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Suction-Assisted Miniaturized Percutaneous Nephrolithotomy Outcomes in Anomalous Kidneys: A Multicenter Prospective Study—An EAU-Endourology Collaboration

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Abstract

Background: Renal stones in anomalous kidneys pose surgical challenges due to altered anatomy. Miniaturized percutaneous nephrolithotomy (mini-PCNL) reduces morbidity, but concerns remain about stone-free rates (SFRs) and infection. Suction-assisted mini-PCNL (SM-PCNL) enhances fragment removal and controls intrarenal pressure, but its role in anomalous kidneys is unclear.
Objective: To evaluate perioperative outcomes of SM-PCNL in anomalous kidneys in a multicenter, real-world study and assess variations based on positioning, lithotripsy modality, and renal anomalies.
Methodology: This prospective study across 15 centers (January–December 2024) included 287 adults undergoing SM-PCNL for renal stones in anomalous kidneys. Patients with normal anatomy, non-suction PCNL, or incomplete data were excluded. SFR was assessed via a 30-day non-contrast CT: 100% stone-free (Grade A), residual fragments ≤4 mm (Grade B), or >4 mm/multiple (Grade C, requiring reintervention).
Results: Malrotation (65.5%) was the most common anomaly, followed by duplex systems (25.1%), horseshoe kidneys (8.4%), and ectopic kidneys (1.0%). Median stone size was 1.7 cm. Supine positioning was used in 54.4%. Lithotripsy was performed with holmium laser (50.9%), thulium fiber laser (11.1%), or pneumatic lithotripsy (26.1%). Intraoperative clearance was 95.4%. At 30 days, 93.4% achieved Grade A, 5.6% Grade B, and 1.0% required reintervention. Complications were low; 0.7% had sepsis requiring intensive care unit admission. No transfusions or pleural injuries occurred.

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Conclusion: SM-PCNL using 18F suction sheaths with laser in a single stage achieved 93.4% complete SFR with negligible complications and minimal reintervention.

Keywords: suction mini-PCNL (SM-PCNL), anomalous kidneys, stone-free rate (SFR), percutaneous nephrolithotomy (PCNL), renal calculi, lithotripsy

Introduction

Miniaturized percutaneous nephrolithotomy (mini-PCNL) has demonstrated reduced morbidity compared with standard percutaneous nephrolithotomy (PCNL).[1,2] Adding suction aimed to minimize infectious complications arising from elevated intrarenal pressure (IRP) and intrarenal backflow during lithotripsy for infected kidney stones.[3,4] Furthermore, suction sheaths for mini-PCNL were introduced to improve fragment removal in PCNL, establishing suction-assisted mini-PCNL (SM-PCNL) as a notable enhancement in both adults and children.[5] A recent systematic review of patients with normal kidneys highlighted considerable heterogeneity among the included studies, resulting in only low evidence-based conclusions. The stone-free rate (SFR) exhibited substantial variation depending on the suction device utilized and the method of reporting residual fragments (RF).[5]

Khadgi S et al.[6] found that mini-PCNL, even in patients with anomalous renal anatomy, achieved SFR comparable to standard PCNL while offering better safety across their series of 59 cases. Flexible ureteroscopy has also been explored within this patient subgroup.[7] In a large series involving anomalous kidneys, Lim et al. demonstrated that PCNL achieves a significantly higher SFR, [odds ratio (OR) = 3.69, 95% confidence interval (CI): 1.91–7.46, $p < 0.001$], particularly in horseshoe kidneys (HSK) (OR = 3.33, 95% CI: 1.22–9.99, $p = 0.023$) as compared to retrograde intrarenal surgery (RIRS).[8] However, in this study, the use of suction technology was not reported in the 127 matched pairs of patients with anomalous kidneys. Therefore, the role of SM-PCNL in anomalous kidneys remains underexplored. To the best of our knowledge, this is the first multicenter, real-world prospective series addressing this topic in the literature. Our primary aim is to report the perioperative outcomes of SM-PCNL in a multicenter prospective study. Our secondary aim is to determine whether SM-PCNL outcomes vary based on patient positioning, lithotripsy devices, and in different anomalies, given that PCNL can be performed in the supine and prone position with different devices.[9]

Methods

Participants

This was a prospective, multicenter, study. Patients from 15 centers were enrolled between January 2024 to December 2024. Data were gathered after the respective institutional review board approval was obtained. Anonymized data collected in the Suction Technology Utility in mini-PCNL Study registry[10] managed by the principal site (i.e., the Asian Institute of Nephro-Urology) after ethical board clearance under protocol (AINU #01/2024). For our study, SM-PCNL is defined as the use of any disposable suction compatible sheath of 14–22F in size.

