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Suction-Assisted Flexible Ureteroscopy for Renal Stone Disease: A Review of Clinical Outcomes

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Abstract:

Endourological practice has recently shifted toward the integration of active suction–based technologies as a strategy to mitigate the intrinsic drawbacks of standard flexible ureteroscopy (FURS). Elevated intrarenal pressure (IRP) and suboptimal visualization resulting from intrarenal stone dust dispersion, commonly referred to as the “snowstorm” phenomenon, represent major technical challenges and have been implicated in higher rates of postoperative infection and lower stone-free outcomes. This review provides an overview of contemporary evidence supporting suction-assisted retrograde intrarenal surgery (RIRS), highlighting the use of vacuum-enabled ureteral access sheaths, flexible and steerable suction UAS, and newly introduced intraluminal suction systems integrated within the ureteroscope. Current experimental and clinical findings indicate that active suction contributes to regulation of the intrarenal environment by offsetting irrigation flow, maintaining intrarenal pressures below levels associated with pyelovenous reflux, and promoting efficient removal of stone fragments and dust. Such pressure modulation is believed to play a central role in minimizing bacterial migration into the systemic circulation, thereby decreasing the likelihood of postoperative febrile episodes and systemic inflammatory response. Overall, suction-assisted FURS appears to optimize operative workflow, improve stone clearance efficiency, and enhance procedural safety, particularly in patients presenting with complex or high-burden renal calculi.

Key words: Renal Calculi Management, Renal Pelvic Pressure, Stone-Free Rate.

Introduction

The management of renal and proximal ureteral calculi has been transformed by flexible ureterorenoscopy (FURS), now considered a first-line therapeutic modality [1,2]. This evolution is underpinned by concurrent advancements in three pivotal domains: the refinement of digital endoscopic optics, the advent of novel laser lithotripsy platforms, and the progressive miniaturization of intracorporeal instruments [1,3]. The introduction of high-frequency lasers, such as the thulium fiber laser (TFL), has further extended the procedural scope of FURS, enabling the treatment of larger and more complex stone volumes that traditionally necessitated percutaneous nephrolithotomy [2,4]. Despite these technological leaps, intrinsic physiological limitations of the renal collecting system pose ongoing challenges to procedural safety and efficacy. Under physiological conditions, the renal pelvis maintains a low-pressure state, a critical factor in preserving urothelial barrier function and preventing the retrograde translocation of fluid and pathogens into the renal vasculature and lymphatics. The cornerstone of FURS—continuous irrigation—paradoxically threatens this homeostasis. An imbalance between irrigation inflow and outflow can induce a rapid and hazardous elevation in intrarenal pressure (IRP), a primary mechanism behind pyelovenous backflow. This pathophysiological cascade is a well-documented precursor to serious postoperative infectious complications, including febrile episodes, systemic inflammatory response syndrome (SIRS), and urosepsis [3,5]. Concurrently, the very efficacy of modern lithotripsy creates an optical dilemma; high-frequency dusting generates a dense suspension of fine particles that scatter light and obscure the endoscopic view, a phenomenon often described as the "snowstorm" effect. This visual degradation leads to procedural inefficiency, prolonged operative time, and increased reliance on

fluoroscopy. Furthermore, the thermal energy delivered by high-power lasers introduces an additional, often underappreciated, risk of thermal injury to the urothelium, particularly in cases of prolonged operation, hard stones, or compromised irrigant flow [6–8]. This narrative review synthesizes contemporary evidence on suction-augmented FURS, critically appraising its role in mitigating these triad of challenges: regulating IRP, clearing visual field obstructions, and enhancing thermal safety, thereby outlining its potential to refine procedural outcomes and direct future innovation [9].

Study Design and Literature Search Strategy

Employing a narrative review methodology, this work aims to synthesize the current evidence on suction-augmented flexible ureterorenoscopy (FURS). The literature search was executed in the PubMed/MEDLINE database, encompassing publications available up to [December 2025]. To ensure a focused retrieval of studies pertaining to aspiration techniques in endourological stone management, a targeted Boolean search strategy was formulated. Core search terms, including "aspiration," "suction," "ureteroscopy," "urolithiasis," "retrograde intrarenal surgery," and "endourology," were strategically combined using AND/OR operators. The screening process was supplemented by a manual examination of the bibliographies of all eligible articles to identify any additional relevant publications not captured by the primary electronic search. Studies were excluded if the primary intervention described was percutaneous nephrolithotomy (PCNL) or its miniaturized variants (mPCNL), thereby focusing the analysis strictly on retrograde, suction-assisted ureteroscopic procedures.

