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Holmium laser enucleation of the prostate: Learning curve analysis and comparison with TURP

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Introduction Benign prostatic obstruction (BPO) is a prevalent cause of lower urinary tract symptoms (LUTS), traditionally managed with transurethral resection of the prostate (TURP). However, advances in technology, particularly holmium laser enucleation of the prostate (HoLEP), offer an alternative approach. Our aim was to compare the outcomes of HoLEP, during both the surgeon's learning and expert phases, to TURP, assessing perioperative safety, efficacy, and functional recovery.

Material and methods This prospective study included 200 men with BPO-related LUTS, divided into three groups: group 1: TURP (n = 100), group 2: HoLEP during the learning curve (n = 50), and group 3: post-learning curve (n = 50). Outcomes analyzed included learning curve analysis, IPSS, QoL, Q_{max}, PVR, surgical efficiency, and complication rates. Postoperative outcomes were assessed at 1 and 6 months.

Results The HoLEP learning curve reached a plateau around case 30, and improved after case 50. Group 3 demonstrated significantly better outcomes in surgical efficiency and functional recovery compared to groups 1 and 2. Enucleation efficiency in group 3 was higher, and the operative time was shorter. Postoperatively, the Q_{max}, IPSS and PVR improved significantly across all groups but were highest in group 3, followed by group 2 and group 1.
Regarding safety, group 3 had the lowest complication rates, with significantly less frequent postoperative bleeding. Catheter removal time was slightly shorter in group 2 compared to both groups 1 and 3.

Conclusions HoLEP, especially after overcoming the learning curve, provides better perioperative safety, greater efficiency, and improved functional outcomes compared to TURP, making it a highly effective treatment.

Key Words: prostate ‹› prostatectomy ‹› laser ‹› learning curve ‹› education

INTRODUCTION

Transurethral resection of the prostate (TURP) has been the gold standard surgical treatment for benign prostatic obstruction (BPO) for many years [1]. However, advances in laser technology and surgical techniques have led to the increased popularity of anatomical endoscopic enucleation of the prostate (AEEP) using lasers such as holmium yttrium-aluminum-garnet (YAG), thulium YAG, and thulium fiber lasers in the past decade [2, 3]. HoLEP is quite versatile in achieving complete anatomic enucleation of prostate adenoma, which provides permanent relief of obstruction and prevents re-growth of remnant prostatic tissue [4].

The scientific evidence supports the superiority of HoLEP compared to TURP, which has long been the gold standard [5–8]. However, the learning curve is a critical consideration in HoLEP, which requires significant technical skills and experience to achieve optimal outcomes. Perioperative and postoperative variables are evaluated to assess surgeon performance over consecutive cases.

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The learning curve has been reported to vary among different studies, showing results between 25 to 80 cases in different cohorts [9–12].

In this study, we aimed to evaluate the learning curve of HoLEP, surgical outcomes during both the learning curve and expert periods, and to compare these results with the long-established gold standard, TURP. The study was conducted with a prospective, consecutive patient cohort, while incorporating cumulative sum-based proficiency assessment, and comparing outcomes directly with bipolar TURP performed by the same surgeon. This allowed for a controlled and practical evaluation of the clinical impact of surgical experience with HoLEP.

MATERIAL AND METHODS

This study was a prospective clinical study involving a single center as the center of enrollment: Marmara University, Istanbul, Turkey. The study was conducted between June 2022 and June 2024.

The study was carried out in compliance with the protocol and Good Clinical Practice, as described in the ICH Harmonized Tripartite Guidelines for Good Clinical Practice 1996, and with the Declaration of Helsinki, concerning medical research in humans (Recommendations Guiding Physicians in Biomedical Research Involving Human Subjects, Helsinki 1964, amended Tokyo 1975, Venice 1983, Hong Kong 1989, Somerset West 1996).

Eligible patients were men >50 years of age with LUTS attributed to BPO with an indication for surgical treatment according to the EAU Guidelines on Non-Neurogenic Male Lower Urinary Tract Symptoms [13] and who underwent either TURP or HoLEP. Patients with a prior history of benign prostate enlargement (BPE) surgery and prostate cancer diagnosis were excluded.

All the patients included in the study were operated on by a single surgeon, with experience in bipolar TURP (>500 cases) but no hands-on experience with HoLEP prior to this series. Before initiating the HoLEP cases, the surgeon attended a HoLEP masterclass and structured training courses, and observed both live and semi-live HoLEP procedures. However, no direct mentorship or proctoring was provided during the initial cases. HoLEP patients were divided into 2 groups. The initial 50 patients who underwent HoLEP were considered to be operated on during the learning curve of the surgeon. The subsequent 50 patients were considered to be operated in the expert phase. En-bloc enucleation technique was used consistently in all HoLEP cases without any transition to 2-lobe or 3-lobe techniques. For comparative analysis, the study included the most recent 100 consecutive patients who underwent bipolar TURP performed by the same surgeon within the year preceding the initiation of HoLEP procedures.

TURP patients were grouped as group 1, the initial 50 HoLEP patients were grouped as group 2, and the subsequent 50 HoLEP patients were grouped as group 3.

