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Holmium Laser Lithotripsy versus Pneumatic Lithotripsy for The Treatment of Vesicolithiasisn Patients: A Systematic Review

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ABSTRACT

Vesicolithiasis remains a common urological condition increasingly managed through transurethral cystolithotripsy. Holmium:yttrium-aluminum-garnet (Ho:YAG) laser lithotripsy and pneumatic lithotripsy are widely used energy modalities for endoscopic bladder stone fragmentation. However, comparative evidence regarding their efficacy and safety in the transurethral management of vesicolithiasis remains limited. This systematic review aimed to compare the clinical outcomes of holmium laser lithotripsy and pneumatic lithotripsy in patients undergoing transurethral cystolithotripsy. The review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. PubMed, Scopus, and the Cochrane Library were systematically searched for studies published between January 2015 and January 2025. Eligible studies directly compared holmium laser lithotripsy with pneumatic lithotripsy for transurethral bladder stone fragmentation. Four studies, comprising two randomized controlled trials and two retrospective studies, were included, with a reported total of 276 patients. Of these, 106 patients underwent holmium laser lithotripsy and 115 underwent pneumatic lithotripsy. Three of the four studies reported significantly shorter stone fragmentation times in the holmium laser group ($p < 0.0001$, $p < 0.001$, and $p = 0.04$). Stone-free rates exceeded 93% in both treatment groups across the included studies. One study reported a significantly higher incidence of prolonged hospitalization in the pneumatic group than in the laser group (48.5% vs. 16.1%, $p = 0.006$). Another comparison showed a significantly higher rate of adverse events in the pneumatic group (63.6% vs. 38.7%, $p = 0.046$). Conversely, one study reported significantly higher postoperative pain scores in the laser group (5.80 vs. 4.98, $p < 0.001$). Overall, holmium laser lithotripsy was associated with shorter stone fragmentation times, while both techniques achieved high stone-free rates. Although some findings favored holmium laser lithotripsy regarding hospitalization and adverse events, the limited and heterogeneous evidence did not establish its consistent superiority in safety outcomes.

INTRODUCTION

Vesicolithiasis accounts for approximately 5% of all urinary tract calculi and remains an important urological condition affecting both adults and children worldwide (Cicione et al., 2018). In adults, bladder outlet obstruction associated with benign prostatic hyperplasia is among the most common predisposing factors for bladder stone formation (Hughes et al., 2020). In children, bladder stones remain endemic in certain developing regions, where nutritional deficiencies, dehydration, and low-protein diets contribute to their development

(Esposito et al., 2021). The global burden of urolithiasis has increased over the past three decades, potentially reflecting changes in dietary patterns, increasing obesity prevalence, and improvements in diagnostic capabilities (Qian et al., 2022).

Advances in endourology have progressively shifted the management of bladder stones from open cystolithotomy toward minimally invasive techniques, particularly transurethral and percutaneous cystolithotripsy (Philippou et al., 2012). The European Association of Urology (EAU) recommends transurethral cystolithotripsy as the preferred surgical approach for bladder stones in adults and children when technically feasible and clinically appropriate (Donaldson et al., 2019). Several energy modalities are available for endoscopic stone fragmentation, including pneumatic, ultrasonic, electrohydraulic, and laser lithotripsy systems (Torricelli et al., 2013). The selection of an appropriate lithotripsy modality depends on several factors, including stone size and characteristics, patient age, equipment availability, and surgeon expertise (Deliktas et al., 2015).

Pneumatic lithotripsy has been widely adopted in urological practice because of its relatively low cost, durability, and ease of maintenance (Fauzan et al., 2023). However, its mechanical impact mechanism may produce relatively large stone fragments and cause fragment displacement within the bladder, potentially requiring additional retrieval maneuvers and increasing operative time (Karami et al., 2016). Holmium:yttrium-aluminum-garnet (Ho:YAG) laser lithotripsy has emerged as a versatile alternative for intracorporeal stone fragmentation (Kronenberg & Somani, 2018). The Ho:YAG laser primarily utilizes a photothermal mechanism to fragment urinary calculi of various compositions, with the potential to produce fine particles and reduce stone retropulsion under appropriate treatment settings (Aldoukhi et al., 2017). Furthermore, its flexible optical fibers are compatible with small-caliber endoscopic instruments, making the technique potentially advantageous for selected pediatric patients (Aboulela et al., 2015).

Among pediatric patients, transurethral cystolithotripsy performed using semirigid ureteroscopes with either pneumatic or laser lithotripsy has demonstrated favorable clinical outcomes and may reduce procedure-related morbidity compared with open surgical approaches (Davis et al., 2022). Although several studies have evaluated these modalities individually in pediatric populations, direct comparative evidence remains limited (Javanmard et al., 2018). A previous meta-analysis examining holmium laser treatment for bladder stones suggested potential advantages in stone clearance and hospitalization duration; however, substantial heterogeneity in patient populations, procedural techniques, and study methodologies limited the generalizability of its findings (Lv et al., 2021).

