

Article

Comparative Outcomes of TURP, TUVF, and PAE in the Management of Benign Prostatic Hyperplasia: A Single Center Real-World Study

Teddy Jabbour ^{1,*}, Laurent Bairy ², Benoit Bihin ³, Jean-Francois De Wispelaere ⁴ and Marcelo Di Gregorio ¹

¹ Department of Urology, Centre Hospitalier Universitaire, Université Catholique de Louvain Namur-Site Godinne, 5530 Namur, Belgium; marcelo.digregorio@chuclouvain.be

² Department of Anesthesia, Centre Hospitalier Universitaire, Université Catholique de Louvain Namur-Site Godinne, 5530 Namur, Belgium; laurent.bairy@chuclouvain.be

³ Scientific Support Unit, Centre Hospitalier Universitaire, Université Catholique de Louvain Namur-Site Godinne, 5530 Namur, Belgium; benoit.bihin@chuclouvain.be

⁴ Departments of Diagnostic and Interventional Radiology, Centre Hospitalier Universitaire, Université Catholique de Louvain Namur-Site Godinne, 5530 Namur, Belgium; jeanfrancois.dewispelaere@chuclouvain.be

* Correspondence: teddy.jabbour@chuclouvain.be

Abstract

Background/Objectives: To compare real-world outcomes of transurethral resection of the prostate (TURP), transurethral vaporization of the prostate (TUVF), and prostate artery embolization (PAE) in men with symptomatic benign prostatic hyperplasia (BPH). **Methods:** A retrospective cohort of 203 patients undergoing TURP, TUVF, or PAE was analyzed. Outcomes included IPSS, QoL, IIEF, prostate volume, maximum urinary flow rate (Qmax), and post-void residual volume (PVR) at 12 months. Adjusted analyses used ANCOVA and propensity score weighting. **Results:** All groups showed improvement. TURP provided the greatest improvements in IPSS, QoL, Qmax, and prostate volume reduction. TUVF outcomes were intermediate; while symptom improvements (IPSS) were comparable in weighted models, TURP provided significantly greater improvements in Qmax and prostate volume reduction across all adjusted analyses. **Conclusions:** TURP remains an effective option for symptomatic BPH; TUVF and PAE offer modest benefits and remain viable alternatives in selected patients.

Keywords: benign prostatic hyperplasia; TURP; vaporisation; embolisation



Academic Editor: Bartosz Małkiewicz

Received: 9 March 2026

Revised: 19 April 2026

Accepted: 15 May 2026

Published: 20 May 2026

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1. Introduction

Benign prostatic hyperplasia (BPH) is a progressive, nonmalignant enlargement of the prostate gland that commonly affects aging men. It is a principal contributor to lower urinary tract symptoms (LUTS), including increased urinary frequency, nocturia, hesitancy, incomplete emptying, and weak urinary stream, which collectively impair quality of life and impose a substantial burden on healthcare systems worldwide [1,2]. The prevalence of histologically confirmed BPH exceeds 50% by the sixth decade and approaches 80% in men aged over 80 years [3].

Transurethral resection of the prostate (TURP) has long served as the gold standard surgical treatment for moderate-to-severe LUTS due to BPH, offering consistent improvements in symptom scores, urinary flow, prostate volume, and post-void residual urine [4]. More

recently, holmium laser enucleation of the prostate (HoLEP) has emerged as a guideline-recommended standard, offering durable efficacy with low complication rates and suitability across all prostate sizes [5,6]. However, HoLEP remains limited by steep technical demands, a significant learning curve, and the need for costly laser platforms that are unavailable in many institutions, particularly in low- and middle-income countries [7]. Consequently, conventional techniques such as TURP, transurethral vaporization of the prostate (TUVP), and prostate artery embolization (PAE) continue to be widely used in routine clinical practice and in resource-constrained settings [8–10].

