A decade of pediatric laser lithotripsy: Location-driven outcomes and a targeted analysis of lower-pole stone clearance

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KEY MESSAGES

- Stone location is the primary determinant of success following pediatric endoscopic laser lithotripsy.
- Lower-pole stones remain the most challenging.
- Use of thulium fiber laser, older patient age (>12 years), single-stone disease, and favorable stone composition were associated with significantly higher lower-pole clearance rates.
- Stone size alone did not predict success in lower-pole stones.
- Targeted counseling and tailored operative strategies may improve outcomes for children with lower-pole stones.

ABSTRACT

Introduction: Endoscopic laser lithotripsy is becoming the mainstay for pediatric urolithiasis management, and the location of stones strongly influences the stone-free outcome. This study reports location-specific stone-free rates and evaluates factors associated with the clearance of lower-pole stones.
Methods: We conducted a single-center, retrospective review of all children ≤18 years undergoing endoscopic laser lithotripsy between January 2015 and December 2024. Stone-free status was defined as the absence of a residual fragment >2 mm on imaging, obtained at least eight weeks postoperatively. Location-specific clearance was compared, and predictors of lower-pole clearance were evaluated.
Results: Among 164 cases (mean age 10.4±5.4 years), the overall stone-free rate was 73.8%. Outcomes varied significantly by location ($p<0.001$): bladder 96.4%, distal ureter 96.2%, upper calyx 71.4%, renal pelvis 68.4%, proximal ureter 66.7%, and lower pole 52.5%. Repeat procedures were required in 14% of cases. In the lower-pole cohort (n=40), clearance was associated with thulium fiber laser use (77.8% vs. 31.8% for holmium:YAG, $p=0.004$), single vs.

multiple stones (80% vs. 36%, p=0.007), favorable composition (mixed calcium or cystine, p=0.036), and older age (>12 years, p=0.04). Stone size was not associated with the stone-free rate.
Conclusions: Endoscopic laser lithotripsy is effective across most pediatric stone sites, but lower-pole stones remain challenging, with clearance achieved in only half of cases. Adoption of thulium fiber laser, careful counseling for younger children or those with multiple stones, and tailored operative strategies may improve outcomes. Prospective, multicenter studies are warranted.

INTRODUCTION

Pediatric urolithiasis is a growing health concern, with a rising global incidence across all pediatric age groups, partly due to lifestyle and dietary changes and increase use of imaging.[1] Management of urinary tract stones in children poses unique challenges due to smaller anatomical dimensions, varying degrees of urinary tract maturity and the potential long-term implications of intervention.[2, 3] Endoscopic laser lithotripsy has emerged as a primary treatment option, offering precision, minimal invasiveness and a favorable safety profile compared to more invasive surgical options.[2, 4, 5] While the efficacy of laser lithotripsy is generally high, the anatomical location of the stone has consistently been shown to influence procedural complexity, stone fragmentation efficiency and eventual clearance rates.[3, 6]
A recent retrospective analysis from our institution, which reviewed over 160 pediatric cases treated with laser lithotripsy across a decade, demonstrated that stone-free rates varied significantly by location.[7] The highest success rates were observed in bladder and distal ureteral stones, exceeding 96%, while intermediate results were achieved for upper pole, pelvic and proximal ureteral stones.[7] Notably, lower pole stones demonstrated the lowest clearance rate, with only approximately half of patients achieving stone-free status despite standardized surgical protocols. These findings highlight the unique technical and anatomical challenges presented by the lower pole, including acute infundibulopelvic angles, dependent calyceal position and impaired fragment clearance due to gravity-assisted drainage.[3, 5]
Given this persistent disparity in outcomes, we sought to conduct a dedicated sub-analysis of lower pole stones to identify patient, stone and procedural factors that influence stone clearance. Prior studies have implicated variables such as patient age, the number of stones and stone composition; however, recent technological advances may be shifting the paradigm.[4, 5, 8] By evaluating a well-characterized cohort of pediatric patients treated over ten years, this study aims to provide a contemporary, evidence-based assessment of predictors of treatment success for lower pole stones.

The objective of this study is two-fold: first, to report the overall outcomes of pediatric laser lithotripsy across all anatomical locations, and second, to highlight and analyze the lower pole as a site of persistently reduced clearance rates, to inform surgical strategy, patient counseling and future technological innovations in pediatric stone disease management.