All the patients were scheduled for surgery with a sterile urine culture and received second generation cephalosporins as preoperative prophylaxis as advised by the local institution's Infections Committee protocol. Anticoagulant or antiaggregant therapies were bridged with low molecular weight heparin.

The primary objective was to evaluate the success rate by comparing changes in scores on the International Prostate Symptom Score (IPSS) and Quality of Life (QoL) questionnaire, maximum urinary flow rate (Q_{max}) on uroflowmetry, and post-void residual urine volume (PVR), and to compare operation duration, resection and enucleation efficiencies of the initial 50 HoLEP cases performed by a single surgeon during the learning curve to the subsequent 50 cases after the learning curve, using bipolar TURP as the benchmark. The surgical outcomes including IPSS, QoL, Q_{max}, PVR were evaluated at the postoperative first month. The postoperative complications were evaluated both at the postoperative first and sixth months. According to these parameters, the learning curve of HoLEP was defined using cumulative sum (CUSUM) analysis, for which enucleation efficiency and complication rates are used as evaluated parameters.

The secondary objective was to evaluate the safety profile by comparing postoperative complications, fever status, incontinence rate, stricture rate, hemoglobin decrease and transfusion rates, and to evaluate catheter removal time in the same set of patients.

Surgical positioning

All patients were operated on in the lithotomy position under general or spinal anesthesia, depending on the anesthesiologist's decision.

HoLEP surgical technique

The en-bloc HoLEP technique with early apical release was used consistently throughout the study, as initially learned by the surgeon. A 26 Fr continuous flow resectoscope with an active laser bridge and a 550-μm end-firing laser fiber was used. A highpowered 60 W holmium:YAG laser (Cyber Ho 60W, Quanta System, Samarate, Italy) was used, with settings of 2.0 J × 30 Hz (60 W) for enucleation and 1.2 J × 35 Hz (42 W) for hemostasis. A pulse modulation mode known as Virtual Basket, provided by the laser manufacturer, was used. Room-temperature saline was used for gravitational irrigation, maintained at a height of 100 cm above the patient.

Bipolar TURP surgical technique

Bipolar TURP procedures were performed using the Mauermayer technique. Resection began at the 5 and 7 o'clock positions to remove the prostatic tissue at the posterior aspect of the prostate, including the median lobe when present. This approach created an initial irrigation channel at the base of the prostatic fossa, allowing for improved irrigation and optimal exposure. A 12 o'clock anterior commissurotomy was then performed to separate the lateral lobes, which were subsequently resected one by one in a top-down fashion. A 26 Fr continuous flow resectoscope with an active resection loop bridge was employed. The electrosurgical generator was used in the bipolar cutting mode at 200 W and bipolar coagulation mode at 120 W (Olympus ESG-400, Olympus Medical Systems, Tokyo, Japan). Room-temperature saline was used for gravitational irrigation, maintained at a height of 100 cm above the patient.

Statistical analysis

The data were analyzed using SPSS Statistics version 22 (IBM Corp., Armonk, NY, USA) and GraphPad Prism version 6 (GraphPad Software, Inc. Boston, USA).

The data were analyzed for distribution using the Shapiro-Wilk normality test. For homogeneously distributed numerical variables, parametric tests (one-way ANOVA for comparison of 3 or more variables and t-tests for comparison of 2 variables) were used for comparison. For non-homogenously distributed numerical variables, the non-parametric Kruskal-Wallis test was used for comparisons. Categorical variables were compared using the χ^2 test. P-values <0.05 were considered statistically significant. No corrections for multiple comparisons were applied, as the study was exploratory and focused on descriptive comparisons across groups.

The learning curve was analyzed using CUSUM analysis, for which expected benchmarks were defined from the outcomes of the expert HoLEP group (group 3) and a strict threshold of 80% of the benchmark was used to define proficiency. For each case, the deviation from the expected benchmark was calculated according to the formula: CUSUM Deviation = Observed Efficiency – Benchmark Efficiency. Afterwards, the CUSUM was calculated by summing the deviations from all previous cases, as follows: CUSUM = n∑i=1(CUSUM Deviation for Case i). Positive deviations indicated performance above the benchmark, while negative deviations highlighted underperformance. The point where the CUSUM values stabilize is considered the proficiency point. The expert phase was defined as the point at which the five-case moving average of enucleation efficiency consistently exceeded 80% of the benchmark value, which was derived from the median efficiency of the expert HoLEP group. CUSUM analysis was used to identify when this threshold was reached and maintained.

Bioethical standards

The study was approved by the Institutional Review Board (IRB) with the protocol number of Marmara University Ethics Committee 09.2023.337. The study is registered at ClinicalTrials.gov Protocol Registration and Results System (ClinicalTrials.gov ID NCT06849089).