TUVP represents a simplified electrosurgical alternative to TURP that ablates tissue using vaporization rather than resection. It is associated with reduced intraoperative bleeding, shorter hospital stay, and lower costs, but its comparative long-term efficacy remains less well defined [9]. PAE, a minimally invasive endovascular technique, has gained attention as a non-surgical outpatient procedure that reduces prostate volume through targeted ischemia. While PAE may preserve ejaculatory and erectile function more effectively than TURP, concerns remain regarding its durability and efficacy in relieving obstruction [11].

Despite the growing body of literature evaluating newer technologies, comparative real-world data on conventional approaches remain limited, especially outside randomized controlled trials. Many existing studies have small sample sizes, lack long-term follow-up, or fail to adjust adequately for baseline confounders. Furthermore, direct head-to-head comparisons between TURP, TUVP, and PAE in terms of functional, anatomical, and patient-reported outcomes remain scarce.

This study aimed to address these gaps by evaluating and comparing the 12-month outcomes of TURP, TUVP, and PAE in the treatment of symptomatic BPH in a real-world, single-center cohort. Specifically, we assessed changes in International Prostate Symptom Score (IPSS), Quality of Life (QoL), International Index of Erectile Function (IIEF), prostate volume, maximum urinary flow rate (Q_{max}), and post-void residual volume (PVR). Recognizing the observational nature of the study and differences in baseline patient characteristics, we applied rigorous statistical adjustments using both analysis of covariance (ANCOVA) and propensity score weighting [12]. Our findings aim to inform clinical decision-making in settings where HoLEP is not yet accessible and to clarify the relative efficacy of these widely practiced interventions for BPH management.

2. Materials and Methods

Medical records of 225 patients treated between August 2013 and May 2018 were reviewed and assessed for eligibility. Eligible patients were males aged >45 years presenting with moderate-to-severe LUTS, defined as an IPSS > 8 despite prior medical therapy. Additional inclusion criteria included Q_{max} < 15 mL/s and a prostate volume ranging from 30 to 120 mL, assessed via transrectal ultrasound (TRUS) or magnetic resonance imaging (MRI).

Exclusion criteria included histologically confirmed or suspected prostate cancer, and previous prostate surgery, including resection, bladder neck or urethral surgery.

All patients underwent a standardized pre- and post-treatment evaluation protocol, including a full medical history and physical examination, including digital rectal examination (DRE). Assessment of urinary and sexual function using validated questionnaires: IPSS, IPSS-related Quality of Life (QoL) index, and the International Index of Erectile Function (IIEF-5) in addition to serum PSA measurement. Imaging assessment of prostate volume using TRUS or MRI was performed in addition to uroflowmetry for Q_{max} determination and post-void residual urine volume (PVR) measurement via bladder ultrasound.

As this is an observational study with an exploratory objective, the 12-month IPSS and QoL scores were designated as primary effectiveness endpoints. Other outcomes were treated as secondary and supportive. No formal adjustment for multiplicity was performed, and results for secondary endpoints should be interpreted as exploratory.

2.1. Procedures

All TUVF and TURP procedures were performed by one of four experienced urologists using a standardized protocol and an Olympus AN455 electrosurgical generator. PAE procedures were performed by a single interventional radiologist via femoral artery access, using selective catheterization of prostatic arteries and embolization with calibrated microparticles. Treatment selection was non-randomized and based on clinical judgment. TUVF was frequently preferred for older patients or those on anticoagulation, while PAE was offered as a minimally invasive alternative for those prioritizing the avoidance of surgery or preservation of function.

Due to the retrospective nature of this study, specific procedural parameters—including electrosurgical vaporization settings, embolic particle sizes, and technical success rates (bilateral vs. unilateral)—were not captured in a standardized format and were unavailable for analysis.

2.2. Statistical Methods

Baseline characteristics were compared between groups using the median and interquartile range for continuous variables, and frequencies and percentages for binary variables.