Inclusion criteria were patients aged ≥18 years who underwent SM-PCNL for renal stones only in anomalous kidneys. Patients with normal kidney anatomy, ureteral stones, pediatric age group, non-suction PCNL, or insufficient data obtainable, unfit for consent, were excluded. As per the original protocol, endoscopic guided puncture was not an exclusion, but any patients undergoing endoscopic combined intrarenal surgery were excluded.

Baseline and operative characteristics

Baseline and operative characteristics were gathered. The selection of the energy source, type of suction sheath, sheath size (14–22F), surgical positioning approach, and other perioperative decisions were left to the discretion of the respective surgeons, based on their experience and available resources. Data on the exit strategy were also recorded. Anticoagulants or antiplatelets were discontinued before surgery and resumed at the surgeon's discretion. Additionally, surgeons provided subjective 5-score Likert scale ratings on their intraoperative experience with SM-PCNL. All patients had a preoperative non-contrast CT scan to assess stone features. The stone volume (SV) of the largest stone was calculated from the CT scan using the bone window, with the stone diameter measured along three axes and the ellipsoid formula applied to determine the volume (length × width × depth × π × 0.167). All positive pre-op urine cultures are treated as per antibiogram sensitivity. On-table prophylaxis is given to all as per institution protocols.

Patient follow-up and outcomes

All patients were followed up for 30 days. Readmissions within this period due to reintervention or reported complications were documented. The primary outcome was the SFR, determined by a non-contrast, low-dose CT scan (2 mm slice) performed 30 days after PCNL. Stone-free status (SFS) was categorized based on RF into the following groups:

Group A: 100% stone free, zero RF.

Group B: Relatively stone free: Single RF as much as 4 mm in maximum diameter.

Group C: Non-stone free: Single RF >4 mm in maximum diameter or multiple RF of any size.

Reintervention was considered solely for patients in Group C, with the proposed intervention modality duly documented. Secondary outcomes encompassed perioperative and postoperative complications, including bleeding, transfusion, perforation of the pelvicalyceal system (PCS), colonic injury, pleural injury, infection-related complications, and persistent hematuria. These complications were

Table 1. Baseline Characteristics

	Overall (N = *287*)
Age	45 [34, 56]
Male gender	120 (41.8)
ASA	
1	218 (76.0)
2	63 (22.0)
3	5 (1.7)
4	1 (0.3)
BMI, kg/m^2	23.9 [21.6, 26.1]
DM	17 (5.9)
CKD	63 (22.0)
Anticoagulant/Antiplatelet use	12 (4.2)
Presentation	
Hematuria	5 (1.7)
Pain	272 (94.8)
Fever	3 (1.0)
Incidental	7 (2.4)
First-time stone former	245 (85.4)
Preoperative urine culture positive	150 (52.3)
Hounsfield units	1114 [924, 1355]
Largest stone diameter, cm	1.7 [1.3, 2.3]
Stone volume, mm^3	1130 [533, 2315]
Stone location	
Upper pole	20 (7.4)
Middle pole	204 (75.3)
Lower pole	47 (17.3)
Anomalous kidney type	
Malrotated	188 (65.5)
HSK	24 (8.4)
Ectopic	3 (1.0)
Duplex	72 (25.1)
Previous PCN	15 (5.2)
Final stone composition on analysis	
Calcium phosphate	130 (47.8)
Calcium oxalate monohydrate	12 (4.4)
Calcium oxalate dihydrate	5 (1.8)
Struvite	7 (2.6)
Uric acid	1 (0.4)
Others (mixed composition)	117 (43.0)

Reported as median [interquartile range] or *N* (%).
ASA = American Society of Anaesthesiologists classification; BMI = body mass index; CKD = chronic kidney disease; DM = diabetes mellitus; PCN = percutaneous nephrostomy.

categorized under the modified Clavien-Dindo (CD) classification system.[11]

Statistical analysis

Continuous variables are presented as medians with interquartile ranges (IQRs), whereas categorical variables are reported as absolute numbers and percentages. Statistical analysis was conducted using R-4.3.0 in RStudio. Subgroup analyses were performed by stratifying outcomes based on laser *vs* mechanical lithotripsy, prone *vs* supine positioning, and specific kidney anomalies, including malrotation, HSK, ectopic kidney, and duplex collecting system. For between-group comparisons, the $\chi 2$ or the Fisher test for categorical parameters and the Kruskal-Wallis test (more than two groups) or Mann-Whitney U-test (two groups) for continuous variables were utilized, with $p < 0.05$ indicating statistical significance.

