

Comparison of Super Mini Percutaneous Nephrolithotomy (smPCNL) and Extracorporeal Shock Wave Lithotripsy (ESWL) in Pediatric 1-2 cm Kidney Stones: A Single-Center Retrospective Controlled Study

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Purpose: To compare outcomes of super mini percutaneous nephrolithotomy (smPCNL) with extracorporeal shock wave lithotripsy (ESWL) for stones 1-2 cm.

Materials and methods: After receiving ethics committee approval for this study (Date: 10/09/2021 Decision No: 2021/10-01), the files of patients who underwent smPCNL and ESWL for kidney stones between January 2017 and June 2021 by the Urology Department of Van YYU Dursun Odabaşı Medical Center were retrospectively scanned. A total of 300 patients' data were scanned retrospectively. After applying the exclusion criteria and omitting ESWL patients whose sessions were not completed, a total of 159 patients, including 82 in the ESWL group and 77 in the smPCNL group, were included in our study.

Results: The mean age in the ESWL group was 6.72 ± 3.71 , and the mean age in the smPCNL group was 6.63 ± 3.59 (range: 1-18 years). There was no significant difference in the age profile between the groups ($p = .87$). Regarding the direction of the stone procedure in the smPCNL group, the procedure was performed on the right side in 42 patients (54.54%) and on the left side in 35 patients (45.46%). In the ESWL group, the procedure was performed on the right side in 38 patients (46.35%) and on the left side in 44 patients (53.65%). No statistically significant difference was found between the groups in terms of side direction ($p = .38$). The mean body mass index (BMI) in the ESWL group was 20.10 ± 2.01 , while it was 20.23 ± 2.05 in the smPCNL group. No statistically significant difference was observed between the two groups in terms of BMI ($p = .68$). The mean stone size in the ESWL group was calculated as 13.74 ± 1.91 mm (10-20 mm) and 149.75 ± 45.46 mm², which would provide more accurate results. The mean value in the smPCNL group was 14.06 ± 2.6 mm (10-20 mm) and 150.87 ± 50.34 mm². No statistically significant difference was found between the groups in terms of stone size ($p(\text{mm}) = .37$, $p(\text{mm}^2) = .88$). Among 82 patients treated with ESWL, 21 (25.6%) were stone-free after the first session, increasing to 40 (48.8%) by the end of the second session, and to 50 (61.0%) at the end of the third session. In terms of sedoanalgesia, 19 patients (23.20%) were exposed to 1 session, 16 (19.5%) were exposed to 2 sessions, and 31 (37.80%) were exposed to 3 sessions. Sixteen (19.5%) patients did not receive anesthesia. When evaluated in terms of the need for re-intervention, it was observed in 22 patients (26.8%) in the ESWL group and 4 patients (5.2%) in the smPCNL group ($p = .0003$). In the comparison of the stone-free rate of the smPCNL and ESWL groups, a statistically significant difference was observed in both the early and late periods ($p = .001$). When comparing the early and late periods of smPCNL ($p = .79$) and ESWL ($p = .19$) within their own groups, no statistical difference was observed. When smPCNL and ESWL were classified according to the Clavien-Dindo classification in terms of complications, no statistically significant difference was observed ($p = .51$).

Conclusion: ESWL remains the preferred first-line option for many pediatric patients due to its safety and non-invasive nature. However, smPCNL provides higher single-session stone-free rates for 10–20 mm renal stones and may reduce repeated anesthesia exposure. SmPCNL should be considered a viable first-line alternative to achieve higher stone-free rates without increasing complication risks. Prospective, multicenter randomized trials are warranted.

Keywords: child; nephrolithiasis; nephrolithotomy, percutaneous; shockwave lithotripsy

INTRODUCTION

Urolithiasis is among the oldest known diseases. In a study conducted in Turkey in 2010, the prevalence of urinary tract stones was reported as 10%⁽¹⁾. Although the rates vary across geographical regions, the prevalence of pediatric urolithiasis has been reported to range between 1% and 3% in different studies⁽²⁾. The incidence of pediatric stone disease is increasing

significantly worldwide. Urinary tract stones can occur in all age groups, including neonates, and may even be detected prenatally by ultrasonography⁽³⁾. The etiology is multifactorial, involving ethnicity, genetic predisposition, dietary factors, and geographical location⁽⁴⁾. As stone disease tends to recur more frequently and with a shorter interval in children compared with adults, every effort should be made to achieve complete stone

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Table 1. Distribution of gender, age, side, localization, stone burden and BMI in ESWL and smPCNL groups