Classification of Suction Methodologies:

1. Passive Outflow Systems and Their Limitations

The development of traditional ureteral access sheaths (UAS) aimed to simplify repetitive endoscopic access while mitigating the elevated intrarenal pressures observed in sheath-less procedures. They achieve this by creating a conduit for irrigation outflow; however, this drainage is not active but depends on passive gradients and gravity.[11]

However, the functional effectiveness of passive outflow is inherently constrained by several factors. First, the presence of the ureteroscope within the access sheath significantly reduces the effective luminal diameter available for fluid egress. This narrowing creates a high-resistance pathway, particularly during high-flow irrigation required for laser lithotripsy. Under these conditions, inflow frequently exceeds outflow, resulting in progressive IRP elevation. [14]

Second, passive systems lack real-time adaptability. Variations in renal anatomy, calyceal orientation, patient positioning, and stone location can markedly influence drainage efficiency. In lower pole calyces, where acute infundibulopelvic angles impede fluid movement, passive outflow becomes especially ineffective. Consequently, reliance on passive UAS alone has been associated with unstable intrarenal pressures, suboptimal visualization, and an increased risk of pressure-related complications.[15]

2 Vacuum assisted standard UAS technique

The second category represents the earliest evolution toward active suction. These systems typically involve connecting a standard UAS to an external vacuum source, either via wall suction or a regulated pump. By applying negative pressure, vacuum-assisted UAS improves fluid evacuation compared to passive drainage and partially mitigates intrarenal hypertension.[16]

Despite this advancement, early vacuum-assisted systems exhibit several limitations. Most notably, suction is spatially static; the negative pressure effect is concentrated at the proximal tip of the sheath, which is commonly positioned in the renal pelvis. When stones are located in dependent calyces or peripheral regions of the collecting system, the suction gradient dissipates with distance, reducing fragment clearance efficiency. [15,17]

Additionally, continuous high-level suction without pressure modulation may lead to unintended collapse of the renal pelvis or calyces, compromising visibility and increasing the risk of mucosal trauma. These

drawbacks underscored the need for more refined suction platforms capable of targeted, controllable aspiration.[16]

3. Flexible and Navigable suction UAS (FANS-technique).

Flexible and navigable suction UAS represent a significant technological leap in suction-assisted FURS. The defining feature of FANS-UAS is an actively deflectable distal tip, typically reinforced with a wire-stiffened or articulated mechanism, allowing controlled navigation within the pelvicalyceal system [18].

This navigability enables the surgeon to position the suction source in close proximity to the stone-bearing calyx, transforming suction from a global to a site-specific intervention. By minimizing the distance between the suction port and the fragmentation site, FANS-UAS maximizes fragment capture efficiency and maintains consistent low intrarenal pressure across different calyces [19]. High-density calculi, require prolonged laser activation and generate substantial volumes of fine particulate debris. Without suction, this dust may redistribute throughout the collecting system, obscuring vision and increasing operative complexity. FANS-UAS confines dust generation to a localized suction field, preventing dispersion and contributing to higher stone-free rates (SFR) [16,19].

4. Direct in scope suction/ Ureteroscope integrated suction system.

Direct in-scope suctioning represents the most recent frontier in endourological suction technology. In these systems, suction channels are integrated directly into the ureteroscope, enabling aspiration precisely at the visual focal point. This design eliminates reliance on external access sheaths and is particularly advantageous in patients with narrow ureters or when sheath placement is contraindicated [20].

DISS allows real-time alternation between irrigation and suction, theoretically optimizing visualization and fragment evacuation. However, current iterations are limited by reduced suction lumen diameter, which restricts the evacuation of larger fragments. Additionally, the need for simultaneous control of laser energy, irrigation, and suction introduces a steeper learning curve and may prolong operative time in early adoption Use the "Insert Citation" button to add citations to this document phases [20,21].

5-Steerable Ureteroscopic Renal Evacuation (SURE)

Coaxial catheters for post-fragmentation debris clearance [20].