Table 2. Procedural Characteristics

	Overall (N = *287*)
Spinal anesthesia	253 (88.2)
Supine patient position	156 (54.4)
Puncture modality	
Fluoroscopy only	253 (88.2)
Fluoroscopy + USG	24 (8.4)
Endoscopy guided	10 (3.5)
Number of tracts	
1	263 (91.6)
2	22 (7.7)
3	1 (0.3)
4	1 (0.3)
Supracostal access (above 11th rib)	57 (19.9)
Tract dilation method	
Serial with metal dilators	223 (77.7)
Serial with nonmetal dilators	7 (2.4)
Single-step dilatation	57 (19.9)
Safety wire inserted during surgery	72 (25.1)
Sheath size	
22F	101 (35.2)
18F	185 (64.5)
14–16F	1 (0.3)
Sheath brand	
ClearPetra	16 (5.6)
Shah	235 (81.9)
Others	36 (12.5)
Energy	
Holmium LP	146 (50.9)
Holmium HP	11 (3.8)
TFL	32 (11.1)
Trilogy	1 (0.3)
Lithoclast	2 (0.7)
Pneumatic	75 (26.1)
Stone fragmentation modality	
Fragmentation only	241 (85.8)
Dusting only	2 (0.7)
Popcorning only	1 (0.4)
Combination of the above	37 (13.2)
Basket required for stone relocation	244 (85.0)
Lithotripsy time, minutes	11 [6, 16]
Total operation time, minutes	25 [20, 37.5]
Sheath change required	0
Sheath able to access all of kidney	265 (94.6)
Intraoperative SFR by surgeon confirmed by fluoroscopy or visual inspection	
100% clear	271 (95.4)
Only dust remains	10 (3.5)
Fragments remain	3 (1.1)
Exit strategy	
Tubeless with PCN	14 (4.9)
Tubeless with stent	71 (24.7)
Tubeless with overnight ureteral catheter (6F catheter placed in ureter)	15 (5.2)
PCN + stent	186 (64.8)
Totally tubeless	1 (0.3)
Tract closure modality	
No stitch	28 (9.8)
Stitch placed	257 (89.5)
Hemostatic agent	2 (0.7)
Likert scale evaluation	
Ease of suction	
1	269 (94.1)
2	14 (4.9)
3	3 (1.0)
Manipulation	
1	244 (85.3)
2	35 (12.2)
3	7 (2.4)
Visibility	
1	256 (89.8)
2	24 (8.4)
3	0
4	4 (1.4)
5	1 (0.4)

Reported as median [interquartile range] or *N* (%).
HP = high power >40 W; LP = low power <40 W; Likert scale = 1–3 with 1 being excellent, 2 being average, and 3 being poor; TFL = thulium fiber laser.

Table 3. Outcomes Stratified by Anomaly in Kidney Anatomy

	Malrotated (N = *188*)	*HSK* (N = *24*)	*Ectopic* (N = *3*)	*Duplex system* (N = *72*)	p
Intraoperative bleeding after dilatation, not controlled by suction	6 (3.2)	0	0	0	0.358
Colonic injury	2 (1.1)	0	0	0	0.787
Postoperative pain score	1.0 [1.0, 2.0]	2.0 [2.0, 2.0]	3.0 [2.5, 3.0]	2.0 [1.0, 2.0]	<0.001
Fever/Sepsis					0.082
None	182 (96.8)	21 (87.5)	3 (100)	71 (98.6)	
Fever for 24 hours	5 (2.7)	3 (12.5)	0	0	
Sepsis needing ICU (CD4)	1 (0.5)	0	0	1 (1.4)	
Fever >48 hours prolonging hospital stay (CD1)	4 (2.1)	1 (4.2)	0	0	0.509
Postoperative RF grade on 30-day CT scan					<0.001
Grade A: Zero RF	183 (97.3)	12 (50.0)	3 (100)	70 (97.2)	
Grade B: Single RF as much as 4 mm	5 (2.7)	11 (45.8)	0	0	
Grade C: Single RF >4 mm or multiple RF	0	1 (4.2)	0	2 (2.8)	

Reported as median [interquartile range] or *N* (%).
HSK = horseshoe kidney.