RESULTS

Patient demographics and preoperative characteristics

A total of 200 patients were included: group 1 (n = 100), group 2 (n = 50), and group 3 (n = 50). The mean age of the patients was similar across the groups, with group 1 having a mean age of 65 ±8 years, group 2 at 65 ±5.8 years, and group 3 at 67.5 ±6.9 years. However, prostate volumes varied significantly among the groups. Group 1 had a median prostate volume of 54 ml, whereas groups 2 and 3 had significantly larger prostate volumes, 82.5 ml and 87 ml, respectively, with $p < 0.005$ when compared to group 1 (Table 1).

Preoperative catheterization rates were higher in group 1 (18 patients) than in groups 2 (9 patients) and 3 (10 patients). The duration of the operation was shortest in group 3 (median: 82.5 min), slightly longer in group 1 (80 min), and longest in group 2 (90 min). Group 3 demonstrated significantly reduced enucleation time (55 min) compared to group 2 (70 min), $p < 0.005$, indicating increased proficiency during the expert phase of the surgeon's learning curve.

Intraoperative and postoperative outcomes

Intraoperative complications were more frequent in group 2, with 17 (34%) incidents compared to 15 (15%) in group 1 and 10 (20%) in group 3. Capsular perforation occurred most frequently in group 1 (15 patients), while only 6 and 4 patients in groups 2 and 3, respectively, experienced this complication. Bladder mucosal injuries and bladder perforations were rare but occurred in groups 2 and 3.

Postoperatively, the urethral catheter was removed sooner in group 2, with a median of 2 days compared to 3 days in both group 1 and group 3. Postoperative bleeding before catheter removal was most frequent in group 1, occurring in 12 patients, but was significantly lower in groups 2 and 3 (2 and 1 patients, respectively) ($p < 0.005$). Similarly, postoperative complications at the first and sixth month follow-ups were more frequent in group 1, with significantly fewer complications observed in both HoLEP groups (Table 1).

Preoperative and postoperative functional outcomes

Postoperative PSA levels decreased significantly across all groups. Group 1 showed a median reduction from 2.15 ng/ml to 1.35 ng/ml, while group 2 had a more substantial reduction from 4.7 ng/ml to 0.75 ng/ml, and group 3 from 3.85 ng/ml to 0.61 ng/ml, $p < 0.005$ for both HoLEP groups compared to TURP (Table 2, Figure 1). The change in PSA was also significantly higher in HoLEP groups, with group 2 showing the greatest reduction (3.52 ng/ml) compared to group 1 (0.71 ng/ml), $p < 0.01$ (Table 2, Figure 2).

Maximum urinary flow rates (Q_{max}) improved significantly in all groups postoperatively. Group 1 had an increase from 8 ml/s to 12 ml/s, while groups 2 and 3 showed improvements to 16 ml/s and 17.5 ml/s, respectively, $p < 0.005$ (Table 2, Figure 1). Similarly, postoperative PVR volumes decreased substantially in all groups, with the greatest reductions seen in the HoLEP groups (Table 2, Figure 2).

Table 1. *Demographic information, preoperative catheterization status and postoperative complications*

		Group 1 Bipolar TURP	Group 2 HoLEP (initial 50 patients)	Group 3 HoLEP (subsequent 50 patients)
Age (years)		65 ±8	65 ±5.8	67.5 ±6.9
Prostate volume (ml)		54 (19–182)	82.5 (30–159)***	87 (40–450)***
Catheterized preoperatively		18	9	10
Operation duration (min)		80 (30–120)	90 (55–170)*	82.5 (40–220)++
Enucleation duration (min)		n/a	70 (40–135)	55 (20–130)+++
Morcellation duration (min)		n/a	20 (10-45)	25 (10-90)
Intraoperative complications	None	85	33*	40*
	Capsular perforation	15	6	4
	Subtrigonal undermining	0	8	3
	Bladder mucosal injury	0	2	3
	Bladder perforation requiring open repair	0	1	0
Postoperative catheter retrieval (days)		3 (2–10)	2 (1–7)***	3 (2–7)**
Postoperative prolonged bleeding before catheter removal		12	2	1 **
Postoperative complications at 1st month	None	89	40	42
	Delayed bleeding	0	0	0
	Stress urinary incontinence	11	10	8
	Urethral stricture	0	0	0
Postoperative complications at 6th month	None	95	44	47
	Delayed bleeding	0	0	0
	Stress urinary incontinence	5	4	2
	Urethral stricture	0	2	1

Mean ± standard deviation (SD) values are given for normally distributed variables, and median (minimum-maximum) values are given for non-normally distributed variables according to the Shapiro-Wilk test. Statistical significance values: * p <0.05, ** p <0.01, *** p <0.005 compared to group 1; + p <0.05, ++ p <0.01, +++ p <0.005 compared to group 2

Table 2. *Prostate-specific antigen, maximum urinary flow, post-void residual urine volume, International Prostate Symptom Score and hemoglobin values*