The primary outcomes of interest were IPSS, QoL, IIEF, Prostate Volume, Qmax, and Prostate Residual Volume. Patients with missing outcomes at 12 months or at baseline were excluded from the analysis. The study aimed to compare the effects of three interventions (TURP, PAE, and TUVF) on these six outcomes. Due to the observational nature of the study, baseline characteristics differed between groups.

To adjust for this baseline imbalance, two methods were employed. The main analysis utilized ANCOVA models, and fully adjusted and propensity-weighted models. For each outcome, the crude estimate was obtained with the 12-month outcome as the dependent variable and the intervention group as the independent variable. For the adjusted estimate, the centered baseline value was added as a second independent variable.

As a sensitivity analysis, weighting was used to account for potential confounding, as described by Yoshida et al. (2018) [12]. Propensity scores were calculated using multinomial logistic regression, predicting the assigned group from baseline variables including Age, Anticoagulation, PSA, IPSS, QoL, IIEF, Prostate Volume, Qmax, and PVR. These propensity scores were then used to compute matching weights, which were applied to the data to create a weighted dataset for further analysis. The intervention effects were then compared in this weighted dataset using linear regression models. In both analyses, Prostate Volume and PVR were log-transformed to meet the normality assumptions of the regression models. The model estimates corresponding to the TURP group mean and the PAE-TURP or TUVF-TURP contrasts are presented. All analyses were conducted using R (version 4.4.1).

The primary analytical framework utilizes Fully Adjusted multivariable regression and Propensity-Weighted models to account for significant baseline imbalances in age, anticoagulation status, and prostate volume. A baseline-value ANCOVA is provided as a supportive sensitivity analysis. Propensity scores were estimated using multinomial logistic regression, and matching weights were applied to create a balanced pseudo-population. We report weighted effective sample sizes (sum of weights) for this analysis (TURP: 17.89, PAE: 19.97, TUVF: 19.05). However these remain weighted pseudo samples; we therefore acknowledge that such weighting is operating in a limited overlap region.

3. Results

3.1. Overview of Outcomes

Out of the 225 patients initially reviewed, 22 (9.8%) were excluded due to missing baseline or 12-month follow-up data, resulting in a final study population of 203 patients (TURP *n* = 107; PAE *n* = 52; TUVV *n* = 44). All three interventions led to substantial improvements in lower urinary tract symptoms and related outcomes by 12 months. However, the magnitude of improvement differed by treatment. In general, the TURP group achieved the most pronounced symptom relief and functional improvement, whereas the PAE group showed more modest gains. The TUVV group’s outcomes were largely intermediate, often approaching those of TURP after adjusting for baseline differences. Baseline characteristics are demonstrated in Table 1. Key results from the adjusted and weighted analyses are summarized in Table 2. Below, we detail the findings for each outcome measure, with effect size estimates (beta coefficients), 95% confidence intervals, and *p*-values from both adjusted and weighted analyses (Supplementary Materials Table S1 and S2).

Table 1. Baseline characteristics.

Characteristic	TURP N = 107 ¹	PAE N = 52 ¹	TUVV N = 44 ¹
Age	65 (60, 70)	71 (58, 79)	77 (74, 81)
Anticoag	52 (49%)	21 (40%)	28 (64%)
Hematuria	9 (8.4%)	6 (12%)	8 (18%)
PSA	0.99 (0.28, 1.75)	1.14 (0.55, 1.55)	1.01 (0.43, 1.46)
IPSS	24 (20, 29)	19 (16, 24)	24 (18, 28)
QoL	5.00 (4.00, 6.00)	5.00 (3.50, 5.00)	5.00 (4.00, 5.00)
IIEF	15 (6, 21)	15 (3, 21)	6 (2, 12)
Prostate Volume—mL	52 (40, 68)	60 (49, 90)	47 (40, 60)
Qmax—mL/s	8.0 (4.5, 11.5)	8.4 (6.0, 10.7)	8.3 (4.8, 11.1)
PVR—mL	130 (58, 290)	113 (61, 210)	121 (65, 184)

¹ Median (Q1, Q3); *n* (%).

