician specifies the contour to remove the maximum amount of obstructing tissue while preserving the bladder neck, verumontanum, peripheral sphincter and neurovascular bundle. Because Aquablation does not use heat and is robotically driven, it can provide more precise and rapid removal of prostatic adenoma compared with traditional manual heat-based approaches. Faber et al. [2] reported the first-generation use in a canine study. Subsequently, Gilling

et al. [3] reported high levels of efficacy with a reasonable safety profile using the first-generation AQUABEAM system in a first-in-man and then a multicentre experience [4]. Herein, we present a larger single-centre experience using a second-generation AQUABEAM system in 47 patients with symptomatic BPH.

## Patients and Methods

The AQUABEAM India Study for the treatment of BPH (the ABS) is a single-centre prospective clinical trial with 3-month follow-up (NCT03167294, CTRI/2014/12/005238). The study, conducted at Muljibhai Patel Urological Hospital (Nadiad, India), was reviewed and approved by the Institutional Ethics Committee and conducted in accordance with Good Clinical Practice and in compliance with ISO 14155.

Previous phase I and II studies [3,4] using a previous-generation system in a smaller cohort showed good results at 1-year follow-up, but the procedure process was cumbersome and less intuitive. In the present study a second-generation AQUABEAM system was used. Compared with the previous system reported in Gilling et al. [3], enhancements included the following: an integrated scope was used to provide real-time visualization of the procedure; the maximum radial treatment angle for the water jet was reduced from 300° to 220°; the resection length was increased from 30 to 70 mm to allow treatment of larger prostates with just a single pass to remove tissue; and the maximum radius (depth) of resection was increased from 15 to 25 mm. The AQUABEAM system is illustrated in Fig. 1. The planning software allowed a contoured resection such that most adenomas could be resected in a single pass of the probe from the bladder neck to the verumontanum.

The objectives of the present study were as follows: (i) to confirm procedural process improvements associated with the next-generation device system in preparation for a larger, multicentre international pivotal trial; (ii) to confirm safety and effectiveness of the device system for the treatment of moderate-to-severe BPH; and (iii) to obtain feedback on the procedure from multiple surgeons. In total, seven surgeons from four institutions used the device in the present study. The study's primary device performance endpoint was completion of the intended surgical procedure; the primary safety endpoint was the peri-operative complication rate. Secondary outcomes included change in IPSS and uroflow measures (maximum urinary flow rate [$Q_{max}$] and post-void residual urine volume [PVR]).

Men aged 50–80 years, with symptomatic LUTS, were invited to participate if they had an IPSS [5] >12, a prostate size of 20–120 mL, as assessed with TRUS, a $Q_{max} \leq 15$ mL/s and a history of inadequate response, contraindication to or refusal of medical therapy. Men were excluded if they had a history



**Fig. 1** AQUABEAM Generation 2 shows the planning station (red arrow), pressure generator (green arrow) and hand-piece (blue arrow).

of prostate or bladder cancer, elevated PSA level, neurogenic bladder, prostatitis within the last year, urethral stricture, meatal stenosis or bladder neck contracture, previous prostate surgery, active infection, use of anticoagulants, gross haematuria, allergy to device materials, use of immune suppressants or corticosteroids, and serious medical or mental illness. All patients signed a study-specific consent form prior to participation.

At baseline, patients underwent medical history and physical examination, prostate volume measurement using TRUS, standard uroflow measurements ($Q_{max}$ and PVR), and assessment of serum haemoglobin, electrolyte and PSA levels. Baseline questionnaires included IPSS and IPSS quality-of-life (QoL) index and Incontinence Severity Index [6].

The procedure is performed under general or spinal anaesthesia in the lithotomy position. A bi-plane TRUS probe (Transducer Type 8848; BK Medical, Peabody, MA, USA) is inserted into the rectum and secured using a custom stand-mounted stepper. The 24-F rigid handpiece is advanced transurethrally until the distal end of device is in the bladder just beyond the bladder neck or intravesical lobe. A second custom-built articulating arm locks the handpiece in place to avoid displacement during treatment. The scope is withdrawn proximally and positioned at the distal end of the verumontanum (proximal to the peripheral sphincter) and marks the distal aspect of treatment. Using live transverse