		Group 1 Bipolar TURP	Group 2 HoLEP (initial 50 patients)	Group 3 HoLEP (subsequent 50 patients)
PSA (ng/ml)	Preop	2.15 (0.37–16)	4.7 (0.38–18)	3.85 (0.3–19)
	Postop	1.35 (0.05–6.6)	0.75 (0.02–5.2)&&&	0.61 (0.02–6)&&&
Change in PSA (ng/ml)		0.71 (from –4.1 to 11.5)	3.52 (from –1.97 to 12.8)**	2.23 (from –1.1 to 18.9)*
Q_{max} (ml/s)	Preop	8 (1–18)	7 (3–16)	8 (2–45)
	Postop	12 (5–31)&&&	16 (4–30)&&&	17.5 (9–45)&&&
Change in Q_{max} (ml/s)		3 (from –10 to 27)	8 (from –4 to 25)***	8.5 (from –1 to 28)***
PVR (ml)	Preop	150 (0–1,100)	140 (20–1,050)	150 (10–900)
	Postop	50 (0–185)&&&	31 (0–272)&&&	40 (0–250)&&&
Change in PVR (ml)		100 (from –89 to 1065)	112 (from –70 to 870)	100 (from –48 to 810)
IPSS	Preop	20 (6–34)	20 (10–35)	22.5 (9–33)
	Postop	13 (1–26) &&&	10 (1–29)&&&	9 (2–25)&&&
Change in IPSS		6 (from –1 to 22)	10 (from –7 to 29)	11 (from –1 to 26)**
QoL	Preop	4 (1–6)	4 (2–6)	4.5 (2–6)
	Postop	2 (0–5)&&&	2 (0–5)&&&	1 (0–4)&&&
Change in QoL		2 (from –2 to 6)	2 (from –1 to 6)	3 (0–5)**,+
Hemoglobin (ng/ml)	Preop	13 (9.7–17.7)	14.7 (10.7–17.7)	13.95 (10.7–17.1)
	Postop	12.8 (8.2–16.6)&&&	13.55 (10–16)&&	13.4 (10.5–17.5)
Change in hemoglobin (ng/ml)		0.8 (from –1.6 to 5.6)	1.15 (from –1.8 to 4.7)	0.7 (from –1.3 to 4.1)+

*p <0.05, **p <0.01, ***p <0.005 compared to group 1 values; +p <0.05, ++p <0.01, +++p <0.005 compared to group 2 values; &p <0.05, &&p <0.01, &&&p <0.005 compared to preoperative values
IPSS – International Prostate Symptom Score; PSA – prostate-specific antigen; PVR – post-void residual urine volume; Q_{max} –maximum urinary flow

IPSS scores and QoL scores improved across all groups, with group 3 showing the most gain. Median postoperative IPSS scores decreased to 13, 10, and 9 in groups 1, 2, and 3, respectively, with group 3 showing the greatest improvement from baseline. Quality of life scores also showed a significant improvement in group 3 compared to other groups (Table 2, Figures 1 and 2).
Hemoglobin levels showed a decrease in the postoperative period compared to preoperative values in groups 1 and 2; however, values were similar in group 3 (Table 2, Figure 1). The magnitude of change in hemoglobin level was similar between all groups (Table 2, Figure 2).

Surgical efficiency

Surgical efficiency was calculated based on enucleation and resection rates. Group 1 had a resection efficiency of 0.44 g/min, while group 2 had an efficiency of 0.67 g/min and group 3 0.9 g/min, p <0.005 compared to group 1. Enucleation efficiency improved significantly between groups 2 and 3, with group 3 demonstrating an efficiency of 1.29 g/min compared to 0.91 g/min in group 2 (Table 3, Figure 3).

In summary, the transition from the learning to the expert phase in HoLEP resulted in improved surgical efficiency, reduced complication rates, and better functional outcomes compared to bipolar TURP.

Learning curve

The learning curve for HoLEP was evaluated using CUSUM analysis and trendline modeling for enucleation efficiency. A threshold for proficiency was applied, defined as achieving 80% of the expert group's benchmark efficiency sustained over a 5-case moving average. The median enucleation efficiency of the HoLEP expert group was 1.29 g/min, and the benchmark efficiency was calculated as 1 g/min. Accordingly, the CUSUM values were determined based on this benchmark value.
The CUSUM graph showed three distinct phases in the learning curve. In the initial phase, between cases 1 and 30, the CUSUM values declined, indicating a slight decrease in surgical performance below the benchmark. This period was considered the early learning phase, after which the efficiency gradually improved with growing experience. Around cases 31 to 50, the graph flattened out, reached a plateau phase, suggesting that

