ARTICLE

Clinical Research

Incidence and management of BPH surgery-related urethral stricture: results from a large U.S. database

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INTRODUCTION AND OBJECTIVES: Urethral stricture (US) is a well-known complication after surgical treatment of benign prostatic hyperplasia (BPH). This study aimed to evaluate the contemporary incidence of the US after different types of BPH surgery, to identify associated risk factors and to assess its management.

METHODS: A retrospective analysis was conducted using the PearlDiver™ Mariner database, containing de-identified patient records compiled between 2011 and 2022. Specific International Classification of Diseases (ICD) and Current Procedural Terminology (CPT) codes were employed to identify population characteristics and outcomes. All the most employed surgical procedures for BPH treatment were considered. Multivariable logistic regression was employed to evaluate factors associated with diagnosis of post-operative US.

RESULTS: Among 274,808 patients who underwent BPH surgery, 10,918 developed post-operative US (3.97%) within 12 months. Higher incidence of US was observed following TURP (4.48%), Transurethral Incision of the Prostate (TUIP) (3.67%), Photoselective Vaporization of the Prostate (PVP) (3.92%), HoLEP/ThuLEP (3.85%), and open Simple Prostatectomy (SP) (3.21%). Lower incidence rates were observed after laparoscopic\robot-assisted SP (1.76%), Aquablation (1.59%), Prostatic Urethral Lift (PUL) (1.07%), Rezum (1.05%), and Prostatic Artery Embolization (PAE) (0.65%). Multivariable analysis showed that patients undergoing PUL, Rezum, Aquablation, PAE, and PVP were associated with a reduced likelihood of developing US compared to TURP. US required surgical treatment in 18.95% of patients, with direct visual internal urethrotomy (DVIU) and urethroplasty performed in 14.55% and 4.50% of cases, respectively. Urethral dilatation (UD) in an outpatient setting was the primary management in most cases (76.7%).

CONCLUSIONS: The present analysis from a contemporary large dataset suggests that the incidence of US after BPH surgery is relatively low (<5%) and varies among procedures. Around 94% of US cases following BPH surgery are managed using minimally invasive treatment approaches such as UD and DVIU.

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INTRODUCTION

Benign Prostatic Hyperplasia (BPH) is a prevalent condition among aging males, representing the most common etiological factor for lower urinary tract symptoms in this population [1]. The management of symptomatic BPH is often multimodal. In selected cases, or when pharmacological treatments lose efficacy, a surgical intervention is indicated [2, 3]. For decades, transurethral resection of the prostate (TURP) represented the gold standard. The introduction of new minimally invasive (MIST) and ultra-minimally invasive surgical treatments with the aim of reducing the incidence of treatment-related morbidity, has significantly broadened the spectrum of management options available for BPH treatment [4–8]. These advances have allowed for a more tailored approach to symptomatic BPH, considering both clinical features and patient preference [9–11].

Despite notable improvements in surgical techniques, the incidence of late complications such as urethral stricture (US) has not declined [12]. As a matter of fact, BPH surgery still represents the most common cause of iatrogenic stricture disease, accounting for up to 41% of all cases [13]. The development of urethral strictures in this setting is attributed to several etiological factors, including the use of wide-caliber surgical devices, mechanical or energy-induced damage, urinary tract infections, prolonged surgical time, and extended catheterization time [14, 15].

The incidence of urethral stricture disease after BPH procedures has been variably reported, ranging from 1% to 10–12% [16–19]. Its onset is typically 6–12 months [20]. The clinical relevance of the US after new surgical approaches remains to be determined [21].

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The management of urethral strictures can span from conservative options, such as observation and suprapubic tube placement, to endoscopic treatments, such as direct vision internal urethrotomy (DVIU) and urethral dilatation (UD), to more invasive options, such as urethroplasty procedures. Iatrogenic US can be particularly challenging to manage since less invasive treatment options carry a considerable risk of recurrence [22, 23]. Urethral reconstructive surgery, on the other hand, has demonstrated greater long-term success rates. Such evidence has prompted guidelines to consolidate the role of urethroplasty in managing recurrent US and to expand its indication as primary treatment [24].