and sagittal ultrasonography, the surgeon identifies the target resection area of the transitional zone on the planning station. Resection is initiated manually using a foot pedal, and a pump delivers a high-velocity sterile saline stream orthogonally (at a 90° angle) at pre-programmed flow rates based on the depth of penetration required. The probe emitting the high-velocity waterjet moves from the bladder neck (or just proximal to the intravesical median lobe if one is present) to the distal end of the verumontanum at a steady speed of 0.25 mm/s with a rotational arc as determined during treatment planning so as to ablate (i.e. resect) the entire target zone in a single pass. A channel in the hand-piece aspirates fluid from the bladder and collects the granules of resected adenoma tissue in a specimen filter. The entire resection procedure is monitored in real time by TRUS imaging in the sagittal plane (Fig. 2). The enlarged prostatic channel is evident on TRUS after resection is complete. Haemostasis is achieved by Foley catheter traction or by focal non-resective electrocautery coagulation using a standard resectoscope loop based on the surgeon's assessment of bleeding. Postoperatively, a three-way 22-F Foley catheter is placed under moderate traction and continuous bladder irrigation is initiated. Traction is removed the evening after the procedure and continuous bladder irrigation is progressively decreased according to the colour of the drainage; the Foley catheter is removed prior to hospital discharge. All patients underwent a serum haemoglobin and electrolyte analysis postoperatively.

Treated patients had scheduled clinic visits at 1 week, 1 month and 3 months after Aquablation. In addition to repeating baseline questionnaires, the following questionnaires were completed in follow-up: visual analogue scale pelvic pain scale measurement (scale 0–10) and a dysuria questionnaire, which consisted of two questions (frequency and severity of dysuria, the latter assessed on a 0–10 scale). Adverse events were collected at each study visit or as they occurred and classified using the Clavien–Dindo peri-operative complication rating system [7].

Continuous variables were summarized using mean, SD and range values. For measurements performed repeatedly, changes from baseline were assessed using ANOVA. Single measurements or before–after continuous variables were assessed using the $t$-test. All statistical analysis was performed using R, an open-source statistical package [8].

## Results

A total of 47 patients provided informed consent and underwent the procedure. Follow-up was obtained in 45, 44 and 41 patients at 1 week, 1 month and 3 months, respectively. At 3 months, two patients were lost to follow-up and one patient withdrew consent. Baseline characteristics of the study participants are summarized in Table 1. The mean (range) prostate volume was 48 (20–118) mL; 25 patients (53%) had a median lobe and eight patients had urinary retention prior to Aquablation.

All procedures were technically successful (primary device performance endpoint). The mean total procedure time (defined as pre-Aquablation cystoscopy to post-Aquablation catheter insertion) was 35 min and the mean resection time was 4 min (Table 2). Haemostasis was achieved adequately in 27 patients (57%) by Foley catheter traction and by focal non-resective electrocautery in 20 patients (43%). The mean (range) post-Aquablation instrumentation time to achieve haemostasis was 9 (1–70) min.

Fig. 2 Sagittal TRUS image during Aquablation showing the contour resection plan of the transitional zone enclosed within the green box. The bladder neck (blue arrow), verumontanum (red arrow) and water jet (green arrow) are seen.
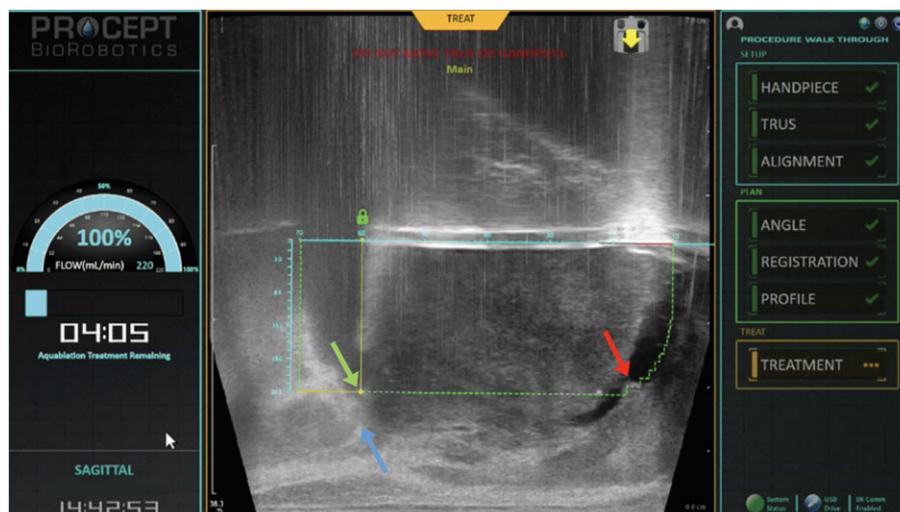
**Table 1** Demographic characteristics of treated patients.