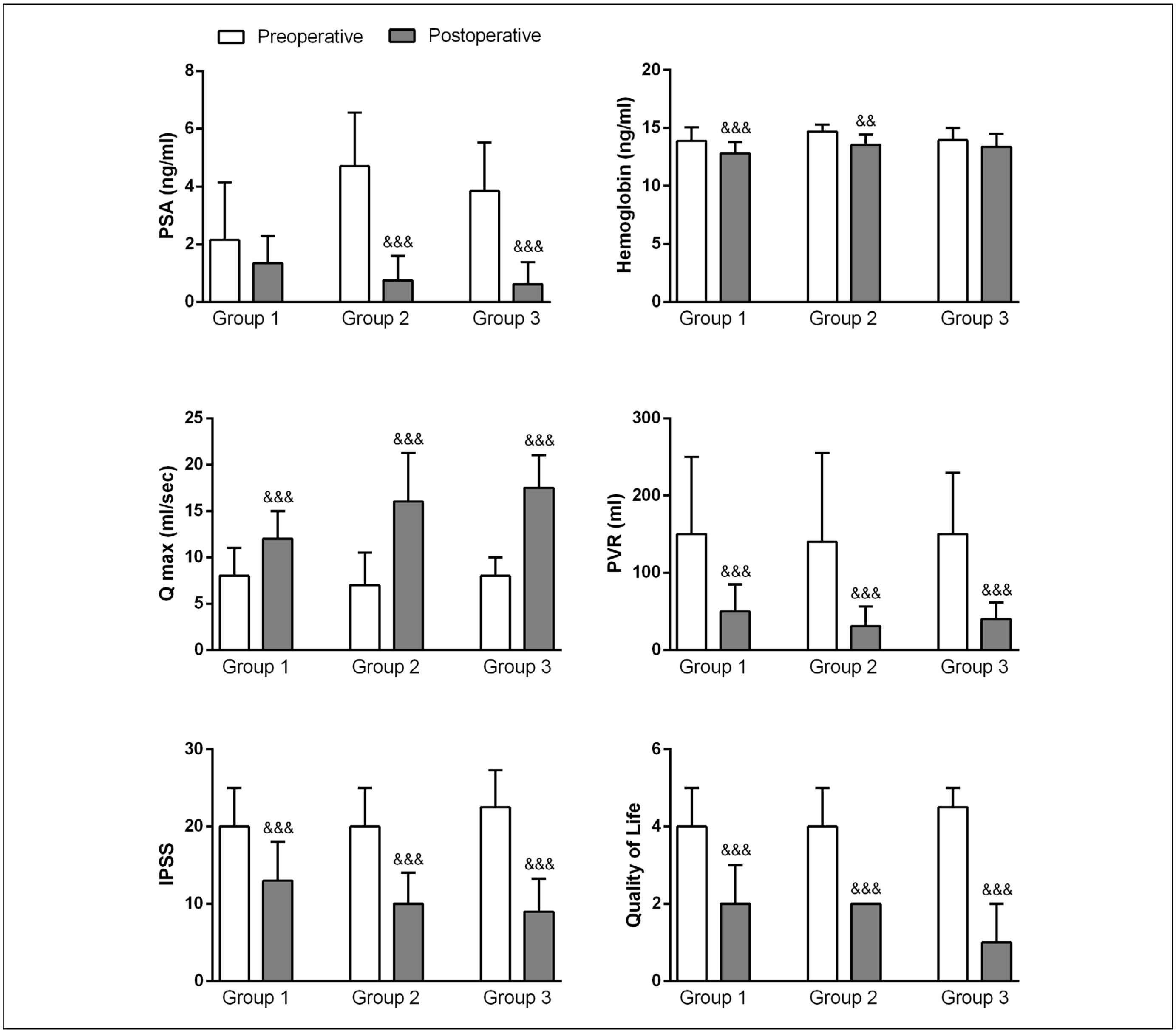

Figure 1. *Comparison of PSA, maximum urinary flow (Q_{max}), post-void residual urine volume (PVR), International Prostate Symptom Score (IPSS) and hemoglobin values.*

p <0.05, &&p <0.01, &&&p <0.005 compared to preoperative values

enucleation efficiency was stabilizing. This period was considered the end of the learning phase. After case 58, the CUSUM values started rising, showing that performance had improved above the benchmark. This indicated that proficiency had been achieved, with a surgical performance at the expert level (Figure 4).

DISCUSSION

Transurethral resection of the prostate has long been the gold standard for benign prostatic hyperplasia (BPH) [14]. However, with recent developments in laser technologies, laser enucleation of the prostate has gained popularity, with HoLEP being the leading option [15–17].

In our study, we compared the outcomes of bipolar TURP, HoLEP during the learning phase, and the expert phase, to evaluate the learning curve and evolution of efficacy, safety, and patient outcomes with increasing experience.

HoLEP has a steep learning curve, requiring extensive training to achieve proficiency. Early challenges include difficulties with enucleation technique,