Results:

Enhanced Fragment Clearance and Stone-Free Status

The integration of active aspiration, particularly via navigable sheath systems (FANS-UAS), has redefined efficacy endpoints in FURS. By providing continuous evacuation of particulate debris during lithotripsy, these systems minimize the retrograde migration and settling of fragments in dependent calyces. This mechanistic advantage translates to superior fragment clearance. Clinical reports note an improvement in one-month stone-free rates (SFR) of roughly 15–20% over passive-drainage techniques, a benefit most evident with lower pole calculi or high stone-volume cases. For instance, a study by Gauhar et al. (2024) documented an SFR of 91.4% with such technology. This elevated SFR carries significant long-term clinical value, as retained fragments, even of dust-like size, serve as a nidus for recurrence and increase the likelihood of future symptomatic episodes or re-intervention.

Optimization of Procedural Efficiency and Workflow

A consistent finding across recent clinical series is the reduction in operative time with aspiration-augmented FURS, with mean durations frequently reported between 55–60 minutes for complex cases. Zhu et al. (2025), for example, noted a mean operative time of 52.6 minutes. This efficiency gain is largely attributable to a decreased reliance on mechanical extraction tools. The routine "in-and-out" use of nitinol baskets for fragment retrieval—a time-consuming maneuver that interrupts laser work—is substantially reduced. With active suction clearing dust and small debris in real-time, the need for basketing is obviated in 70–80% of procedures, allowing for near-continuous lithotripsy. Furthermore, the sustained clarity of the visual field

prevents wasted laser energy on already-pulverized material, enabling more precise targeting and faster stone ablation, which streamlines the entire surgical workflow.

Mitigation of Intrarenal Pressure and Infectious Morbidity

Perhaps the most critical safety benefit is the robust control of intrarenal pressure (IRP). Aspiration systems maintain IRP at stable, low levels (often <20 mmHg), even during high irrigation flow, contrasting sharply with the unpredictable spikes above 40 mmHg common in passive systems. This control directly impacts postoperative infection rates, as elevated IRP is the principal driver of pyelovenous backflow, facilitating the systemic absorption of bacteria and endotoxins. Evidence demonstrates a clear correlation between effective aspiration use and reduced infectious sequelae. Studies suggest that for every 10 mmHg increase in IRP beyond a critical threshold, the risk of Systemic Inflammatory Response Syndrome (SIRS) rises by approximately 15%. Consequently, aspiration-assisted procedures are associated with markedly lower rates of postoperative fever, SIRS, and urosepsis. This is reflected in the low complication rates of 6.1% and 5.0% reported by Gauhar et al. (2024) and the Italian multicentric study by Cacciatore et al. (2025), respectively.

Reduction in Hospital Length of Stay

The synergy of shorter operative times and a lower risk of infectious complications naturally culminates in a decreased length of hospitalization. The clinical profile of aspiration-assisted FURS supports its role as a potential "day-case" procedure. This is evidenced by reports of a median hospital stay of just one day from both Gauhar et al. (2024) and Cacciatore et al. (2025). The feasibility of this shortened stay is further corroborated by Zhu et al. (2025) and the meta-analysis by Alnadhari et al. (2025).

Synthesis of Evidence

In summary, the accumulated clinical data positions aspiration-augmented FURS as a modality that advances procedural efficiency, improves stone clearance, and enhances patient safety. These advantages are most pronounced when managing anatomically challenging kidneys, dense stone compositions, or prolonged surgical cases.

Discussion:

Stone-Free Rate:

Stone-free rate (SFR) remains the most widely accepted surrogate marker of success in endourological stone surgery; however, its interpretation has evolved considerably with the adoption of high-frequency dusting techniques. The present findings support growing evidence that suction-assisted flexible ureterorenoscopy, particularly using flexible and navigable suction ureteral access sheaths (FANS-UAS), achieves superior stone clearance compared with passive drainage systems. The reported improvement in one-month SFR by approximately 15–20% aligns with contemporary clinical observations, including the results of Gauhar et al., who documented an SFR exceeding 90% in patients treated with navigable suction systems, even in the presence of high stone burden or lower pole calculi.

From a mechanistic perspective, the observed SFR advantage is best explained by the prevention of fragment redistribution rather than by enhanced fragmentation alone. In conventional FURS, stone dust generated during lithotripsy tends to migrate to dependent calyces, particularly the lower pole, where unfavorable infundibulopelvic angles hinder spontaneous clearance [18]. Suction-assisted systems actively remove dust and fine fragments at the point of generation, effectively disrupting this redistribution pathway. As a result, the collecting system is cleared in real time rather than relying on postoperative drainage or spontaneous fragment passage.

