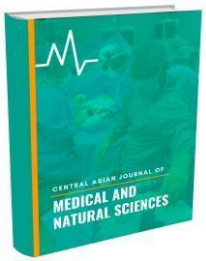

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Article

Optimisation of Minimally Invasive Treatment Methods for Solitary Kidney Stones

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Abstract: Nephrolithiasis is one of the most prevalent urological disorders worldwide, with a global recurrence rate of 50% within ten years and a particularly high prevalence in Central Asia reaching 18–22% of the adult population. In patients with a solitary functioning kidney, stone disease represents a critical clinical situation requiring precise, minimally invasive intervention to preserve renal function while achieving maximum stone clearance. This prospective comparative study aimed to optimize minimally invasive treatment protocols — specifically percutaneous nephrolithotomy (PCNL) and ureteroscopy with holmium laser lithotripsy (URS-LL) — in patients with solitary kidney urolithiasis, and to evaluate their comparative safety and efficacy profiles. Materials and Methods. A total of 137 patients with solitary kidney stone disease were enrolled and allocated to two groups: PCNL group (n=72, stones 11–42 mm) and URS with holmium laser lithotripsy group (n=65, stones 6–20 mm). Diagnostic evaluation included renal ultrasound, multislice CT (stone density measurement in HU), urine culture, and complete blood count. Statistical analysis was performed using SPSS v.26 (IBM, USA); Student t-test, chi-squared test, and logistic regression were applied; $p<0.05$ was considered statistically significant. Results. Stone-free rate (SFR) at 3 months was 93.1% for PCNL and 87.7% for URS-LL ($p=0.012$). Mean operative time was significantly shorter in the URS group (51.8±17.4 vs 74.3±22.1 min, $p<0.001$). Hospital stay was 1.9±0.8 days for URS versus 3.8±1.2 days for PCNL ($p<0.001$). Overall complication rates were 13.9% (PCNL) and 7.7% (URS), predominantly Clavien grade I–II. 12-month recurrence rates were 11.1% (PCNL) and 15.4% (URS, $p=0.426$). Return to social activity was significantly faster in the URS group (5.2±2.1 vs 12.4±3.7 days, $p<0.001$). Conclusions. Both PCNL and URS with holmium laser lithotripsy demonstrate high efficacy and acceptable safety profiles in solitary kidney nephrolithiasis. Stone size and density are the primary determinants of technique selection. URS is preferred for stones ≤20 mm due to shorter hospitalization and faster recovery; PCNL remains the gold standard for stones >20 mm. Individualized treatment planning based on stone characteristics is essential for optimal outcomes in this high-risk patient population.

Keywords: Solitary Kidney, Nephrolithiasis, Minimally Invasive Urology, PCNL, Ureteroscopy, Holmium Laser Lithotripsy, Stone-Free Rate, Endourology, Urolithiasis Complications, Recurrence Rate, Urology, Treatment Optimization.

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1. Introduction

Urolithiasis (kidney stone disease — KSD) remains one of the most significant challenges in modern urology, affecting approximately 1–15% of the global population, while in Central Asian countries the prevalence reaches 18–22% (EAU, 2024; WHO, 2023). According to the World Health Organization, the recurrence rate of nephrolithiasis reaches nearly 50% within ten years, indicating the chronic and recurrent nature of the disease. In

Uzbekistan, more than 47,800 hospitalizations associated with kidney stone disease were registered in urological departments in 2022, representing a 23% increase compared to 2018 [1].

In patients with a solitary kidney (SK), urolithiasis represents an especially high-risk clinical condition. Obstruction caused by urinary stones may result in complete loss of renal function, which is considered a urological emergency requiring immediate intervention. Patients with a solitary kidney constitute approximately 1.2–2.8% of the overall population with urolithiasis. In this category of patients, the selection of an optimal treatment strategy is of particular importance, as effective stone removal and maximal preservation of renal function must be achieved simultaneously without compromising patient safety [2].

Traditional open surgical procedures, including pyelolithotomy and nephrolithotomy, remained the primary treatment methods for kidney stone disease for many years. However, with the rapid development of endourological technologies, two minimally invasive approaches — percutaneous nephrolithotomy (PCNL) and ureteroscopy with holmium laser lithotripsy (URS-LL) — have become the leading treatment modalities in modern clinical practice. According to the EAU Guidelines 2024, PCNL is recommended as the gold standard treatment for stones larger than 20 mm, whereas URS is considered the first-line approach for stones measuring 10–20 mm [3].

