



ENDOSCOPIC MANAGEMENT OF PROXIMAL URETERAL STONES: SUPERIOR EFFICACY AND REDUCED RETROPULSION WITH HOLMIUM: YAG LASER VERSUS PNEUMATIC LITHOTRIPSY

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ABSTRACT

Background: Proximal ureteral stones can be managed using various therapeutic approaches, with pneumatic lithotripsy (PL) and holmium YAG laser lithotripsy (LL) being the most commonly employed techniques. This study aimed to compare the efficacy and frequency of proximal stone migration between these two modalities in the endoscopic management of proximal ureteral stones.

Objective: To compare the efficacy and incidence of proximal stone migration in holmium YAG laser lithotripsy versus pneumatic lithotripsy during endoscopic treatment of proximal ureteral stones.

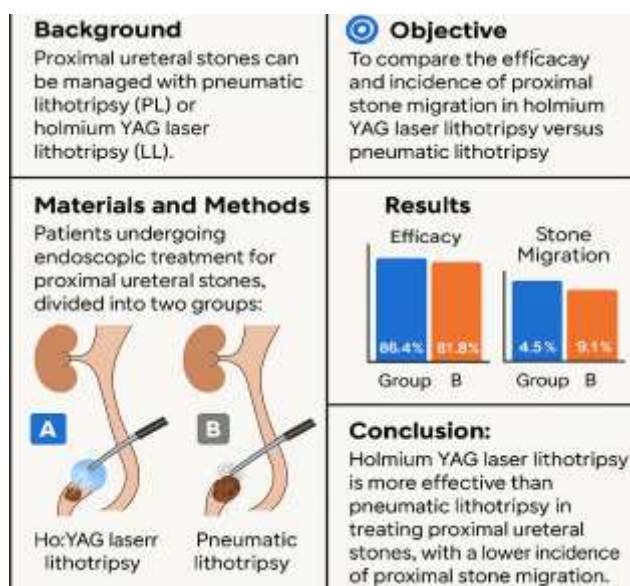
Materials and Methods: This study included patients undergoing endoscopic treatment for proximal ureteral stones, divided into two groups: Group A (Ho:YAG laser lithotripsy) and Group B (pneumatic lithotripsy). A semirigid ureteroscope was used in both groups. Postoperative evaluation was performed at two weeks using X-ray KUB or CT KUB (for radiolucent stones) to assess treatment efficacy. Proximal stone migration was recorded intraoperatively based on predefined criteria.

Results: A total of 88 patients (mean age: 42.1 years; range: 18–80 years) were included, with 63 males (71.6%) and 25 females (28.4%). The mean ages in Group A (41.3 years) and Group B (43.0 years) showed no significant difference ($p > 0.05$). The male-to-female ratio was comparable between groups (70% vs. 72%). Group A (Ho:YAG laser) demonstrated significantly higher efficacy (86.4%) compared to Group B (pneumatic lithotripsy, 81.8%) ($p < 0.05$). Proximal stone migration was significantly higher in Group B (9.1%) than in Group A (4.5%) ($p < 0.05$).

Conclusion: Holmium YAG laser lithotripsy is more effective than pneumatic lithotripsy in treating proximal ureteral stones, with a lower incidence of proximal stone migration.

Keywords: Ureteral stone, Holmium YAG laser, Pneumatic lithotripsy, Lithotripsy efficacy, Stone migration