Variables	ESWL (n=82)	smPCNL (n=77)	P-value
Sex			
Male (M)	n:47 (57.3%)	n:44 (57.1%)	.087
Female (F)	n:35 (42.7%)	n:33 (42.9%)	
Side			
Right	n:38 (46.35%)	n:42 (54.54%)	.38
Left	n:44 (53.65%)	n:35 (45.46%)	
Age, year; mean \pm SD (range)	6.72 \pm 3.71	6.63 \pm 3.59	.67
BMI (kg/m ²)	20.10 \pm 2.01	20.23 \pm 2.05	.68
Stone (mm ²)	149.75 \pm 45.46	150.87 \pm 50.34	.88
Pelvis	n:47 (57.3%)	n:43 (55.8%)	.84
Upper Calyx	n:6 (7.3%)	n:1 (1.29%)	.07
Middle Calyx	n:18 (21.9%)	n:23 (29.8%)	.26
Lower Calyx	n:11 (13.4%)	n:10 (12.9%)	.93

Abbreviations: BMI, body mass index; ESWL, extracorporeal shock wave lithotripsy; smPCNL, super mini percutaneous nephrolithotomy.

clearance and prevent recurrence⁽⁵⁾. Retrograde intrarenal surgery (RIRS), extracorporeal shock wave lithotripsy (ESWL), percutaneous nephrolithotomy (PCNL), and open or laparoscopic surgery are the surgical modalities employed in the management of renal calculi. In recent years, open surgery has been required in only 0.7–4% of urinary tract stone cases.

Extracorporeal shock wave lithotripsy (ESWL) was initially introduced in 1980 at the University of Munich Urology Clinic in Germany. Both radiographic and ultrasonographic modalities may be employed for stone localization. Ultrasonography has gained preference due to its lack of ionizing radiation, while radiographic imaging remains useful for identifying radiopaque stones at all anatomical sites⁽⁶⁾. Given the elevated risk of complications associated with standard PCNL, urologists have sought to minimize adverse events by employing smaller tract sizes⁽⁷⁾. In line with this approach, smPCNL using an access sheath of 10–14F was developed to reduce the complication rates observed with conventional PCNL. SmPCNL has been shown to result in fewer complications while maintaining an acceptable stone-free rate for renal calculi smaller than 25 mm⁽⁸⁾. In the present study, we retrospectively compared the efficacy and safety of ESWL and smPCNL for the management of renal calculi measuring 10–20 mm in pediatric patients.

MATERIALS AND METHODS

Study design

Following approval from the ethics committee for this study (Date: 10/09/2021, Decision No: 2021/10-01), the medical records of patients who underwent smPCNL or ESWL for renal calculi between January 2017 and June 2021 at the Urology Department of Van YYU Dursun Odabaşı Medical Center were retrospectively reviewed. Complete records were available for 300 patients. After applying the exclusion criteria and omitting ESWL cases with incomplete sessions, a total of 159 patients—82 in the ESWL group and 77 in the smPCNL group—were included in the analysis. Demographic data, laboratory results, radiological images, and stone history were extracted from patient records. Computed tomography (CT) scans were evaluated in transverse and coronal planes, with 1.5 mm slice thickness. Images were assessed using the Picture Archiving and Communication System (PACS). The affected kidney and intrarenal stone localization were determined from the CT images. To ensure accuracy, the stone burden was calculated in mm² by multiplying the two longest diameters on the

transverse CT section, rather than relying on a single measurement. All treatment-related parameters, including the number of sessions, stone-free rates, treatment duration, hospitalization, residual stones, complications, and the need for additional interventions, were recorded, and comparative analyses were conducted between the two groups.

Patient Selection Criteria

Inclusion Criteria: Age 0–18 years, informed consent obtained from parents or legal guardians, two kidneys with normal renal function, American Society of Anesthesiologists (ASA) physical status 1–2, no congenital urinary tract abnormalities, and a single kidney stone measuring 10–20 mm in diameter.

Exclusion Criteria: Age \geq 18 years, parents/legal guardians refuse to provide informed consent, acute or chronic renal failure, active urinary tract infection, ASA >2 or coagulopathy, kidney malformations (e.g., ureteropelvic junction (UPJ) stenosis, horseshoe kidney), and solitary kidney.

