Original Article

Comparative Efficacy of Holmium Laser versus Pneumatic Lithotripsy in Mini-Percutaneous Nephrolithotomy

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Abstract

Objective: Kidney stones are common. Mini-percutaneous nephrolithotomy (mini-PCNL) is important for treating renal stones. This randomized controlled trial was designed to compare the Holmium YAG (Ho: YAG) laser and pneumatic lithotripsy for achieving a stone-free rate (SFR) during mini-PCNL.

Methods: A total of 352 eligible patients (18–70 years old with renal calculi <2.5 cm) were enrolled at the Urology Department of Benazir Bhutto Hospital from 5 October 2025 to 5 January 2026. Patients were split into Group A (Ho: YAG laser, n=176) or Group B (pneumatic lithotripsy, n=176). All procedures were performed under general anesthesia using a 16–18 Fr tract. The stone-free rate (SFR) was defined as the absence of residual fragments or fragments <4 mm on non-contrast computed tomography (NCCT) one month post-operatively.

Results: The Ho: YAG laser group achieved an SFR of 71.6% (126/176), which was significantly higher than the 49.4% (87/176) SFR achieved by the Pneumatic Lithotripsy group ($p < 0.0001$).

Conclusion: Ho:YAG laser lithotripsy is significantly more effective than pneumatic lithotripsy in achieving stone clearance during mini-PCNL for renal calculi ≤ 2.5 cm. This finding supports the use of Ho: YAG laser as the preferred lithotripsy modality to optimize stone clearance and reduce the risk of residual disease and subsequent patient morbidity.

Keywords: Kidney Calculi; Lithotripsy, Laser; Nephrolithotomy, Percutaneous; Pneumatic Lithotripsy; Treatment Outcome

Introduction

Kidney stones are one of the most common forms of urological disease, affecting millions of people globally. They have a substantial impact on patient health, quality of life, and healthcare expenses. These stones require surgery, especially when they are large, complex, or do not respond to conservative treatment or extracorporeal shockwave lithotripsy.[1]

Percutaneous nephrolithotomy (PCNL) has become the gold standard treatment for renal calculi > 2 cm. Traditional PCNL carries considerable morbidity from its large tract, leading to more blood loss and other complications.[2] To overcome these limitations, mini-percutaneous nephrolithotomy (mini-PCNL) was developed, which uses smaller access tracts (<20 Fr) to decrease trauma to the tissue and achieve superior patient outcomes while maintaining high rates of stone clearance.[3]

A key factor in the success of mini-PCNL is the method of stone fragmentation because effective disintegration and removal of calculi not only minimizes operative time and reduces complications but also enhances the likelihood of achieving a stone-free status.[4,5] Among the various techniques available for intracorporeal lithotripsy, Holmium laser and pneumatic lithotripsy are two of the most widely utilized modalities.[6]

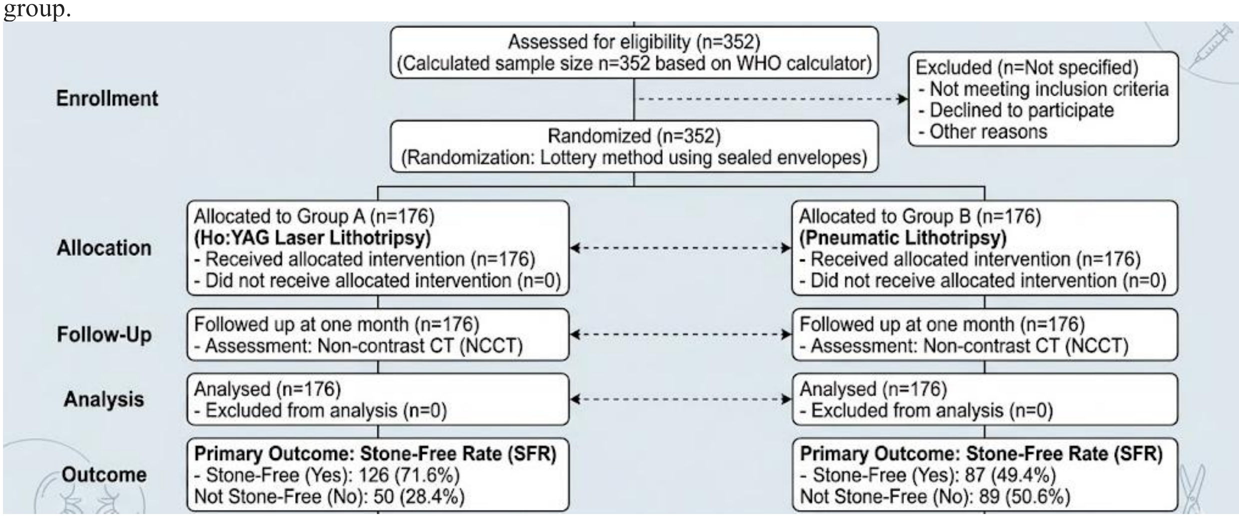
In a large randomized study of 300 patients, the stone-free rate for Holmium laser was 81.25%, significantly higher than the 67.65% rate observed with pneumatic lithotripsy ($p < 0.001$).[6] The rationale of this study was to compare Holmium laser and pneumatic lithotripsy in terms of their efficacy in patients undergoing mini-PCNL.