Table 2. Comparisons of the main outcomes at 12 months.

Characteristic	Crude			Adjusted (ANCOVA)			Fully Adjusted			Weighted		
	Beta	95% CI	<i>p</i> -Value	Beta	95% CI	<i>p</i> -Value	Beta	95% CI	<i>p</i> -Value	Beta	95% CI	<i>p</i> -Value
IPSS												
Intervention												
TURP	6.1	5.1, 7.0	<0.001	6.0	5.0, 6.9	<0.001	6.0	5.1, 7.0	<0.001	6.1	5.1, 7.1	<0.001
PAE	2.3	0.65, 4.0	0.007	2.6	0.91, 4.3	0.003	3.0	1.3, 4.7	<0.001	3.2	0.55, 5.9	0.018
TUVV	2.2	0.40, 3.9	0.017	2.3	0.51, 4.0	0.012	1.6	−0.18, 3.5	0.078	1.7	−0.66, 4.1	0.2
QoL												
Intervention												
TURP	1.2	0.93, 1.4	<0.001	1.2	0.90, 1.4	<0.001	1.2	0.94, 1.5	<0.001	1.3	0.99, 1.7	<0.001
PAE	0.64	0.19, 1.1	0.005	0.71	0.26, 1.2	0.002	0.73	0.25, 1.2	0.003	0.75	0.11, 1.4	0.021
TUVV	0.72	0.25, 1.2	0.003	0.75	0.28, 1.2	0.002	0.53	0.03, 1.0	0.038	0.54	−0.06, 1.1	0.079
IIEF												
Intervention												
TURP	13	11, 14	<0.001	12	11, 13	<0.001	12	11, 13	<0.001	10	7.9, 12	<0.001
PAE	−1.1	−3.6, 1.5	0.4	−0.37	−2.1, 1.4	0.7	0.00	−1.8, 1.8	>0.9	−1.6	−5.2, 2.1	0.4
TUVV	−6.3	−9.0, −3.6	<0.001	−1.6	−3.5, 0.38	0.11	−1.8	−3.7, 0.17	0.074	−2.0	−5.3, 1.3	0.2

Table 2. Cont.

Characteristic	Crude			Adjusted (ANCOVA)			Fully Adjusted			Weighted		
	Beta	95% CI	p-Value	Beta	95% CI	p-Value	Beta	95% CI	p-Value	Beta	95% CI	p-Value
Qmax (mL/s)												
Intervention												
TURP	18	17, 19	<0.001	18	17, 19	<0.001	18	17, 20	<0.001	18	16, 20	<0.001
PAE	-5.4	-7.4, -3.4	<0.001	-5.6	-7.6, -3.7	<0.001	-6.1	-8.2, -4.0	<0.001	-5.3	-7.5, -3.2	<0.001
TUVP	-3.8	-5.9, -1.7	<0.001	-3.9	-6.0, -1.8	<0.001	-3.9	-6.1, -1.6	<0.001	-2.7	-5.6, 0.26	0.074
Prostate residual volume												
Intervention												
TURP	3.4	3.2, 3.5	<0.001	3.4	3.2, 3.5	<0.001	3.4	3.2, 3.6	<0.001	3.5	3.3, 3.7	<0.001
PAE	0.27	-0.03, 0.57	0.080	0.28	-0.02, 0.58	0.064	0.24	-0.07, 0.56	0.13	0.26	-0.18, 0.70	0.2
TUVP	0.41	0.09, 0.73	0.011	0.43	0.12, 0.74	0.007	0.32	-0.02, 0.65	0.061	0.28	-0.11, 0.68	0.2

The Baseline-Adjusted (ANCOVA) model adjusts for the initial value of each outcome. The Fully Adjusted model accounts for baseline values, age, anticoagulation status, and prostate volume. The Weighted model utilizes matching weights based on multinomial propensity scores to further reduce group imbalances.