In this study, our primary endpoint was to assess contemporary incidence of urethral strictures following different BPH surgical treatments. The secondary endpoint was to identify risk factors for urethral stricture development and to assess their management.

MATERIALS AND METHODS

Dataset

We conducted a retrospective analysis using the extensive PearlDiver™ Mariner database (PearlDiver Technologies, Colorado Springs, CO). It is a commercially available, all-payer national claims database, containing over 41 billion Health Insurance Portability and Accountability Act- compliant patient records collected between 2011 and 2022. The dataset uses unique patient identifier codes which allows for time-specific research while also keeping patient information de-identified. Moreover, this resource catalogs healthcare interactions across inpatient and outpatient settings, facilitating the longitudinal study of patient trajectories. Coverage is comprehensive, extending to all payer models across the entirety of United States territories. Data integrity is ensured via rigorous audits and review processes by independent third parties.

Institutional Review Board provided exemption prior to data collection [25, 26].

Specific International Classification of Diseases (ICD), both 9th and 10th editions, and Current Procedural Terminology (CPT) codes were used to identify populations and outcomes within the database.

Study population and procedures

We queried the database from January 1st, 2011 to December 31st, 2021, for all patients who underwent BHP surgery. The procedures considered for this study were: TURP, transurethral incision of the prostate (TUIP), holmium/thulium laser enucleation of the prostate (HoLEP/ThuLEP), open simple prostatectomy (OSP), laparoscopic-/robot-assisted simple prostatectomy (Lap/RobSP), photoselective vaporization of the prostate (PVP), prostatic urethral lift (PUL), robotic waterjet treatment (Aquablation®), water vapor thermal therapy (Rezum®) and prostatic artery embolization (PAE). The absence of a unique procedural CPT code was considered an exclusion criterion from the study.

We then refined the cohort to include only those with active insurance claims. Within this patient population, we identified individuals who received a first diagnosis of urethral stricture within 12 months after a BPH procedure. The choice of this time frame aims to minimize the capture of other potential causes of urethral stricture [13]. Demographic variables included age, obesity, diabetes mellitus, smoking habits, and the Charlson Comorbidity Index (CCI).

Subsequently, using appropriate CPT codes, we assessed the utilization rates of different active management strategies for US treatment. These treatments included: DVIU, urethroplasty, UD, and their combination.

Statistical analyses

Categorical variables are reported as frequencies and percentages, while continuous variables are reported as mean and standard deviation (SD).

To identify procedures associated with higher risk of urethral stricture, we performed a multivariable logistic regression analysis adjusting for variables such as age, obesity, smoking habits, and diabetes, and using patients who underwent TURP as reference group. Statistical analyses were performed using the R computing software incorporated into the PearlDiver™ Bellwether user interface. All p values were two-tailed with significance defined as $p < 0.05$.

RESULTS

We identified a total of 274,808 patients undergoing BPH treatment between 2011 and 2021. Baseline characteristics of the study population are summarized in Supplementary Table 1.

The mean age at surgery was 70.05 (SD 7.7) years, with the oldest patients undergoing PAE (71.55 years SD 7.8) and the youngest undergoing Rezum® (59.15 years SD 8.5). The PAE group also had the highest mean CCI compared to all the other procedures (4.26 SD 4.4). Of the total cohort, 10,918 patients were diagnosed with post-operative urethral stricture after BPH treatment, accounting for 3.97% of the patients captured.

Incidence of urethral stricture categorized by treatment group is shown in Table 1. Higher incidence was observed following TURP, PVP, HoLEP/ThuLEP, TUIP, and open SP. Lower incidence rates were observed after laparoscopic/Robotic SP, Aquablation®, PUL, Rezum®, and PAE.