Surgical Technique

Super Mini Percutaneous Nephrolithotomy (smPCNL)
A 3-French ureteral catheter was retrogradely inserted in all patients. Patients were then positioned prone. After appropriate sterile preparation, the stone or ureteral catheter was visualized within the renal collecting system using C-arm fluoroscopy. Contrast medium was administered retrogradely via the ureteral catheter, and access to the appropriate posterior calyx was achieved using an 18-gauge needle under fluoroscopic guidance. A 0.035-inch J-type guidewire was advanced through the needle into the ureter or kidney. Tract dilation was performed over the guidewire using 10–14 F fascial dilators, similar to standard nephrostomy dilation. Subsequently, a 14-F irrigation-suction sheath was introduced into the pelvicalyceal system, and the kidney was accessed with a nephroscope. Isotonic saline at 37°C was used as the irrigation fluid. The smPCNL cover set was connected to the aspirator, allowing continuous aspiration of irrigated fluid, while irrigation was maintained via a pump through the endoscope's working channel. Once the stone was visualized, lithotripsy was performed using a Holmium:YAG laser. During the procedure, stones were either passively removed as they entered the nephroscope sheath or extracted using forceps or baskets when necessary. Post-procedural fluoroscopic imaging was performed to evaluate residual stones. A double-J ureteral stent was inserted in cases with residual stones >3 mm, concurrent ipsilateral ureteral stones, or significant hematuria/clot formation following litho-

Table 2. Early and late success rates of smPCNL and ESWL.

Variables	smPCNL GROUP (n:77)		ESWL GROUP (n:82)		P-value (Fisher, 1st day)	p-value ^a (Fisher, 3rd month)
	1st day	3rd month	1st day	3rd month		
UPPER POLE	0 (0%)	0 (0%)	3 (50%)	4 (66.7%)	= 1.00	= 1.00
Middle pole	20 (86.9%)	21 (91.3%)	11 (61.1%)	13 (72.23%)	.075	.209
LOWER POL	9 (90%)	9 (90%)	6 (54.55%)	6 (54.5%)	.149	.149
PELVIS	39 (90.7%)	40 (93%)	30 (63.83%)	35 (74.4%)	.0029	.0236
TOTAL	68 (88.3%)	70 (91%)	50 (61%)	58 (70.73%)	<.001	<.001

Abbreviations: ESWL, extracorporeal shock wave lithotripsy; smPCNL, super mini percutaneous nephrolithotomy.

^aFisher's exact test was used for subgroup comparisons. Statistically significant differences were observed only in the pelvis and overall success rates. Differences in upper, middle, and lower poles were not statistically significant, likely due to small subgroup sizes.

tripsy. Finally, an 8–10 F nephrostomy tube was placed at the conclusion of smPCNL.

Extracorporeal Shock Wave Lithotripsy (ESWL)

ESWL procedures were performed by a technician with five years of experience under the supervision of a urologist in our department. For patients under 10 years of age, the procedure was carried out under sedoanalgesia using ketamine (0.5–1 mg/kg) and midazolam (0.05–0.1 mg/kg) administered by an external anesthesia team. Older children received only analgesic support with ibuprofen (10–20 mg/kg). All patients were continuously monitored, with appropriate protection for the lungs and gonads.

Fluoroscopy was used to localize radiopaque stones and monitor fragmentation during treatment. Each session involved 1,400–2,000 shock waves (mean 1,500), delivered using C-arm fluoroscopy with an initial shock power of 16 kV, which could be increased to 21 kV depending on the stone's resistance. The average duration of each ESWL session was approximately 30 minutes (range: 20–45 minutes), and a mean of 3,500 shock waves (range: 1,300–5,000) was applied per session. Following each session, the status of stone fragmentation was evaluated using renal ultrasonography and/or direct urinary system radiography. Additional sessions were performed in cases of incomplete or unsuccessful stone fragmentation.

Postoperative Evaluation

All patients were assessed postoperatively using kidney–ureter–bladder (KUB) X-ray and/or urinary system ultrasonography (USG) to determine treatment success. In the smPCNL group, imaging follow-up was performed at 1 day and 3 months post-procedure to evaluate residual stone burden and the presence of obstruction, such as hydronephrosis. In the ESWL group, imaging was obtained after each session, and subsequent sessions were scheduled if stones persisted. For non-opaque ureteral stones following smPCNL, if the stone was not visible on USG but hydronephrosis was present, a low-dose non-contrast CT was performed. Stones measuring ≤ 3 mm after the procedure were classified as stone-free.

Statistical Analysis

Continuous variables are presented as mean \pm standard deviation (SD), along with minimum and maximum values, whereas categorical variables are expressed as counts and percentages. The assumptions for one-way ANOVA were evaluated, with normality assessed using the Shapiro–Wilk test and homogeneity of variances tested by Levene's test. One-way ANOVA was applied to compare group means for continuous variables. Pear-

son correlation coefficients were calculated separately for each group to examine the relationships between variables. The chi-square test was primarily used to assess associations between groups and categorical variables; however, for subgroup analyses with small sample sizes or low expected cell counts, Fisher's exact test was applied. A significance level of 0.05 was adopted for all analyses, which were conducted using the SPSS statistical software package (version 21).