Despite increasing interest in minimally invasive bladder stone management, comparative evidence specifically addressing holmium laser lithotripsy versus pneumatic lithotripsy during transurethral cystolithotripsy remains insufficiently synthesized. Differences in stone fragmentation efficiency, stone-free rates, operative duration, postoperative complications, and hospitalization outcomes warrant systematic evaluation to clarify the relative clinical performance of these modalities. Therefore, this systematic review aimed to compare the efficacy and safety of Ho:YAG laser lithotripsy and pneumatic lithotripsy for the transurethral treatment of vesicolithiasis, with particular attention to stone clearance, procedural efficiency, and postoperative outcomes.

METHOD

This systematic review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure transparency and methodological rigor throughout the review process.

Literature Search Strategy

A comprehensive literature search was carried out across three major electronic databases, PubMed, Scopus, and the Cochrane Library, covering publications from January 1, 2015, through January 1, 2025, to ensure the review reflects the most current available evidence. Search terms were structured using Boolean operators (AND/OR) and developed based on the PICOS framework (Population, Intervention, Comparator, Outcome, and Study Design), as detailed in Table 1. Two reviewers independently screened all retrieved records against predefined inclusion and exclusion criteria. Where disagreements arose, they were resolved through discussion; when consensus could not be reached, a third independent reviewer was consulted to reach a final decision on study inclusion.

Table 1. Search Strategy

Database	Search Strategy	Hits
PubMed	(("bladder stone"[MeSH Terms] OR "urinary bladder calculi"[MeSH Terms] OR "bladder stone" OR "bladder stones" OR "bladder calculi" OR "bladder calculus" OR "vesical calculi" OR "vesical calculus" OR "vesicolithiasis" OR "cystolithiasis" OR "vesical stone" OR "vesical stones" OR "bladder lithiasis" OR "vesical lithiasis") AND ("lithotripsy"[MeSH Terms] OR "lithotripsy" OR "lithotriptor" OR "lithotriptors" OR "cystolithotripsy" OR "cystolitholapaxy" OR "cystolithotomy" OR "holmium" OR "Ho:YAG" OR "Ho-YAG" OR "HoYAG" OR "laser lithotripsy" OR "pneumatic lithotripsy" OR "ballistic lithotripsy" OR "lithoclast" OR "intracorporeal lithotripsy" OR "electrohydraulic lithotripsy" OR "ultrasonic lithotripsy" OR "stone fragmentation" OR "stone management" OR "endoscopic stone" OR "transurethral stone" OR "percutaneous cystolithotripsy" OR "percutaneous cystolithotomy"))	916
Scopus	TITLE-ABS-KEY(("bladder stone" OR "bladder stones" OR "bladder calculi" OR "bladder calculus" OR "vesical calculi" OR "vesical calculus" OR "vesicolithiasis" OR "cystolithiasis" OR "vesical stone" OR "vesical stones" OR "bladder lithiasis" OR "vesical lithiasis" OR "urinary bladder calculi" OR "bladder urolithiasis") AND ("lithotripsy" OR "lithotriptor" OR "lithotriptors" OR "cystolithotripsy" OR "cystolitholapaxy" OR "cystolithotomy" OR "holmium" OR "Ho:YAG" OR "Ho-YAG" OR "HoYAG" OR "laser lithotripsy" OR "pneumatic lithotripsy" OR "ballistic lithotripsy" OR "lithoclast" OR "intracorporeal lithotripsy" OR "electrohydraulic lithotripsy" OR "ultrasonic lithotripsy" OR "stone fragmentation" OR "stone management" OR "endoscopic stone" OR "transurethral stone" OR "percutaneous cystolithotripsy" OR "percutaneous cystolithotomy" OR "extracorporeal shock wave" OR "shockwave lithotripsy"))	1531
Cochrane Library	("bladder stone" OR "bladder stones" OR "bladder calculi" OR "bladder calculus" OR "vesical calculi" OR "vesical calculus" OR "vesicolithiasis" OR "cystolithiasis" OR "vesical stone" OR "vesical stones" OR "bladder lithiasis" OR "vesical lithiasis" OR "urinary bladder calculi") AND ("lithotripsy" OR "lithotriptor" OR "cystolithotripsy" OR "cystolitholapaxy" OR "cystolithotomy" OR "holmium" OR "Ho:YAG" OR "Ho-YAG" OR "laser lithotripsy" OR "pneumatic lithotripsy" OR "ballistic lithotripsy" OR "lithoclast" OR "intracorporeal lithotripsy" OR "electrohydraulic lithotripsy" OR "ultrasonic lithotripsy" OR "stone fragmentation" OR "endoscopic stone" OR "transurethral	65

	stone" OR "percutaneous cystolithotripsy" OR "percutaneous cystolithotomy" OR "extracorporeal shock wave" OR "shockwave lithotripsy")