METHODS

Study design, setting and ethical approval

We performed a single-centre retrospective cohort study at a tertiary pediatric referral hospital in a single payer health system. All consecutive patients aged ≤18 years who underwent endoscopic laser lithotripsy for symptomatic or radiographically confirmed urinary-tract calculi between January 1, 2015, and December 31, 2024, were screened for eligibility. The study protocol conformed to the Declaration of Helsinki, and it was approved by The Hospital for Sick Children research ethics board (REB 1000076091).

Study population and case definitions

The overall cohort comprised 164 cases (mean age 10.4 ± 5.4 years) treated for stones at any anatomic location. From this cohort, we identified a pre-specified subgroup of 40 children with isolated lower-calyceal ("lower-pole") stones for focused analysis of factors influencing clearance. Inclusion criteria for both cohorts were: 1. Age ≤ 18 years at the time of the index operation. 2. Endoscopic laser lithotripsy (retrograde intrarenal surgery or ureteroscopic approach) performed at our institution during the study period. 3. Availability of complete operative records and ≥ 2-month postoperative imaging. Patients were excluded if they had congenital renal anomalies altering calyceal anatomy, underwent simultaneous percutaneous or open lithotomy, or lacked follow-up imaging.

The stone location was identified by the operating surgeon dictation and confirmed on perioperative imaging. A stone was considered stone-free when no residual fragment > 2 mm was visible on any imaging modality (renal ultrasonography with or without low-dose non-contrast spiral CT) obtained at least 8 weeks post-procedure.

Surgical technique and perioperative management

All procedures were performed under general anesthesia by fellowship-trained pediatric urologists using flexible digital or fibre-optic ureteroscopes (outer diameter 7.5–9.5 Fr). When ureteral caliber allowed, a 9.5/11.5 Fr, 10/12 Fr or 12/ 14 Fr ureteral access sheath (UAS) was introduced to facilitate repeated scope passage; the decision to use a UAS was left to the surgeon's discretion and was recorded in the operative notes.

Two laser platforms were available throughout the study: Holmium:YAG (pulse energy 0.6–1.2 J, frequency 10–15 Hz, long-pulse "dusting" mode); Thulium-fiber laser (TFL) (0.15–0.6 J, 20–40 Hz). In all cases, a 200 µm or 150 µm reusable laser fiber was used. The surgeon's preference determined the stone fragmentation strategy (dusting vs. basketing). Fragments larger than 3 mm were retrieved using disposable nitinol baskets; smaller debris was left to pass spontaneously. At procedure end, a 4.7 Fr- 8Fr double-J stent was placed at the surgeon's discretion (routine for solitary kidneys, high stone burden fragmentation and ureteral edema) and removed after 2-4 weeks.

Data collection and variables

Demographic variables (age, sex), perioperative parameters (laser type, operative time and stenting) and stone characteristics (number, largest dimension on preoperative imaging, radioopacity and composition when available) were abstracted from electronic medical records into a REDCap database. 0.5-cm increments categorized stone size and age was stratified into clinically relevant groups (<3 years, 3–5 years, 5–8 years, 8–12 years, >12 years). For the lower-pole cohort, we a priori identified six candidate predictors, age group, laser platform, stone count (single vs multiple), maximal stone diameter and stone composition, as potential determinants of clearance.

The primary outcome (overall cohort) for this study includes the proportion of children rendered stone-free after a single laser procedure, stratified by anatomic location. Furthermore, the exploratory variables for outcome assessment for the lower-pole cohort: association between the six clinical/ operative variables and stone-free status. The dataset was collected consistently by one member of the research team (HE) and counter-verified by another member (SM). Additionally, 20% of the dataset was audited for accuracy, revealing less than 1% inconsistency.

Statistical analysis

Continuous variables were summarized as mean ± SD or median (IQR) according to distribution, and categorical variables were summarized as counts and percentages. Univariate associations with stone-free status were assessed using χ^2 or Fisher's exact test for categorical predictors and Student's t-test or Mann–Whitney U for continuous variables. Due to the limited sample size of the lower-pole subgroup ($n = 40$), we restricted analyses to univariate testing. While multivariable logistic regression was considered, the study was underpowered for stable modeling; thus, results should be interpreted as exploratory. All analyses were conducted with SPSS v27 (IBM Corp., Armonk, NY); two-sided $p < 0.05$ denoted statistical significance.