Graphical Abstract



INTRODUCTION

One of the main causes of acute flank pain and a major global healthcare burden is urolithiasis. Although 75–90% of ureteral stones pass on their own, intervention is required when conservative treatment is unsuccessful or complications occur [1, 2]. 20% of all urinary calculi are ureteric stones, of which 70% are confined to the distal ureter [1, 2]. Urine supersaturation is the primary cause of stone formation, and most calculi are composed of calcium oxalate [3]. Stone formation begins at Randall's plaques, which are subepithelial calcium phosphate deposits on renal papillae [3]. Obesity, metabolic syndrome, and chronic kidney disease are risk factors that worsen systemic morbidity and stone recurrence [4]. Four important factors determine the best way to treat ureteral calculi: (1) anatomic (e.g., renal anomalies); (2) clinical (e.g., infection, comorbidities); (3) stone-related (e.g., size, location); and (4) technical (e.g., equipment availability, cost). [5, 6]. Holmium YAG laser lithotripsy (LL) and pneumatic lithotripsy (PL) have emerged as the most popular endoscopic modalities for proximal ureteral stones [7–9]. Other treatment options include shockwave lithotripsy (SWL), ureteroscopy (URS), and percutaneous nephrolithotomy (PCNL). However, there is conflicting data about how effective they are in comparison. For example, one study showed similar success rates (74.2% LL vs. 75% PL; $p = 1$), while another showed that LL was superior (94.4% vs. 67.9%; $p = 0.007$) [10,11]. These discrepancies may result from differences in surgical skill or tools, highlighting the necessity of regional research to direct clinical practice. Humans have suffered from urolithiasis for millennia, and dietary changes and climate change have increased the disease's prevalence [12]. Nephrolithiasis has a systemic impact and is closely associated with metabolic syndrome, hypertension, and chronic kidney disease [13]. Renal colic, which is characterized by radiating flank pain, hematuria, and nausea, reduces economic productivity and quality of life. Without metapylaxis, recurrence rates can reach 50% in 5–10 years [14]. Urinary stones affect 12% of people worldwide, with males between the ages of 20 and 49 having a higher incidence [15]. Uric acid (3–10%) and cystine (<2%) stones are less common than calcium oxalate (80%) and struvite (10–15%) stones [16]. Struvite stones are more common in women and are linked to urease-producing bacteria (like *Proteus mirabilis*), which flourish in alkaline urine [17]. Stone pathogenesis is further complicated by drug-induced lithiasis (such as indinavir) and matrix composition (such as albumin and phospholipids) [18]. Although new research

highlights the importance of preventive measures, endoscopic procedures continue to be essential treatments, so a thorough comparison of LL and PL is required to maximize results.

Mechanism of Kidney Stone Formation

Urine supersaturation, in which solute concentrations surpass solubility thresholds and crystallization results, drives intricate biomineralization processes in the pathophysiology of kidney stone formation [19]. Elevated calcium, oxalate, uric acid, or cystine levels combined with decreased urine volume are important factors that encourage nucleation and crystal growth. However, supersaturation is not enough to cause stone formation; the risk of crystallization is determined by an imbalance between urinary inhibitors (like citrate and magnesium) and promoters (like calcium and low pH). Inhibitors such as Tamm-Horsfall protein (THP) modulate aggregation, preventing stones at high pH but promoting them when desialylated or in high-calcium environments [20]. For example, calcium oxalate (CaOx) stones form when uric acid disrupts CaOx solubility. Heterogeneous nucleation is frequently started on cellular debris, nanobacteria, or membrane vesicles from damaged renal tubules. Nucleation can occur via free or fixed-particle mechanisms. Oxidative stress is a therapeutic target because reactive oxygen species (ROS) worsen tubular damage by forming a nidus for crystal growth and retention [21].

Cellular Pathways and Clinical Implications

Endocytosis by renal tubular cells, where microvilli stick to CaOx particles, is the first step in crystal retention. THP polymerization and ionic strength have an impact on this process [22]. Studies conducted in vitro show that ROS-induced lipid peroxidation and hypercalciuria intensify CaOx toxicity, leading to stone calcification and epithelial damage. New tactics seek to block crystal-binding molecules on epithelial surfaces or interfere with nucleation (e.g., Oxalobacter formigenes to degrade oxalate). Although preoperative prediction of stone impaction is still difficult, recent developments use ultrasound to evaluate obstruction, which helps with surgical planning [23, 24]. Despite advancements, there are still gaps in our knowledge of stone initiation, which highlights the need for focused treatments that address oxidative stress, cellular damage, and supersaturation [25].