We will observe outcomes such as the stone-free rate. This study aims to inform clinical decision-making for patients with renal stones.

Materials And Methods

This randomised controlled trial was designed to compare the efficacy of Holmium: YAG laser and pneumatic lithotripsy. It was registered in the Clinical Trials Unit (CTU/02/2026/008/RMU) and approved by the ethical committee. The study duration was from 5 October 2025 to 5 January 2026. The efficacy parameter was the stone-free rate (SFR) during mini-percutaneous nephrolithotomy (mini-PCNL). Conducted at the Urology Department of Benazir Bhutto Hospital, Rawalpindi, the study was scheduled for three months. The primary objective was to test the null hypothesis that both lithotripsy modalities are equally effective against the alternative hypothesis that their effectiveness differs significantly.

The operational definition of efficacy was set as the stone-free rate (SFR). The SFR is the percentage of patients with no remaining fragments identified or tiny residual fragments <4 mm in size, seen on non-contrast computed tomography (NCCT). NCCT was performed one month postoperatively. The sample size was calculated using the World Health Organization (WHO) sample size calculator. We used a power of 80% and a 5% level of significance. Based on previous research, an SFR of 81.25% was reported for Holmium laser and 67.65% for pneumatic lithotripsy. We plugged these values, and the required sample size was calculated as 352 patients, with 176 participants in each group.



Consort Diagram

The inclusion criteria were patients aged 18–70 years. Only those presenting with single or multiple renal calculi less than 2.5 cm were eligible for inclusion, but they required normal contralateral renal function and no active urinary tract infection. The exclusion criteria were congenital anomalies of the kidney, non-functioning kidneys, uncorrected coagulopathy, pregnancy, a history of prior PCNL on the same kidney, and medical unfitness for surgery. After approval from the Ethical Review Committee and informed consent, these patients were enrolled using daily admission logs and surgical rosters.

Participants were randomised into Group A (Holmium YAG laser) or Group B (pneumatic lithotripsy) using the lottery method of randomisation, utilising sequentially numbered, opaque, sealed envelopes. All surgical procedures were performed under general anaesthesia by a single surgical team to ensure consistency. Prophylactic intravenous antibiotics were administered 30 minutes before the procedure. Percutaneous renal access was established using fluoroscopic guidance. The tract was dilated to 16–18 French. A rigid nephroscope was used to visualise the stones. Group A underwent fragmentation with the Holmium YAG laser, and Group B underwent pneumatic lithotripsy. The Ho: YAG laser used with settings ranging from 0.8–1.5 J energy and 8–15 Hz frequency, corresponding to a power of approximately 6.4–22.5 W. The pneumatic lithotripter was operated at a minimum pressure setting of 2–3 bar (approximately 2–3 atm), adjusted as required for effective fragmentation.

The fragments were removed using forceps or suction. A nephrostomy tube was placed at the end of each procedure. Postoperative assessment was performed using a follow-up NCCT at one month to evaluate the primary outcome by a radiologist blinded to the group allocation. Demographic and clinical data, including age, sex, BMI, stone side, and symptom duration, were recorded in a structured proforma.