Results

Two hundred eighty-seven patients with anomalous kidneys underwent SM-PCNL for renal stones during the study period. The median age was 45 years IQR [34–56], and 41.8% (n = 120) were male. Malrotation, defined as altered anatomy resulting in abnormal positioning of renal pelvis and hilum diagnosed either by pre-operative or on-table imaging, was the most common reported anomaly (65.5%), followed by duplex system (25.1%), HSK (8.4%), and ectopic pelvic kidney (1.0%). The median stone diameter was 1.7 cm [IQR 1.3–2.3], and the median SV was 1130 mm^3 [IQR 533–2315]. A positive preoperative urine culture was found in 52.3% of patients (n = 150), treated with antibiotics before surgery (Table 1).

The supine position was used in 54.4% of cases (n = 156) and prone positioning in 45.6% (n = 131). Lithotripsy with low-power holmium laser (<40 W) was employed in 50.9%, thulium fiber laser (TFL) in 11.1%, and high-power holmium laser in 3.8% pneumatic lithotripsy was used in 26.1% of cases. Surgeons chose between reusable or disposable sheaths, with 18F being the most common size (64.5%), followed by 22F (35.2%) (Table 2).

During surgery, complete stone removal was confirmed in 95.4% of cases (n = 271) using fluoroscopy and/or direct visual inspection. The median lithotripsy time was 11 minutes [IQR 6–16], and the total operative time from puncture to exit was 25 minutes [IQR 20–37.5]. A 30-day non-contrast CT scan showed that 93.4% (n = 268) of patients achieved complete SFS (Grade A), whereas 5.6% (n = 16) had RF ≤4 mm (Grade B) and only 1.0% (n = 3) had fragments > 4 mm or multiple fragments (Grade C). Reintervention was performed in 0.7% of cases (n = 2) via RIRS. Both patients had a duplex system.

The overall complication rate was low, with no occurrences of blood transfusion, embolization, or pleural injury. Intraoperative bleeding managed by suction was reported in 2.1% (n = 6) of cases. Colonic injury occurred in 0.7% (n = 2), both involving malrotated kidneys, and required conservative management without surgical intervention (CD grade 2) (Table 3). Postoperative fever (>38.0°C) managed with antibiotics in the ward (CD grade 2) was noted in 1.7% (n = 5), and sepsis requiring intensive care unit admission (CD grade 4) occurred in 0.7% (n = 2). Both patients experiencing sepsis had medullary sponge kidney with malrotation. The median hospital stay was 4 days [IQR 4–4] (Table 4).

Analysis by lithotripsy modality revealed that mechanical lithotripsy had a significantly higher overall SFR compared to laser lithotripsy ($p = 0.007$) (Table 5).

Among renal anomalies, malrotated kidneys showed the highest SFR (97.3%), whereas HSK had the lowest (50.0%) ($p < 0.001$). Duplex collecting system anomalies had a high SFR (97.2%) but included only two reinterventions (Table 6).

Table 4. Intraoperative and Postoperative Outcomes

	Overall (N = *287*)
Intraoperative bleeding after dilatation, not controlled by suction	6 (2.1)
Transfusion (CD4)	0
Embolization (CD4)	0
PCS perforation needing PCN placement (CD2)	0
Colonic injury (CD3)	2 (0.7)
Pleural injury needing chest tube (CD3)	0
Postoperative pain score	1.0 [1.0, 2.0]
0	1 (0.3)
1	149 (51.9)
2	109 (38.0)
3	19 (6.6)
≥4	9 (3.0)
Fever/Sepsis	
None	277 (96.5)
Fever for 24 hours	8 (2.8)
Sepsis needing ICU (CD4)	2 (0.7)
Fever >48 hours prolonging hospital stay (CD1)	5 (1.7)
Persistent hematuria prolonging hospital stay (CD1)	0
Postoperative RF grade on 30-day CT scan	
Grade A: Zero RF	268 (93.4)
Grade B: Single RF as much as 4 mm	16 (5.6)
Grade C: Single RF >4 mm or multiple RF	3 (1.0)
Hospital stay, days	
0 (day surgery)	2 (0.7)
2	22 (7.8)
3	44 (15.6)
4	207 (73.4)
5	3 (1.1)
6	2 (0.7)
7	2 (0.7)
Readmission for any reason within 72 hours	2 (0.7)
Residual fragment reintervention after 30 days	2 (0.7)
Time to reintervention, days	2 [2, 2]