| Characteristic | |
|---|---|
| Age, years | 66 (6.0, 50–79) |
| IPSS | 24.4 (4.4, 14–33) |
| IPSS QoL | 4.5 (0.9, 2–6) |
| $Q_{max}$, mL/s | 7.1 (4.1, 0–14.9) |
| PVR, mL | 119 (122, 0–400) |
| Prostate size, mL | 48 (24, 20–118) |
| Median lobe present, % (*n/N*) | 53 (25/47) |
| Urinary retention at baseline, % (*n/N*) | 17 (8/47) |

$Q_{max}$, maximum urinary flow rate; PVR, post-void residual urine volume; QoL, quality of life. Values are mean (SD, range) unless otherwise indicated.

**Table 2** Peri-operative characteristics of treated patients.

| Variable | |
|---|---|
| Technical success, *n* (%) | 47 (100) |
| Total procedure time, min | 35 (19, 13–128) |
| Handpiece in/out time, min | 26 (11, 10–58) |
| Resection time, min | 4 (2.4, 1–10) |
| Time to catheter removal, days | 1.9 (1.6, 1–11) |
| Time to hospital discharge, days | 3.1 (1.6, 1–8) |

Values are mean (SD, range) unless otherwise indicated.

**Table 3** Complications (10 events occurring in eight patients) by day 90, rated according to the Clavien–Dindo classification system.

| Adverse events | Number |
|---|---|
| Clavien–Dindo I | |
|   Acute urinary retention | 3 |
| Clavien–Dindo II | |
|   Haematuria requiring transfusion | 1 |
|   Infection | 1 |
| Clavien–Dindo III | |
|   Urinary retention | 3 |
|   Urethral stricture | 2 |

Compared with preoperative values, haemoglobin levels dropped by 1.4 g/dL ($P < 0.01$) and serum sodium levels dropped by 0.4 mEq/dL ($P = 0.34$) at the time of discharge. The mean (range) length of hospital stay was 3.1 (1–8) days and duration of urethral catheterization was 1.9 (1–11) days. One patient had prolonged hospitalization (8 days) that was primarily for social/travel reasons. A patient with preoperative chronic urinary retention had prolonged (11-day) catheter use.

One patient underwent TURP 3 weeks after Aquablation because of inability to void, dribbling and haematuria. Two patients, who had urinary retention at baseline, did not void after catheter removal on day 3 after Aquablation. Approximately 2 weeks later, they underwent TURP for inability to urinate after catheter removal.

A total of 10 Clavien–Dindo complications occurred in eight patients (Grade 1, *n* = 3; Grade 2, *n* = 2; Grade 3, *n* = 5) over the 3-month follow-up (Table 3). These included acute urinary retention (*n* = 6), haematuria requiring transfusion (*n* = 1), infection (*n* = 1) and stricture (*n* = 2). Of the six patients with acute urinary retention, one required cystoscopy for removal of bladder clots, three required TURP, and two started voiding after temporary re-catheterization. There were no reported occurrences of urinary incontinence, erectile dysfunction or retrograde ejaculation.

Improvement in BPH symptoms (IPSS and IPSS QoL score) was seen within 1 week of Aquablation and improved even further by month 3 (Fig. 3). The mean IPSS total score improved from 24.4 at baseline to 5.0 (19.4-point improvement), the mean QoL score improved from 4.5 to 0.3 (4.1-point improvement), the mean $Q_{max}$ improved from 7.1 to 16.5 mL/s (9.3 mL/s improvement), and PVR improved from 119 to 43 mL (76-mL improvement). All improvements were statistically significant ($P < 0.01$, repeated-measures ANOVA). Incontinence severity scores improved after treatment ($P < 0.01$). Pelvic pain scores were low postoperatively and decreased rapidly. Dysuria intensity and frequency scores were low throughout follow-up and improved by 3 months (Fig. 4).