Table 2. PICOS Framework

PICOS	Inclusion Criteria	Exclusion Criteria
Population	Patients of any age diagnosed with vesicolithiasis	Neurogenic bladder, urethral stricture, bladder tumor, previous urinary tract surgery
Intervention	Holmium laser lithotripsy via transurethral approach	Non-transurethral laser approaches
Comparator	Pneumatic lithotripsy via transurethral approach	Percutaneous cystolithotripsy, open cystolithotomy, extracorporeal shock-wave lithotripsy
Outcome	Operation time, stone-free rate, hospitalization, complications, pain scores	Studies without extractable quantitative outcome data
Study	Prospective randomized trials and retrospective observational studies in English	Case reports, case series, reviews, meta-analyses, editorials, conference abstracts, non-English publications

Inclusion and Exclusion Criteria

All retrieved studies were evaluated against the PICOS criteria established for this review, with the full framework outlined in Table 2.

Population

Studies were included if they enrolled patients of any age diagnosed with vesicolithiasis who underwent transurethral cystolithotripsy. The population encompassed both adult patients with bladder stones secondary to benign prostatic hyperplasia and pediatric patients with endemic or primary bladder stones. Patients with neurogenic bladder, urethral stricture, bladder tumor, or previous urinary tract surgery were excluded.

Intervention

The intervention of interest was holmium laser lithotripsy performed through a transurethral approach for the fragmentation and removal of bladder stones. Laser energy was delivered via flexible quartz fibers ranging from 365 to 550 μm, passed through cystoscopes or semirigid ureteroscopes. Laser settings varied across studies, with energy levels from 0.5 to 2.5 J and frequencies from 6 to 15 Hz.

Comparator

The comparator was transurethral pneumatic lithotripsy using pneumatic lithotripter probes for bladder stone fragmentation. Pneumatic probes with varying diameters were introduced through cystoscopes or semirigid ureteroscopes. Fragment removal was achieved using bladder wash with an evacuator or stone grasping forceps. Studies comparing holmium laser lithotripsy with percutaneous cystolithotripsy, open cystolithotomy, or extracorporeal shock-wave lithotripsy alone were excluded.

Outcome

Primary outcomes included operation time or stone fragmentation time and stone-free rate. Secondary outcomes encompassed hospitalization duration, catheter removal time, discharge time, and postoperative complications. Complications assessed included hematuria, urinary tract infection, bladder mucosa injury, bladder perforation, urethral stricture, residual

stones, urinary retention, extended hospitalization, and requirement for secondary procedures. Visual pain scale scores were also evaluated when reported.

Study

Both prospective randomized controlled trials and retrospective observational studies comparing holmium laser lithotripsy with pneumatic lithotripsy for bladder stone treatment were eligible. Case reports, case series without a comparator group, review articles, meta-analyses, editorials, conference abstracts, and non-English language publications were excluded. Studies without extractable quantitative data on at least one predefined outcome were also excluded from this systematic review.

Data extraction

Two reviewers independently extracted data from the included studies using a standardized extraction form. Information collected included first author, publication year, study design, country, population characteristics, sample size, mean age, sex distribution, stone size, lithotripsy device, energy settings, endoscope used, concomitant procedures, and follow-up duration. Outcome data were extracted as continuous variables, including mean, standard deviation, and number of participants for operation time, hospitalization, and pain scores. Dichotomous data were recorded as number of events and total participants for complications and stone-free rates. Disagreements were resolved by consensus.

Quality of Studies Assessment

The methodological quality of included studies was assessed using risk of bias tools based on study design. Randomized controlled trials were evaluated using the Revised Cochrane Risk-of-Bias tool (RoB 2) across five domains. Non-randomized studies were assessed using the ROBINS-I tool across seven domains. Each domain was judged according to the respective tool's predefined risk-level classification. Two reviewers independently performed all assessments and disagreements were resolved by consensus.

RESULTS AND DISCUSSION

Inclusion studies

The included studies can be seen in **Figure 1**. Our initial search strategy found a total of 2.512 studies from electronic databases. After removing 755 duplicates, 1757 studies were evaluated based on their titles and abstracts, leaving 18 studies that were then screened through full text. Of these, zero studies not retrieved and 14 studies were excluded because they did not meet the inclusion criteria. After going through a careful screening process, we obtained 4 studies that were considered eligible and included in this final analysis.