In Uzbekistan, endourological surgery has been developing rapidly in republican and regional medical institutions since 2016. Currently, PCNL and URS procedures are routinely performed in 14 specialized urology departments across the country. Nevertheless, local empirical studies evaluating the comparative efficacy, complication profiles, and stone-free rates of these techniques in patients with a solitary kidney remain insufficient, which determines the scientific relevance of the present study.

The aim of this study was to evaluate the comparative effectiveness of PCNL and URS-LL in patients with a solitary kidney by assessing stone-free rates, complication risks, duration of hospitalization, and recurrence outcomes, as well as to develop an individualized treatment algorithm. The objectives of the study were: (1) to prospectively compare the clinical outcomes of PCNL and URS-LL; (2) to determine the optimal treatment modality according to stone size and density; (3) to classify postoperative complications using the Clavien–Dindo classification system; (4) to compare the obtained results with international studies; and (5) to propose a minimally invasive treatment algorithm for patients with a solitary kidney [4].

2. Materials and Methods

A prospective controlled clinical study was conducted at the Urology Clinic of Andijan State Medical Institute between January 2021 and December 2024. The study protocol was approved by the Ethics Committee of Andijan State Medical Institute. Written informed consent was obtained from all participants prior to enrollment. The study was carried out in accordance with the CONSORT guidelines.

Inclusion criteria were as follows: (1) presence of a solitary functioning kidney confirmed by radionuclide renography and CT urography; (2) symptomatic nephrolithiasis manifested by pain, hematuria, infection, or urinary obstruction; (3) stone size ranging from 6 to 45 mm; (4) patient age between 18 and 75 years; and (5) possibility of discontinuing anticoagulant therapy at least 7 days before surgery. Exclusion criteria included severe coagulation disorders (PT >2.5 INR), untreated active upper urinary tract infection, history of anaphylactoid reactions, severe cardiopulmonary diseases (ASA class IV), pregnancy, and refusal to participate in the study [5].

All patients underwent comprehensive diagnostic evaluation, including ultrasonography of the kidneys and urinary tract (Philips Affiniti 70G, 3.5 MHz), non-

contrast multislice spiral computed tomography (Siemens SOMATOM Definition AS+, slice thickness 1 mm) for assessment of stone size, density (HU), localization, and degree of hydronephrosis. Intravenous urography was performed in selected cases. Clinical and laboratory examinations included complete blood count, biochemical profile, serum creatinine, urine culture, and coagulation testing [6].

The effectiveness of treatment was assessed by the stone-free rate (SFR) evaluated using non-contrast computed tomography three months after surgery. Residual stone fragments ≤4 mm were considered clinically insignificant and classified as successful treatment outcomes.

The PCNL group (n=72). All procedures were performed under general anesthesia. Nephrostomy access was established under fluoroscopic guidance in the prone or supine position. A rigid nephroscope (Karl Storz 26 Fr) was introduced through a 30 Fr percutaneous tract. Stone fragmentation was performed using pneumatic lithotripsy (Swiss LithoClast) or ultrasonic lithotripsy systems. At the end of the procedure, a nephrostomy drain and JJ stent were inserted. The nephrostomy tube was removed after 48–72 hours, while the JJ stent was removed endoscopically after 3–4 weeks [7].

The URS group (n=65). Spinal anesthesia was used in 72.3% of patients, whereas 27.7% underwent general anesthesia. Semi-rigid or flexible ureterorenoscopes (Storz Flex-X2 or Karl Storz 7.5/8.7 Fr) were utilized. Stone fragmentation was carried out using a holmium: YAG laser system (Lumenis PowerSuite 100W). Depending on stone characteristics, either the dusting mode (0.5 J/20 Hz) or the fragmentation mode (1.0 J/10 Hz) was selected. JJ stents were inserted in all patients for a duration of 2–4 weeks [8].

Statistical analysis was performed using SPSS Statistics 26.0 software (IBM, USA). Quantitative variables were expressed as mean ± standard deviation (M±SD). Differences between groups were analyzed using Student's t-test for normally distributed variables or the Mann–Whitney U-test for nonparametric data. Qualitative variables were evaluated using the chi-squared test or Fisher's exact test. Correlation analysis was conducted using Pearson's correlation coefficient, while multivariate logistic regression analysis was applied to identify independent predictors of stone-free rate (SFR). Statistical significance was accepted at $p < 0.05$, and 95% confidence intervals (CI) were calculated [9].