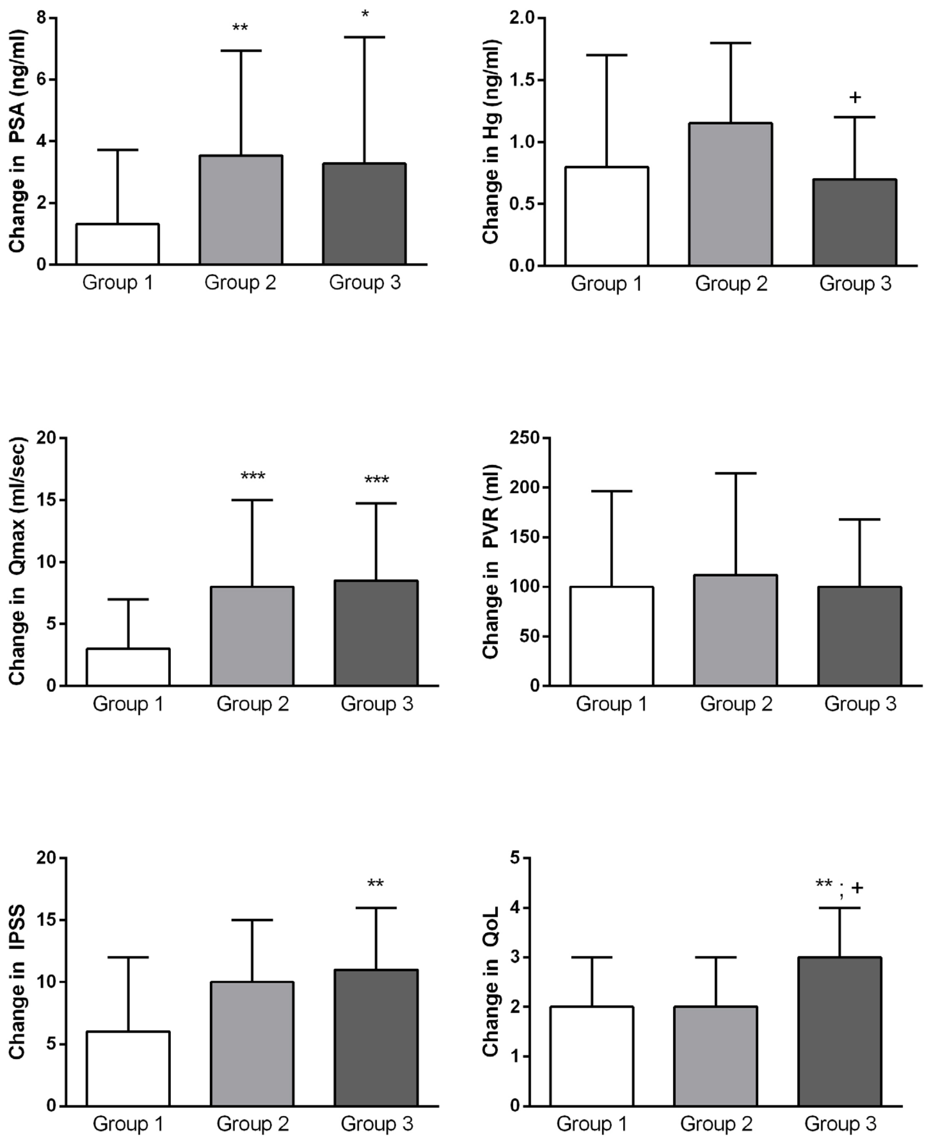

Figure 2. *Comparison of changes in PSA, maximum urinary flow (Q_{max}), post-void residual urine volume (PVR), International Prostate Symptom Score (IPSS) and hemoglobin values in preoperative and postoperative periods.*

*p <0.05, **p <0.01, ***p <0.005 compared to group 1 values; +p <0.05, ++p <0.01, +++p <0.005 compared to group 2 values

longer operative times, and higher complication rates. With experience, surgeons improve in navigating anatomical planes, leading to shorter procedures, fewer complications, and consistent enucleation efficiency. Various studies suggest that a surgeon typically needs to perform around 50 cases to overcome the learning curve, with some variability based on prior experience and availability of proctorship [18]. When the initial learning phase is completed, surgeons achieve expert-level outcomes, particularly in terms of efficiency, enucleation time, and patient safety, making HoLEP a valuable long-term skill for BPH management [11]. While several reports in the literature explore the HoLEP learning curve, few studies combine a prospective case series with detailed CUSUM analysis and a direct comparison to bipolar TURP by the same surgeon. This approach can minimize variability and provide a real-life evaluation of the learning process and its effect on surgical outcomes. Our study demonstrated significant differences between learning phase and expert phase HoLEP cases, reflecting the impact of the surgeon's experience on clinical outcomes. The learning phase was

Table 3. *Enucleation, resection, and total surgical efficiencies. Efficiency results are described as follows: Enucleation efficiency: prostate volume / enucleation duration; Resection efficiency: prostate volume / total operation duration; Surgical efficiency: prostate volume / total operation duration*

	Group 1 Bipolar TURP	Group 2 HoLEP (initial 50 patients)	Group 3 HoLEP (subsequent 50 patients)
Enucleation efficiency (g/min)	n/a	0.91 (0.6–1.81)	1.29 (0.6–3.88)$^{+++}$
Resection efficiency (g/min)	0.44 (0.09–1.6)	n/a	n/a
Surgical efficiency (g/min)	0.44 (0.09–1.6)	0.67 (0.26–1.43)***	0.9 (0.41–2.52)***, $^{++}$