RESULTS

During the study period, only 300 complete patient records were available for retrospective review. After applying exclusion criteria, 159 patients were included: 82 in the ESWL group and 77 in the smPCNL group. Demographic characteristics (age, gender, BMI) and stone burden were similar between the groups, with no statistically significant differences (all $p > .05$, Table 1). Likewise, no significant difference was observed regarding the side distribution of the procedures (right vs. left; $p = .38$, Fisher's exact test). When stone localization was compared (pelvis, upper calyx, middle calyx, lower calyx), no significant differences were found between the groups (all $p > .05$, Fisher's exact test, Table 2). In the ESWL group, 21 patients (25.6%) became stone-free after the first session, 40 patients (48.8%) after the second session, and 50 patients (61.0%) after the third session. In contrast, smPCNL achieved stone-free rates of 88.3% on the first postoperative day and 91.0% at three months. The difference in overall stone-free rates between smPCNL and ESWL was statistically significant both in the early and late periods ($p < .001$, Table 2). In subgroup analyses of stone-free rates by location, smPCNL achieved higher success rates than ESWL in the renal pelvis, middle calyx, and lower calyx, although these differences did not reach statistical significance in all subgroups due to small patient numbers (Fisher's exact test, Table 2). The mean hospital stay in the smPCNL group was 60.0 ± 12.6 hours, whereas ESWL patients were discharged after an average of 40 minutes plus a 4-hour observation period. One ESWL patient required 24-hour monitoring due to respiratory arrest. The need for re-intervention was significantly lower in the smPCNL group compared with the ESWL group (5.2% vs. 26.8%, $p < .001$). Complication rates, classified according to the Clavien–Dindo system, were similar between groups ($p = .51$, Table 3).

DISCUSSION

Urolithiasis is a long-standing condition, and its management has evolved significantly with advances in endourology. Current treatment strategies depend on

Table 3. Classification of smPCNL and ESWL according to Clavien-Dindo.

Clavien-Dindo	smPCNL Clavien-Dindo Classification		ESWL Clavien-Dindo Classification		P-value
	N	(%)	N	(%)	
Grade 1	6 (Fever)	7.5	7 (Fever)	8.75	=.51
Grade 2	2 (Transfusion)	2.5	0	0	
Grade 3 ^a	0	0	0	0	
Grade 3 ^b	1 (URS)	1.25	3 (URS)	3.75	
Grade 4 ^a	0	0	1 (Respiratory Arrest)	1.25	
Total	9	11.68	11	13.41	

Abbreviations: ESWL, extracorporeal shock wave lithotripsy; smPCNL, super mini percutaneous nephrolithotomy.

stone size, location, number, anatomical anomalies, and patient-related factors such as age and comorbidities. The main goal is to achieve the highest possible stone-free rate while minimizing morbidity.

Surgical options include ESWL, RIRS, rigid ureteroscopy (URS), PCNL, and, less frequently, open or laparoscopic procedures. With ongoing advances, open surgery is now rarely used and reserved for highly selected cases. According to EAU guidelines, PCNL is recommended for renal stones >2 cm, whereas ESWL is generally preferred for stones ≤2 cm⁽⁹⁾. Pediatric patients, although less frequently affected, require more specialized approaches due to their developing kidneys, higher recurrence risk, and increased susceptibility to complications. In this population, treatment goals should prioritize complete clearance, preservation of renal function, and prevention of recurrence.

Historically, open surgery was the standard for large renal stones, but it required prolonged hospitalization and left significant scars. Today, minimally invasive approaches such as ESWL, PCNL, and RIRS have replaced it⁽¹⁰⁾. Children, with smaller kidneys, are more vulnerable to blood loss and associated complications. Moreover, pediatric stones are linked to higher re-intervention rates within six months⁽¹¹⁾. The miniaturization of percutaneous instruments has reduced bleeding and postoperative morbidity, prompting comparisons between ESWL and mini-PCNL as alternatives for medium-sized stones in children⁽¹²⁾.