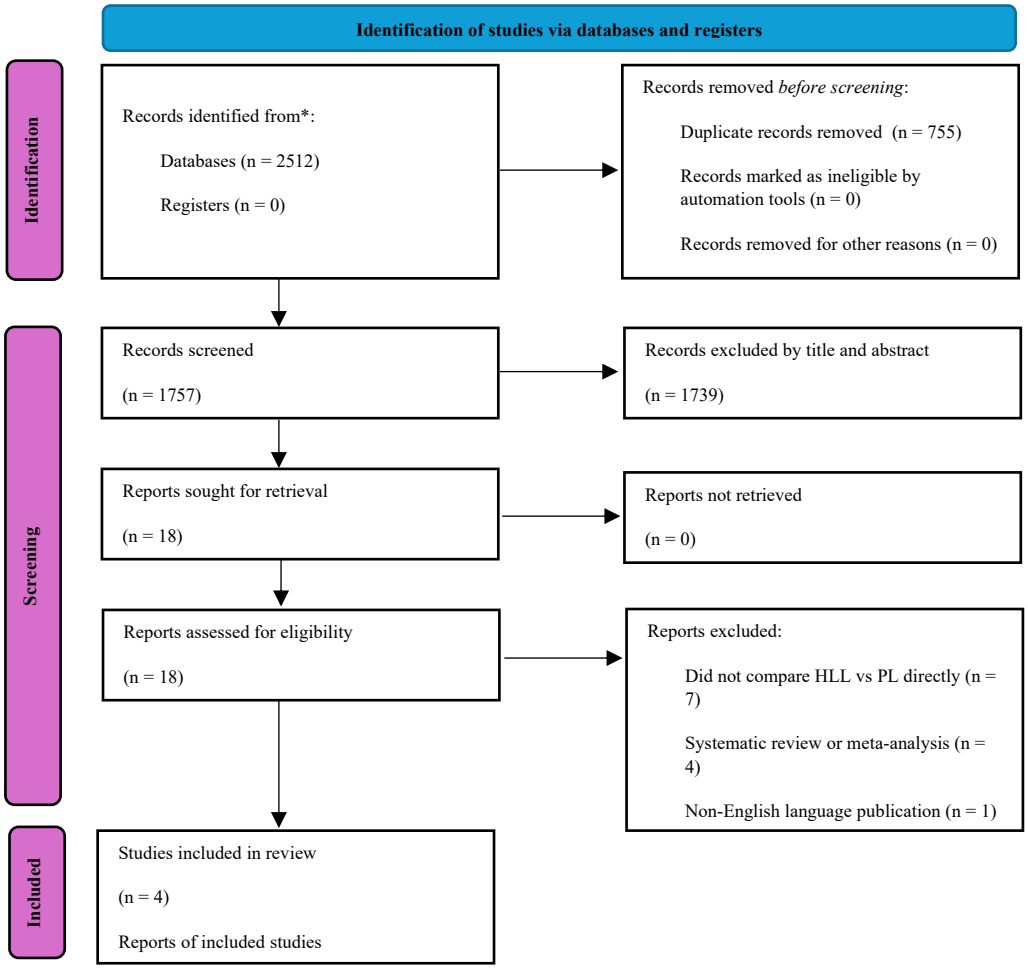


Figure 1. PRISMA 2020 Selection Study Process

Study Characteristics

A total of four studies published between 2016 and 2023 were included in this systematic review. Two studies were prospective randomized trials conducted by Abd and Muter in Iraq and Gangkak et al. in India, while two were retrospective observational studies conducted by Ercil et al. and Yalçın, both in Turkey. The combined sample across all studies comprised 276 patients, with 106 patients in the holmium laser lithotripsy group and 115 patients in the pneumatic lithotripsy group. Follow-up duration ranged from postoperative Day 1 to a mean of 18.7 months.

Two studies enrolled adult patients with benign prostatic hyperplasia and concomitant bladder stones. Ercil et al. included adults with stones measuring 20 mm or larger, with a mean age of 67.5 years in the laser group and 70 years in the pneumatic group. Yalçın included adults with stones exceeding 2 cm, with a mean age of approximately 60 years in both groups. Both adult studies performed bipolar plasmakinetic transurethral resection of the prostate simultaneously with cystolithotripsy in the same surgical session.

Two studies enrolled pediatric patients with single bladder stones. Abd and Muter included 64 children aged 12 years or younger with a mean stone size of approximately 15 mm in both groups. Gangkak et al. included 25 male children younger than 12 years with stones smaller than 3 cm, with a mean stone size of 1.8 cm in the laser group and 1.7 cm in the

pneumatic group. Both pediatric studies used a 9 Fr semirigid ureteroscope for stone fragmentation, and no concomitant surgical procedures were performed. (Table 3)

Study Outcomes

All Study outcome summarized on table 4.

