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ORIGINAL PAPER

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In vitro comparison of transurethral vaporization of the prostate (TUVP), resection of the prostate (TURP), and vaporization-resection of the prostate (TUVRP)

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Abstract *Problem*. Transurethral vaporization of the prostate (TUVP) and vaporization-resection of the prostate (TUVRP) ("vapor cut, band electrode") seem to be alternatives to conventional resection of the prostate (TURP). For TUVP and TUVRP, little in vitro data has yet been published. The aim of this study was to determine settings for optimal performance with TUVP and TUVRP and to investigate electrosurgical parameters relevant to safety. *Methods*. Standardized experiments were performed on porcine muscle. Mass loss and coagulation zones were measured optically. Additionally, electrical parameters were recorded. *Results*. The maximum tissue ablation rates were 3.8 cm^3 per min and 6.1 cm^3 per min for TUVP and TUVRP, respectively, compared to 6.5 cm^3 per min for TURP. The maximum coagulation depths reached 2.1 mm (TUVP), 1.4 mm (TUVRP), and 0.9 mm (TURP). Optimal in vitro settings for TUVP/TUVRP/TURP were as follows: generator power of 250/120/90 W, drag speed of 5/15/20 mm/s, and pressure of 0.40/0.15/0.05 N. Different power generators and electrodes showed considerably varying performance. The energy to remove 1 g of tissue averaged 7.500 J (TUVP), 620 J (TUVRP), and 400 J (TURP). *Conclusions*. These results allow quantification of the influence of different variables on TUVP, TUVRP, and TURP in vitro. The TUVP proves to be an effective ablation alternative. Nevertheless, a 15 to 20 times higher energy demand has to be considered. TUVRP combines excellent ablation features with greater coagulation volumes, indicating better hemostasis.

Keywords Transurethral vaporization of the prostate (TUVP) · Transurethral vaporization-resection of the prostate (TUVRP) · Transurethral resection of the prostate (TURP) · In vitro electrosurgical parameters

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Objectives

With the introduction of transurethral vaporization of the prostate (TUVP) ("rollerball vaporization") [4, 5], followed by the so-called transurethral vaporization-resection of the prostate (TUVRP) ("vapor cut, band electrode, and wedge electrode") [2, 13], the surgical management of benign prostatic hyperplasia (BPH) has experienced significant changes over the last years. Reduced morbidity and costs have made TUVP and TUVRP increasingly popular among urologists for the treatment of BPH. [5, 7, 19]. On the other hand, little basic research data has yet been published on these new modalities. Especially for TUVRP, little in vitro information necessary to establish guidelines for efficiency and safety in human application is available. While an effort was made to characterize the different parameters that influence pure tissue vaporization in vitro [9, 10, 16], there is little data for the emerging TUVRP. Furthermore, electrosurgical parameters, of utmost importance for safe in vivo use, have not yet been investigated sufficiently for these promising therapy options.

In this in vitro study, we precisely determined the different variables that affect tissue ablation and coagulation volume for TUVP, TUVRP, and TURP. By means of a custom-made, high-frequency generator, we were able to quantitate and record electrosurgical and ablation parameters for all experimental settings.

Methods

Experimental setup (Fig. 1)

The specimens (see below) were fixed on a cork plate with a neutral grounding electrode underneath. Specimens and grounding electrode were positioned in a plastic tank that could be filled with glycine irrigation (Purisole, Fresenius, Bad Homburg, Germany). To determine pressure application, the tank was placed upon an electronic scale (BP 2100, Sartorius, Göttingen, Germany) which was set upon an infinitely variable lift (Boy 116, Grauer, Degersheim, Switzerland). In that way, the whole unit could be moved in a well-defined manner towards the active electrode. Thus, a constant, reproducible application pressure of the electrodes could be generated. Pressure application varied between 0 N and 1.0 N. The electrodes (see below) were attached to a standard, 26 CH continuous flow resectoscope (Karl Storz, Tuttlingen, Germany). The angle between tissue and resectoscope remained unchanged at 45°. To achieve a constant drag speed, the resectoscope was clamped into a stepper motor (Isel-Automation, Eiterfeld, Germany), which was controlled by custom-made software. Drag speed was varied from 1 mm/s to 20 mm/s. The length of the lesions was 50 mm in all cases. Activation of electrodes was performed either in irrigation fluid or in room air (both at 20°C). Despite sufficient homogeneity and reproducibility, every lesion was repeated eight times under identical settings for statistical reasons (Fig. 1).

