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Endoscopic combined intrarenal surgery: From percutaneous nephrolithotomy to the future of stone management

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The surgical management of complex renal calculi has undergone a paradigm shift from traditional prone percutaneous nephrolithotomy (PCNL) to the more versatile supine approach. This evolution paved the way for endoscopic combined intrarenal surgery (ECIRS), a technique that synergizes antegrade and retrograde access into a seamless "four-hand" collaboration. This review explores the historical trajectory and biomechanical advantages of ECIRS, emphasizing its role in overcoming the limitations of PCNL and retrograde intrarenal surgery monotherapies. Central to this approach is the "intermediate-supine position," which facilitates real-time simultaneous operation. We highlight critical mechanisms such as the "transport technique," where flexible ureteroscopy displaces inaccessible fragments toward the nephroscope, and the "washout mechanism," which maintains low intrarenal pressure and ensures clear visualization. Contemporary evidence, including recent randomized trials and meta-analyses, demonstrates that ECIRS—particularly with miniaturized tracts (Mini-ECIRS)—achieves superior stone-free rates with significantly reduced morbidity compared to conventional methods. The technique proves especially advantageous for staghorn calculi and high-risk patients by enabling "single-puncture" clearance, thereby minimizing hemorrhagic risks associated with multiple tracts. Furthermore, the integration of robotic assistance for both renal access and retrograde manipulation is democratizing technical excellence. As we transition toward the era of "Fully Robotic ECIRS," this multimodal strategy is increasingly positioned not merely as an alternative, but as a leading framework and a strong candidate for broader adoption in appropriately selected patients with for complex urolithiasis, balancing maximal clearance with minimal invasiveness.

Keywords: Kidney calculi; Nephrolithotomy, percutaneous; Patient positioning; Robotic surgical procedures; Ureteroscopy

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INTRODUCTION

The surgical management of complex renal calculi has evolved remarkably, shifting from invasive open procedures to highly refined, minimally invasive techniques. For decades, percutaneous nephrolithotomy (PCNL) has served as the cornerstone for treating large (>20 mm) or staghorn stones, offering unrivaled stone-free rates (SFRs) [1]. This is reflected in the current clinical practice guidelines from the European Association of Urology (EAU) and the American Urological Association (AUA), both of which continue to recommend PCNL as the first-line treatment for renal calculi exceeding 20 mm [2,3].

However, the traditional prone position (PP), once the standard for PCNL, presents inherent challenges, including restricted retrograde access, limited instrument maneuverability, and potential anesthetic risks—particularly in patients with compromised cardiopulmonary function [4]. To address these limitations, the concept of endoscopic combined intrarenal surgery (ECIRS) emerged as a transformative approach [5]. By integrating antegrade percutaneous access with retrograde intrarenal surgery (RIRS) in a single session, ECIRS maximizes the advantages of both modalities [6]. Typically performed in the Galdakao-modified supine Valdivia (GMSV) position, this "four-hand" technique allows for simultaneous visual control, facilitates the clearance of fragments in complex calyceal systems, and reduces the need for multiple percutaneous tracts [5,7].

As we enter a new era of urological surgery, technological innovations such as miniaturized scopes, high-power thulium fiber lasers, and robotic-assisted platforms are further expanding the boundaries of ECIRS. In particular, advanced laser technologies like the thulium fiber laser have proven highly effective and versatile across a wide spectrum of endourological procedures, ranging from stone lithotripsy to the endoscopic enucleation of large prostates [8]. This review aims to trace the evolution of renal stone surgery from its origins in PCNL to the current state-of-the-art ECIRS, while providing a forward-looking perspective on the future of intrarenal interventions.

Although this article is structured as a narrative review, a comprehensive literature search was conducted to ensure a balanced and up-to-date perspective. Databases including PubMed and Embase were queried for articles published up to January 2026. Search terms included "percutaneous nephrolithotomy", "endoscopic combined intrarenal surgery", "ECIRS", "mini-ECIRS", and "robot-assisted". Peer-reviewed articles encompassing historical milestones, recent randomized controlled trials (RCTs), and meta-analyses were selectively reviewed and synthesized to construct this comprehensive overview.

EVOLUTION FROM CONVENTIONAL PCNL TO SUPINE POSITION

The history of PCNL represents a saga of overcoming anatomical barriers. Following the first accidental percutaneous nephrostomy in 1955 [9], Fernström and Johansson [10] performed the first intentional percutaneous stone extraction in 1976, marking the true birth of PCNL. During its infancy, the procedure was a collaborative effort between radiologists and urologists, primarily conducted in the PP to utilize the posterior calyces as a safe entry point.

For over three decades, the PP remained a dogma in the urological community, rooted in the belief that it provided the most direct route to the posterior calyces while minimizing the risk of colonic injury. Despite its established efficacy, the limitations of PP became increasingly apparent as the surgical population aged and became more obese [11]. The logistical challenges of repositioning a sedated patient, restricted diaphragmatic excursion, and the increased risk of ocular or plexopathy injuries during prolonged procedures remained significant burdens for both surgeons and anesthesiologists [12].