RESULTS

Between January 1, 2015, and December 31, 2024, 164 cases (mean age ± SD, 10.4 ± 5.4 years) underwent endoscopic laser lithotripsy at our centre. Overall, 121/164 (73.8 %) rendered the patient stone-free. Anatomical location was the dominant determinant of outcome (Table 1). Stone-free rates were highest for the bladder (27/28, 96.4%) and the distal ureter (25/26, 96.2%). Intermediate success was achieved in the upper calyx (5/7, 71.4 %), renal pelvis (39/57, 68.4 %), and proximal ureter (4/6, 66.7 %). In contrast, only 21 of the 40 lower-pole stones (52.5%) cleared, making this the least responsive location (Figure 1). When bladder stones were excluded, the upper-tract stone-free rate was 69.1% (94/136). A χ^2 test confirmed a significant association between location and clearance ($p < 0.001$).

Figure 1 illustrates the stone-free status per stone location, and 104/121 children (86 %) who ultimately became stone-free did so after just one laser procedure. Nonetheless, repeat interventions were mostly required for renal-pelvic (9/39, 23.1%), whereas most of the upper-calyx and proximal-ureter stone cleared in a single session.

Due to the persistently inferior results for the clearance of lower pole stones, we analyzed the dedicated lower-pole cohort (n = 40) in greater detail. Overall clearance remained at 21/40 (52.5%). Several variables showed statistically significant associations with success (Table 2 of the lower-pole analysis): Age: Adolescents > 12 years achieved the best outcome (12/18, 66.7 %; p = 0.04). Laser platform: Thulium fibre laser achieved 14/18 clearances (77.8%) versus 7/22 (31.8%) for holmium-YAG (p = 0.004). Stone number: Single calculi were cleared in 12/15 cases (80 %), whereas multiple stones were cleared in 9/25 (36 %) (p = 0.007). Stone composition: Mixed-calcium (10/13, 76.9 %) stones responded best compared to other stone composition (p = 0.036). In contrast, maximal stone diameter showed no significant impact on clearance across six size brackets (p = 0.79), underscoring that an unfavourable lower-pole anatomy and intrinsic stone characteristics, rather than size alone, dictate outcomes.

DISCUSSION

Our analysis reveals that stone-free outcomes following pediatric endoscopic laser lithotripsy vary significantly by anatomical location. Bladder and distal ureteral stones had the highest clearance rates (>96%), reflecting easier access and more reliable fragment removal, as also demonstrated in prior pediatric series.[4, 9–11] In contrast, renal stones presented greater challenges, particularly in the lower pole, where clearance reached only 52.5%. These results mirror well-documented adult and pediatric data attributing poorer outcomes in the lower pole to unfavorable infundibulopelvic angles, dependent calyceal positions and limited fragment drainage.[12–14] Even with modern flexible ureteroscopy, this anatomical disadvantage persists. Our chi-square analysis confirmed stone location as a significant determinant of clearance (p < 0.001). Excluding bladder stones did not alter the location-dependent pattern of outcomes. These findings confirm that the lower pole remains the most challenging site in pediatric endoscopic stone management, warranting particular attention in treatment planning.[3, 8, 9, 15]
A closer examination of the lower-pole stones revealed several predictors of clearance. Age emerged as a significant factor, with adolescents (>12 years) achieving higher clearance rates (66.7%) compared to younger children (≤12 years), who experienced lower success (45.5%) (p = 0.04). This likely reflects anatomical maturity and the ability to accommodate larger instruments, facilitating better scope.[16] In contrast, very young children present technical limitations due to the small caliber of their ureters and calyces, which reduces procedural efficacy. Clinically, this suggests the need for counseling families of younger children about the increased likelihood of residual fragments and possible staged procedures. Such counseling may improve parental expectations and decision-making, particularly in cases involving technically challenging lower-pole stones.[17, 18]

Similarly, laser technology significantly influenced clearance in lower-pole stones. TFL use resulted in a 77.8% clearance rate compared to 31.8% with holmium:YAG ($p = 0.004$). This aligns with emerging pediatric and adult data showing TFL's superior fragmentation efficiency, minimal retropulsion and enhanced dusting ability.[19–21] These properties are particularly advantageous in lower-pole calyces, where fine particles can pass more readily. While pediatric experience with TFL is limited, our findings corroborate its promise as a superior modality. The results suggest TFL adoption could represent a paradigm shift in pediatric endourology, provided device settings are adapted for safety in small systems. Wider pediatric-specific studies are needed; however, our data strongly support transitioning toward TFL as the preferred option for complex cases.

