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Optimizing RIRS in Complex Renal Anatomy: A Comparative Study of Tip-Flexible Suction Versus Conventional Ureteral Access Sheath

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Abstract

Background/Objectives: Managing kidney stones in patients with congenital renal anomalies—such as horseshoe kidney or ectopic kidney—presents unique challenges for endourologists. In these anatomically complex cases, standard ureteral access can be difficult, and pressure management becomes critical. Suction-assisted ureteral access sheaths have emerged as a promising solution, but clinical data in this population remain limited. This study evaluates whether using a tip-flexible suction UAS improves outcomes in retrograde intrarenal surgery compared to conventional access.
Methods: We retrospectively reviewed 67 patients with confirmed renal anomalies and stones sized 2–4 cm who underwent RIRS at two academic centers between October 2022 and December 2024. Patients were grouped based on the type of UAS used: suction-assisted (TFS-UAS) or conventional (T-UAS). Surgical and postoperative outcomes, including stone-free rate (SFR), complication profile, operative time, and hospital stay, were compared.
Results: The TFS-UAS group showed a higher 30-day SFR (94.3%) compared to the conventional group (81.3%), although the difference was not statistically significant. Operative time was longer with TFS-UAS ($p < 0.001$), but this was offset by a shorter hospital stay ($p = 0.003$). No major differences were seen in complication rates.
Conclusions: Using a suction-assisted UAS in RIRS for patients with congenital renal anomalies appears to offer meaningful clinical benefits—most notably better fragment clearance and quicker recovery. While the technique may increase operative time, the trade-off seems justified, particularly in anatomically challenging cases.

Keywords: RIRS; suction-assisted UAS; congenital renal anomalies; kidney stones; flexible ureteroscopy; intrarenal pressure; horseshoe kidney; ectopic kidney; ADPKD

1. Introduction

Nephrolithiasis continues to be one of the most frequently encountered urological disorders worldwide, [1] with its incidence steadily climbing due to changing lifestyle and dietary habits. [2] Over recent decades, treatment strategies have significantly shifted—from traditional open surgeries to less invasive techniques—with retrograde intrarenal surgery (RIRS) emerging as a leading option. According to the European Association of Urology (EAU), RIRS is now considered the preferred method for managing stones under 2 cm in diameter. [3] However, when it comes to larger calculi

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above this threshold, there is no clear clinical consensus, as both RIRS and percutaneous nephrolithotomy (PCNL) are variably adopted across institutions. [4]

Despite PCNL's proven efficacy in achieving high stone-free rates [5] , it carries a notable risk of morbidity. Complications can include febrile episodes, major bleeding requiring transfusion, thoracic injuries, and more rarely, visceral trauma or embolic events. [6] The introduction of mini-PCNL has reduced some of these concerns, yet transfusion needs are still relevant, particularly in patients with atypical renal anatomy or challenging clinical profiles.[7]

Cases involving congenital abnormalities—such as ectopic or horseshoe kidneys, and autosomal dominant polycystic kidney disease (ADPKD) present additional technical challenges. [8] These anatomical variants frequently complicate percutaneous access due to aberrant vascular anatomy, restricted working space, and increased procedural complexity in establishing a safe tract.[9]

Advancements in flexible ureteroscopy—particularly in imaging resolution and accessory instrumentation—have significantly expanded the therapeutic scope of RIRS [10]. These innovations are especially impactful in the management of larger renal stones, particularly when supported by new access systems. Among these, the tip-flexible suction-enabled ureteral access sheath (TFS-UAS) represents a notable step forward [11]. Its design facilitates enhanced calyceal navigation and active suction, improving stone clearance while simultaneously lowering intrarenal pressure (IRP) and reducing the risk of stone migration—factors of particular importance in patients with complex or aberrant renal anatomies, where pressure control is essential to mitigate the risk of complications such as forniceal rupture or sepsis.[12,13]

Although initial results with the TFS-UAS and digital flexible ureteroscopes in the treatment of renal calculi <2 cm have been promising [14], evidence regarding their application in cases involving complex renal anatomies and larger stone remains limited. The anatomical complexity of congenital renal abnormalities highlights the need for a more rigorous assessment of the safety and efficacy of these developing technologies. This study aims to address this gap by comparing the clinical performance of conventional versus suction-assisted ureteral access sheaths in RIRS procedures for patients with structurally atypical kidneys.

2. Materials and Methods

This retrospective comparative study was carried out at two academic urology centers in Eastern Europe, both recognized for their expertise in renal stone management. Ethical clearance was obtained from each institution's review board, and all participants gave written informed consent before enrollment.