Tissue source

Fresh porcine skeletal muscle was obtained from the slaughterhouse. The specimens were immediately transformed into invariable level blocks of 8×8×3 cm with a special cutting device (Tomomat, Mautner, Selb, Germany). They were used within 6 h after this preparation and stored at 8°C.

Prior to this study, experiments with porcine muscle and human prostatic tissue, acquired from ex vivo cystoprostatectomy specimens from patients with transitional cell carcinomas of the bladder, showed comparable ablation and coagulation effects. Compared to other organs like liver or kidney, skeletal muscle demonstrates a superior homogeneity and reproducibility.

Active electrodes (Fig. 2)

For TUVP, the following active electrodes were utilized (Fig. 2):

1. VE-B Vaportrode (Circon ACMI, Stamford, Conn., USA), diameter 3 mm, width 3 mm, grooved

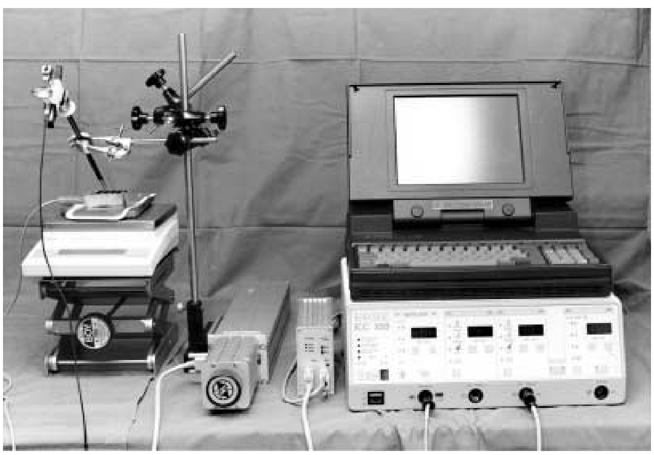

Fig. 1. Experimental set-up

Fig. 2. Different active electrodes: conventional TURP loop (*left*), TUVRP electrode (*middle*), and grooved TUVP bar (*right*)

2. Richard Wolf ball electrode 8423.024 (Richard Wolf, Knittlingen, Germany), diameter 3 mm, width 3 mm, grooved
3. Richard Wolf ball electrode 8423.025 (Richard Wolf), diameter 3 mm, width 3 mm, ungrooved

For TUVRP, the Band Electrode (Olympus, Winter and Ibe, Hamburg, Germany) and the Vapor Cut (Karl Storz) were used. For TURP, a standard electrocautery loop (Karl Storz) was applied.

Electrosurgical units

The Erbotom ICC 350 (ERBE Elektromedizin, Tübingen, Germany), a high-frequency (HF) generator which incorporates automatic voltage control (AutoCut) as well as automatic electric arc control (HighCut) was utilized for the majority of the experiments. In the HighCut setting, the unit delivers the precise power required for igniting electric arcs, thus avoiding unnecessarily high power levels. This feature is not dependent on electrode speed and depth. Both modes deliver a current of 350 kHz in sinusoidal wave form.

Alternatively, the Force 40S (Valleylab, Boulder, Colo., USA) was tested. In the PureCut mode, this generator delivers a maximum power output of 300 W and current of 500 kHz in sinusoidal wave form. At a defined tissue impedance, the actual power output is equivalent to the preselected generator power setting.

Ablation volume

The volumes of the lesions were measured optically using a specially designed microscope that incorporates a measuring caliper. The length of the lesions was 50 mm in all cases due to the setting of the stepper motor. Maximum width and depth were quantified by the microscope. Since the lesions were not right-angled but spheroidal, specific conversion factors had to be found for each electrode. These were generated by prior filling of the lesions with paraffin followed by determination of volumes by water displacement. Ablation volume was thus calculated by the following formula: volume = 50 mm×width×depth×conversion factor.

Coagulation zones

After the lesions were numbered and photographed and the volumes were optically measured, the tissue blocks were cut vertically to the craters. The coagulation zones were then determined with the measuring caliper under the microscope.