In addition, stone burden and number also proved influential. Single lower-pole stones had an 80% clearance rate compared to 36% for multiple stones ($p = 0.007$). This echoes prior pediatric and systematic review data indicating that greater stone burden often necessitates staged procedures and reduces the likelihood of complete clearance in a single session.[9, 22–24] Fragment scatter during lithotripsy may further complicate cases with multiple stones. These results reinforce the need for careful preoperative planning, particularly counseling families about the increased probability of staged interventions. Surgeons may also adopt intraoperative strategies such as stone relocation or aggressive dusting to address higher burdens. Thus, stone number, more than stone size, emerged as a key driver of outcomes.

Interestingly, stone size was not a significant predictor of clearance in our lower-pole cohort ($p = 0.79$). This contrasts with traditional assumptions but likely reflects that some huge stones could be softer in density and or in an easily accessible location. Within the typical pediatric stone size range (5–20 mm), anatomical and compositional factors appear more determinative than size alone. Adult series similarly demonstrate that flexible ureteroscopy can clear stones up to 2 cm with modern technology and staged procedures if necessary.[8, 12, 25] In our cohort, small stones sometimes failed to clear due to unfavorable infundibular anatomy, while larger stones fragmented effectively with TFL or basketing.[3, 15] Thus, while size should inform the choice of modality, it should not be viewed as the dominant determinant of pediatric stone-free outcomes.

Conversely, stone composition added further complexity, with clearance varying by mineral type ($p = 0.036$). Mixed calcium stones cleared best (76.9%), while pure calcium oxalate monohydrate and calcium phosphate stones were least responsive, with clearance rates of 14.3% and 20%, respectively. These results are consistent with known differences in hardness and fragmentation response.[21, 26] Interestingly, cystine stones, while resistant to shockwave lithotripsy, cleared more readily (66.7%) in our cohort, likely due to TFL's improved dusting effect. These findings underscore the value of preoperative assessment of stone composition, or CT Hounsfield density as a surrogate, to guide surgical strategy. For example, dense oxalate stones in lower-pole locations may warrant more aggressive adjuncts or even mini-PCNL consideration.[4, 24] Anticipating stone type can therefore improve operative planning and patient counseling.

Finally, ureteral access sheaths (UAS) were not universally applied and inconsistently used in our series, preventing factorial analysis was not possible for UAS. Nonetheless, literature strongly supports UAS use in improving irrigation, scope protection and fragment retrieval, with multicentre pediatric studies reporting clearance rates of up to 100% after minimal secondary procedures.[5, 27–29] Experts recommend cautious use, favoring the smallest adequate sheath size and pre-stenting when needed.[27, 29] These findings collectively suggest that UAS should be considered routine in complex pediatric cases, particularly for lower-pole stones, where improved irrigation dynamics have a direct influence on outcomes.

This study has several limitations. Its retrospective, single-centre design limits generalizability and introduces selection bias. The lower-pole subgroup (n = 40) was underpowered for multivariable analysis, so predictors should be viewed as exploratory. Complication and long-term recurrence data were incompletely captured and therefore not reported.

Despite these constraints, this study provides contemporary, location-specific pediatric outcomes and highlights modifiable factors, particularly laser type and stone number, that can inform surgical strategy and counseling. From a broader clinical perspective, our findings support several practice-changing implications. TFL should be prioritized where available due to its superior clearance efficiency. UAS use, particularly suction-enabled models, should be encouraged for lower-pole or high-burden stones. Stone relocation, especially in older children, offers an additional means to overcome lower-pole anatomical challenges.[14, 30] Age and stone number should be considered during counseling to set realistic expectations and plan for possible staged interventions. This reinforces ureteroscopy as a safe and minimally invasive first-line option, even for challenging lower-pole stones, provided modern technology and careful technique are employed.