Statistical analysis was performed using SPSS version 25. Quantitative variables were expressed as means and standard deviations. Qualitative variables (gender and SFR) were reported as frequencies and percentages, respectively. The chi-square test was used to compare the SFR between the two groups. Statistical significance was set at $p < 0.05$. To account for potential confounders, data were stratified by age, BMI, sex, and symptom duration, followed by a post-stratification chi-square test.

Results

This study included 352 patients. They were divided equally into two groups: Pneumatic Lithotripsy (n = 176) and YAG Laser (n = 176). Age, BMI, sex, affected side, and duration of symptoms at baseline were compared. Statistical comparisons were performed using independent samples t-tests for continuous variables and chi-square tests for categorical variables.

Table 1: Comparison of Baseline Characteristics and Outcomes Between Groups

Variable	Pneumatic Lithotripsy (n=176)	YAG Laser (n=176)	p-value	95% CI	Sig.
Continuous Variables — Mean ± SD (independent samples t-test)					
Age (years)	42.41 ± 15.34	44.73 ± 15.06	0.153	−5.50 to 0.86	NS
BMI (kg/m²)	26.93 ± 5.28	27.04 ± 5.26	0.848	−1.21 to 0.99	NS
Duration of Symptoms (months)	2.85 ± 1.33	2.90 ± 1.49	0.734	0.34 to 0.25	NS
Categorical Variables — n (%) (Chi-square test)					
Gender			0.393	−5.3% to 15.5%	NS
Male	98 (55.7%)	89 (50.6%)			
Female	78 (44.3%)	87 (49.4%)			
Affected Side			0.194	−17.1% to 3.5%	NS
Left	97 (55.1%)	109 (61.9%)			
Right	79 (44.9%)	67 (38.0%)			
Stone-Free Rate			<0.0001	−32.1% to −12.3%	***
Stone-Free (Yes)	87 (49.4%)	126 (71.6%)			
Not Stone-Free (No)	89 (50.6%)	50 (28.4%)			

*NS = Not Significant (p > 0.05); *** p < 0.001. Continuous data expressed as Mean ± SD. Categorical data expressed as n (%).*