3. Results and Discussion

During the period from 2021 to 2024, a total of 137 patients who fully met the inclusion criteria were enrolled in the study. Following the initial screening process, 23 patients were excluded from participation, including 14 patients due to exclusion criteria and 9 patients who declined to provide informed consent. The demographic and clinical characteristics of the study population are presented in Table 1 [10].

Table 1. Demographic and Clinical Characteristics of Patients.

Parameters	PCNL Group (n=72)	URS Group (n=65)	Total (n=137)	p-value
Male patients, n (%)	44 (61.1%)	38 (58.5%)	82 (59.9%)	0.761
Female patients, n (%)	28 (38.9%)	27 (41.5%)	55 (40.1%)	0.761
Mean age (years, M±SD)	46.3±12.8	43.7±11.4	45.1±12.2	0.183
Age range (years)	21–74	19–71	19–74	—
Stone size (mm, M±SD)	24.8±7.3	11.4±3.2	18.4±8.9	<0.001
Stone density (HU, M±SD)	1124±248	876±312	1007±297	0.002
Hydronephrosis, n (%)	38 (52.8%)	21 (32.3%)	59 (43.1%)	0.014
Disease duration (months)	18.4±14.2	14.7±11.8	16.7±13.2	0.062
History of previous surgery	19 (26.4%)	11 (16.9%)	30 (21.9%)	0.181

Source: Research data, Urology Clinic of Andijan State Medical Institute, 2021–2024. M±SD — mean ± standard deviation.

The data presented in Table 1 demonstrate that the groups were statistically comparable in terms of sex distribution (p=0.761) and age (p=0.183). Stone size differed significantly between the groups (24.8±7.3 mm in the PCNL group versus 11.4±3.2 mm in the URS group, p<0.001), which represented an expected distribution since treatment selection was primarily based on stone size. Hydronephrosis was observed more frequently in the PCNL group (52.8% versus 32.3%, p=0.014), reflecting a more severe degree of urinary obstruction in these patients [11].

Intraoperative outcomes are presented in Table 2. Operative time was significantly longer in the PCNL group (74.3±22.1 minutes for PCNL versus 51.8±17.4 minutes for URS, p<0.001), which was associated with the technically more complex access stage of PCNL. Intraoperative blood loss was also significantly higher in the PCNL group (184.6±78.3 mL versus 42.1±18.7 mL, p<0.001); however, clinically significant bleeding requiring blood transfusion was rarely observed in both groups [12].

Table 2. Comparison of Intraoperative Parameters (PCNL vs URS/Laser).

Parameters	PCNL (n=72)	URS/Laser (n=65)	Difference (95% CI)	p-value
Operative time (min, M±SD)	74.3±22.1	51.8±17.4	+22.5 (15.1–29.9)	<0.001
Blood loss (mL, M±SD)	184.6±78.3	42.1±18.7	+142.5 (123.8–161.2)	<0.001
Fluoroscopy time (min)	8.4±3.2	3.1±1.4	+5.3 (4.4–6.2)	<0.001
General anesthesia, n (%)	72 (100%)	18 (27.7%)	—	<0.001
Spinal anesthesia, n (%)	0 (0%)	47 (72.3%)	—	<0.001
Conversion cases, n (%)	3 (4.2%)	2 (3.1%)	—	0.724

Source: Surgical protocols of the study, Andijan State Medical Institute, 2021–2024. p<0.001.

An important finding of the study was that the requirement for general anesthesia was significantly lower in the URS group compared with the PCNL group (27.7% vs 100%, p<0.001). The possibility of performing URS under spinal anesthesia substantially reduces anesthetic risk, which is particularly important in patients with a solitary kidney. Fluoroscopy exposure time was also significantly lower in the URS group (3.1±1.4 minutes versus 8.4±3.2 minutes, p<0.001), which represents a clinically important factor during prolonged procedures [13].

The stone-free rate (SFR) and other postoperative outcomes are presented in Table 3.

Table 3. Comparison of Postoperative Efficacy and Clinical Outcomes.