Notably, 18.95% of patients received an active treatment—including UD, DVIU, urethroplasty, or a combination of treatments—following a diagnosis of post-operative urethral stricture. Higher incidence of treatment was observed for patients undergoing Rezum® (20.39%), TURP (19.66%), and TUIP (19.75%).

Proportions of application of each treatment and their combination, stratified by BPH-surgery group, are shown in Table 2. Around 94% of urethral strictures were managed through minimally invasive treatments, with UD in an outpatient setting performed in 76.7% and DVIU in 14.5% of cases, and a combination of these approaches accounted for 2.8% of the total. Urethroplasty represented the less common primary treatment, performed in only 4.5% of instances. Considering only more representative procedure subgroups (>10 patients), a higher incidence of DVIU was noted for TUIP (38.71%) and PVP (20.27%) procedures. A very low proportion of patients (0.1%) received a combination of all the three different analyzed treatments (UD, DVIU, and urethroplasty).

Multivariable logistic regression analysis showed that patients undergoing PUL (OR 0.27, 95% CI 0.25–0.29; $p < 0.001$), Rezum (OR 0.28, 95% CI 0.23–0.34; $p < 0.001$), Aquablation (OR 0.38, 95% CI 0.19–0.67; $p = 0.002$), PAE (OR 0.24, 95% CI 0.16–0.34; $p < 0.001$) and PVP (OR 0.95, 95% CI 0.92–0.99; $p = 0.01$) were associated with a reduced likelihood of developing urethral stricture compared to TURP (Table 3). Open SP showed an increased likelihood of urethral stricture (OR 1.23, 95% CI 1.07–1.41; $p = 0.002$), whereas no significant difference was noted for Lap \Rob SP, HoLEP/ThuLEP, and TUIP when compared to TURP. Moreover, multivariable analysis identified tobacco use and diabetes as significant risk factors for US development (all p values < 0.001) after BPH surgery, while age was a protective factor (OR 0.98, 95% CI 0.98–0.99; $p < 0.001$).

DISCUSSION

Through the analysis of this extensive national database, encompassing data collected over a 10-year period, we can offer a broad picture on BPH surgery-related development of urethral strictures, including their management.

We identified 274,808 patients who underwent various BPH treatment modalities, including recently introduced ones. The observed rates of post-operative incidence of urethral strictures varied from 0.65% to 4.48% (Table 1). PAE, Rezum®, PUL, and Aquablation® showed the lowest rates (0.65–1.59%) of US development. This finding could be explained by the reduced operative time and consequent reduced urethral manipulation usually required during MIST such as PUL, Rezum®, and Aquablation®, as well as the absence of a potentially harmful energy source [27–29]. Similarly, since PAE may require only the positioning of a urethral catheter as a reference point for the interventional radiologist [30], if not already present before, is it

Table 1. Incidence of urethral strictures diagnosis and treatment in the total sample and stratified by procedure.

Variable	Overall ($n = 274,808$)	TURP ($n = 197,146$)	TUIP ($n = 4281$)	HoLEP/ ThuLEP ($n = 18,169$)	Open SP ($n = 9949$)	Lap/Rob SP ($n = 6362$)	PVP ($n = 11,813$)	PUL ($n = 13,850$)	Rezum ($n = 9852$)	Aquablation (627)	PAE (2759)
Urethral Strictures[a], *n* (%)	10,918 (3.97)	8834 (4.48)	157 (3.67)	699 (3.85)	319 (3.21)	112 (1.76)	463 (3.92)	203 (1.47)	103 (1.05)	10 (1.59)	18 (0.65)
Age at diagnosis, mean (SD)	69.43 (7.4)	69.67 (7.3)	69.43 (7.4)	68.66 (7.5)	70.96 (6.8)	67.85 (7.3)	69.16 (7.23)	69.56 (8.3)	71.02 (8.8)	–	71.78 (6)
Patients treated for US, *n* (%)	2069 (18.95)	1737 (19.66)	31 (19.75)	112 (16.02)	55 (17.24)	15 (14.29)	74 (15.98)	20 (9.85)	21 (20.39)	1 (10)	2 (11.11)