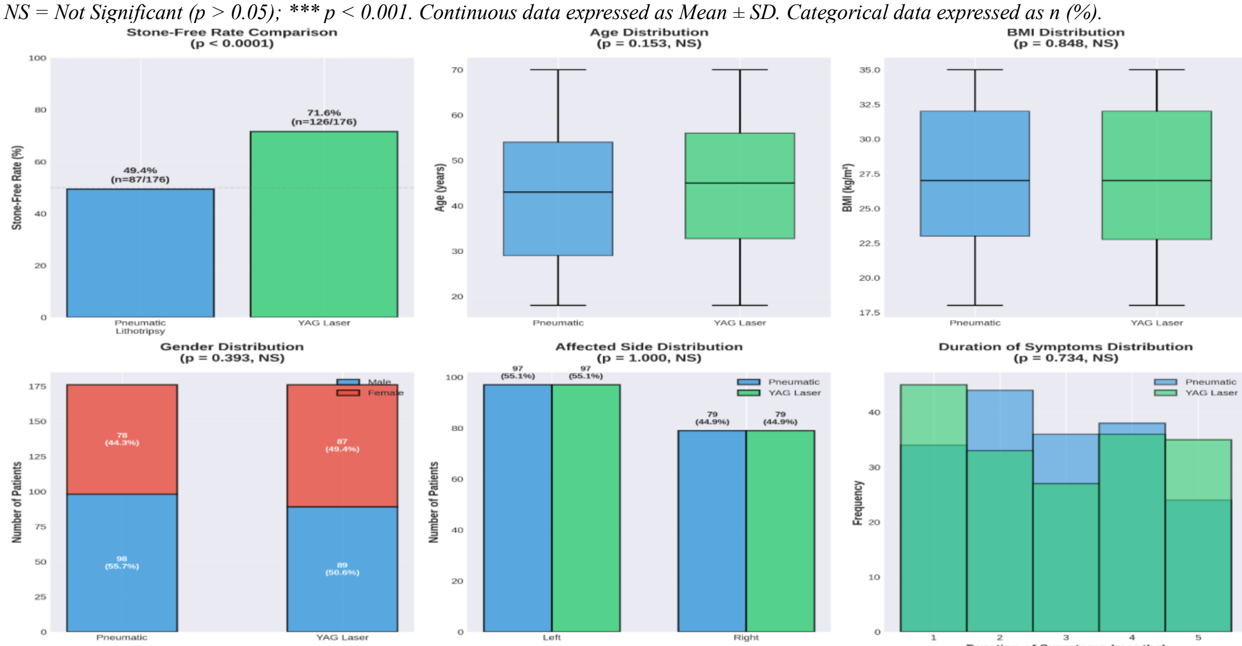


Figure 1: Comparison Of Baseline Characteristics And Outcome Between Groups

Baseline demographic variables were comparable between the two groups owing to a lack of statistically significant differences. The mean age was 42.41 ± 15.34 years in the Pneumatic Lithotripsy group and 44.73 ± 15.06 years in the YAG Laser group ($t = -1.431$, $p = 0.153$). The mean BMI was comparable between the Pneumatic Lithotripsy group

(26.93 ± 5.28 kg/m²) and the YAG Laser group (27.04 ± 5.26 kg/m²) ($t = -0.192$, $p = 0.848$). The mean duration of symptoms was similar across both groups, 2.85 ± 1.33 months in the Pneumatic group and 2.90 ± 1.49 months in the YAG Laser group ($t = -0.340$, $p = 0.734$).

The Pneumatic Lithotripsy group included 98 men (55.7%) and 78 women (44.3%), while the YAG Laser group comprised 89 men (50.6%) and 87 women (49.4%) ($\chi^2 = 0.730$, df = 1, $p = 0.393$). Stone laterality (left/right) did not differ significantly between the pneumatic lithotripsy and laser groups ($\chi^2 = 1.686$, df = 1, $p = 0.194$).

Primary Outcome (Stone-Free Rate)

A highly significant difference in the stone-free rates was observed between the two treatment groups. The YAG Laser group achieved a stone-free rate of 71.6% (126/176), compared to 49.4% (87/176) in the Pneumatic Lithotripsy group ($\chi^2 = 17.168$, df = 1, $p < 0.0001$), indicating that YAG Laser lithotripsy was significantly more effective in achieving stone clearance than Pneumatic Lithotripsy.

Discussion

This study aimed to settle an open debate in everyday urology: when performing mini-PCNL for renal stones up to 2.5 cm, does the choice between Holmium YAG (Ho: YAG) laser and pneumatic methods matter for stone clearance? Based on our findings, the answer appears to be a clear yes. The Ho: YAG laser group achieved a better stone-free rate (SFR); however, drawing clinical conclusions, it is worth comparing these results with the literature on this topic, as the picture is not one-sided.

The baseline comparability of the two groups was important. Age, BMI, sex distribution, laterality, and symptom duration were all statistically equivalent between the arms, meaning that the observed difference in SFR can be reasonably attributed to the lithotripsy modality itself rather than to patient-level confounding factors. This internal validity strengthens our primary outcome.

Our finding of superior stone clearance with the Ho: YAG laser is consistent with the evidence reported in the literature. Brunaiova et al. pooled data from 43 studies with 7,377 patients. They found that laser lithotripsy had higher stone-free rates than pneumatic lithotripsy (95% CI 1.63–2.94, $p < 0.001$).[7] Franco et al. also reported that Ho: YAG laser lithotripsy achieved an SFR of 92% compared to 77% for pneumatic lithotripsy during ureteroscopic treatment of ureteral calculi (OR 3.43, 95% CI 1.76–6.70), mirroring our findings.[8]

The Ho: YAG laser fragments stones through photothermal vaporisation, which converts stones into fine particles and gaseous matter. This effect reduces large residual fragments and stone migration, which is a well-known limitation of the pneumatic probe. The pneumatic device releases a jackhammer-like impulse on the stone, displacing it into calyceal recesses that are harder to access using an endoscope. This leads to the pneumatic group requiring more ancillary fragment retrieval, as Sharma et al. reported that 29.3% of patients in the pneumatic lithotripsy group required forceps or basket use for stone removal, compared to only 7.4% in the laser group during mini-PCNL.[9]