Operation and Stone Fragmentation Time

Operation time was reported across all four studies. Ercil et al. reported that the mean stone fragmentation time was 40.36 ± 13.7 minutes in the holmium laser group versus 56.93 ± 14.04 minutes in the pneumatic group, with a statistically significant difference at $p < 0.0001$. The total operation time was also significantly shorter in the laser group at 109.42 ± 19.76 minutes versus 127.7 ± 18.4 minutes in the pneumatic group, $p < 0.0001$. Yalçın reported cystolithotripsy times of 36.53 ± 7.56 minutes for laser versus 45.20 ± 6.04 minutes for pneumatic lithotripsy, $p < 0.001$. Gangkak et al. found no significant difference in overall operative time, 35.5 ± 14.0 versus 36.6 ± 8.7 minutes, $p = 0.81$. However, for stones smaller than 1.5 cm, the laser group had a significantly shorter time of 25.6 ± 4.9 versus 31.6 ± 5.9 minutes, $p = 0.04$. For stones between 1.5 and 3 cm, the times were similar at 49.4 ± 9.8 versus 44.6 ± 7.8 minutes, $p = 0.40$. In contrast, Abd and Muter reported significantly longer operation time in the laser group at 74.5 ± 26.6 minutes compared to 51.5 ± 17.2 minutes in the pneumatic group, $p = 0.001$.

Stone-Free Rate

Stone-free rate was reported in all four studies. Ercil et al. reported a success rate of 97% in the holmium laser group versus 93.1% in the pneumatic group. Gangkak et al. achieved 100% stone clearance in both the laser group, with 12 of 12 patients stone-free, and the pneumatic group, with 13 of 13 patients stone-free. Yalçın similarly reported complete stone clearance of 100% in both groups, with 30 of 30 laser patients and 40 of 40 pneumatic patients achieving stone-free status. Abd and Muter found no significant difference in residual stone rates between laser at 1 of 31 and pneumatic at 2 of 33, $p = 1.0$.

Hospitalization Duration and Discharge

Hospitalization outcomes were reported in three studies. Ercil et al. found no significant difference in hospitalization duration, with 3.5 ± 1.1 days in the laser group versus 3.6 ± 1.0 days in the pneumatic group, $p = 0.784$. Gangkak et al. reported mean hospital stays of 1.2 ± 0.7 days for laser versus 1.8 ± 0.8 days for pneumatic lithotripsy, $p = 0.55$. Yalçın reported discharge times of 1.87 ± 0.57 days for laser versus 1.73 ± 0.64 days for pneumatic, with no significant difference. Abd and Muter found that extended hospitalization beyond one day was significantly more frequent in the pneumatic group at 16 of 33 patients, 48.5%, compared to 5 of 31 patients, 16.1%, in the laser group, $p = 0.006$.

Postoperative Complications

All four studies reported postoperative complications. Ercil et al. found total complications in 7 of 33 laser patients, 21.2%, versus 9 of 29 pneumatic patients, 31.03%, with no significant difference at $p = 0.337$. Superficial bladder mucosa injury occurred in 3 of 33 laser patients versus 5 of 29 pneumatic patients. Bladder perforation occurred in one pneumatic patient and none in the laser group. Abd and Muter reported that pneumatic lithotripsy was associated with a significantly higher risk of at least one adverse outcome, occurring in 21 of 33 pneumatic patients versus 12 of 31 laser patients, $p = 0.046$. Postoperative infection occurred in 4 of 33 pneumatic patients versus 1 of 31 laser patients, $p = 0.36$. Gangkak et al. reported

hematuria in 1 of 12 laser patients versus 3 of 13 pneumatic patients, $p = 0.45$, and fever in 3 of 12 laser patients versus 2 of 13 pneumatic patients, $p > 0.5$. Yalçın reported urethral stricture in 2 of 40 pneumatic patients and 0 of 30 laser patients. High fever occurred in 1 of 30 laser patients versus 2 of 40 pneumatic patients.

Postoperative Pain

Postoperative pain was reported by one study. Yalçın evaluated patients using the visual pain scale on postoperative Day 0 and Day 1. The mean pain score was 5.80 ± 0.71 in the holmium laser group versus 4.98 ± 0.89 in the pneumatic lithotripsy group, and this difference was statistically significant at $p < 0.001$. The higher pain score in the laser group was attributed to possible micro-damage to the bladder mucosa caused by laser energy, although no visible mucosal damage was observed during the procedure.