Aquablation®: robotic waterjet treatment, Rezum®: water vapor thermal therapy.
US urethral stricture, *TURP* transurethral resection of the prostate, *TUIP* transurethral incision of the prostate, *SP* simple prostatectomy, *HoLEP/ThuLEP* holmium/thulium laser enucleation of the prostate, *PVP* photoselective vaporization of the prostate, *PUL* prostatic urethral lift, *PAE* prostatic artery embolization.
[a]Within 12 months after procedure.

Table 2. Urethral stricture treatment type in the total sample and stratified by procedures.

Variable	Overall ($n = 2069$)	TURP ($n = 1737$)	TUIP ($n = 31$)	HoLEP/ ThuLEP ($n = 112$)	Open SP ($n = 55$)	Lap/Rob SP ($n = 16$)	PVP ($n = 74$)	PUL ($n = 20$)	Rezum ($n = 21$)	Aquablation ($n = 1$)	PAE ($n = 2$)
UD, *n* (%)	1587 (76.70)	1345 (77.43)	17 (54.83)	87 (77.68)	40 (72.72)	11 (68.75)	53 (71.63)	17 (85)	16 (76.2)	1 (100)	–
DVIU, *n* (%)	301 (14.55)	244 (14.05)	12 (38.71)	16 (14.29)	8 (14.54)	2 (12.5)	15 (20.27)	1 (5)	2 (9.5)	–	1 (50)
Urethroplasty, *n* (%)	93 (4.50)	74 (4.26)	1 (3.23)	4 (3.57)	5 (9.1)	2 (12.5)	2 (2.70)	1 (5)	3 (14.3)	–	1 (50)
UD + DVIU, *n* (%)	58 (2.80)	51 (2.94)	1 (3.23)	3 (2.68)	1 (1.82)	–	2 (2.70)	–	–	–	–
UD + Urethroplasty, *n* (%)	21 (1.02)	16 (0.92)	–	2 (1.78)	1 (1.82)	–	1 (1.35)	1 (5)	–	–	–
DVIU + Urethroplasty, *n* (%)	7 (0.33)	6 (0.35)	–	–	–	1(6.25)	–	–	–	–	–
UD + DVIU + Urethroplasty, *n* (%)	2 (0.1)	1 (0.05)	–	–	–	–	1 (1.35)	–	–	–	–

Aquablation®: robotic waterjet treatment, Rezum®: water vapor thermal therapy.
UD urethral dilation, *DVIU* direct visual internal urethrotomy, *TURP* transurethral resection of the prostate, *TUIP* transurethral incision of the prostate, *SP* simple prostatectomy, *HoLEP/ThuLEP* holmium/thulium laser enucleation of the prostate, *PVP* photoselective vaporization of the prostate, *PUL* prostatic urethral lift, *PAE* prostatic artery embolization.

Table 3. Multivariate logistic regression analysis for predictors of US after BPH surgery.

Variable	Adjusted odds ratio (95% CI)	*p* value
Age	0.98 (0.98–0.99)	**<0.001**
Diabetes	1.07 (1.03–1.11)	**<0.001**
Tobacco use	1.08 (1.05–1.12)	**<0.001**
Obesity	1.02 (0.99–1.06)	0.12
TURP	1 *(reference)*	–
TUIP	1.09 (0.94–1.26)	0.20
HoLEP/ThuLEP	0.96 (0.89–1.04)	0.37
Open SP	1.23 (1.07–1.41)	**0.002**
Lap/Rob SP	1.27 (0.83–1.87)	0.23
PVP	0.95 (0.92–0.99)	**0.01**
PUL	0.27 (0.25–0.29)	**<0.001**
Rezum	0.28 (0.23–0.34)	**<0.001**
Aquablation	0.38 (0.19–0.67)	**0.002**
PAE	0.24 (0.16–0.34)	**<0.001**