*p <0.05, **p <0.01, ***p <0.005 compared to group 1 values; $^{+}$p <0.05, $^{++}$p <0.01, $^{+++}$p <0.005 compared to group 2 values

associated with longer enucleation and total operation times, higher complication rates, and lower enucleation efficiency. This aligns with existing literature, which reports that HoLEP requires 20–70 cases to achieve proficiency [9, 10]. In a previous study, the authors evaluated 132 cases – the initial 50 and subsequent 82 cases – and demonstrated a significant improvement in enucleation time and efficiency in the latter. They also found that 20–30 procedures are needed to become relatively comfortable with en-bloc enucleation technique [19]. Our findings were in alignment with the literature. In the initial learning phase, the CUSUM values were below the benchmark, which indicated that the surgical performance is below expert level, which was the expected outcome. In this phase, operative times were longer and enucleation efficiency was lower. At around case 30, the CUSUM line ceased to decline and reached a plateau, which indicated an ongoing learning phase, but operative times and efficiency were no longer fluctuating. Finally, after case 58, CUSUM values began to rise, showing that the surgical performance had exceeded the benchmark performance. At this point, the surgeon was considered to be at an expert level, with high efficiency. That is why the group 3 patients were considered to be operated on in the expert phase of the surgeon.

TURP has been the gold standard surgical option for BPO for years, but in the last decade, HoLEP has become the preferred treatment due to advancements in laser technology and enucleation techniques. A recent meta-analysis showed that while HoLEP had longer operation times than TURP, it offered shorter catheter duration, hospital stay, and bladder irrigation, along with better urinary flow rates, lower residual volumes, and improved symptoms [20]. Our study compared early HoLEP outcomes with bipolar TURP, finding that HoLEP, even during the learning curve, provided comparable or superior functional improvements, including greater reductions in PSA levels, improved Q_{max}, and lower PVR.

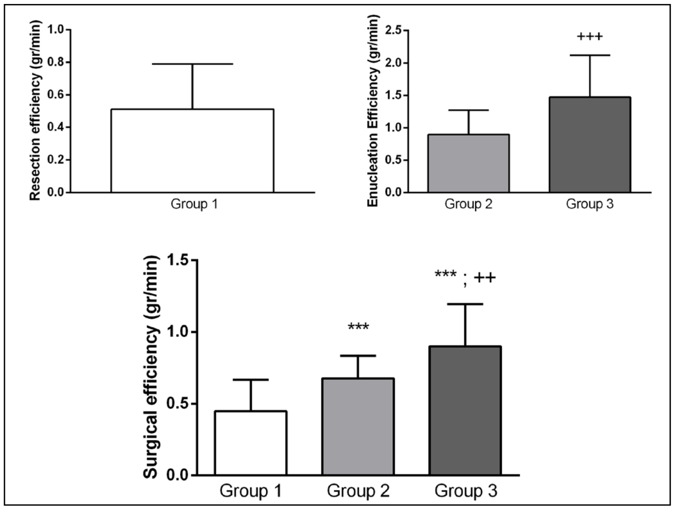

Figure 3. *Resection efficiency of group 1, comparison of enucleation efficiency of groups 2 and 3, and comparison of total surgical efficiency of all groups. Efficiency results are described as follows: Enucleation efficiency: prostate volume / enucleation duration; Resection efficiency: prostate volume / total operation duration; Surgical efficiency: prostate volume / total operation duration.*

*p <0.05, **p <0.01, ***p <0.005 compared to group 1 values; $^{+}$p <0.05, $^{++}$p <0.01, $^{+++}$p <0.005 compared to group 2 values

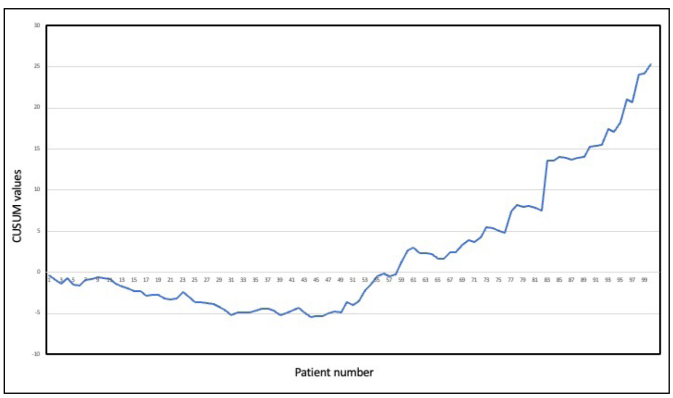

Figure 4. *Cumulative sum (CUSUM) analysis of enucleation efficiency in HoLEP cases. The x-axis represents the patient number, while the y-axis displays CUSUM values, indicating cumulative deviations from the benchmark efficiency.*

Prostate volume does not seem to be a limiting factor for patients undergoing HoLEP [21, 22]. The largest prostate size operated by HoLEP reported in the literature is 696 ml [23]. In our study, the median prostate volumes were 54 ml, 82.5 ml and 87 ml for groups 1, 2 and 3, respectively. The largest volume was 450 g, which was in the expert HoLEP group.

HoLEP and TURP differ in technique: TURP removes tissue centrally, while HoLEP enucleates the entire adenoma from the periphery, ensuring more complete removal. Studies have shown that HoLEP provides better efficacy than TURP [5]. Surgical efficiency, measured by enucleation and resection rates, was higher in expert HoLEPs (1.29 g/min) compared to the learning phase (0.91 g/min) and TURP (0.44 g/min). This demonstrated the importance of experience for HoLEP's ability to remove larger prostate volumes more efficiently.