Parameters	PCNL (n=72), %	URS/Laser (n=65), %	International Data (%)	p-value
Stone-free rate (SFR)	93.1%	87.7%	90–95% / 85–90%	0.012
Hospital stay (days, M±SD)	3.8±1.2	1.9±0.8	3–5 / 1–2	<0.001
Total complications, n (%)	10 (13.9%)	5 (7.7%)	10–15% / 5–10%	0.209
Clavien I–II complications, n (%)	7 (9.7%)	4 (6.2%)	7–12% / 4–8%	0.424
Clavien III–IV complications, n (%)	3 (4.2%)	1 (1.5%)	2–5% / 1–3%	0.321
Reoperation, n (%)	4 (5.6%)	6 (9.2%)	—	0.367

12-month recurrence, n (%)	8 (11.1%)	10 (15.4%)	10–18%	0.426
VAS pain score (Day 1, M±SD)	5.4±1.8	3.1±1.2	—	<0.001
Return to social activity (days)	12.4±3.7	5.2±2.1	—	<0.001

Source: Research data, SPSS 26.0 analysis, Andijan State Medical Institute, 2024. VAS — Visual Analogue Scale.

The stone-free rate (SFR) was statistically significantly higher in the PCNL group compared with the URS group (93.1% versus 87.7%, p=0.012). This difference is clinically important and confirms the superiority of PCNL for the treatment of larger renal stones. However, the duration of hospitalization was nearly two times shorter in the URS group (1.9±0.8 days versus 3.8±1.2 days, p<0.001), which is of considerable clinical and economic significance. A reduction in hospital stay may decrease the burden on the healthcare system and minimize additional treatment-related costs for patients within the healthcare conditions of Uzbekistan [14].

The VAS pain score on postoperative day 1 was significantly higher in the PCNL group (5.4±1.8 versus 3.1±1.2, p<0.001), which can be explained by the relatively more invasive nature of PCNL. The time required for return to normal social activity was also significantly longer in the PCNL group (12.4±3.7 days versus 5.2±2.1 days for URS, p<0.001). These findings are fully consistent with international literature and further confirm the practical advantages of URS in selected patients.

The 12-month recurrence rates did not differ significantly between the groups (11.1% for PCNL versus 15.4% for URS, p=0.426). This result is consistent with international meta-analyses demonstrating that recurrence of kidney stone disease is primarily associated with metabolic and dietary factors rather than the surgical technique itself (Assimos et al., 2022). To reduce recurrence risk, all patients were advised to maintain high fluid intake, regularly monitor urinary pH, and undergo metabolic evaluation, including 24-hour urine analysis.

Table 4. Complications According to the Clavien–Dindo Classification (PCNL and URS Groups).

Type of complication	Clavien grade	PCNL, n (%)	URS/Laser, n (%)	Management strategy
Atelectasis / pulmonary complications	I	2 (2.8%)	0 (0%)	Conservative treatment
Infectious complications (UTI)	II	3 (4.2%)	3 (4.6%)	Antibiotic therapy
Bleeding (without transfusion requirement)	I–II	2 (2.8%)	1 (1.5%)	Observation, hemostatic therapy
Bleeding (requiring transfusion)	III	2 (2.8%)	0 (0%)	Transfusion, angioembolization
Residual stones (requiring reintervention)	III	1 (1.4%)	1 (1.5%)	URS/ESWL
Ureteral injury	III	0 (0%)	1 (1.5%)	JJ stent insertion
TOTAL COMPLICATIONS	—	10 (13.9%)	5 (7.7%)	p = 0.209

Source: Author's analysis based on research data, 2024.

The total complication rate was 13.9% in the PCNL group and 7.7% in the URS group (p=0.209), indicating no statistically significant difference between the groups. In both

groups, Clavien grade I–II complications predominated. Two cases of significant bleeding requiring transfusion (Clavien grade III) were observed in the PCNL group; both cases were successfully managed with angioembolization and conservative treatment, and nephrectomy was not required. This finding is particularly important in patients with a solitary kidney.

In the URS group, one case of ureteral injury was observed and was successfully managed by JJ stent placement. Infectious complications, mainly urinary tract infections, occurred in 4.2% of patients in the PCNL group and 4.6% in the URS group, demonstrating the effectiveness of prophylactic antibiotic therapy in both treatment modalities [15].

The effectiveness of treatment methods according to stone size is presented in the following table.

Table 5. Effectiveness of Treatment Methods According to Stone Size and EAU Recommendations.