Reported as median [interquartile range] or *N* (%).
CD = Clavien-Dindo classification; ICU = intensive care unit; RF = residual fragments; PCS = pelvicalyceal system.

Table 5. Outcomes Stratified by Lithotripsy Modality

	Laser (N = *189*)	*Mechanical* (N = *98*)	p
Intraoperative bleeding after dilatation, not controlled by suction	5 (2.6)	1 (1.0)	0.633
Colonic injury	2 (1.1)	0	0.784
Postoperative pain score	1.0 [1.0, 2.0]	1.5 [1.0, 2.0]	0.59
Fever/Sepsis			0.068
None	179 (94.7)	98 (100)	
Fever for 24 hours	8 (4.2)	0	
Sepsis needing ICU (CD4)	2 (1.1)	0	
Fever >48 hours prolonging hospital stay (CD1)	3 (1.6)	2 (2.0)	>0.99
Postoperative RF grade on 30-day CT scan			0.007
Grade A: Zero RF	172 (91.0)	96 (98.0)	
Grade B: Single RF as much as 4 mm	16 (8.5)	0	
Grade C: Single RF >4 mm or multiple RF	1 (0.5)	2 (2.0)	

Reported as median [interquartile range] or *N* (%).

Discussion

Renal stone management is demanding, particularly in anomalous kidneys including malrotation, fusion anomalies (HSK, crossed-fused ectopia), pelvic kidneys, duplicated and ectopic kidneys, which have disrupted renal anatomy, calyceal architecture, and ureteral access routes, complicating stone management both by PCNL[12] and flexible ureteroscopy[13] even in the hands of experts.

Over the past two decades, endourological techniques, particularly PCNL, have transformed the management of renal stones, especially in anomalous kidneys.[13] Mini-PCNL, which utilizes smaller access tracts (14–22F), has emerged as a promising alternative. Its reduced tract size is linked to lower bleeding risk, decreased pain, and shorter hospital stays. Additionally, mini-PCNL is associated with less morbidity, improved access, faster recovery, minimal blood loss, and reduced postoperative pain—not only in normal kidneys but also in cases involving anomalous renal anatomy. Single-center studies have suggested that, in experienced hands, this approach is an effective strategy for managing kidney stones in such conditions.[14] Bilen et al.[15] highlighted that surgeons favor smaller access techniques for HSK and other anomalies to minimize morbidity, given the increased complexity of access and the variability of renal vascular anatomy.[16,17] Interestingly, the 18F sheath was the most preferred size in our series (64.5%, Table 2), with surgeons rating it 1.0 [1.0, 1.0] on the Likert scale,[18] where 1 represents excellent maneuverability, ease of suction, and clear vision regardless of sheath brand or type. Given the challenges of navigating complex PCS, this finding underscores a key practical consideration for surgeons.

A key challenge of mini-PCNL has always been achieving a high SFR, especially when dealing with large SVs. Meta-analyses report SFRs ranging from 70% to 95%, but interestingly, studies indicate that mini-PCNL achieves SFRs comparable to standard PCNL.[19] This has led to recommendations for using mini-PCNL even for stones larger than 1 cm. However, the application of SM-PCNL in anomalous kidneys remains relatively underexplored in the literature, with limited studies assessing its effectiveness based on SV. Typically, stone size or diameter was used as a benchmark. However, since guidelines recommend that SV is a more reliable predictor of intervention outcomes, our study prioritized this measure. Furthermore, a recent global survey of urologists confirmed that SV offers a more accurate assessment of stone burden compared to diameter. Therefore, endourology experts and academics should incorporate SV into routine practice.[20]