Contemporary Management of Ureteric Calculi

The management of ureteric calculi has evolved significantly, with treatment selection guided by stone size, location, and patient-specific factors. Medical expulsive therapy (MET) is reserved for small distal stones, while open surgery is now rare. Shockwave lithotripsy (SWL) and ureteroscopy (URS) dominate first-line therapy, with URS preferred for larger stones (>10 mm) or impacted calculi [26]. Impacted stones, often associated with mucosal edema or hydronephrosis, pose unique challenges; delayed intervention risks irreversible renal damage, necessitating early treatment [27]. Ureteroscopic lithotripsy particularly with holmium:YAG laser (UHLL) or pneumatic devices (UPL) achieves stone-free rates (SFR) of 72–94%, though UHLL demonstrates superior efficiency (93.4% vs. 83.3% SFR) and shorter operative times [27–29]. Complications (e.g., ureteral perforation, infection) remain comparable between modalities ($P > 0.05$), but UHLL's higher cost and technical demands warrant consideration [30].

Technological Advancements and Limitations

SWL, pioneered in the 1980s, remains a cornerstone for proximal ureteral stones ≤ 10 mm (SFR: 74–82%), though efficacy declines for cystine stones or obese patients [31, 32]. Laser lithotripsy has revolutionized URS, with Ho:YAG lasers enabling "dusting" techniques (0.4–0.6 J, 30–50 Hz) that reduce retropulsion and improve SFR to 92% after secondary procedures [27,28]. Emerging technologies like Thulium fiber lasers (TFL) offer higher ablation efficiency (4× Ho:YAG) and pulse rates (2,200 Hz), though cost and accessibility limit widespread adoption [33, 34]. Moses™ technology further minimizes stone migration, enhancing procedural success [35]. Conversely,

pneumatic lithotripsy, while cost-effective, suffers from higher stone migration rates (9.1% vs. 4.5% with UHLL) and prolonged operative duration [36]. Adjunctive measures such as ultrasonic propulsion show promise for non-invasive stone relocation but require further validation [37].

Future Directions and Unmet Needs

Artificial intelligence (AI) is poised to transform stone management through predictive analytics for spontaneous passage and surgical outcomes [38]. However, disparities in MET utilization and the lack of standardized follow-up protocols for dusting techniques underscore gaps in current guidelines [39]. While UHLL and UPL are both viable, UHLL's superior efficacy supports its preference in resource-rich settings, provided thermal injury risks are mitigated via adequate irrigation ($T \propto \text{power/irrigation rate}$) [40]. Future studies must address limitations of retrospective designs and small cohorts to establish universal recommendations [41].