Electrosurgical recordings

Electrical parameters were measured by a specially designed record and documentation generator. This prototype was developed at the Institute for High Frequency Technology at the Army University in Munich, Germany, on the basis of the Erbotom ICC 350 (ERBE Elektromedizin). The output performance of the unit remains totally identical, since recording and high-frequency circuit are galvanically separated.

Statistical analysis

The two-tailed unpaired *t*-test between the different variable parameters was utilized to study unpaired data.

Results

Ablation performance

Generally, the ablation volume and the depth of coagulation varied to a different extent with the drag speed, pressure application, power setting, electrosurgical unit, and type of electrode.

Impact of drag speed (Fig. 3A)

For TUVP, the optimum ablation per time (cm^3/min) is achieved at a drag speed of 5 mm/s. Slower speed leads to higher absolute volumes but is less efficient. A speed of more than 10 mm/s leads to insufficient, irregular vaporization effects due to the diminishing contact between tissue and electrode. For standard TURP, as expected, the ablation rate increased approximately linearly with drag speed up to the limit of 20 mm/s. The TUVRP, however, displayed a maximum ablation rate at 15 mm/s, unless the wattage was increased to 250–300 W for continuous adequate tissue vaporization (Fig. 3 A).

Impact of pressure application (Fig. 3B)

Up to 0.40 N, a steady increase in ablation volume is noticed for TUVP with rising pressure. Above 0.40 N, saturation can be observed. Additionally, experiments with pressures of more than 0.40 N necessitate a drag speed of less than 10 mm/s. Even without mechanical pressure on the tissue (0 N), volume reduction can be seen with sufficient electric light arcs. As expected again, for conventional TURP, the ablation rate increases linearly with the pressure application up to 1.0 N. A similar increase is found for TUVRP up to 0.8 N. With the TURP and the TUVRP loops, the selected pressure application is maintained only for a few milliseconds during the very first cutting of tissue. After the loop "caves" into the tissue, the value drops down to 0.05 N (TURP) or 0.15 N (TUVRP).