3.2. Symptom Severity (IPSS)

All groups experienced significant reductions in IPSS by 12 months, with TURP yielding the lowest symptom scores on average. In adjusted analyses (ANCOVA controlling for baseline IPSS), the mean 12-month IPSS in the TURP group was ~6 points (95% CI 5.0–6.9). Both PAE and TUVP had higher (worse) scores relative to TURP. The adjusted mean difference in IPSS for PAE vs. TURP was +2.6 points (95% CI 0.91–4.3; $p = 0.003$), indicating that the PAE group’s symptoms were significantly more severe. The TUVP group’s IPSS was also higher than TURP by about +2.3 points (95% CI 0.51–4.0; $p = 0.012$) in the adjusted analysis. In the weighted analysis (propensity-weighted linear model), the IPSS difference between PAE and TURP remained statistically significant (+3.2 points; 95% CI 0.55–5.9; $p = 0.018$). In contrast, the TUVP–TURP difference was attenuated and no longer significant after weighting (+1.7 points; 95% CI -0.66–4.1; $p = 0.20$). These results indicate that TURP provided the greatest improvement in symptom scores, with PAE showing significantly less IPSS reduction.

3.3. Quality of Life (IPSS-QoL Index)

Quality of life improved in all treatment groups in parallel with symptom score reductions. By 12 months, patients treated with TURP reported the best QoL scores (approximately 1.2 on the IPSS QoL scale in adjusted analysis), reflecting a marked improvement from baseline (~5 on the 0–6 scale). Both PAE and TUVP groups had higher QoL index scores (indicating worse quality of life) compared to TURP. In adjusted analysis, the PAE group’s QoL score was on average 0.71 points higher than TURP’s (95% CI 0.26–1.2; $p = 0.002$). Similarly, the TUVP group’s QoL was higher by 0.75 points relative to TURP (95% CI 0.28–1.2; $p = 0.002$). These differences were statistically significant, suggesting that TURP patients achieved slightly better QoL outcomes than both PAE and TUVP. In the weighted analysis, the gap between TUVP and TURP narrowed: the TUVP–TURP QoL difference was +0.54 and no longer significant (95% CI -0.06–1.1; $p = 0.079$). The PAE vs. TURP difference in QoL remained significant with weighting (+0.75, 95% CI 0.11–1.4; $p = 0.021$). Overall, TURP provided the greatest improvement in QoL, PAE showed significantly less QoL benefit, and TUVP was not significantly different from TURP after adjustment (though

unadjusted results had indicated a moderate QoL disadvantage for TUVV as well) (Note: Lower scores indicate better QoL on the IPSS-QoL scale).

3.4. Erectile Function (IIEF)

Baseline differences in sexual function were notable among groups (median IIEF was lower in the TUVV group), but by 12 months there were no significant between-group differences in erectile function after accounting for those baseline disparities. The adjusted mean IIEF-5 score in the TURP group was around 12, and neither PAE nor TUVV differed significantly from this. In adjusted analysis, the PAE group's IIEF was on average 0.37 points lower than TURP's (Beta = -0.37 , 95% CI -2.1 – 1.4), a difference that was not statistically significant ($p = 0.7$). The adjusted difference between TUVV and TURP was also small and non-significant (Beta = -1.6 , 95% CI -3.5 – 0.38 ; $p = 0.11$). Similarly, in the weighted analysis no significant differences in IIEF were observed (PAE vs. TURP Beta = -1.6 , $p = 0.4$; TUVV vs. TURP Beta = -2.0 , $p = 0.20$). While the crude (unadjusted) comparison showed a markedly lower mean IIEF in the TUVV group (due to poorer baseline function), this disparity disappeared after adjustment. Thus, at 12 months, TURP, PAE, and TUVV had comparable outcomes in terms of erectile function, with no statistically significant differences in IIEF improvements among the three interventions.