Stone Fragment Retrieval

Stone fragment retrieval was reported by one study. Gangkak et al. found that bladder wash for stone removal was required in 3 of 12 laser patients versus 7 of 13 pneumatic patients. Forceps use for stone extraction was needed in 0 of 12 laser patients versus 2 of 13 pneumatic patients. The reduced need for fragment retrieval maneuvers in the laser group was related to the ability of holmium laser to pulverize stones into submillimeter fragments, whereas pneumatic lithotripsy produced larger fragments that required additional extraction efforts using bladder wash or forceps.

Risk of Bias Assessment

The two prospective randomized controlled trials by Abd and Muter and Gangkak et al. were assessed using the Revised Cochrane Risk-of-Bias tool. Both studies were judged as having "some concerns" overall. Abd and Muter demonstrated low risk across domains D1, D2, D3, and D5, with randomization performed using computer software and all 64 patients completing follow-up. However, domain D4 raised some concerns because outcome assessors were not blinded and stone-free status was determined by the treating team without independent adjudication.

Gangkak et al. raised some concerns in domain D1 because the randomization method was described as "consecutively randomized" without clear reporting of sequence generation or allocation concealment. Domain D4 also raised some concerns due to unblinded outcome assessment. The remaining domains D2, D3, and D5 were judged as low risk, as all 25 patients completed follow-up at three weeks, all procedures were performed by a single surgeon, and all predefined outcomes were reported in the results.

The two retrospective studies by Ercil et al. and Yalçın were assessed using the ROBINS-I tool and both were judged as having moderate overall risk of bias. Ercil et al. received moderate risk judgments in five of seven domains, primarily driven by temporal selection bias in treatment assignment, multicenter variability, and unblinded outcome assessment. Yalçın received moderate risk in domains D1, D2, and D6, related to non-randomized treatment allocation and subjective pain measurement. Both studies were judged as low risk for classification of interventions and selection of reported results. (see and Figure 2 and Figure 3)

Table 3. Study characteristics

Study	Design (country)	Population	n (HLL/PL)	Mean age, years (HLL/PL)	Mean stone size (HLL/PL)
Ercil et al., 2016	Retrospective multicenter (Turkey)	Adults with BPH, stones ≥20 mm	33/29	67.5/70.0	31.4/28.8 mm
Abd & Muter, 2022	RCT (Iraq)	Children ≤12 years	31/33	3.9/4.2	15.7/15.9 mm
Gangkak et al., 2016	RCT (India)	Boys <12 years, stones <3 cm	12/13	5.8/7.0	18/17 mm
Yalçın, 2023	Retrospective single-center (Turkey)	Adults, stones >2 cm	30/40	60.7/60.4	37/37 mm

HLL, holmium laser lithotripsy; PL, pneumatic lithotripsy; RCT, randomized controlled trial.

Table 4. Main outcomes (HLL vs PL)

Study	Procedure time, min	Hospital stay	Stone-free rate	Complications
Ercil et al., 2016	40.4 vs 56.9 (p < 0.0001)[a]	3.5 vs 3.6 days (p = 0.784)	97% vs 93.1%	7/33 vs 9/29 (p = 0.337)
Abd & Muter, 2022	74.5 vs 51.5 (p = 0.001)[b]	Extended: 5/31 vs 16/33 (p = 0.006)	96.8% vs 93.9%[c]	Any adverse outcome: 12/31 vs 21/33 (p = 0.046)
Gangkak et al., 2016	35.5 vs 36.6 (p = 0.81)[b]; stones <1.5 cm: 25.6 vs 31.6 (p = 0.04)	1.2 vs 1.8 days (p = 0.55)	100% vs 100%	Fever: 3/12 vs 2/13 (p > 0.5)
Yalçın, 2023	36.5 vs 45.2 (p < 0.001)[a]	1.87 vs 1.73 days (NS)	100% vs 100%	Stricture 0/30 vs 2/40; high fever 1/30 vs 2/40; pain (VPS) 5.8 vs 4.98 (p < 0.001)

[a] Stone fragmentation/cystolithotripsy time. [b] Total operation time. [c] Calculated from residual stones (1/31 vs 2/33). NS, not significant.

