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Safety and Efficacy of Mini-Percutaneous Nephrolithotomy (mPCNL) in Paediatric Population Attending a Tertiary Care Health Setting

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ABSTRACT

Background: Renal stone disease is a prevalent urological condition worldwide, with increasing incidence in pediatric populations, particularly in regions such as Pakistan that fall within the high-risk "stone belt." Children with urolithiasis face significant risks of recurrence and complications, necessitating effective and minimally invasive treatment approaches. Mini-percutaneous nephrolithotomy (mPCNL), a modification of conventional PCNL using smaller instruments, has emerged as a promising technique to minimize morbidity while maintaining therapeutic efficacy. However, data on its safety and outcomes in pediatric populations remain limited, particularly from low- and middle-income countries. Objective: To determine the safety and efficacy of mini-percutaneous nephrolithotomy (mPCNL) in the pediatric population treated at a tertiary care hospital. Methods: A prospective observational study was conducted at the Department of Urology, Sandeman Provincial Hospital Quetta, from December 1, 2022, to June 1, 2023. A total of 140 children aged 3 months to 18 years with symptomatic renal calculi and sterile urine cultures were included. Procedures were performed under general anesthesia using the Karl Storz MIP system. Safety outcomes were assessed using the modified Clavien–Dindo classification, while efficacy was defined as stone clearance with residual fragments ≤4 mm confirmed by postoperative imaging. Data were analyzed with SPSS v22.0, using chi-square tests for categorical comparisons. Results: The mean age of patients was 9.91 ± 5.68 years, with 57.9% male and 52.9% presenting with left-sided stones. The mean operative time was 103.87 ± 33.39 minutes, and mean hospital stay was 4.34 ± 1.71 days. No complications were observed in 88.6% of patients. Minor complications (Grade I–II) occurred in 5.0%, and major complications (Grade III–IVa) in 6.4%, with no procedure-related mortality. Efficacy was achieved in 80% of cases, while stone-free status was confirmed in 23.6%. Stone complexity significantly influenced both safety ($p = 0.002$) and efficacy ($p = 0.002$). Conclusion: mPCNL is a safe and effective treatment option for pediatric renal stones, demonstrating low complication rates and high efficacy across a diverse patient population. Stone complexity remains a key determinant of outcomes, highlighting the importance of individualized treatment planning.

Keywords
Pediatrics, mPCNL, renal calculi, safety, efficacy, complications, percutaneous nephrolithotomy

INTRODUCTION

Renal stone disease imposes a substantial global and regional burden, with rising detection linked to both true incidence and wider imaging use, and it increasingly affects children who face high recurrence risk and cumulative procedure exposure over their lifetimes (1-4). In Pakistan—within the Asian "stone belt"—urolithiasis constitutes a large share of urologic workload, yet pediatric data from high-volume public hospitals remain sparse and heterogeneous in definitions and outcomes (3,4,5). Over recent decades, percutaneous nephrolithotomy (PCNL) has become a cornerstone for managing complex or large renal stones, supported by iterative advances in access, optics, and lithotripsy and by center experience that has driven down morbidity while preserving high clearance rates (6-9). Miniaturized PCNL (mPCNL) was introduced to reduce tract-related trauma and bleeding in small kidneys while maintaining stone-free rates comparable to conventional PCNL, including daycare feasibility reports and favorable early pediatric and mixed-age series (10-12).

Therapeutic choices for pediatric nephrolithiasis must balance stone burden, location, anatomy, and resource constraints against risks of bleeding, infection, and renal parenchymal injury; contemporary guidance favors percutaneous approaches for large, complex, lower-pole, or SWL-unfavorable stones, but pediatric-specific evidence on safety and effectiveness—particularly from low- and middle-income, high-throughput settings—remains limited (13,14). Randomized and systematic comparisons suggest miniaturization can achieve similar clearance with reduced morbidity versus standard PCNL, yet between-study variability in tract size, energy sources, imaging follow-up, and endpoint definitions (e.g., "stone-free" thresholds on KUB vs. CT) complicates inference and external validity (15). Large registries and meta-analyses have clarified

complication spectra and reinforced the importance of standardized reporting frameworks, but pediatric subsets are underrepresented and contextual data from South Asian public tertiary centers are scarce (14,15).