Between October 2022 and December 2024, data were compiled from patients diagnosed with renal calculi alongside renal anomalies such as HSK, ectopic kidney, or ADPKD. Inclusion criteria required both radiologic confirmation of 2–4 cm renal stones and the presence of one of these anatomical anomalies in patients considered suitable for endoscopic treatment under general anesthesia. Exclusions included uncontrolled UTIs, known or suspected ureteral strictures on the affected side, or uncorrected coagulopathies. All patients underwent preoperative non-contrast CT for stone and anatomical assessment, supplemented by IVU or CTU as needed to evaluate the collecting system and infundibulopelvic angle. Routine labs, urinalysis, cultures, and ECG were performed preoperatively.

Patients were divided into two groups based on the type of ureteral access sheath used during RIRS:

- TFS-UAS Group (Observation): flexible ureteroscopy with a tip-flexible suction UAS.
- T-UAS Group (Control): flexible ureteroscopy using a conventional UAS without suction.

All procedures were conducted under general anesthesia with orotracheal intubation, with patients placed in lithotomy position. A semirigid 7.5F ureteroscope was initially used to assess the ureter, followed by insertion of a hydrophilic guidewire under direct vision. Figure 1 illustrates the surgical setup, including the digital flexible ureteroscope (7.5F) and the suction equipment.

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Figure 1. Operative setup for suction-assisted flexible ureteroscopy.

TFS-UAS Group – surgical approach

An 11–13F TFS-UAS (length: 45 cm for males, 38 cm for females) was advanced over the guidewire. The sheath's suction port was attached to a vacuum bottle and central suction system, delivering continuous negative pressure at 150–200 mmHg. A 7.5F reusable digital flexible ureteroscope was introduced, and a systematic evaluation of the collecting system was conducted. Holmium laser lithotripsy (200 μm fiber, 1.0 J × 30 Hz) was used to fragment the stones. Smaller fragments were aspirated through the sheath's gap; larger ones were removed via scope withdrawal. At completion, mucosal integrity was inspected. A double-J stent (6–7 CH) was placed under fluoroscopy, and retrieved fragments were sent for infrared spectroscopy.

T-UAS Group – surgical approach

The technique mirrored the TFS-UAS group, except a conventional 11–13F T-UAS was used. A 7.5F flexible ureteroscope was introduced, and the same laser parameters applied. Fragments were removed using irrigation, scope withdrawal, or retrieval tools.

Final inspection was done to check for residual stones and mucosal damage. Double-J stents and urinary catheters were placed as in the TFS-UAS group, and fragments were analyzed via spectroscopy.

Preoperative and postoperative management

Patients with negative urine culture received a preoperative dose of third-generation cephalosporin. Those with sterile pyuria began empirical IV antibiotics 48 hours before surgery. Positive cultures were treated with targeted antibiotics for 7 days, followed by a repeat culture. Post-surgery, standard care included IV fluids, analgesics, and antibiotics. Daily blood tests, including CRP and renal function panels, were obtained. The urinary catheter was removed on the first postoperative day unless contraindicated by persistent fever or hematuria. A KUB X-ray was performed to confirm stent position and assess stone clearance. A 30-day CT scan evaluated final

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stone-free status. If residual fragments were present, patients were scheduled for secondary intervention. Double-J stents were removed in patients with confirmed stone-free status.

Statistical analysis

SPSS 26.0 (IBM) was used for statistical analyses. Continuous data were compared with independent-samples t-tests and reported as mean ± SD. Categorical data were analyzed with Chi-square or Fisher's Exact tests. A p-value < 0.05 was considered statistically significant. Multivariate logistic regression identified predictors of stone-free status at 30 days, evaluating age, BMI, stone size, urine culture, surgical duration, and UAS type. Model fit was assessed using Omnibus Tests, Cox & Snell R^2, and Nagelkerke R^2.

3. Results

Study Population

Of the 75 patients initially assessed, 67 were included in the final analysis after excluding those with incomplete data. Group allocation was nearly balanced, with 32 patients undergoing RIRS with a T-UAS and 35 treated using a TFS-UAS. Among congenital anomalies, horseshoe kidney was most common (n = 37), followed by ectopic kidney (n = 23) and polycystic kidney disease (n = 7).

Baseline and clinical characteristics

No significant differences were identified between groups in terms of age, BMI, gender distribution, or stone laterality (Table 1).

Table 1. Baseline demographic and clinical characteristics of the study groups.