While ESWL remains widely used due to its non-invasive nature, it is not without risks. Studies have shown associations between ESWL and long-term renal damage, including parenchymal fibrosis, irreversible tissue loss⁽¹³⁾, hypertension⁽¹⁴⁾, and reduced GFR⁽¹⁵⁾. Other reported complications include renal hematoma⁽¹⁶⁾, and in rare cases, myocardial infarction⁽¹⁷⁾, intestinal perforation⁽¹⁸⁾, splenic rupture⁽¹⁹⁾, abdominal compartment syndrome, and necrotizing pancreatitis⁽²⁰⁾. Additionally, repeated anesthesia sessions, often necessary for multiple ESWL treatments, raise concerns about potential neurotoxicity in children⁽²¹⁾.

In published ESWL series involving patients under 18, the mean age typically ranges between 6–12 years, and stones are most often localized in the renal pelvis, though upper, middle, and lower calyces are also involved⁽²²⁾. In our study, age and stone distribution in the ESWL group were consistent with this literature. Sarica et al. reported stone-free rates of 72.2% at one week and 77.8% at three months⁽²³⁾. The broader literature reports short-term ESWL success ranging from 57–92%, and overall rates from 57–97%⁽²⁴⁾. Our early and late-term findings aligned with these results. As described in prior reports, lower calyx stones remain the most challenging location for ESWL⁽²⁵⁾, which was also observed in our series. Additional interventions after ESWL have

been reported in 4–50% of cases⁽²⁶⁾, and our data were similar. Although no significant difference was seen between early- and late-term ESWL outcomes, 9.7% of patients achieved delayed clearance.

Comparative studies of smPCNL demonstrate higher single-session stone-free rates. Liu et al. reported 84.7% at day one and 90.1% at three months in 111 children, with a mean hospital stay of 2.7 days⁽²⁷⁾. Sarica et al. found early and late rates of 90.9% and 92.8% in 111 patients, with complications in 10.8% and a 4.5% re-treatment rate⁽²³⁾.

Yuan et al. observed an 88.2% success rate in 17 patients⁽²⁸⁾, while other series reported early rates of 84.7–94.4% and late rates up to 95.8%⁽²⁷⁻³⁰⁾. An ultra-mini-PCNL series reported 95.5% success⁽³¹⁾. Furthermore, a 2022 meta-analysis demonstrated a pooled smPCNL stone-free rate of 91.4%⁽³²⁾, consistent with our late success rate of 91%. A 2024 meta-analysis confirmed that PCNL and RIRS were superior to ESWL in children, with no significant differences in complication rates⁽³³⁾.

Our findings—early (88.3%) and late (91%) smPCNL success rates—were comparable to these reports. Notably, 2.5% of patients with residual fragments early on achieved stone-free status later. Complication rates, classified by Clavien–Dindo, were consistent with prior studies. Moreover, all procedures in our series used a 14F tract, which has been shown to reduce transfusion and complication rates⁽³⁴⁾. Only 2.5% required intraoperative transfusion, aligning with previous reports of smPCNL safety^(24,30).

When smPCNL and ESWL were compared in our series, smPCNL consistently achieved higher stone-free rates. Intra-group analyses (early vs. late) showed no significant differences, but between-group comparisons clearly favored smPCNL. Subgroup analysis by stone localization revealed no significant differences in upper, middle, or lower calyx stones, likely due to small sample sizes. However, smPCNL demonstrated clear superiority for pelvic stones.

From a clinical perspective, ESWL often required multiple anesthetic sessions, with nearly half of the children receiving three sedoanalgesia exposures and many subsequently requiring additional procedures such as URS. In contrast, smPCNL achieved high single-session success rates, reducing the risks associated with repeated anesthesia.

Overall, our results emphasize that while ESWL is less invasive, smPCNL offers higher stone-free rates with acceptable complication profiles. With appropriate patient selection, smPCNL can serve as a reliable alternative to ESWL, particularly for medium-sized pediatric stones, challenging lower pole cases, or scenarios where repeated anesthesia should be avoided.

CONCLUSIONS

ESWL remains a widely used first-line option for pediatric kidney stones due to its noninvasive nature. However, smPCNL provided significantly higher single-session stone-free rates for 10–20 mm calculi, with comparable complication rates.

Although subgroup analyses of stone-free rates by stone location did not always reach statistical significance—likely due to small sample sizes—the overall results consistently favored smPCNL. These findings highlight smPCNL as a safe and effective alternative to ESWL, reducing the need for repeated anesthesia and additional interventions in children.

Well-designed prospective multicenter trials are required to further validate these results.

SUMMARY

Super-mini percutaneous nephrolithotomy (smPCNL) offers higher stone-free rates than shock wave lithotripsy (ESWL) in children with 1–2 cm kidney stones, reducing repeated anesthesia and complications.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest related to this study.

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