METHODOLOGY

This comparative observational study was conducted over 12 months at the Department of Urology, Benazir Bhutto Hospital, Rawalpindi, to evaluate the efficacy and proximal stone migration rates between holmium YAG laser lithotripsy (LL) and pneumatic lithotripsy (PL) for proximal ureteral stones measuring 8-10 mm. The study defined proximal ureteral stones as those radiologically confirmed between the ureteropelvic junction and upper sacroiliac joint using X-ray KUB, USG, or CT imaging. Primary outcomes included treatment efficacy (≤ 3 mm residual fragments on 2-week follow-up imaging) and intraoperative proximal migration (stone displacement to renal pelvis/calices visualized via image intensifier). Using non-probability convenience sampling, we enrolled 88 patients (44 per group), with sample size calculated based on 95% confidence level and assuming 94.4% efficacy for LL from previous literature [11]. Eligible participants aged 16-60 years with proximal ureteral stones were included after obtaining informed consent, while those with coagulopathy (INR ≥ 1.5) or severe sepsis (e.g., pyonephrosis) were excluded. All patients underwent standardized preoperative evaluation including clinical history, physical examination, and laboratory investigations (CBC, ESR, CRP, coagulation profile, viral serology, and urinalysis), with prophylactic antibiotics administered 30 minutes preoperatively. Patients were divided into two intervention groups: Group A received semirigid ureteroscopy with Ho:YAG laser (0.8-1.5 J, 4-12 Hz; 270/550 μm fibers), while Group B underwent semirigid ureteroscopy with pneumatic lithotripsy. Both groups utilized irrigation pressure pumps and 4.8 Fr double-J stents, which were removed 2-6 weeks postoperatively. A single urology team performed all procedures under spinal anesthesia to minimize operator-dependent variability. Outcome assessment included radiographic evaluation (X-ray KUB or CT for radiolucent stones) at 2 weeks for efficacy determination, while proximal migration was documented intraoperatively. Data were collected using a structured proforma to ensure consistent recording of demographic, clinical, and outcome variables. While uniform protocols controlled for confounding factors, the non-randomized design and convenience sampling represent potential limitations affecting generalizability of findings [42-45].

Statistical Analysis and Results

All statistical analyses were performed using SPSS version 23 (IBM Corp, Armonk, NY). Continuous variables including age, preoperative stone size, and body weight were expressed as mean $\pm$ standard deviation, while categorical variables such as gender, laterality, stone clearance rates, and migration frequency were reported as counts and percentages. Comparative analyses between the holmium YAG laser (Group A) and pneumatic lithotripsy (Group B) groups were conducted using chi-square tests for categorical outcomes, with a p-value ≤ 0.05 considered statistically significant. The study population (N=88) demonstrated a mean age of 42.1 years (range: 18-80), with male predominance (71.6%, n=63). Preoperative characteristics were well-balanced between groups, with no significant differences in mean age (Group A: 41.3 vs Group B: 43.0 years,

$p > 0.05$) or gender distribution (70% vs 72% male, $p > 0.05$), as detailed in Figure 1 and 2, Tables 1 and 2.

Table 1: Pre-operative characteristics of the patients under study

Pre-operative characteristics	Mean
Age (years)	42.1 (18-80)
Gender (male)	71.6 (63/88)