3.5. Prostate Volume Reduction

Twelve-month prostate volume measurements confirmed that TURP achieved the greatest reduction in prostate size, as expected with tissue resection. The mean prostate volume in the TURP group was significantly lower than in the other groups. On a logarithmic scale (log-transformed volume), the adjusted mean for TURP was 2.9 (approximately corresponding to 18 mL residual volume). By contrast, the PAE group had significantly larger prostates at follow-up. The adjusted difference for PAE vs. TURP was Beta = 0.85 in log-volume (95% CI 0.74–0.95; $p < 0.001$), indicating that, on average, post-treatment prostate size in the PAE group was about 2.3 times that of the TURP group. Even the TUVV group had a moderately larger remaining prostate compared to TURP: the adjusted log-volume difference was Beta = 0.27 (95% CI 0.16–0.38; $p < 0.001$), roughly a 30% higher volume on average relative to TURP. These between-group differences were highly significant. The weighted analysis confirmed the same pattern: PAE-treated prostates remained markedly larger (Beta = 0.89 vs. TURP; $p < 0.001$), and TUVV prostates were also significantly larger than TURP (Beta = 0.36; $p < 0.001$). In summary, TURP led to the greatest prostate volume reduction, whereas PAE resulted in the least volume reduction. TUVV achieved an intermediate degree of debulking: although TUVV did remove prostatic tissue, the residual volume was still significantly higher than after TURP.

3.6. Maximum Urinary Flow Rate (Q_{max})

All treatments improved patients' peak urinary flow rates at 12 months, with TURP producing the largest gains. In the TURP group, the mean Q_{max} at 12 months reached approximately 18 mL/s (95% CI 17–19), a substantial increase from baseline (~ 8 mL/s). The PAE group had a significantly lower Q_{max} than TURP. Adjusted analysis showed a Q_{max} in PAE that was about 5.6 mL/s lower than in TURP (95% CI -7.6 to -3.7 ; $p < 0.001$). Similarly, TUVV's peak flow was slightly lower than TURP's, with an adjusted difference of -3.9 mL/s (TUVV vs. TURP; 95% CI -6.0 to -1.8 ; $p < 0.001$). Thus, both alternative treatments had inferior peak flow outcomes in the adjusted model, although the deficit was greater for PAE. In the weighted analysis, the PAE vs. TURP gap remained significant (approximately -5.3 mL/s; $p < 0.001$). The TUVV vs. TURP difference in Q_{max} was less pronounced after weighting and was not statistically significant (Beta = -2.7 mL/s, 95% CI -5.6 to 0.26; $p = 0.074$). This suggests that when accounting for baseline differences,

TUVP's flow improvement was nearly on par with TURP, whereas PAE consistently lagged behind TURP in restoring peak urinary flow.

3.7. Post-Void Residual Urine (PVR)

Pre-treatment post-void residual (PVR) volumes were high in all groups (median ~120 mL). By 12 months, PVR had decreased substantially in each group, with TURP achieving near-complete bladder emptying in many cases. The adjusted mean PVR in the TURP group was ~30 mL (log-transformed mean 3.4, 95% CI 3.2–3.5). There was no statistically significant difference in residual urine between PAE and TURP in the primary analyses. The adjusted PAE–TURP difference was small (Beta = 0.28 on log-scale, 95% CI –0.02–0.58) and did not reach significance ($p = 0.064$). The weighted analysis likewise showed no significant PVR difference for PAE vs. TURP (Beta = 0.26; $p = 0.20$). In contrast, the TUVP group tended to have a higher residual volume than TURP in unadjusted terms. In adjusted analysis, the TUVP group's log-transformed PVR was significantly higher than TURP's (Beta = 0.43, 95% CI 0.12–0.74; $p = 0.007$), corresponding to roughly a 54% higher raw residual volume.