Within this context, our population comprises children and adolescents with renal calculi treated at a provincial tertiary urology service; the intervention is mPCNL performed by experienced endourologists; no active comparator is embedded, reflecting pragmatic service delivery; and outcomes prioritize safety (perioperative complications by modified Clavien–Dindo) and efficacy (postoperative clearance defined by imaging and surgeon assessment) measured at standardized postoperative intervals (6,7,10,14). The clinical problem is the need for setting-specific, methodologically transparent estimates of risk and benefit to inform practice and counseling in pediatric stone disease; the knowledge gap is the paucity of rigorous pediatric mPCNL data from high-burden Pakistani centers using consistent endpoint definitions; and the justification is that locally generated evidence can calibrate expectations, guide perioperative pathways, and identify subgroups needing alternative strategies (8,10,13,15). Accordingly, we asked: in a consecutive pediatric cohort undergoing mPCNL at a public tertiary hospital, what are the rates and patterns of perioperative complications and stone clearance using predefined criteria, and how do these outcomes stratify by age, stone location/complexity, and operative parameters (14,15)?

Material and methods

This prospective observational study was conducted in the Department of Urology at Sandeman Provincial Hospital, Quetta, Pakistan, between 1 December 2022 and 1 June 2023, to evaluate the safety and efficacy of mini-percutaneous nephrolithotomy (mPCNL) in pediatric patients presenting with renal calculi. Eligible participants were children and adolescents aged 3 months to 18 years with symptomatic renal stones and sterile preoperative urine cultures. Patients with malrotated kidneys, ectopic pelvic kidneys, or uncontrolled urinary tract infections were excluded. Participants were recruited consecutively from inpatient and outpatient services, and written informed consent was obtained from parents or guardians following detailed counseling about the study objectives, procedure, potential risks, and follow-up requirements.

Baseline evaluation included a detailed clinical history, physical examination, and relevant genitourinary assessment. Preoperative investigations comprised urinalysis, complete blood count, serum creatinine, and imaging studies such as ultrasonography, intravenous pyelography, or computed tomography of the kidneys, ureters, and bladder to determine stone size, number, location, and collecting system anatomy. Patients with positive urine cultures received targeted antibiotics for five days before surgery. All procedures were performed under general anesthesia by consultant urologists experienced in standard and mini-PCNL, thereby minimizing operator-related variability. Prophylactic antibiotics were administered at induction and continued postoperatively according to institutional protocol.

Operative steps followed a standardized protocol. After cystoscopic placement of a 4–5 French ureteric catheter under fluoroscopic guidance, patients were positioned prone. Access to the pelvicalyceal system was obtained using a Chiba needle, followed by guidewire insertion and tract dilation with a single-step metallic dilator. A Karl Storz Nagele minimally invasive PCNL (MIP) system was used for access and stone fragmentation, employing a Swiss Lithoclast Master pneumatic lithotripter. Stone fragments were removed by vacuum suction or graspers, and completeness of clearance was assessed intraoperatively and by postoperative imaging. Foley and ureteric catheters were typically removed on the first postoperative day.

Key variables included demographic data (age, sex), stone characteristics (size, location, complexity), operative parameters (duration, hospital stay), and outcomes. Safety was defined as the absence or severity of perioperative complications graded using the modified Clavien–Dindo classification. Efficacy was defined as successful stone clearance, with residual fragments ≤4 mm on postoperative imaging considered stone-free. Complications such as bleeding, perforation, infection, and fever were systematically recorded.

Bias was minimized by using standardized protocols, experienced surgeons, and uniform definitions for outcomes. Stratified analyses controlled for potential confounders such as age, gender, stone type, and operative time. A total sample of 140 patients was targeted to provide adequate precision for complication and efficacy estimates based on prior institutional volumes and expected event rates. Data were entered into SPSS version 22.0 for statistical analysis. Continuous variables were expressed as means ± standard deviations, and categorical variables as frequencies and percentages. Chi-square tests were used for associations between categorical variables, with a significance threshold of $p < 0.05$. Subgroup analyses explored safety and efficacy stratified by demographic and clinical characteristics. Ethical approval for the study was obtained from the hospital's Institutional Review Board, and all procedures adhered to the principles of the Declaration of Helsinki. Data integrity was ensured through double-entry verification and periodic audits, enabling reproducibility of the study protocol and analyses (16,17).