## Discussion

We and others have previously reported on the use of a first-generation system for Aquablation in men with symptomatic BPH [3,4]. Improvements in the second-generation device included changes to the design of the handpiece, software planning for resection and the arms to stabilize the TRUS probe and handpiece to provide better endoscopic visualization, streamlined treatment planning and a faster, larger and contoured tissue resection. The present study confirms that the second-generation system performed as intended, streamlined the procedure (35 min in this study vs 48 min in an initial phase I study [3] and 45 min in a subsequent phase II study [4] with the first-generation system), while providing reasonable efficacy and safety profile. The successful use of the system by multiple surgeons with little or no previous experience with the device potentially highlights the generalizability of results.

Time inefficiency has been a major limitation of heat-based technologies, such as TURP or PVP, in the treatment of larger prostate glands. In TURP, increased resection time, which correlates with prostate size, is associated with higher risks for blood transfusion, peri-operative morbidity, fluid extravasation and the need for a haemostatic procedure [9]. In a large randomized trial of high-energy (180 W) Greenlight photo-selective vaporization of the prostate, with prostate sizes ranging from 17 to 105 mL, the mean (SD) lasing time was 44.5 (21.2) min [10]. With prostate sizes of 17 to 99 mL, the mean (SD) TURP resection times were 34.8 (17.0) min. In the present study, with prostate sizes in a

**Fig. 3** IPSS, maximum urinary flow rate (Q$_{max}$), IPSS quality of life (QoL), and post-void residual urine volume (PVR) at baseline, 1-week, 1-month and 3-month follow-up after Aquablation.
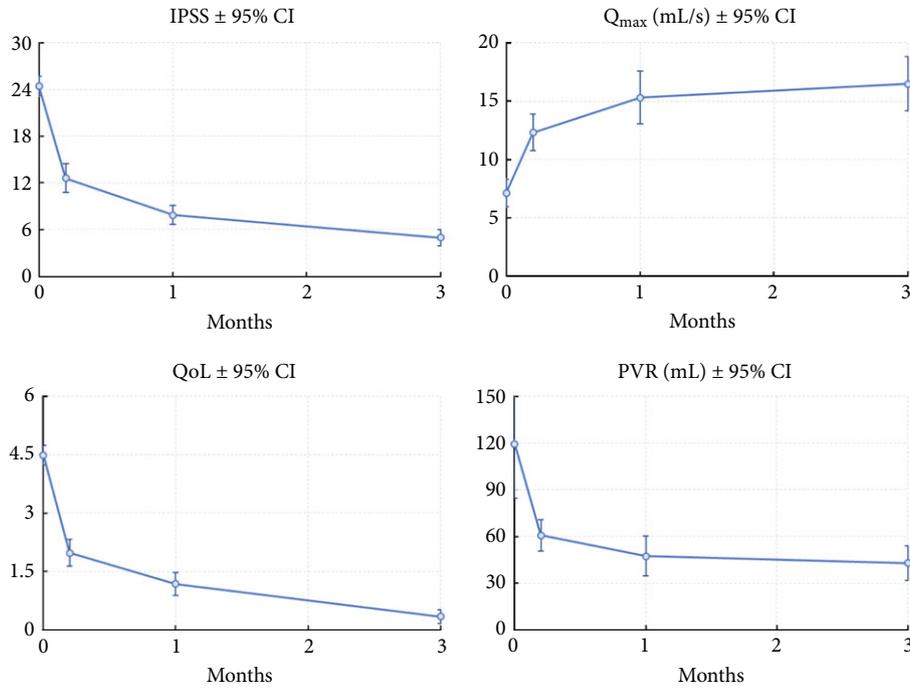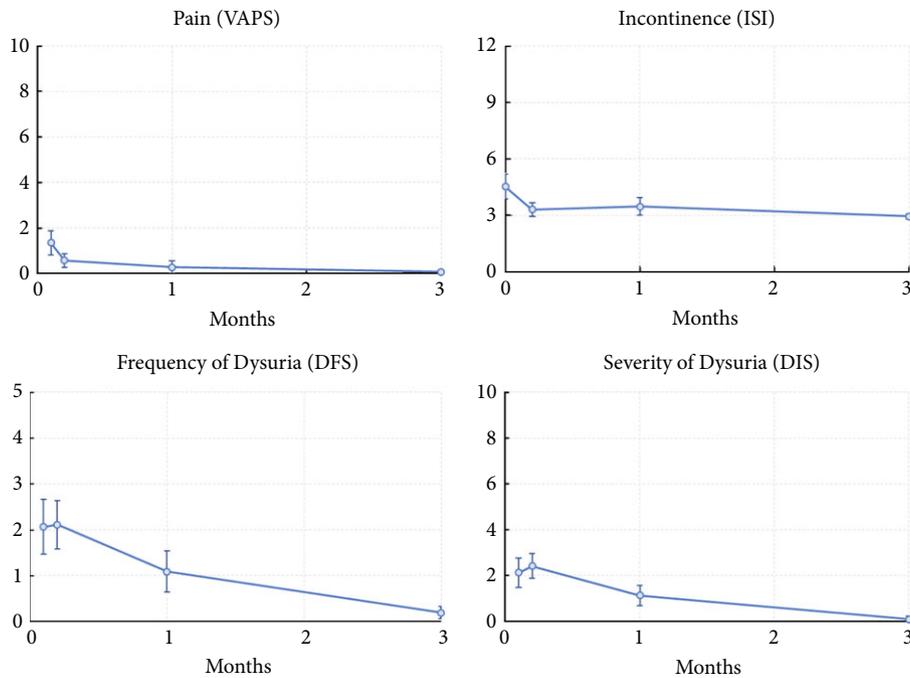