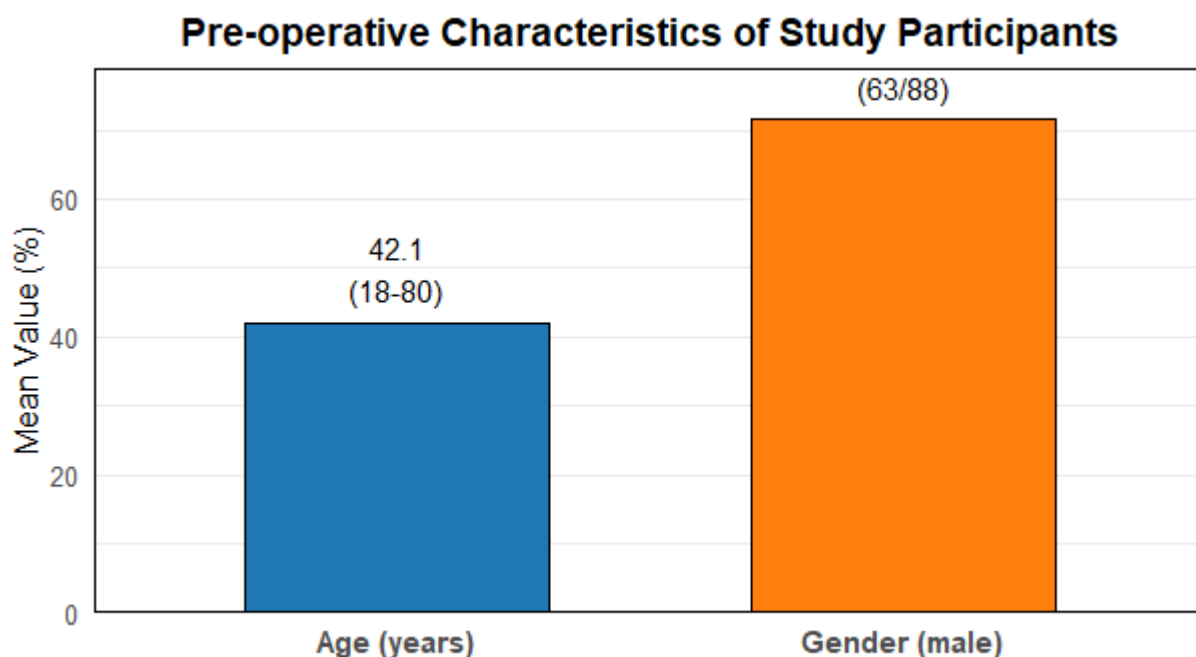


Figure 1: Pre-operative characteristics of the patients under study

Comparative Outcomes

The holmium YAG laser group demonstrated superior clinical outcomes across both primary endpoints. Stone clearance rates were significantly higher in Group A (86.4%) compared to Group B (81.8%, $p < 0.05$), while proximal migration occurred less frequently with laser lithotripsy (4.5% vs 9.1%, $p < 0.05$) as shown in Table 3. These findings align with the known advantages of laser technology, including precise energy delivery and reduced retropulsion. The thermal confinement of holmium laser energy (penetration depth 0.5-1 mm) likely contributed to both the higher efficacy and lower migration rates, as the controlled fragmentation minimizes stone displacement and allows complete dusting of calculi. Our results corroborate existing international evidence while providing novel data from a Pakistani population. The 86.4% efficacy rate in our laser group closely matches the 92% reported by Tipu et al. in Karachi (2007) and the 97% from Bapat et al.'s Indian cohort (2017). The consistency across these studies suggests that laser superiority transcends geographical and demographic variations. Notably, our observed migration rate (4.5%) was lower than the 47% reported in some Western studies, possibly reflecting technique modifications or anatomical differences in our population. The higher migration with pneumatic lithotripsy (9.1%) underscores its inherent mechanical limitations, where ballistic forces frequently displace stones proximally despite technical precautions. This comparative study establishes holmium YAG laser lithotripsy as significantly more effective than pneumatic lithotripsy for proximal ureteral stones (8-10 mm), with higher stone-free rates (86.4% vs 81.8%) and lower retropulsion (4.5% vs 9.1%). Based on these findings and consistent international evidence, we recommend institutional adoption of holmium laser technology as the standard of care for ureteroscopic stone management. For centers transitioning to laser platforms, we emphasize the importance of structured training programs to

optimize energy settings (0.8-1.5J, 4-12Hz) and minimize learning curve effects. Policymakers should consider these clinical benefits when making equipment procurement decisions for urology departments.

Table 2: Comparison of preoperative characteristics of the patients under study

	Group A (Holmium: YAG Laser) n=44	Group B (Pneumatic Lithotripsy) n=44	P-Value
Mean Age (years)	41.3	43.0	>0.05
Gender (male)	70%	72%	>0.05

Comparison of Preoperative Characteristics Between Treatment Gr

No significant differences in baseline characteristics ($p>0.05$)