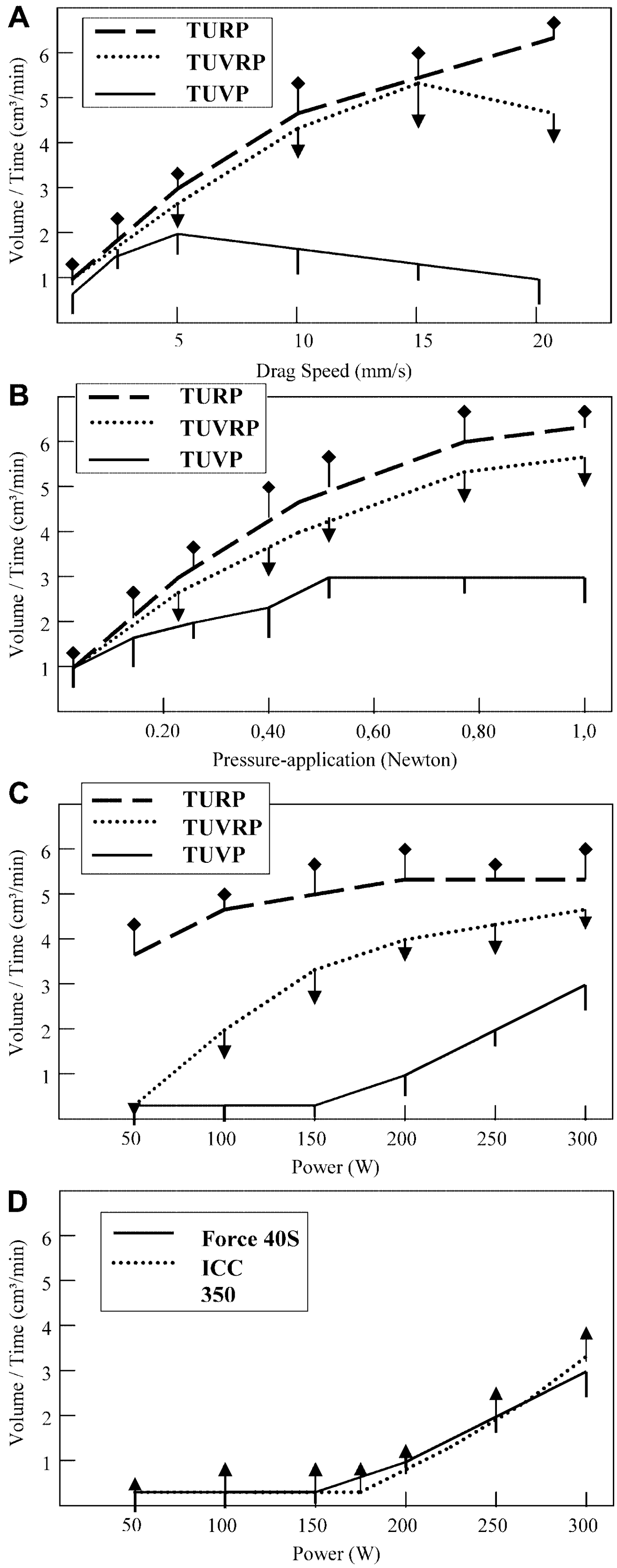

Fig. 3A–D. Impact of drag speed (**A**), pressure application (**B**) and generator power (**C**) on ablation volume/time (cm^3/min) for TURP, TURVP, and TUVP. Influence of generator type (**D**) for TUVP only

Impact of generator power (Fig. 3C)

In irrigation fluid, TUVP requires a minimum wattage of 175 W for sufficient and reproducible tissue ablation. A further increase in power causes an almost linear volume reduction up to 300 W. Wattages of 100 W and 50 W are needed for TUVRP and TURP, respectively. For TURP, a clear saturation can be noticed starting at 150 W.

Impact of generator type (Fig. 3D)

Generally, the ablation performances of the tested units for pure vaporization (TUVP), are very similar. Compared to the Force 40 S, the Erbotom ICC 350 requires a slightly higher onset power (190 W) but achieves a somewhat ($P > 0.10$) higher maximum ablation (+17%). For TUVRP and TURP, no noticeable differences were observed.

Effect of electrodes

Within the TUVP group, the grooved electrodes (VE-B, Wolf ball electrode grooved) achieve significantly ($P < 0.025$) higher ablation performances than ungrooved ones. However, the surface material (gold, silver) does not show any influence on the tissue ablation. For TUVRP, no significant ($P > 0.35$) differences concerning ablation were seen between the Band Electrode and the Vapor Cut. Within the standard TURP group, no different wire loops were tested.

Irrigation vs room air

Ablation performances in irrigation fluid and room air show distinct differences. For TUVP, only 40% of the volume reduction in room air can be achieved in irrigation fluid. For TURVP and TURP, the percentages are 75% and 85%, respectively. Without regarding the electrosurgical findings, it is obvious that for pure TUVP, 60% of the energy is consumed to vaporize the irrigation fluid. Thus, efficiencies of 40% (TUVP), 75% (TURVP), and 85% (TURP) can be postulated.

Prevaporized vs native tissue (Fig. 4)

With standard settings, TUVP on pretreated (prevaporized) tissue displays a decrease in volume ablation of more than of 52% over TUVP on native tissue. As illustrated in Fig. 4, for TUVRP (13%) and TURP (5%) this reduction is considerably smaller.

Optimal settings

Considering the above experiments, we were able to propose optimal in vitro settings and determine maximum ablation rates for each technique (Table 1).

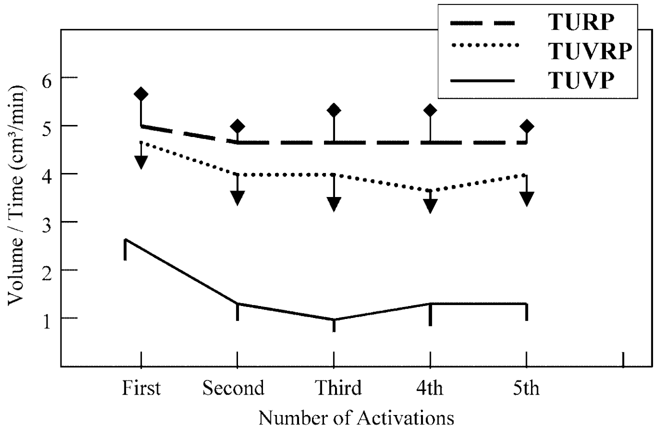

Fig. 4. Performance (ablation per time) of TUVP, TUVRP and TURP on native (first activation) and pretreated tissue (second–fifth activation)