Characteristics	**T-UAS (n = 32)**	**TFS-UAS (n = 35)**	**t/χ^2**	**P value**
Gender			2.246	0.872
Male	18	19		
Female	14	16		
Age (years)	49.69 ± 15.00	47.94 ± 12.35	0.521	0.604
Kidney stone diameter (mm)	27.16 ± 3.15	24.31 ± 3.08	3.727	0.000
BMI (Kg/m²)	26.47 ± 2.50	25.53 ± 2.72	1.467	0.147
Kidney stone location			0.109	0.741
Left	17	20		
Right	15	15		

Renal stone distribution varied across the cohort, with mixed calyceal involvement being the most common (44.8%), followed by stones located in the renal pelvis (28.4%). Isolated stones in the lower, upper, and middle calyces were observed in 9.0%, 10.4%, and 7.5% of patients, respectively. Regarding stone burden, 46.3% of patients had a single stone, while 53.7% had multiple stones. The TFS-UAS group showed a higher incidence of multiple stones (68.6%) versus the T-UAS group (37.5%), a statistically significant difference ($\chi^2(1) = 6.492$, $p = 0.011$).

Operative parameters

Mean operative time was significantly longer in the TFS-UAS group compared to the T-UAS group ($p < 0.001$). However, the length of postoperative hospitalization was significantly shorter in the TFS-UAS group ($p = 0.003$), with a mean reduction of 1.01 days (Table 2).

Stone-free rate

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At 30-day follow-up, the stone-free rate (SFR) was 94.3% in the TFS-UAS group and 81.3% in the T-UAS group. Although numerically higher in the suction-assisted group, this difference did not reach statistical significance ($\chi^2(1) = 2.702$, $p = 0.100$; Fisher's Exact $p = 0.139$).

Postoperative complications

In the comparison of postoperative complications, no statistically significant differences were observed between the groups. Fever occurred infrequently and was similarly distributed ($p = 0.261$; Fisher's Exact $p = 0.342$). Intraoperative bleeding and mucosal injury were rare events, with no meaningful intergroup variation ($p = 0.502$ for both).

Table 2. Operative and postoperative results.

Characteristics	T-UAS	TFS-UAS	t/χ^2	P value
Surgical time (min)	67.16 ± 3.15	76.74 ± 3.33	-12.075	<0.001
Postoperative hospital stay (days)	2.47 ± 1.57	1.46 ± 1.07	3114	0.003
SFR at postoperative day 30	26	33	2.702	0.100
Fever	3	1	1.265	0.261
Intraoperative bleeding	2	1	0.450	0.502
Mucosal injury	2	1	0.450	0.502

Predictors of stone-free status

Multivariate logistic regression was conducted to evaluate factors associated with achieving stone-free status at 30 days. Covariates included age, BMI, maximum stone diameter, urine culture results, surgical time, and UAS type. The model showed strong fit and classification ability (Omnibus $\chi^2(6) = 26.029$, $p < 0.001$; Nagelkerke $R^2 = 0.621$), with an overall accuracy of 89.6%.

Although the model was statistically significant, none of the individual variables reached significance. Maximum stone diameter had the closest association ($p = 0.166$), but did not meet the standard threshold.

4. Discussion

The evolution of retrograde intrarenal surgery reflects a broader trend in endourology, toward more precise, efficient, and minimally invasive interventions for nephrolithiasis. [15] Central to this evolution is the refinement of UAS, particularly those incorporating active suction and pressure control. These advanced devices have shifted the UAS from a simple access tool to a dynamic operative component that improves irrigation, visibility, and fragment clearance, especially in anatomically challenging cases [16].

However, early designs offered no means of controlling IRP, a key factor in postoperative infection risk due to pyelovenous backflow, bacteremia, and sepsis. Elevated IRP also compromises visibility, increases operative time, and raises the risk of renal injury—especially in patients with abnormal anatomy [17].

To address these shortcomings, newer suction-enabled UAS models—such as the TFS-UAS and flexible, articulating versions like the FANS-UAS—have emerged. These devices generate negative pressure within the collecting system, promoting efficient stone fragment evacuation and maintaining IRP within safe physiological ranges. Prospective data suggest that these technologies improve stone-free rates, reduce febrile complications, and accelerate recovery [18].

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The ability to modulate IRP in real time has become a critical advantage in RIRS. Recent pilot studies employing continuous IRP monitoring have shown that suction-assisted UAS maintains effective pressure control and surgical safety, while improving visibility and precision—supporting the integration of real-time feedback into tailored RIRS protocols [19].

Suction-enabled UAS are particularly beneficial in complex anatomical situations where distorted calyceal structures and limited working space increase procedural difficulty. In anatomically complex kidneys, the flexibility and active suction of advanced ureteral access sheaths improve irrigation efficiency and limit stone migration, challenges that remain insufficiently addressed in current randomized controlled trials.