Aquablation®: robotic waterjet treatment, Rezum®: water vapor thermal therapy.
TURP transurethral resection of the prostate, *TUIP* transurethral incision of the prostate, *SP* simple prostatectomy, *HoLEP/ThuLEP* holmium/thulium laser enucleation of the prostate, *PVP* photoselective vaporization of the prostate, *PUL* prostatic urethral lift, *PAE* prostatic artery embolization.
Bold values indicate statistical significance $p < 0.05$.

not surprising that this procedure is the one associated with the lowest rate of US (0.65%).

An interesting observation is the lower US incidence rate in patients undergoing Lap/Rob SP (1.76%), compared to the 3.21% for those undergoing the open SP procedure. This disparity may be attributed to the laparoscopic system's advantages, which include superior visualization and precision during bladder neck reconstruction [9, 10, 31]. Such enhancements not only help in minimizing undue stress and traction from stitches on urethral tissues but may also contribute to better bleeding control, ultimately leading to a shorter catheterization time [32, 33]. Moreover, the advent of various urethra-sparing robot-assisted techniques may further explain the surgical benefits observed with this approach [34, 35].

Further examination is warranted concerning the observed lower rate of US in patients undergoing Lap/Rob SP compared to those receiving endoscopic treatments. While we do not think that our findings allow us to draw definitive conclusions, primarily due to the limitations of the study design, this is something that should be further scrutinized and possibly prompt further research. Indications for BPH treatment remain those recommended by current guidelines. Ultimately, the choice between Lap/Rob SP and MIST should be tailored to the patient's individual risk profile, preferences, and the surgeon's expertise.

HoLEP/ThuLEP and PVP procedures are increasingly favored by urologists [16, 17, 36, 37]. They offer functional results comparable to traditional approaches and may reduce post-operative morbidity. However, our analysis indicates that these procedures have post-operative rates of urethral strictures that are similar to those following TURP (3.85–3.92% vs 4.48%). These data are consistent with the available literature reporting a rate of urethral strictures following TURP between 2.2 and 9.8% [18], and following HoLEP/ThuLEP and PVP between 1.2–7.3% [16, 17, 38]. A possible explanation for this finding could be the use of the same diameter of resectoscope sheath across these techniques. Additionally, in evaluating the similar rates reported in our results, it should be considered that the use of a 'hybrid' approach, which combines new techniques with TURP to address bleeding and inadequate tissue removal in patients with large prostate volumes, is not uncommon [39]. Consistent results are presented in the study by Elsaqa et al., including 208 patients, with 101 undergoing TURP (monopolar or bipolar) and 107 undergoing HoLEP. The groups were matched for age and prostate size, and the authors reported comparable rates of post-operative US (7.9% vs 4.7%; $p = 0.34$) [40].

The overall rate of post-operative strictures observed in our study (3.97%) aligns with the lower limits of ranges reported in literature [13, 41]. This evidence may be attributable to several factors. Firstly, a retrospective analysis might underestimate the actual incidence, especially if we consider patients with mild symptomatic strictures that did not seek evaluation or treatment, ultimately leading to a potential selective reporting of outcomes. This could be further affected by the variability in complication reporting across different healthcare settings, with some institutions possibly having more comprehensive follow-up and reporting protocols that identify more cases. In fact, it is not surprising that higher incidences come from prospective single-center study designs [21]. Moreover, the advancements in established surgical techniques over the years, and the growing awareness of possible complications, might have contributed to their lower incidence.