CONCLUSIONS

Endoscopic laser lithotripsy is highly effective for most pediatric stones; however, lower-pole stones remain challenging, with just over half achieving clearance. Success was associated with older age, the use of thulium fiber lasers, single-stone disease and favorable composition, while stone size was not a predictive factor. These findings underscore the importance of providing careful counseling, selecting technology judiciously and tailoring surgical strategies. Prospective multicentre studies are needed to confirm these predictors and guide standardized management of pediatric lower-pole stones.

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Statements and Declarations*: The data that support the findings of this study are derived from institutional clinical records at The Hospital for Sick Children and contain patient information governed by privacy regulations. Therefore, the datasets are not publicly available. De-identified data may be shared by the corresponding author upon reasonable request and subject to approval by The Hospital for Sick Children Research Ethics Board.*

FIGURES AND TABLES

Figure 1. Stone-free rates (SFR) by anatomical location after pediatric laser lithotripsy.

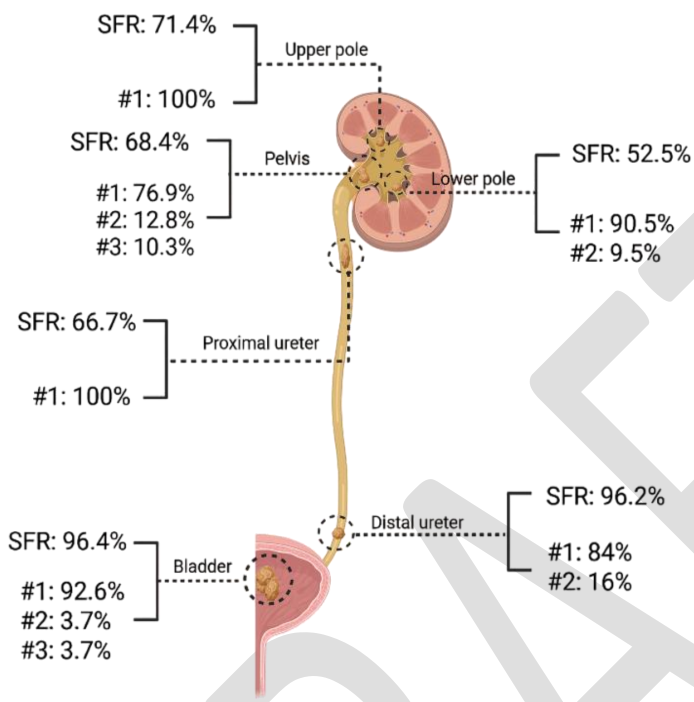

Table 1. Stone-free status by location

Location	Stone-free (%)	Stone-free (n/N)	x^2 p
Bladder	96.4%	27 / 28	0.00017
Distal ureter	96.2%	25 / 26	
Proximal ureter	66.7%	4 / 6	
Renal pelvis	68.4%	39 / 57	
Upper calyx	71.4%	5 / 7	
Lower pole	52.5%	21 / 40	

Table 2. Factors affecting stone clearance for lower-pole renal stones				
Factor	**Category**	**Stone-free (%)**	**Stone-free (n/N)**	**p**
Age group	0–36 months	25.0%	1/4	0.04
	37–60 months	0.0%	0/4	
	61–96 months	100%	3/3	
	97–144 months	45.5%	5/11	
	>144 months	66.7%	12/18	
Laser type	Holmium:YAG	31.8%	7/22	0.004
	Thulium fiber	77.8%	14/18	
Stone number	Single	80.0%	12/15	0.007
	Multiple	36.0%	9/25	
Stone size	0–0.5 cm	0.0%	0/1	0.79
	0.51–1.0 cm	63.2%	12/19	
	1.01–1.5 cm	42.9%	3/7	
	1.51–2.0 cm	50.0%	3/6	
	2.01–2.5 cm	50.0%	1/2	
	>2.5 cm	66.7%	2/3	
Composition	Calcium oxalate	14.3%	1/7	0.036
	Calcium phosphate	20.0%	1/5	
	Mixed calcium	76.9%	10/13	
	Cystine	66.7%	2/3	
	Others	0.0%	0/1	