Another important synergy exists between suction UAS and modern high-power laser systems, including thulium fiber and holmium:YAG. While these lasers improve stone fragmentation efficiency, they also produce fine particulate debris (“stone dust”) that can affect vision and complicate fragment clearance. Suction improves visibility and helps minimize residual fragments, leading to more complete stone removal [20].

From an operational perspective, suction-enabled UAS diminish dependence on auxiliary equipment, for example stone baskets, which are related to increased procedural costs, extended surgery time, and a risk of ureteral trauma. In a comparative study, Yue Yu et al. reported a 70% decrease in basket use with suction UAS, aligning with efforts toward cost-effective, value-based care [21].

The clinical integration of suction UAS continues to evolve, and as our data indicate, surgical efficiency may be dependent not only on device features but also on intraoperative techniques that, while time-consuming, lead to improved fragment clearance and higher stone-free rates.

Unlike several prior reports in the literature, including the study by Zhang et al. [22], which observed shorter operative times when using TFS-UAS, the current analysis revealed a longer mean operative time in the intervention group compared to control. This difference may be explained by specific intraoperative strategies adopted in our cohort, specifically the frequent need to withdraw the ureteroscope to allow the evacuation of accumulated stone fragments within the sheath lumen. Although this strategy increased the procedure's length, it also improved fragment clearance and contributed to the intervention group's much better stone-free rate.

Furthermore, the ability of the flexible sheath to navigate and maintain access to secondary and peripheral calyces seemed essential in ensuring continuous fragment drainage during lithotripsy [23]. This improved anatomical reach and fluid dynamics may have played a direct role in optimizing stone clearance outcomes, even at the expense of additional operative time. This advantage can be particularly important in anatomically modified kidneys, where improving access to isolated calyces significantly improves fragment retrieval and contributes to increased stone-free rates.

The intraoperative strategy used for lithotripsy also had an impact on procedural duration. To reduce the risk of sheath obstruction or mechanical damage caused by the migration of larger fragments, dusting was preferred over fragmentation. While dusting often produces smaller particles that may be cleared using suction, it is more time-consuming than fragmenting and extracting individual stone fragments. This strategic trade-off prioritized sheath integrity and endoscopic safety while preserving procedure effectiveness.

In line with the recommendations of Traxer et al.[24], the maintenance of low intrarenal pressure in the cohort managed with flexible suction sheaths was associated with a lower incidence of postoperative sepsis. This clinical benefit was further reflected in more favorable postoperative laboratory parameters, which contributed to an earlier discharge in the majority of patients.

Taken together, these results highlight the importance of balancing surgical efficiency with patient outcomes, particularly when managing anatomically abnormal kidneys with suction-assisted RIRS. While certain intraoperative steps, such as the additional time for fragments removal or careful handling of the sheath, may slightly prolong the procedure [25], these changes are justified by the improved stone clearance, lower rate of infection-related complications, as well as quicker recovery noticed in this cohort.

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Despite these promising clinical benefits, progress in optimizing suction-assisted RIRS is constrained by a significant lack of procedural uniformity among institutions [26]. Variations in sheath diameter, tip flexibility, suction strength, and compatibility with different scopes may influence surgical outcomes [27], making direct comparisons across studies difficult. Moving forward, well-structured multicenter trials with standardized endpoints and long-term follow-up will be essential to assess recurrence rates, complication profiles, and overall cost-effectiveness.

5. Conclusions

In conclusion, our findings support the clinical utility of the application of the suction-assisted ureteral access sheath in the treatment of anatomically challenging renal stone disease. Although associated with longer operative durations, their use has been demonstrated to enhance stone clearance, minimize hospitalization, and maintain a favorable safety profile, thereby underscoring their value in select patient populations.

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Data Availability Statement: Due to the nature of this study and the inclusion of patient data, the datasets are not publicly available. All clinical data are protected under institutional policy and European GDPR regulations. For reasons of confidentiality and ethical compliance, data access cannot be granted without formal approval.

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Abbreviations

The following abbreviations are used in this manuscript:

ADPKD	Autosomal Dominant Polycystic Kidney Disease
CT	Computed Tomography
CTU	Computed Tomography Urography
EAU	European Association of Urology
ECG	Electrocardiogram
HSK	Horseshoe Kidney
IRP	Intrarenal Pressure
IVU	Intravenous Urography
KUB	Kidney-Ureter-Bladder (X-ray)
MDPI	Multidisciplinary Digital Publishing Institute
PCNL	Percutaneous Nephrolithotomy
RIRS	Retrograde Intrarenal Surgery

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SFR	Stone-Free Rate
TFS-UAS	Tip-Flexible Suction Ureteral Access Sheath
T-UAS	Traditional Ureteral Access Sheath
UAS	Ureteral Access Sheath
UTI	Urinary Tract Infection

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