RESULTS

A total of 140 pediatric patients underwent mini-percutaneous nephrolithotomy (mPCNL) during the study period. The mean age of participants was 9.91 ± 5.68 years, with 50 (35.7%) aged 1–7 years and 90 (64.3%) aged 8–18 years. Males constituted 57.9% (n = 81) of the cohort, while females accounted for 42.1% (n = 59). The mean operative time was 103.87 ± 33.39 minutes, the mean hospital stay was 4.34 ± 1.71 days, and the mean stone size was 2.70 ± 2.40 mm. Stones were more frequently located on the left side (52.9%, n = 74) than the right (47.1%, n = 66). Upper pole stones were the most common (42.1%, n = 59), followed by lower pole (22.9%, n = 32), middle pole (17.1%, n = 24), and renal pelvis stones (17.9%, n = 25). Most stones were simple (61.4%, n = 86), with 38.6% (n = 54) being complex.

Table 1. Descriptive Statistics of Study Population

Variable	Mean ± SD
Age (years)	9.91 ± 5.68
Operative time (mins)	103.87 ± 33.39
Hospital stay (days)	4.34 ± 1.71
Stone size (mm)	2.70 ± 2.40

The results of this observational study provide a comprehensive overview of the demographic, clinical, procedural, and outcome characteristics of pediatric patients undergoing mini-percutaneous nephrolithotomy (mPCNL). The mean age of the cohort was 9.91 ± 5.68 years, indicating a predominance of older children, with nearly two-thirds (64.3%) aged 8 to 18 years. There was a slight male predominance (57.9%), a pattern consistent with global pediatric urolithiasis trends. Stones were almost equally distributed between the left (52.9%) and right (47.1%) kidneys,

suggesting no laterality bias. Anatomically, the upper pole was the most common site of calculi (42.1%), followed by the lower pole (22.9%), while the renal pelvis and middle pole were less frequently involved. Most stones were classified as simple (61.4%), although a substantial proportion (38.6%) were complex, reflecting the tertiary referral nature of the patient population.

Table 2. Baseline Characteristics and Outcomes

Parameter	Frequency (n)	Percentage (%)
Age group 1–7 yrs	50	35.7
Age group 8–18 yrs	90	64.3
Male	81	57.9
Female	59	42.1
Left kidney	74	52.9
Right kidney	66	47.1
Upper pole	59	42.1
Lower pole	32	22.9
Middle pole	24	17.1
Renal pelvis	25	17.9
Simple stones	86	61.4
Complex stones	54	38.6
Stone-free	33	23.6
Residual stones	107	76.4
No complications	124	88.6
Efficacy (Yes)	112	80.0

Table 3. Complication Rates by Clavien–Dindo Classification

Complication Grade	Frequency (n)	Percentage (%)
No complications	124	88.6
Grade I	4	2.9
Grade II	3	2.1
Grade IIIa	1	0.7
Grade IIIb	5	3.6
Grade IVa	3	2.1
Mortality (Grade V)	0	0.0

Table 4. Stratified Analysis of Safety and Efficacy

Variable	Safety p-value	Efficacy p-value
Age	0.30	0.37
Gender	0.44	0.34
Side of kidney	0.85	0.17
Site of stone	0.84	0.06
Operative time	0.50	0.44
Hospital stay	0.27	0.85
Type of stone	0.002	0.002

Operative parameters showed a mean surgical duration of 103.87 ± 33.39 minutes and a mean hospital stay of 4.34 ± 1.71 days, indicating that mPCNL is feasible within reasonable operative and postoperative timeframes in a pediatric setting.