Coagulation zones

With the different techniques, coagulation is mainly a function of wattage and drag speed. Thus, even with the standard wire loop (TURP), extremely low drag speed or resting at a certain position can achieve considerably larger coagulation zones. Applying the above settings relevant for each method, the coagulation depths average 0.9 mm (TURP), 1.4 mm (TURVP, $P < 0.05$), and 2.1 mm (TUVP, $P < 0.01$). Consequently, coagulation depth averages 156% for TUVRP and 233% for TUVP, compared to standard TURP.

Electrosurgical aspects

As shown in Table 2, the amount of energy needed to achieve tissue ablation depends on power setting, drag speed, electrode, and pressure application. In irrigation fluid, approximately 7500 J have to be applied for TUVP to obtain a removal of 1 cm^3 of tissue, given an actual power output of approximately 250 W. Employing optimal settings for TURP as defined above (increased drag speed, decreased power setting, decreased pressure application), the energy need per cm^3 averages only 400 J, with a genuine power output of 140 W. For TUVRP, the energy needed is approximately 620 J/cm^3, whereas the recorded power output is 170 W. Additionally, TUVP on prevaporized areas shows an extra energy need of approximately 20% (5% for TUVRP) compared to conventional TURP.

In summary (Table 3, 4), the amount of energy necessary to achieve identical tissue ablation with TUVP is 15–20 times higher than with standard TURP.

Discussion

Our laboratory model allows investigation and comparison of independent parameters that influence abla-

Table 1. Maximum ablation rates and optimal in vitro settings for TUVP, TUVRP, and TURP

	Maximum ablation (cm^3/min)	Drag-speed (mm/s)	Pressure (N)	Power (W)	Electrode	Generator
TUVP	3.8	5	0.40	250–300	Grooved rolling cylinder	Automatic light arc control
TUVRP	6.1	15	0.15	120	Band-shaped	Automatic light arc control
TURP	6.5	20	0.05	90	–	–

Table 2. Energy demand per volume: influence of power setting for TUVP, TUVRP and TURP

Power setting (W)	150 TUVP	200 TUVP	250 TUVP	150 TUVRP	200 TUVRP	250 TUVRP	150 TURP	200 TURP	250 TURP
Power output (W)	160 ± 5	205 ± 5	250 ± 5	150 ± 5	195 ± 5	235 ± 5	140 ± 5	165 ± 5	190 ± 5
Energy (J)	1600 ± 50	2050 ± 50	2500 ± 50	1500 ± 50	1950 ± 50	2350 ± 50	1400 ± 50	1650 ± 50	1900 ± 50
Ablation (cm^3)	0.11 ± 0.02	0.28 ± 0.03	0.33 ± 0.03	0.81 ± 0.09	0.88 ± 0.09	0.96 ± 0.10	$1{,}02 \pm 0.10$	$1{,}02 \pm 0.10$	$1{,}04 \pm 0.10$
Energy/ablation (J/cm^3)	14545 ± 727	7390 ± 370	7576 ± 379	1852 ± 93	2407 ± 370	2447 ± 122	1373 ± 69	1617 ± 81	1827 ± 91

Table 3. Energy need, actual power output and efficiency in vitro for TUVP, TUVRP, and TURP

	Energy need (J/cm^3)	Power output (W)	Factor	Efficiency (%)
TUVP	7500	250	15–20	40
TUVRP	620	170	1.5–1.8	75
TURP	400	140	–	85

tion and coagulation features of transurethral vaporization of the prostate (TUVP), transurethral vaporization-resection of the prostate (TUVRP), and standard transurethral resection of the prostate (TURP). For TUVP, comparable studies have been conducted by others in vitro [9, 10, 16] and in vivo [14]. Concerning TUVRP, little experimental data is available to date and only insufficient direct comparison of the latter methods with conventional TURP, still considered the gold standard [3], has been performed.