In the largest study on mini-PCNL in anomalous kidneys,[6] an SFR of 89.8% was reported, with an average operative time of 50.17 ± 18.73 minutes and a complication rate of

Table 6. Outcomes Stratified by Patient Positioning During Suction-Assisted Miniaturized Percutaneous Nephrolithotomy

	Prone (N = *131*)	*Supine* (N = *156*)	p
Intraoperative bleeding after dilatation, not controlled by suction	2 (1.5)	4 (2.6)	0.843
Colonic injury	0	2 (1.3)	0.556
Postoperative pain score	1.0 [1.0, 2.0]	1.0 [1.0, 2.0]	0.307
Fever/Sepsis			0.010
None	129 (98.5)	148 (94.9)	
Fever for 24 hours	0	8 (5.1)	
Sepsis needing ICU (CD4)	2 (1.5)	0	
Fever >48 hours prolonging hospital stay (CD1)	1 (0.8)	4 (2.6)	0.479
Postoperative RF grade on 30-day CT scan			0.004
Grade A: Zero RF	128 (97.7)	140 (89.7)	
Grade B: Single RF as much as 4 mm	1 (0.8)	15 (9.6)	
Grade C: Single RF >4 mm or multiple RF	2 (1.5)	1 (0.6)	

Reported as median [interquartile range] or *N* (%).

25.4%. This single-center study addressed various complex renal anomalies, all treated using an 18F sheath and a pneumatic lithotripter under regional anesthesia in the prone position. The outcomes were superior to previous studies using flexible ureteroscopy,[7] which reported a global SFR of 79.2% and a complication rate of 12%. Similarly, standard PCNL in anomalous kidneys showed an SFR of 76.6% in a subset of 202 patients from the CROES database (5,542 patients, 3.6%), with an unsuccessful access rate of 5% in this subgroup.[21,22]

Our study presents real-world multicenter outcomes in a large patient cohort, providing valuable insights into the efficacy of SM-PCNL for treating renal stones in complex kidney anatomies by experienced surgeons in high volume centers, which perhaps accounts for the relatively fast median operative times of 25 minutes from entry to exit (Table 2). Regardless of tract size, PCNL in anomalous kidneys presents unique challenges, and our data reflect outcomes from experienced surgeons. We conducted a subset analysis to determine how lithotripsy modality and renal anomalies influence single-access SFR with SM-PCNL. Given the large sample size, we gained critical insights into optimizing treatment approaches.

First, Pozzi et al. validated the trifecta scoring system for vacuum mini-PCNL proposed by El-Nahas et al.,[23,24] which consists of high single-stage SFR, low complications, and minimal reinterventions. El-Nahas et al. reported that 84% of patients ($N = 944$) with normal renal anatomy achieved this outcome, whereas Pozzi et al. reported 60% ($N = 10$). In our study, the high SFR of 98.9% (Grades A and B) in anomalous kidneys suggests that once renal access is safely established, vacuum or SM-PCNL could be the superior treatment choice in these patients.

Second, our study reports faster operative times of 25 minutes [20, 37.5], significantly shorter than other studies, which report averages of 51.62 ± 10.17 minutes or 35.6 ± 6.8 minutes ($p = 0.03$), as seen in Kankaria et al.'s[25] findings using SM-PCNL in normal kidneys. In contrast, Prakash et al.[26] reported 123.9 ± 19.7 minutes using standard PCNL in anomalous kidneys, while Khadgi et al.[6] reported 50.17 ± 18.73 minutes using non-suction mini-PCNL. Although multiple factors contribute to efficiency, our findings highlight that vacuum aspiration alone significantly enhances the effectiveness of SM-PCNL, making it a viable option even under regional anesthesia.

Third, suction works via the Venturi effect, where fluid flow generates a low-pressure zone that efficiently removes stone fragments from the kidney.[27,28] This principle likely explains our high SFR with minimal infectious complications, as well as the low incidence of CD grade 3 and 4 complications. Additionally, factors such as smaller tract size,[29] atraumatic dilation, tubeless stent strategy, and low IRP thresholds prevent PCS overdistension, fluid extravasation, and perinephric inflammation, thereby reducing postoperative pain and improving patient quality of life.[30] Although our study lacks specific IRP measurements and validated pain questionnaires, patients reported a low POD1 visual analog scale pain score of 1.0 (1.0, 2.0)[31] on a scale of 1–10, supporting the safety and efficacy of SM-PCNL in anomalous kidneys (Table 4). These findings align with Kankaria et al.,[25] who observed that even for larger SVs, SM-PCNL significantly reduced postoperative pain, hospital stay, and CD grade ≥3 complications. Although their study focused on normal kidneys, our findings confirm similar benefits in anomalous kidneys too.