The functional outcome comparisons of HoLEP and TURP demonstrated superior postoperative outcomes in Q_{max} and IPSS both in the short and long term and significantly lower complication rates for HoLEP [5, 24–27]. Similar to these findings, the improvements in IPSS and QoL scores were more pronounced in HoLEP groups, particularly in the expert phase. The expert HoLEP group demonstrated the greatest improvement in postoperative IPSS scores, with a median score reduction of 13 points, compared to 6 points in the TURP group. QoL improvements were also more significant in the HoLEP groups. The marked improvement in postoperative Q_{max} and reduction in PVR observed in the expert HoLEP group further confirmed the procedure's efficacy.

Perioperative complication rates were consistently lower in the expert HoLEP group compared to groups 1 and 2. Notably, intraoperative complications such as capsular perforation were less frequent in the expert group, reflecting increased surgical precision.

The catheter removal time is variable and depends mainly on the postoperative course and surgeon preference. In a recent systematic review, same-day catheter removal rates were around 85.5 to 90% among different studies [28]. In another study, the catheter was removed on postoperative day one [29]. In our study, the catheter removal was on postoperative day 2 in group 2 and day 3 in group 3. This difference from other studies was mainly due to the standardized approach for catheter removal on the 2nd postoperative day. In previous studies, HoLEP has been associated with significantly lower need for transfusion [20]. The reduction in transfusion requirements and faster catheter removal times further support HoLEP as a safer alternative to TURP.

HoLEP can be performed safely under anticoagulation [30]. However, cessation of anticoagulation therapy significantly reduces hospital stay, morcellation and procedure durations and improves rates of same-day Foley removal and discharge [30]. In our study, we held or bridged the anticoagulation therapy for all patients as a standard protocol of the institution. Keeping this in mind, we evaluated postoperative bleeding and prolonged catheterization, which were significantly reduced in HoLEP groups, with the expert phase showing the lowest incidence. This aligned with HoLEP's superior hemostatic properties compared to TURP, as already demonstrated in different studies [6].

Postoperative urinary incontinence is a real concern following HoLEP. Previous studies have reported that factors such as the surgeon's position on the learning curve, patient age, and enucleation time are predictive of postoperative incontinence recovery. In particular, less experienced surgeons or more challenging cases tend to result in higher rates of urinary incontinence during the recovery period [31].

The findings of this study showed that with appropriate training and experience, HoLEP not only matches but exceeds the efficacy and safety of TURP. Therefore, efforts to improve the learning curve through simulation training, mentorship, and standardized protocols could facilitate the adoption of HoLEP in clinical practice.

Moreover, the transition from TURP to HoLEP represents a paradigm shift in the surgical management of BPO, where laser-based enucleation is set to replace resection techniques [5]. As surgical training programs increasingly incorporate HoLEP, it is expected that more urologists may achieve proficiency faster.

This study has several limitations that should be acknowledged. First, the non-randomized design may introduce selection bias. However, all patients were enrolled consecutively, which enhances the external validity and reflects real-world clinical practice. Also, this methodology, involving consecutive patients operated on by a single surgeon, has already been used in prior studies evaluating learning curves in endourology [32]. Second, all procedures were performed by a single surgeon, which may limit the generalizability of the findings to other surgeons. Nevertheless, this design choice was essential to accurately evaluate the surgeon's learning curve and reduce inter-surgeon variability. Third, the influence of potential confounders such as prostate volume, preoperative catheterization, and patient comorbidities was not adjusted for using multivariate analysis. This may have impacted certain outcome measures, particularly surgical efficiency. It is also important to note that prostate volumes differed significantly among the groups, which could have influenced efficiency-related comparisons. However, neither multivariate nor subgroup analyses were performed due to sample size constraints and the study's primary focus on descriptive learning curve evaluation rather than predictive modeling. Lastly, although TURP procedures were performed by the same surgeon, they were conducted during the year preceding the start of the HoLEP series. Therefore, a temporal bias cannot be fully excluded, and should be considered when interpreting the results. Specific measures of urinary incontinence, sexual function, and patient satisfaction were not included and may be considered in future studies.

CONCLUSIONS

In conclusion, this study reaffirms the evolving landscape of BPO treatment, with HoLEP emerging as a superior alternative to TURP, particularly in the hands of experienced surgeons. The demonstrated improvements in safety, efficiency, and functional outcomes with increasing surgical experience advocate for HoLEP as the preferred surgical approach for BPO. Our findings suggest that the learning curve for HoLEP is steep, with a plateau phase observed around case 30 and a substantial increase in surgical performance after case 50. As surgeons progress along the learning curve, complication rates associated with HoLEP decrease significantly, and surgical outcomes improve substantially, surpassing the safety and efficacy profile of TURP, which has long been considered the benchmark for BPO surgery.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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ETHICS APPROVAL STATEMENT

The study is approved by Marmara University Ethics Committee with the protocol number 09.2023.337.

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