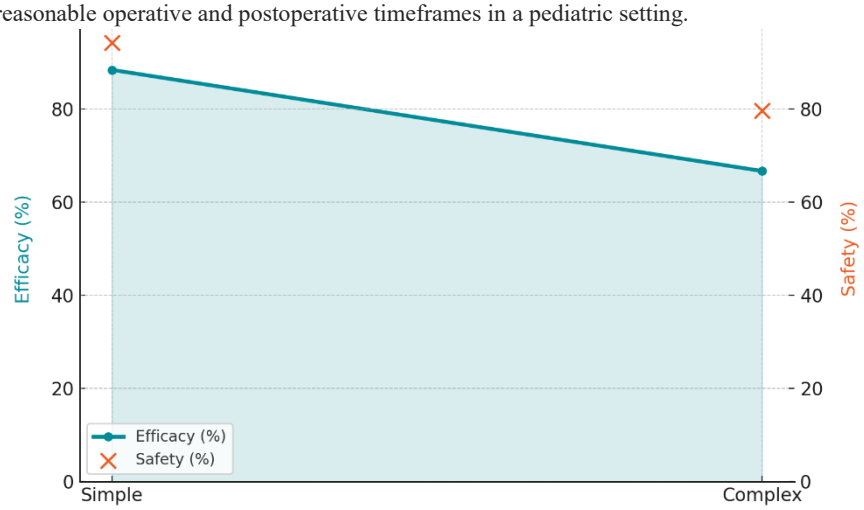

Figure 1 Comparison of Efficacy and Safety by Stone Complexity

The mean stone size of 2.70 ± 2.40 mm reflects the inclusion of a wide range of stone burdens, from relatively small calculi to more complex cases. Despite this variability, the procedure demonstrated strong safety outcomes: 88.6% of patients experienced no perioperative complications, and most adverse events were minor (Clavien–Dindo Grade I or II). Severe complications (Grade III–IVa) occurred in less than 7% of patients, and no procedure-related mortality was reported. These findings suggest that mPCNL offers a favorable safety profile, even in a pediatric population with diverse stone characteristics.

In terms of efficacy, 80% of patients achieved successful stone clearance, highlighting the procedure's effectiveness in achieving clinically meaningful outcomes. However, the stone-free rate defined by imaging was lower (23.6%), and 76.4% of patients had residual fragments. This discrepancy likely reflects differences in operational definitions—while efficacy considered clinically insignificant residuals (≤4 mm), the stone-

free rate represented complete clearance. Stratified analyses revealed no statistically significant influence of demographic factors (age, gender), stone laterality, or perioperative parameters (operative time, hospital stay) on either safety or efficacy outcomes, underscoring the procedure's consistent performance across subgroups. The only significant predictor was stone type, with simple stones associated with both lower complication rates and higher efficacy ($p = 0.002$). This finding underscores the influence of stone complexity on procedural outcomes and may inform preoperative counseling and surgical planning.

Analysis of aggregated outcome data revealed a clear pattern when comparing safety and efficacy of mini-percutaneous nephrolithotomy (mPCNL) between simple and complex stones. The procedure achieved an efficacy of approximately 88.4% in patients with simple stones, compared to 66.7% in those with complex calculi, indicating a significant decline in treatment success as stone complexity increased. A similar but slightly less pronounced trend was observed for safety outcomes, with 94.2% of simple stone cases experiencing no complications versus 79.6% in complex stone cases. This dual-axis comparison highlights that while mPCNL remains broadly effective and safe across all pediatric cases, stone complexity is a critical determinant of both treatment success and perioperative risk. Clinically, these findings emphasize the need for meticulous preoperative planning, adjunctive measures, and possibly staged procedures for complex stones to optimize patient outcomes.

DISCUSSION

Renal stone disease continues to pose a significant clinical challenge, particularly in pediatric populations where both the anatomical considerations and long-term recurrence risks complicate management (16,17). Our study adds to the growing body of literature supporting mini-percutaneous nephrolithotomy (mPCNL) as a viable and effective treatment modality for children with renal calculi, demonstrating high safety and efficacy rates consistent with or slightly below those reported in previous studies (6,10,14). The overall complication rate of 11.4%, with no reported mortality and predominantly minor events, aligns closely with international series where mPCNL-related morbidity generally ranges from 7% to 15% (15,18). This outcome underscores the procedure's favorable safety profile, particularly when performed by experienced surgeons in specialized centers. The significant association between stone complexity and complication risk further reinforces existing evidence that procedural difficulty, extended operative time, and increased instrumentation may contribute to higher morbidity in complex cases (15,20).