Furthermore, electrosurgical aspects of the emerging techniques have not been investigated adequately in prior publications. Using a prototype record and documentation generator, we were able to demonstrate that power setting and actual power output may vary considerably, depending on different variables such as tissue properties, drag speed, pressure, type of electrode, type of generator, and irrigation fluid. This device also enabled us for the first time to quantitate exactly the energy needed to remove a defined volume of tissue for the different procedures.

With a maximum ablation rate of 3.8 cm^3 per min, TUVP proves to be an effective ablation alternative, accomplishing 58% of conventional TURP (6.5 cm^3/min, $P < 0.010$). On the other hand, 93% of tissue reduction compared to TURP can be achieved by TUVRP (6.1 cm^3/min, $P < 0.10$). All maximum ablation rates were observed at optimal settings, as shown in Table 1. As expected, compared to standard loop resection (TURP), pure vaporization (TUVP) requires slower speed, higher voltage, and increased pressure application. Concerning the pressure application at the tip of the electrode, studies with experienced surgeons revealed a relevant in vivo range of 0.10 N to 0.30 N. Thus, clinically, the pressure application has to be adapted to the transurethral approach.

Contrary to Lim et al. [9], we found a remarkable decline in tissue removal of more than 50% for TUVP ($P < 0.01$) (Fig. 4) on pretreated tissue, which can only be compensated in vivo by an additional energy input.

Table 4. Energy demand per volume: influence of drag speed for TUVP, TUVRP and TURP

Drag speed (mm/s)	5 TUVP	10 TUVP	20 TUVP	5 TUVRP	10 TUVRP	20 TUVRP	5 TURP	10 TURP	20 TURP
Power output (W)	250 ± 5	238 ± 5	240 ± 5	235 ± 5	245 ± 5	255 ± 5	190 ± 5	205 ± 5	215 ± 5
Energy (J)	2500 ± 50	1190 ± 50	600 ± 50	2350 ± 50	1225 ± 50	638 ± 50	1900 ± 50	1025 ± 50	538 ± 50
Ablation (cm^3)	0.33 ± 0.04	0.20 ± 0.03	0.11 ± 0.02	0.96 ± 0.10	0.89 ± 0.08	0.78 ± 0.07	1.04 ± 0.11	1.01 ± 0.11	0.96 ± 0.10
Energy/ablation (J/cm^3)	7576 ± 379	5950 ± 298	5455 ± 273	2447 ± 122	1376 ± 69	818 ± 41	1827 ± 91	1015 ± 51	560 ± 28

Adequate knowledge and understanding of electrophysical principles of electrovaporization are mandatory for the safe use of these procedures in humans. A power setting of less than 175 W for TUVP, for instance, intended to reduce energy application for the patient, leads to a tremendously increased energy input (Table 2) due to inadequate tissue ablation (on the basis of insufficient electric light arcs) and subsequently prolonged activation times.

Remarkably, even performed at correct settings, TUVP requires a to date unreported 15 to 20 times higher energy input than conventional TURP (Table 3). On the other hand, several clinical studies on TUVP did not detect any significant postoperative increase in urethral strictures, urinary incontinence, or erectile dysfunction, as could have been expected as a result of the findings above [1, 6, 11, 12, 18]. Since we could demonstrate that 60% of the applied energy in TUVP is consumed to vaporize the irrigation fluid, we conclude that continuous irrigation is of utmost importance. This is confirmed by canine in vivo studies that revealed a rise in irrigation fluid temperature of more than 200% (>60°C) during vaporization of the prostate [14]. Therefore, the finding that interstitial temperature changes are transient and highly localized [8, 17] presumes sufficient irrigation during vaporization procedures.

The so-called transurethral vaporization-resection of the prostate (TUVRP), a synthesis of conventional resection of the prostate (TURP) and pure vaporization of the prostate (TUVP) combines excellent ablation features (93% of TURP, $P<0.05$) with significantly greater coagulation volumes (156% of TURP, $P<0.05$), indicating better hemostasis. These in vitro results have been validated by recent clinical trials on TUVRP using different "vaporization loops" [7, 15, 19]. The authors unanimously describe TUVRP as efficacious as TURP, with lower morbidity due to less perioperative hemorrhage.

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