**Fig. 4** Visual Analogue Pain Scale (VAPS), Incontinence Severity Index (ISI), Dysuria Frequency Score (DFS), and Dysuria Intensity Score (DIS) postoperatively, at 1-week, 1-month and 3-month follow-up after Aquablation.



similar size range of 20 to 118 mL, the mean (SD) Aquablation resection time was only 4 (2.4) min. Although other factors (prostate size, depth of resection) may affect complication rates, the known relationship with resection time [9] suggests potential advantages of short resection times in Aquablation. Total Aquablation procedure time, which

includes treatment planning, resection and haemostasis, was also a promising 35 min.

In the present study of patients with moderate-to-severe BPH, Aquablation resulted in a 19-point improvement in IPSS, a 4-point improvement in the QoL, and a 9 mL/s improvement in $Q_{max}$ at 3-month follow-up. Gilling et al. [4] recently reported a three-centre experience with 21 patients undergoing Aquablation using the previous-generation device and also found a 16-point improvement in IPSS and a 10 mL/s improvement in $Q_{max}$ at 1-year follow-up. These data provide further evidence that improvements in symptom scores, flow rates and PVR values after Aquablation may be in the range of those observed after both TURP [11] and other resection treatments. Quantitative comparisons of functional improvements with those observed with other surgical treatments for symptomatic BPH, however, would require properly designed clinical studies. Nonetheless, despite relatively severe baseline symptoms (including urinary retention in eight patients), improvements in symptom scores and freedom from the need for postoperative catheterization was promising. Absence of thermal energy may also account for lack of acute dysuria and irritative voiding symptoms after catheter removal in patients undergoing Aquablation, as evidenced by low dysuria intensity and frequency scores and low visual analogue pain scales during follow-up (Fig. 4). The length of hospital stay was long in the present study compared with other published studies; however, length of stay in our hospital was primarily driven by non-medical social issues that guide hospital practices.

Three patients in the present cohort underwent TURP soon after Aquablation for non-resolution of symptoms or urinary retention. Two of the three patients had urinary retention at baseline and one of the two patients was unable to void 5 weeks after TURP. We found residual apical adenoma in two patients, suggesting undertreatment potentially related to suboptimal contour planning that did not maximize tissue removal near the prostate apex as we were more conservative in our early experience. In addition, the system generation used did not have the capability to perform a targeted apical cut around the verumontanum, thus, leaving behind tissue potentially causing persistent LUTS. Based on these results, subsequent revisions of the system have incorporated a feature to target apical tissue around and distal to the verumontanum.

In our experience, Aquablation has a reasonable safety profile, with 90-day complications recorded in eight patients. Of the five Clavien–Dindo grade III complications, urinary retention explained three. In some cases, the patients had urinary retention before Aquablation. One patient (2%) required significant electrocautery haemostasis at the conclusion of Aquablation and also required postoperative

blood transfusion. The exact method of post-Aquablation haemostasis is still evolving. Surprisingly, despite the lack of any specific thermal haemostatic method during Aquablation, most oozing after treatment could be treated with traction from the Foley catheter itself. Focal monopolar fulguration was required in some cases, especially in the region of the anterior bladder neck. Additionally, some patients required increasing flow of continuous bladder irrigation in the recovery room during straining after anaesthesia reversal. We are currently in the process of standardizing an athermal reproducible technique of post-procedure haemostasis that will further streamline the procedure.