Finally, it is important to acknowledge the possibility that some clinical entities reported as bladder neck contractures may fall under the diagnosis of urethral stricture. These two conditions can cause similar urinary symptoms at presentation, and there is a possibility that the respective ICD codes could sometimes be erroneously used interchangeably [42, 43]. Despite this potential for diagnostic overlap, the likelihood of it affecting all groups we have analyzed is uniform, and the robust sample size at our disposal ensures the reliability of the incidence ranges we have observed.

Insightful observations also arise from our adjusted multivariable analysis (Table 3). This analysis confirms the incidence rates previously discussed, highlighting a statistically significant reduced risk of urethral stricture for some MISTs (being between 5% and 76% lower compared to TURP). The only procedure significantly associated with an increased risk of stricture, by 23%, is open SP. These data are of particular interest since some techniques, particularly some MIST, are associated with considerable rates of surgical retreatment and the presence of US could influence the therapeutic choices in this scenario [44]. Moreover, it can be speculated that US rates following secondary procedures could increase for patients initially treated with MIST, potentially diminishing the advantage these techniques offer in such contexts.

Finally, we observed that diabetes (1.07 [1.03–1.11], $p < 0.001$) and tobacco use (1.08 [1.05–1.12], $p < 0.001$) were statistically significant risk factors for the development of a urethral stricture. These results are consistent with what is known about the etiology of urethral stricture, which appears connected to impaired angiogenesis, excessive formation of fibrous tissue, and inflammation [45]. Interestingly, age was found to be a protective factor (0.98 [0.98–0.99], $p < 0.001$). This could be attributed to a tendency for reduced post-operative follow-up and diagnosis as age advances. Additionally, healing process in older individuals may vary compared to younger patients, potentially resulting in less aggressive scar formation.

We also examined the rates and treatment strategies employed among the different BPH procedures (Table 2 and Fig. 1). UD and DVIU were the most employed treatments in our cohort. Current literature shows wide and inconsistent ranges of patency rates after UD and DVIU, varying from 35.5–92.3% and 8–77%, respectively [46]. Moreover, these procedures carry a well-known inherent risk of potentially worsening the stricture, thereby significantly increasing treatment failure and recurrence rate [19]. Only a minority of patients in our cohort (4.5%) underwent open urethral reconstruction. These data are of interest considering that urethroplasty has proven to be a durable and definitive