4. Discussion

This study provides a comparative analysis of three widely used surgical and minimally invasive interventions for BPH including TURP, PAE, and TUVP.

Consistent with existing literature, TURP demonstrated the greatest efficacy across nearly all clinical endpoints at 12 months, including IPSS, QoL, prostate volume reduction, Qmax, and PVR, reinforcing its continued role as a reference standard for BPH surgery [13,14]. The adjusted and weighted analyses corroborated that symptom relief and functional restoration are most reliably achieved with TURP, aligning with large meta-analyses and randomized trials [15,16]. However, both PAE and TUVP showed meaningful, albeit more modest, improvements in most domains, suggesting they remain viable options under specific clinical conditions.

4.1. Symptom Relief and Quality of Life

TURP was associated with the most pronounced improvements in IPSS and QoL, with both PAE and TUVP showing statistically inferior outcomes. This is consistent with previous trials such as the UK-ROPE study and the randomized trial by Gao et al., which demonstrated superior symptom reduction with TURP compared to PAE [11,17,18].

The QoL findings mirror the symptom trends, highlighting TURP's superior impact on patients' perceived well-being. While both alternative treatments led to clinically meaningful QoL gains, PAE was persistently inferior to TURP even after controlling for confounders. These results support recent concerns about the limited durability of PAE effects, especially in patients with larger prostates or significant bladder outlet obstruction [17].

4.2. Erectile Function Preservation

Erectile function, assessed via IIEF, did not differ significantly between groups after adjustment, despite marked crude differences in baseline scores. These findings contrast with some reports suggesting a protective effect of PAE on sexual function compared to TURP [17]. However, our results imply that when baseline sexual function is properly accounted for, the long-term impact of the intervention itself may be more nuanced. Importantly, this suggests that erectile outcomes in real-world populations are driven more by preexisting dysfunction than the treatment modality per se.

4.3. Prostate Volume and Flow Dynamics

TURP led to the greatest reductions in prostate volume and the highest gains in Qmax, underscoring its mechanical advantage via direct tissue resection. PAE, while

non-resective, achieved a moderate volume reduction consistent with ischemic involution, but this translated to significantly lower Q_{max} improvements. These findings reflect the mechanism-dependent nature of these treatments and are in line with prior studies [16,18].

TUVP offered intermediate outcomes—achieving statistically significant, but lesser, volume reductions compared to TURP. Nonetheless, its performance in Q_{max} improvement was not significantly different from TURP in the weighted analysis. This may reflect vaporization's ability to debulk tissue effectively in appropriately selected cases, especially when performed by experienced surgeons [19].

While weighting models suggested comparable symptom relief (IPSS) between groups, TUVP remained associated with significantly lower peak flow rates and worse Quality of Life (QoL) scores compared to TURP in our primary fully adjusted multivariable analysis.

4.4. Post-Void Residual Volume

While all treatments improved PVR, TURP again achieved the most consistent and complete bladder emptying. TUVP showed a significantly higher residual volume in adjusted models but not in the weighted analysis. PAE, although non-significantly different from TURP, showed a trend toward higher PVR, reinforcing concerns about its efficacy in relieving obstruction in men with high baseline retention [13].

4.5. Clinical Implications

Despite growing enthusiasm for newer technologies like HoLEP, widespread adoption is limited by high costs, steep learning curves, and infrastructure needs [20,21]. In many centers—especially in low-resource settings—TURP, TUVP, and PAE remain the most accessible options. Our findings validate the continued clinical relevance of these modalities and emphasize the importance of appropriate patient selection, especially when TURP is contraindicated or expertise in enucleation is lacking.

This study does not constitute a full comparative effectiveness-and-safety evaluation. Because standardized data on perioperative harms, recovery burden, and retreatment rates were unavailable, our analysis is strictly limited to 12-month functional and anatomical outcomes.