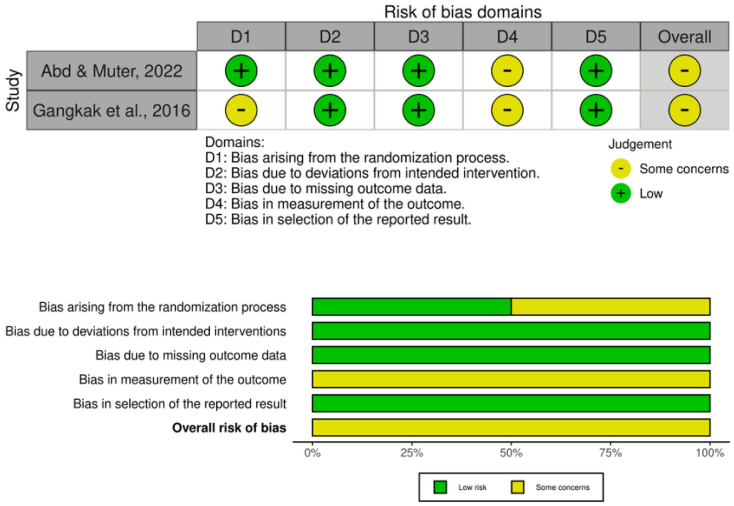


Figure 2. RoB using ROB2.0 for RCTs

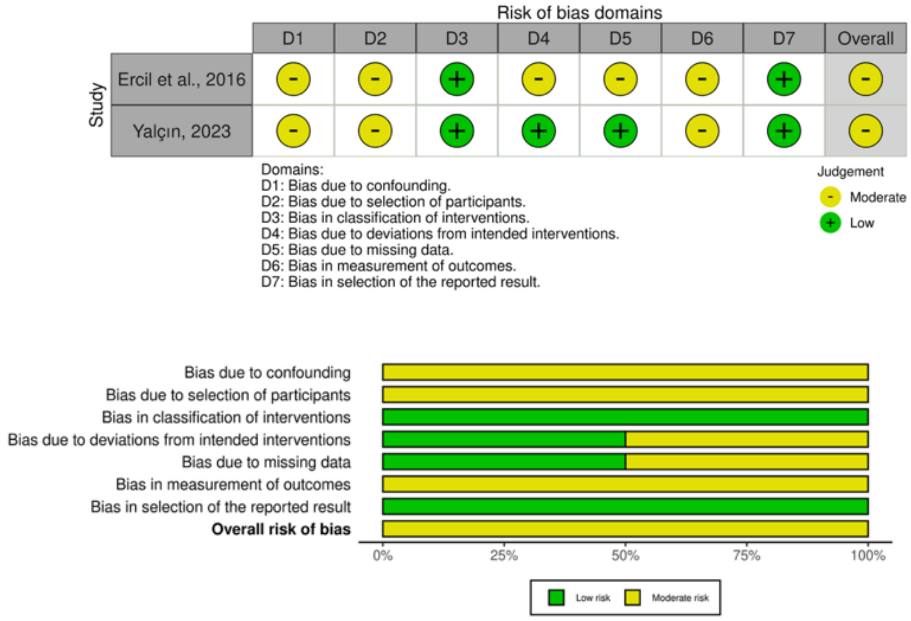


Figure 3. RoB using ROBIN-I for non-RCTs

This systematic review evaluated four studies comparing holmium laser lithotripsy and pneumatic lithotripsy for transurethral cystolithotripsy in patients with vesicolithiasis. The pooled evidence from two randomized controlled trials and two retrospective studies suggests that holmium laser lithotripsy may offer advantages over pneumatic lithotripsy in terms of stone fragmentation time and postoperative adverse outcomes, while both modalities achieved high stone-free rates with comparable complication profiles.

The holmium laser fragments stones through a photothermal mechanism, producing a vapor channel at the fiber tip that transmits laser radiation to the stone surface and breaks it down through thermal decomposition (Aldoukhi et al., 2019). This process generates submillimeter particles that can pass spontaneously during bladder irrigation, reducing the need for additional retrieval maneuvers (Yin et al., 2013). The laser fiber can be set to different energy and frequency combinations, allowing the surgeon to switch between fragmentation and dusting modes depending on the stone size and composition (Matlaga et al., 2018). By contrast, pneumatic lithotripsy relies on a ballistic mechanism in which a metallic probe delivers repetitive kinetic energy to the stone surface (Papatsoris et al., 2012). This mode of action tends to produce larger fragments that migrate freely within the bladder lumen, requiring forceps extraction or repeated bladder wash for clearance (Ali et al., 2016). Fragment migration during pneumatic lithotripsy has been recognized as a major cause of prolonged operative time and reduced first-session stone-free rates (Elashry & Tawfik, 2012).

The smaller caliber of the pediatric urethra presents a unique challenge for transurethral stone surgery (Esposito et al., 2019). Use of semirigid ureteroscopes in children allows passage of both pneumatic probes and laser fibers through the working channel without the need for urethral dilation, thereby minimizing the risk of urethral trauma (Adanur et al., 2014). The flexible quartz fibers used for holmium laser delivery have a diameter as small as 200 to 365 µm, which permits their use through endoscopes as narrow as 4.5 Fr (Li et al., 2019). This technical feature is particularly relevant in very young children in whom even a 9 Fr ureteroscope may occupy the full urethral lumen (Piskin et al., 2021). In developing countries,

where pediatric bladder stones remain endemic and are linked to malnutrition and dehydration, the availability and cost of laser equipment must be weighed against the potential clinical benefits (Rizvi et al., 2016). Pneumatic lithotripters are less expensive and easier to maintain, making them a practical option in resource-limited settings (Jhanwar et al., 2016).