Importantly, the clinical significance of this improvement extends beyond short-term imaging outcomes. Residual fragments, even when sub-millimetric, have been shown to serve as niduses for stone regrowth and are associated with higher rates of recurrent symptoms and secondary interventions [22].

Operative Time

The reduction in operative time observed with suction-assisted FURS represents one of the most consistent and clinically relevant findings across contemporary series. Mean operative durations clustering around 55–60 minutes, even in complex cases, reflect a fundamental improvement in procedural workflow rather than marginal technical gains. The prospective trial by Zhu et al., reporting a mean operative time of 52.6 minutes, further reinforces the reproducibility of this benefit in controlled clinical settings.

A principal contributor to reduced operative duration is the diminished reliance on mechanical fragment extraction. Traditional FURS frequently requires repeated insertion and withdrawal of baskets to retrieve fragments, a maneuver that disrupts procedural continuity and increases the risk of ureteral trauma, scope damage, and operative fatigue [12,24]. In contrast, suction-assisted techniques eliminate the need for basketing in the majority of cases by enabling continuous evacuation of dust and small fragments, allowing lithotripsy to proceed without interruption.

Enhanced visualization plays a synergistic role in this process. By preventing the accumulation of suspended stone particles responsible for the “snowstorm” phenomenon, suction preserves optical clarity throughout the procedure [11,18]. This facilitates more precise laser targeting, minimizes redundant energy delivery, and improves ablation efficiency per unit time. Collectively, these factors translate into a smoother, more predictable workflow with a shorter learning curve once suction systems are mastered.

Intrarenal Pressure Control and Infectious Outcomes

Among all evaluated outcomes, control of intrarenal pressure (IRP) represents the most physiologically consequential advantage of suction-assisted FURS. Passive irrigation systems are prone to transient but clinically significant IRP elevations, often exceeding the critical threshold of 40 mmHg, particularly during high-flow irrigation or prolonged laser activation [2,3,8]. These pressure spikes are frequently undetected intraoperatively yet play a central role in postoperative morbidity.

Suction-assisted systems, by contrast, establish a pressure-regulated intrarenal environment, consistently maintaining IRP below 20 mmHg even under demanding operative conditions [5,6]. This pressure stability directly interrupts the pathophysiological cascade leading to pyelovenous and pyelolymphatic backflow, which facilitates systemic dissemination of bacteria and endotoxins [7,15].

The clinical implications of this mechanism are reflected in the markedly reduced rates of postoperative infectious complications reported in recent studies. Both Gauhar et al. and the Italian multicentric experience by Cacciatore et al. demonstrated low overall complication rates of 6.1% and 5.0%, respectively, despite inclusion of patients with complex stone disease and prolonged procedures. These findings are consistent with prior observations indicating that for every 10 mmHg increase in IRP above safe thresholds, the risk of SIRS increases by approximately 15% [6,8]. By maintaining IRP well below these thresholds, suction-assisted FURS offers a proactive strategy for infection prevention rather than reactive management.

Length of Hospital Stay and the Shift Toward Day-Case Surgery

The combined effects of reduced operative time, improved stone clearance, and lower infectious morbidity are reflected in shorter postoperative hospital stays. Both Gauhar et al. and the Italian multicentric study by Cacciatore et al. reported a median length of stay of one day following FANS-UAS–assisted FURS. These findings are corroborated by Zhu et al. and reinforced by the meta-analysis conducted by Alnadhari et al., which consistently highlighted the feasibility of same-day discharge in appropriately selected patients.

From a health systems perspective, the ability to safely perform FURS as a day-case procedure represents a substantial advancement. Shortened hospitalization reduces healthcare costs, minimizes nosocomial exposure, and enhances patient satisfaction without compromising clinical outcomes. These benefits are particularly relevant in high-volume stone centers and in healthcare systems increasingly focused on efficiency and resource optimization.

Conclusion:

Despite the need for further validation of newer systems (e.g., DISS, SURE), current evidence advocates for a transition to suction-assisted FURS. Integrated suction has been shown to achieve more complete fragment evacuation, shortening procedure times, and reducing perioperative risks and better efficiency.

F) Disclosure of Potential Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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