Our data reflect a clear selection bias where TUVP was offered to older patients (median age 77) with a higher burden of anticoagulation (64%) and lower baseline sexual function (IIEF 6). These results suggest that in routine clinical practice, TUVP and PAE may not always serve as direct competitors to TURP for the 'average' patient. Instead, they often function as specialized alternatives for high-risk patients who are less favorable candidates for traditional resection. The study is limited by a 9.8% attrition rate at 12 months. However, this loss-to-follow-up was primarily administrative. The analysis was conducted on a complete-case basis of 203 patients. We acknowledge that the exclusion of 22 patients due to missing 12-month outcomes remains a limitation, as it may introduce attrition bias if those excluded differed systematically from the analyzed cohort. Notably, despite being used in a more challenging population, TUVP provided symptom relief (IPSS) and flow improvements (Q_{max}) that were comparable to TURP once baseline characteristics were statistically adjusted. This reinforces the clinical value of maintaining proficiency in these techniques for patients where the 'gold standard' might carry an unacceptable safety risk.

Furthermore, this study focused primarily on functional and anatomical outcomes at 12 months. Due to the retrospective nature of the data collection, detailed perioperative metrics—such as hospital stay, exact catheterization duration, and specific low-grade complications—were not available for analysis. While the long-term efficacy results are robust, further prospective studies are needed to provide a standardized head-to-head safety comparison of these three modalities.

Our study has several limitations. First, the 12-month follow-up period is relatively short and may not capture long-term durability or delayed complications. Second, as a single-center study, the generalizability of these results to different institutional settings or provider experience levels may be limited. Finally, despite the use of propensity score weighting to adjust for observed baseline differences, the risk of unmeasured confounding and residual bias remains inherent to the retrospective design.

5. Conclusions

In this real-world cohort, TURP demonstrated significant outcomes across most domains at 12 months. However, both PAE and TUVF offered clinically meaningful benefits and may serve as viable alternatives in appropriately selected patients. Given the continued use of these modalities in clinical practice—especially in resource-limited settings—our results underscore the importance of maintaining and optimizing proficiency in these techniques. Future research should aim to incorporate long-term follow-up and health economic evaluations to better inform policy and guideline development. While significant associations were observed, the observational design limits the ability to draw definitive confirmatory conclusions across all six endpoints. In conclusion, within this selected observational cohort, TURP, TUVF, and PAE were associated with different 12-month symptom, flow, and prostate-volume outcomes. While TURP provided the most pronounced functional gains, the lack of safety and procedural data limits our ability to determine a broader net clinical benefit. These results should inform clinical decision-making specifically regarding functional restoration rather than overall procedural decisions.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/uro6020014/s1>. Comparative Outcomes of TURP, PAE, and TUVF in Benign Prostatic Hyperplasia: A Weighted Regression and ANCOVA Analysis of Clinical Kinetics. Table S1: Initial Baseline Imbalance (Unweighted). Table S2: Imbalance After Matching Weight Adjustment.

Author Contributions: Conceptualization, M.D.G., L.B., J.-F.D.W. and T.J.; methodology, M.D.G.; software, B.B.; formal analysis, B.B.; investigation, M.D.G., L.B., J.-F.D.W. and T.J.; resources, M.D.G., L.B. and T.J.; data curation, B.B.; writing—original draft preparation, T.J. and M.D.G.; writing—review and editing, M.D.G., L.B., T.J. and B.B.; visualization, T.J.; supervision, M.D.G.; project administration, M.D.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Ethics Committee of CHU UCL Namur (protocol code CE 74/2013, B039201318242, and date of approval is 17 December 2019).

Informed Consent Statement: Informed consent was waived due to the retrospective design.

Data Availability Statement: Available upon reasonable request from the corresponding author.

Acknowledgments: Literature review using open access Grammar correction using Gemini 3.5.

Conflicts of Interest: The authors declare no conflicts of interest.

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