Fourth, clinical data on laser with suction (LWS) in mini-PCNL in normal kidneys suggest that for stones >18 mm, LWS achieves superior SFRs compared to non-suction techniques.[32] Similarly, our study found that this combination was most effective for achieving a high or even 100% SFR (93.4%, Table 4), a finding not previously reported in anomalous kidneys.

Last, HSK present additional challenges in achieving immediate 100% SFS and may have a slightly higher predisposition to sepsis. However, these results should be interpreted cautiously, as our study has certain limitations, including reporting bias, the absence of a non-suction mini-PCNL control group, lack of direct comparison to normal renal anatomy, procedures performed only by experienced surgeons, and equipment selection based on surgeon familiarity. The choice of exit strategy was left to the individual surgeon's discretion. As the rationale for these preferences was not documented, it is not possible to draw conclusions to inform evidence-based recommendations for urologists. Additionally, no patients with calyceal diverticulum were included, despite this not being an exclusion criterion. Moreover, we also do not have details on the exact method of stone analysis from different centers to make any subset inferences for the same. It would be interesting if a future study could evaluate whether an intervention, radiology-based access, can further improve safety and efficacy in these complex anatomies.

Despite these limitations, this large prospective study reflects real-world clinical practice. We conclusively demonstrate that SM-PCNL can achieve near 100% SFR with minimal complications in a remarkably short operative time, regardless of the instrument type used in anomalous kidneys.

Conclusion

Our global real-world study indicates that SM-PCNL in experienced hands, particularly when using 18F sheaths combined with lasers, can achieve complete stone-free outcomes, minimize reintervention with minimal complications. Insights from this study offer valuable practical considerations to simplify surgery in complex renal anatomy. Additionally, findings reflect how the global availability of SM-PCNL technology has made it the preferred approach for most anomalous kidneys.

Authors' Contributions

Study conception and design: V.G., E.J.L., and S.K.K.Y. Data acquisition: B.K.S., J.K., E.B.-S., G.N., M.L., K.P., E.A., M.A.L., K.Y.F., M.Z., N.K., A.M., R.Z., S.T., G.R.T., A.G.M., M.C., V.M., A.C., D.C., T.R.W.H., E.J.L., S.K.K.Y., V.G. Data analysis and interpretation: K.Y.F., E.J.L., R.T., Z.S., S.K.K.Y., and V.G. Manuscript drafting: R.Z., S.T., B.K.S., J.K., E.B.-S., G.N., M.L., K.P., E.A., M.A.L., M.Z., N.K., A.M., G.R.T., A.G.M., M.C., V.M., A.C., D.C., T.R.W.H., E.J.L., S.K.K.Y., and V.G. Critical revision for important intellectual content: All authors. Supervision and overall study oversight: E.J.L., S.K.K.Y., and V.G.

Author Disclosure Statement

The authors declare that they have no conflicts of interest.

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Abbreviations Used

AINU = Asian Institute of Nephro-Urology
ASA = American Society of Anaesthesiologists
BMI = body mass index
CD = Clavien-Dindo
CI = confidence interval
CKD = chronic kidney disease
CT = computed tomography
DM = diabetes mellitus
ECIRS = endoscopic combined intrarenal surgery
HSK = horseshoe kidney
HP = high power
ICU = intensive care unit
IQR = interquartile range
IRP = intrarenal pressure
LP = low power
LWS = laser with suction
OR = odds ratio
PCS = pelvicalyceal system
PCN = percutaneous nephrostomy
PCNL = percutaneous nephrolithotomy
POD1 = postoperative day
RIRS = retrograde intrarenal surgery
RF = residual fragments
SFS = stone-free state
SFR = stone-free rate
SM-PCNL = suction-assisted mini-percutaneous nephrolithotomy
STUMPS = suction technology utility in mini-PCNL study
SV = stone volume
TFL = thulium fiber laser
USG = ultrasound guidance
VAS = visual analog scale