Stone size	Number of patients	PCNL SFR	URS SFR	Optimal method	EAU recommendation
≤10 mm	28	97.1%	96.4%	URS	URS / ESWL
11–20 mm	47	94.6%	89.4%	PCNL or URS	URS or PCNL
21–30 mm	42	92.9%	72.3%	PCNL	PCNL
>30 mm (or complex stones)	20	88.5%	58.1%	PCNL ± ESWL	Mini-PCNL / PCNL
TOTAL / AVERAGE	137	93.1%	87.7%	According to stone characteristics	—

Source: Research data and EAU Guidelines on Urolithiasis 2024.

The results presented in Table 5 are fully consistent with the EAU Guidelines 2024. For stones measuring ≤10 mm, the effectiveness of URS and PCNL was nearly identical (96.4% and 97.1%, respectively). Therefore, for stones of this size, the preference for URS is mainly associated with its lower invasiveness. For stones measuring 21–30 mm, PCNL demonstrated statistically significant superiority compared with URS (92.9% versus 72.3%), indicating that complete stone clearance with URS becomes more challenging in this size category and is associated with a higher probability of repeated intervention. For complex stones larger than 30 mm, a combined approach involving PCNL followed by postoperative ESWL should be considered [16].

Multivariate logistic regression analysis demonstrated that stone size (OR 2.84, 95% CI: 1.47–5.48, p=0.002) and stone density (OR 1.003 per HU, 95% CI: 1.001–1.005, p=0.008) were independent predictors of successful stone-free rate (SFR).

The minimally invasive nature of URS provides not only clinical but also economic advantages. In patients treated with URS, the reduction of hospital stay by approximately 1.9 days allowed an average saving of nearly 480,000 Uzbek soums per patient. Faster return to social activity (12.4 versus 5.2 days) enabled restoration of work productivity approximately 7.2 days earlier. In addition, reduced anesthesia-related expenses due to the use of spinal rather than general anesthesia contributed to significant cost-effectiveness. On the other hand, the higher stone-free rate achieved with PCNL (93.1% versus 87.7%) reduces the probability of repeated procedures in patients with larger stones, thereby compensating for long-term treatment costs. Consequently, appropriate selection of the treatment modality represents both a medical and economic optimization strategy [17].

4. Conclusion

This prospective clinical study on the optimization of minimally invasive treatment methods for solitary kidney nephrolithiasis led to the following principal conclusions.

First, both percutaneous nephrolithotomy (PCNL) and ureteroscopy with holmium laser lithotripsy (URS-LL) demonstrated high efficacy and acceptable safety profiles in patients with solitary kidney stone disease. The stone-free rates (SFR) were 93.1% and 87.7%, respectively, corresponding to international standards and EAU Guidelines 2024.

Second, the primary criteria for treatment selection were stone size and stone density. For stones measuring 20 mm or smaller, URS proved to be the preferable approach due to its significantly shorter hospitalization period (1.9 versus 3.8 days), lower postoperative pain intensity (VAS score 3.1 versus 5.4), and 2.4-fold faster return to social activity (5.2 versus 12.4 days). For stones larger than 20 mm, PCNL demonstrated statistically superior stone-free outcomes compared with URS (92.9% versus 72.3% for stones measuring 21–30 mm).

Third, the complication profile of both techniques was clinically acceptable. The overall complication rate was 13.9% for PCNL and 7.7% for URS (p=0.209). In both groups, Clavien grade I–II complications predominated, while severe complications (Clavien grade III–IV) accounted for 4.2% in the PCNL group and 1.5% in the URS group. Importantly, no cases requiring nephrectomy were observed.

Fourth, the 12-month recurrence rates did not differ significantly between the PCNL and URS groups (11.1% and 15.4%, respectively; p=0.426), indicating that recurrence prevention depends more strongly on metabolic control and dietary interventions than on the selected surgical technique itself. Practical recommendations derived from the study are as follows: (1) URS-LL should be recommended as the first-line treatment modality for solitary kidney stones measuring 6–20 mm; (2) PCNL should be preferred for stones larger than 20 mm or after unsuccessful URS procedures; (3) all patients with a solitary kidney should undergo comprehensive preoperative metabolic evaluation, including 24-hour urine analysis; (4) postoperative follow-up with CT examination at 3 and 12 months is mandatory; and (5) recurrence prevention strategies should include high fluid intake (2–3 liters per day), dietary salt restriction, and reduced excessive protein consumption. Future research directions should focus on evaluating the comparative effectiveness of Mini-PCNL (14–20 Fr) and Micro-PCNL (4.8 Fr) in solitary kidney conditions, the implementation of robot-assisted endourological interventions, and the development of individualized recurrence prevention protocols based on metabolic profiling.

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