Not all recent comparative data favour the laser. Ibis et al. found that the high-power Ho: YAG laser and ballistic lithotripsy achieved similar stone-free and complication rates, and the laser demonstrated an advantage primarily in shorter operative time rather than stone clearance per se.[10] This finding is important to acknowledge, as it suggests that in high-volume centres, the efficacy gap between the two modalities may narrow. The discrepancy between that study and ours may reflect differences in laser power settings, stone complexity, and surgeon experience.

Sharma et al, [9] concluded that pneumatic lithotripsy could be used as a better alternative to laser lithotripsy in mini-PCNL for small to medium-sized renal and upper ureteric stones (1–2 cm), and this conclusion diverges from our findings. Our stone size cutoff extended to 2.5 cm (larger than their cohort), our follow-up was conducted using NCCT at one month (a sensitive imaging modality), and our sample size was substantially larger. A larger stone burden is known to amplify the disadvantages of pneumatic lithotripsy.

Shubham et al. compared the thulium fibre laser (TFL), the Ho: YAG laser, and pneumatic lithotripsy for stones sized 10–30 mm. They found that the stone disintegration time was shorter in the TFL group (24.17 ± 4.7 min) than in the Ho: YAG group (31.45 ± 6.3 min) and the pneumatic group (35.26 ± 5.9 min), and that laser achieved superior clearance efficiency overall.[11] These findings align with ours.

Mahajan et al.,[12] compared TFL and Ho: YAG lasers in miniperc and reported SFRs of 94.9% and 90.9%, respectively. TFL also demonstrated a shorter stone disintegration time (11 min vs. 21 min, $p < 0.001$). These rates are higher than the Ho: YAG SFR observed in our study. This discrepancy can be explained by the smaller stone size in their study. They also performed a head-to-head laser comparison without a pneumatic arm. The important message is that the Ho: YAG laser is the most accessible and widely deployed laser platform globally. However, it may be displaced by TFL as that technology matures in the coming years. Currently, Ho: YAG is the most important laser comparator for pneumatic lithotripsy in resource-limited settings such as ours.

Sharma et al. highlighted the advantages of pneumatic probes. They noted that it is a cheaper and more durable alternative to laser lithotripter fibres. These fibres must be changed more frequently. An SFR of 49.4% in the pneumatic group means that nearly one in every two patients was not stone-free at one month. This means that the people have residual disease with risks of secondary procedures, re-hospitalisation, urinary tract infections, obstruction, and, obviously, recurrent stone growth. The procedural economy of pneumatic lithotripsy is lower when the total patient care costs are considered.

There are several limitations. The follow-up period was one month, so assessment of secondary intervention rates, long-term clearance, or complications can not be done. Stone composition and density were not part of our stratification; therefore, harder stone subtypes (e.g., brushite and cystine) may have influenced the outcomes of the pneumatic group. Our lottery-based randomisation was less rigorous than computer-generated allocation with concealment.

This randomised controlled trial provides direct evidence that Ho: YAG laser lithotripsy significantly outperforms pneumatic lithotripsy in achieving stone clearance during mini-PCNL for renal calculi up to 2.5 cm, with a clinically meaningful difference in stone-free rates (SFRs).

Conclusions

This randomized controlled trial demonstrates that Holmium YAG (Ho: YAG) laser lithotripsy is significantly superior to pneumatic lithotripsy in achieving a stone-free rate (SFR) during mini-percutaneous nephrolithotomy for renal calculi up to 2.5 cm (71.6% vs 49.4%, $p < 0.0001$). This clinically meaningful difference strongly supports the Ho: YAG laser as the preferred modality to optimize stone clearance and reduce the substantial morbidity associated with residual stone disease. Future studies should focus on long-term follow-up to assess secondary intervention rates and explore the cost-effectiveness of laser lithotripsy, especially when factoring in the cost of managing residual fragments from the pneumatic approach.

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