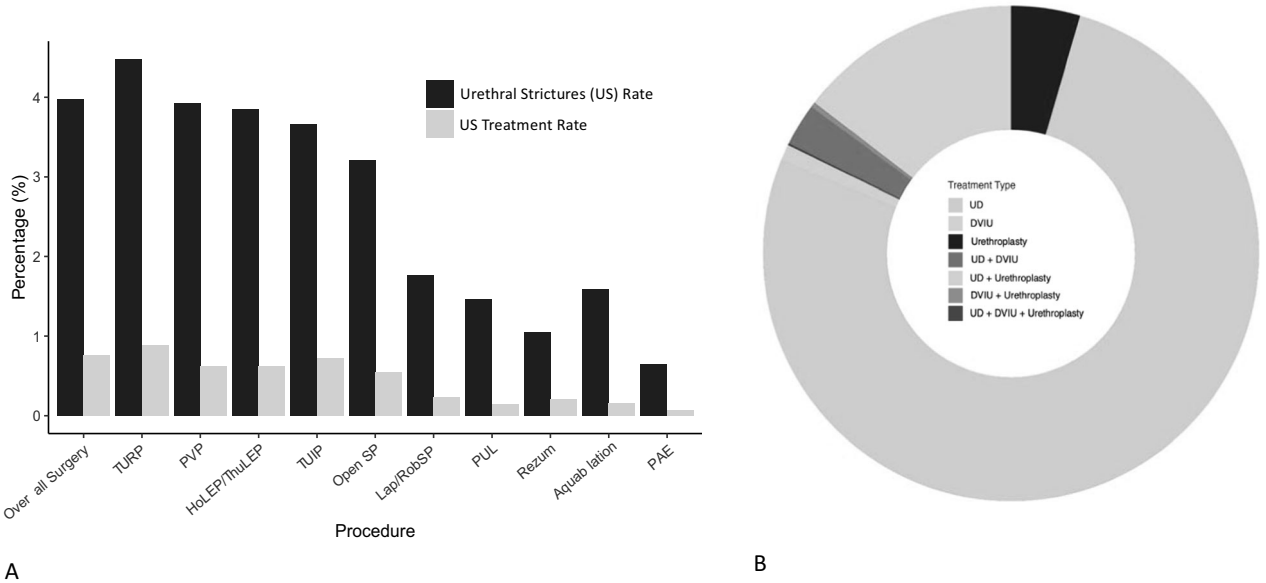

Fig. 1 Overview of urethral stricture diagnosis and treatment patterns. A Rate of urethral stricture (US) diagnosis and treatment stratified by procedures. **B** Graphic representation of the different US treatment strategies in our cohort. UD urethral dilation, DVIU direct visual internal urethrotomy, TURP transurethral resection of the prostate, TUIP transurethral incision of the prostate, SP simple prostatectomy, HoLEP/ThuLEP holmium/thulium laser enucleation of the prostate, PVP photoselective vaporization of the prostate, PUL prostatic urethral lift, Aquablation® robotic waterjet treatment, Rezum® water vapor thermal therapy, PAE prostatic artery embolization.

treatment with lifetime success rates between 75% and 100% [47]. Additionally, prolonged stricture-free rates contribute to decreasing the economic burden associated with US surveillance strategies, thereby making this treatment option also a more cost-effective choice [48]. A possible explanation for this phenomenon is the concern about iatrogenic urinary incontinence. Because endoscopic BPH treatments disrupt the internal urethral sphincter, continence relies on the external sphincter muscle. Therefore, it is plausible that to preserve sphincter control, some urologists recommend repeated endoluminal treatments in place of open repair [19]. Moreover, such procedure is technically demanding and thus predominantly performed in specialized centers by dedicated surgeons [19, 49]. This expertise requirement is a further point that might explain why, despite its high success rates, urethroplasty was the least frequently performed intervention in our study population.

Nevertheless, it is essential to acknowledge the limitations of this retrospective study, particularly those associated with the PearlDiver™ Mariner database. ICD codes do not allow for differentiation between procedure types like monopolar versus bipolar TURP or HoLEP versus ThuLEP. Moreover, since it was not made for this purpose, the database does not provide specific clinical information that could further characterize the diagnosis of interest. Our reliance on diagnosis codes, without details on the anatomical location and length of the stricture, therefore, limits our capacity to draw definitive conclusions about urethral stricture treatment strategies.

However, if we are aware of the nature and limits of this kind of database, these data still provide a valuable representation of the medical practice's reality.

The study provides valuable information on the United States population; however, these findings may not be generalizable to other countries with different medical practices and patient demographics.

CONCLUSIONS

The present analysis from a contemporary large dataset suggests that the incidence of US after BPH surgery is relatively low (<5%) and varies among procedures. The overwhelming majority of cases (over 90%) are managed using minimally invasive (UD and DVIU) treatment approaches. These findings can be used as source of information for future studies as well as for patient counseling.

DATA AVAILABILITY

The analyses conducted in this study are based on custom code developed to interface with the PearlDiver™ Mariner database. The code is maintained and available upon reasonable request under a nondisclosure agreement to ensure compliance with privacy regulations and database usage policies.

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AUTHOR CONTRIBUTIONS

Conception and design: LCL, EB. Acquisition of data: CM, AF, FD. Analysis and interpretation of data: LCL, EB, CM. Statistical analysis: LCL, EB, FD. Drafting of manuscript: LCL, AF, RA, CL, LC, GS. Critical revision of the manuscript for important intellectual content: CDN, AA, EEC, EOO, MDS, RA.

COMPETING INTERESTS

The authors declare no competing interests.

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