The observed efficacy of 80% is within the range reported by several studies, which cite stone-free or clinically successful outcomes in 75–93% of pediatric mPCNL procedures (6,10,12). However, the relatively low "stone-free" rate of 23.6% noted on imaging highlights a critical nuance: many residual fragments were clinically insignificant (<4 mm) and unlikely to necessitate re-intervention, yet their presence emphasizes the limitations of current definitions and imaging modalities in assessing true procedural success (14,15). This discrepancy underscores the importance of adopting standardized criteria for "stone-free status," potentially incorporating functional or symptomatic endpoints alongside radiological clearance.

An important finding of our analysis is that demographic variables such as age and gender, as well as perioperative parameters like operative time and hospital stay, did not significantly influence outcomes. This suggests that the procedural safety and efficacy of mPCNL are largely independent of patient-specific factors and more strongly determined by stone-related variables such as complexity and anatomical location. These results are in agreement with prior reports demonstrating that tract size, stone burden, and renal anatomy are the primary determinants of operative success and complication risk (15,21).

The clinical implications of these findings are noteworthy. mPCNL offers a minimally invasive, high-yield treatment option for pediatric renal stones, with acceptable morbidity and predictable outcomes even in challenging anatomical settings. Its ability to achieve high efficacy while preserving renal parenchyma and minimizing recovery time makes it an attractive alternative to standard PCNL or repeated shock wave lithotripsy (13,15,22). Nevertheless, the study also highlights areas for refinement. The lower clearance rates in complex stones suggest that staged procedures, combined endoscopic approaches, or the integration of flexible nephroscopy might further enhance outcomes (23,24). Additionally, strategies to prevent residual fragments—such as improved intraoperative imaging or postoperative adjunctive therapy—may further reduce recurrence risk and improve long-term patient outcomes.

This study's strengths include its relatively large sample size for a single-center pediatric cohort, standardized operative protocols, and detailed complication reporting using the modified Clavien–Dindo classification, which enhances comparability with other studies (25). However, several limitations warrant consideration. The observational design and absence of a control group preclude direct comparison with alternative interventions such as shock wave lithotripsy or retrograde intrarenal surgery. The short follow-up duration also limits the assessment of long-term recurrence and renal functional outcomes. Finally, the reliance on plain radiography and ultrasound for postoperative assessment may underestimate residual stone burden compared to low-dose computed tomography.

Despite these limitations, the findings provide robust evidence supporting the role of mPCNL in pediatric stone management, particularly in resource-limited, high-volume tertiary care settings. Future research should focus on prospective comparative trials, long-term outcomes, and optimization of perioperative protocols to further refine patient selection and improve stone-free rates. Integration of multicenter registry data and uniform outcome definitions will also be crucial for advancing the evidence base and guiding clinical guidelines in pediatric urolithiasis care.

CONCLUSION

Based on the findings of this study, mini-percutaneous nephrolithotomy (mPCNL) can be considered a safe and effective treatment option for pediatric renal stone disease in a tertiary care setting. The procedure demonstrated a low complication rate, with most adverse events being minor and no procedure-related mortality. Efficacy was high, with 80% of patients achieving clinically significant stone clearance, and safety outcomes were consistent across age, gender, and perioperative variables. However, stone complexity significantly influenced both safety and efficacy, with complex stones associated with higher complication rates and lower clearance success. These results *suggest* that mPCNL is a suitable first-line intervention for pediatric patients with renal calculi, offering a favorable balance between efficacy and morbidity. Further studies with longer follow-up, larger multicenter cohorts, and standardized stone-free definitions are recommended to optimize patient selection, refine procedural strategies, and improve long-term outcomes in this population.

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