Strengths of the present study include the use of multiple surgeons, many of whom had no experience with the device. Surgeon feedback was helpful and the study confirmed the system improvements.

Limitations of our study include the following. Throughout the treatment of this cohort, several parameters and treatment settings were improved to derive the best workflow. Whether these improvements affected safety or decreased symptom-reduction efficacy in the long term is not known. The study did not have long-term follow-up (many patients were from outlying rural areas and such follow-up was not feasible); however, the focus of the study was the confirmation of device system enhancements as well as feedback on usability from multiple surgeons. Nonetheless, short-term safety and efficacy up to 3 months were consistent with the 3-month results reported in previous studies [3,4]. Finally, for cultural reasons, the study did not include questions about sexual function, an important topic. Although previous reports have suggested preserved sexual function after Aquablation, prospective trials underway are comparing sexual function results, as well as other safety and effectiveness measures, against TURP outcomes.

In conclusion, the present study confirmed that second-generation modifications in the AQUABEAM system improved procedure process across multiple surgeons while preserving safety and short-term effectiveness in the treatment of LUTS attributable to BPH. Advantages of this procedure may include improved time efficiency and lack of dysuria. Comparative studies against established transurethral techniques will probably determine its role in the surgical treatment of symptomatic BPH.

## Conflict of Interest

Dr. Mihir M. Desai is a consultant for PROCEPT Biorobotics.

## References

1　**Meskawi M**, **Hueber P-A**, **Valdivieso R et al.** Multicenter international experience of 532 nm-laser photo-vaporization with Greenlight XPS in

men with large prostates (prostate volume > 100 cc). *World J Urol* 2017; 35: 1603–9

2   **Faber K**, **de Abreu ALC**, **Ramos P et al.** Image-guided robot-assisted prostate ablation using water jet-hydrodissection: initial study of a novel technology for benign prostatic hyperplasia. *J Endourol* 2015; 29: 63–9

3   **Gilling P**, **Reuther R**, **Kahokehr A**, **Fraundorfer M**. Aquablation - image-guided robot-assisted waterjet ablation of the prostate: initial clinical experience. *BJU Int* 2016; 117: 923–9

4   **Gilling P**, **Anderson P**, **Tan A**. Aquablation of the prostate for symptomatic benign prostatic hyperplasia: 1-year results. *J Urol* 2017; 197: 1565–72

5   **Barry MJ**, **Fowler FJ**, **O'Leary MP et al.** The American Urological Association symptom index for benign prostatic hyperplasia. The Measurement Committee of the American Urological Association. *J Urol* 1992;148:1549–57

6   **Hanley J**, **Capewell A**, **Hagen S**. Validity study of the severity index, a simple measure of urinary incontinence in women. *BMJ* 2001; 322: 1096–7

7   **Mamoulakis C**, **Efthimiou I**, **Kazoulis S**, **Christoulakis I**, **Sofras** F. The modified Clavien classification system: a standardized platform for reporting complications in transurethral resection of the prostate. *World J Urol* 2011; 29: 205–10

8   **R Core Team**. *R: A Language and Environment for Statistical Computing [Internet]*. Vienna, Austria: R Foundation for Statistical Computing, 2016. Available at: https://www.R-project.org/. Accessed 24 September 2017

9   **Uchida T**, **Ohori M**, **Soh S et al.** Factors influencing morbidity in patients undergoing transurethral resection of the prostate. *Urology* 1999; 53: 98–105

10   **Bachmann A**, **Tubaro A**, **Barber N et al.** 180-W XPS GreenLight laser vaporisation versus transurethral resection of the prostate for the treatment of benign prostatic obstruction: 6-month safety and efficacy results of a European Multicentre Randomised Trial–the GOLIATH study. *Eur Urol* 2014; 65: 931–42

11   **Marszalek M**, **Ponholzer A**, **Pusman M**, **Berger I**, **Madersbacher S**. Transurethral resection of the prostate. *Eur Urol Suppl* 2009; 8: 504–12

Correspondence: Mihir M. Desai, Clinical Urology, USC Institute of Urology, University of Southern California, 1441 Eastlake Ave, Suite 7416, Los Angeles, CA 90089, USA.

e-mail: mihir.desai@med.usc.edu

Abbreviations: $Q_{max}$, maximum urinary flow rate; PVR, post-void residual urine volume; QoL, quality of life.