Three of the four included studies reported shorter stone fragmentation or cystolithotripsy times with holmium laser lithotripsy compared to pneumatic lithotripsy, consistent with findings from previous meta-analyses on ureteral stones (Chen et al., 2017). Abd and Muter, however, reported longer operative times in the laser group, which the authors attributed to a learning curve effect and smaller laser fiber size requiring more passes over the stone surface (Rabani et al., 2019). This discrepancy is similar to findings in pediatric ureteral stone series, where laser operative time was occasionally longer during the initial institutional experience but improved with surgeon familiarity (Fahmy et al., 2016). Stone-free rates exceeded 93% in both groups across all four studies, a finding that aligns with the high clearance rates reported in multicenter pediatric laser lithotripsy surveys (Garg et al., 2015). Regarding complications, Abd and Muter found that pneumatic lithotripsy carried a substantially higher adjusted risk of adverse outcomes compared to laser lithotripsy, with their regression model showing a 5.7-fold increase in the odds of at least one adverse event in the pneumatic group (Abd & Muter, 2022). This observation is supported by data from ureteral stone studies showing that pneumatic lithotripsy is associated with greater fragment retropulsion and secondary procedure requirements than laser lithotripsy (Yağmur et al., 2022). The higher postoperative pain score reported by Yalçın in the laser group may be explained by localized thermal effects on the bladder mucosa, even though no visible mucosal injury was observed endoscopically (Harris et al., 2022). One study reported that the need for bladder wash and forceps extraction was lower in the laser group, reflecting the smaller fragment size produced by the dusting technique (Mishra et al., 2020). Mini-percutaneous cystolithotripsy has been proposed as an alternative approach in preschool children with large bladder stones, and comparative studies have shown outcomes similar to those of transurethral cystolithotripsy, although the percutaneous route requires a suprapubic puncture that may not be acceptable in all clinical contexts (Kim & Ghani, 2022).

The findings of this review carry practical relevance for pediatric urological practice. Holmium laser lithotripsy appears to offer faster stone fragmentation and fewer fragment retrieval maneuvers in children with bladder stones smaller than 1.5 cm. For larger stones, the operative time difference between the two modalities narrows, and the choice of energy source should be guided by equipment availability, cost constraints, and surgeon experience. Both modalities remain acceptable for transurethral cystolithotripsy in children.

This review has several limitations. Only four studies met the inclusion criteria, and the combined sample size of 276 patients limits the statistical power to detect differences in rare adverse events. Two of the four studies enrolled adult populations with concomitant benign prostatic hyperplasia, which reduces the direct applicability of those findings to pediatric patients. Study designs were heterogeneous, with variations in laser settings, endoscope selection, and outcome definitions that preclude formal meta-analytic pooling.

CONCLUSION

Holmium:yttrium-aluminum-garnet (Ho:YAG) laser lithotripsy demonstrated favorable outcomes compared with pneumatic lithotripsy for transurethral cystolithotripsy, with shorter stone fragmentation times reported in three of the four included studies and stone-free rates exceeding 93% with both techniques. Some evidence also suggested fewer postoperative adverse events with laser lithotripsy, although this finding was not consistent across all studies. The laser technique may reduce the need for additional fragment retrieval maneuvers, potentially offering advantages in pediatric patients. However, higher equipment costs and reports of increased postoperative pain in some patients remained important considerations when selecting the appropriate treatment modality. Overall, the limited available evidence suggested that Ho:YAG laser lithotripsy offered advantages in fragmentation efficiency, but its superiority in safety and other clinical outcomes could not be conclusively established.

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CONFLICT OF INTEREST

The authors hereby declare that there is no conflict of interest in this research. In addition, the authors have no commercial affiliations or financial relationships with any party that could be considered to have the potential to influence the conduct of the research, the results of the analysis, or the presentation of the findings in this manuscript.

AUTHOR CONTRIBUTIONS

All authors made equal roles and contributions at every stage of the preparation of this work. The division of tasks was carried out fairly and evenly, from the development of the initial ideas and the conduct of the analysis to the writing and refinement of the manuscript, so that no single author contributed more dominantly than the others.

GENERATIVE AI STATEMENT

In the preparation of this manuscript, the authors made limited use of Artificial Intelligence (AI) technology. This use was intended only to help improve grammar and check the accuracy of language use. All ideas, analyses, and the substance of the manuscript are entirely the product of the authors' own thinking and responsibility.

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