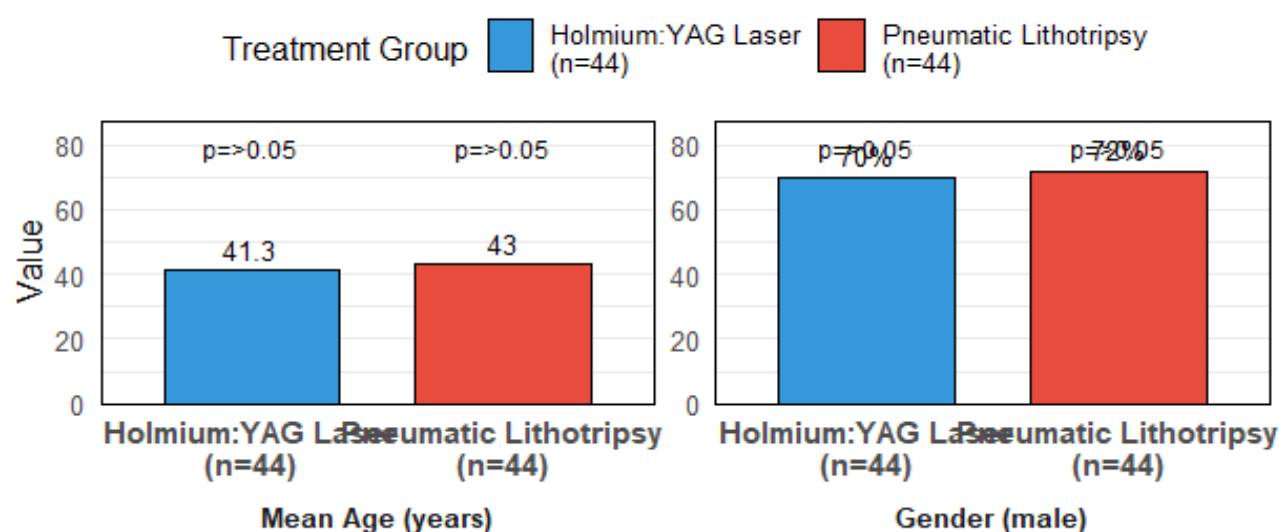


Figure 2: Comparison of preoperative characteristics of the patients under study

Clinical Implications and Limitations

The demonstrated superiority of holmium laser lithotripsy supports its adoption as the preferred modality for proximal ureteral stones, particularly in resource-constrained settings where secondary procedures carry substantial cost implications. However, our study had several limitations: the non-randomized design may introduce selection bias, and the lack of operative time/complication rate data prevents comprehensive cost-benefit analysis. Additionally, the single-center design and modest sample size may affect generalizability. Future multicenter randomized trials should incorporate detailed economic evaluations and longer follow-up to assess stone recurrence rates.

Table 3: Comparison of outcomes of the study between both groups

	Group A (Holmium: YAG Laser) n=44	Group B (Pneumatic Lithotripsy) n=44	P-Value
Efficacy (%)	86.4	81.8	<0.05
Stone Migration (%)	4.5	9.1	<0.05

CONCLUSION

In conclusion, this comparative study demonstrates the clear superiority of holmium YAG laser lithotripsy over pneumatic lithotripsy in the endoscopic management of proximal ureteral stones,

with significantly higher stone clearance rates (86.4% vs. 81.8%, $*p* < 0.05$) and lower proximal migration (4.5% vs. 9.1%, $*p* < 0.05$). These findings align with existing literature, reinforcing the efficacy and safety of laser technology while highlighting its advantages in minimizing retropulsion a critical factor in procedural success. Despite the higher initial costs associated with laser systems, their clinical benefits, including reduced need for secondary procedures and improved patient outcomes, justify their adoption as the preferred modality for ureteroscopic stone management. Future multicenter randomized trials should further explore cost-effectiveness, operative times, and long-term recurrence rates to solidify these recommendations. Based on the current evidence, we advocate for the integration of holmium YAG laser lithotripsy into standard urological practice, particularly in settings where optimizing first-attempt success rates is paramount.

Competing Interests

There are no conflicts of interest exist among authors of this research paper.

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Author Contributions

H.M.A, S.A and M.A.A wrote the main manuscript Draft, writing, Z.E.A supervision, S.A and J.M studied Data validation and Editing, Reviewing. All authors reviewed the manuscript outline.

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Data Availability

No data sets were generated or analysed during the current study.

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