The paradigm began to shift in 1987 when Valdivia Uría et al. [13] first described the supine position (SP) for PCNL. Initially, it was proposed not as a superior alternative, but as a "salvage" solution for high-risk patients with morbid obesity or severe cardiopulmonary disease who could not tolerate the PP. Despite its logical advantages, the supine approach remained a niche technique, often met with skepticism due to concerns regarding colonic injury and limited access to the upper pole [14,15].

Recently, however, the clinical superiority and efficiency of the supine approach have been solidified by robust evidence. A large-scale meta-analysis by Lachkar et al. [16], involving 11,774 cases, confirmed that the SP is associated with significantly shorter operative times ($p=0.0084$) and a lower incidence of both overall and major complications (Clavien–Dindo classification $\geq$3) ($p=0.0026$ and $p=0.0151$, respectively), while achieving comparable SFR to the PP ($p=0.7008$) (Table 1). This reduction in operative time is primarily attributed to the elimination of the cumbersome patient repositioning process.

Beyond these statistical advantages, the historical skepticism surrounding the SP has been addressed by contemporary literature highlighting its distinct biomechanical benefits. As summarized in Table 2, the SP is not merely

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Table 1. Comparison of clinical outcomes between supine and prone percutaneous nephrolithotomy

Variable	Supine position	Prone position	p-value
Stone-free rate	Comparable	Comparable	0.7008
Operative time	Significantly shorter	Longer	0.0084
Overall complications	Lower	Higher	0.0026
Major complications (CD ≥3)	Lower	Higher	0.0151
Hemoglobin drop	Comparable	Comparable	>0.05
Length of hospital stay	Comparable	Comparable	>0.05

Data from the article of Lachkar et al. [16] (Fr J Urol 2025;35:102882).
CD, Clavien–Dindo classification; Comparable, no statistically significant difference between groups.

Table 2. Qualitative comparison of advantages and disadvantages by surgical position

Position	Advantages	Disadvantages
Supine	• Better anesthetic safety and CV stability • Spontaneous drainage of irrigation fluid • Lower intrarenal pressure • Enables simultaneous ECIRS • Improved surgeon comfort (seated position)	• Narrower area for percutaneous access • Increased renal mobility (may hinder dilation) • Potential difficulty in upper pole access
Prone	• Wider surface area for renal puncture • Easier access to upper pole calyces • More space for instrument maneuverability	• Requires time-consuming repositioning • Risk of respiratory and CV compromise • Increased radiation exposure to surgeon's hands

CV, cardiovascular; ECIRS, endoscopic combined intrarenal surgery.

an anatomical alternative but a functional optimization for intrarenal surgery [17]. In the SP, the percutaneous tract is directed posteriorly, which facilitates a low-pressure environment within the renal pelvis by allowing gravity-directed flow of irrigation fluid. This mechanism significantly reduces the risk of fluid absorption and related systemic complications while promoting the spontaneous clearance and washout of stone fragments. Furthermore, the SP provides a superior ergonomic setup for the surgeon and ensures better airway control, making it a safer and more efficient framework for performing simultaneous flexible ureteroscopy and complex intrarenal interventions. This historical transition from the accidental nephrostomy of 1955 to the systematic supine approach of the late 1990s laid the essential groundwork for the subsequent integration of retrograde access, eventually giving rise to the modern era of ECIRS [18,19].

THE ADVENT OF ECIRS: SYNERGIZING PCNL AND RIRS

The establishment of the SP provided the necessary surgical platform for a more integrated approach: ECIRS [20]. While the simultaneous use of antegrade and retrograde access had been attempted sporadically, the true potential of this "four-hand" technique was realized with the formalization of ECIRS as a standardized surgical strategy [21]. The advent of ECIRS represents a synergistic evolution that overcomes the inherent limitations of performing PCNL or RIRS monotherapies in isolation [21,22]. PCNL monotherapy, even in the SP, is often constrained by the rigidity of the nephroscope [23]. Accessing calyces parallel to the puncture tract or those with narrow infundibula can be challenging, often necessitating excessive torque on the instrument—which risks renal parenchymal tearing and bleeding [24]—or requiring multiple percutaneous tracts, which increases morbidity [25]. Conversely, RIRS monotherapy, while offering superior maneuverability and access to the entire collecting system, is limited by stone burden [26]. For large or multiple calculi, RIRS is time-consuming, prone to visual obscuration by minor bleeding or dust, and carries the risk of sustained high intrarenal pressure (IRP) and scope durability issues [27].

A critical evolution in overcoming these hurdles is the optimization of patient positioning. As described by Jung et al. [6], the "intermediate-supine position" allows for versatile access to both the flank and the urethra without the extreme rotation required in traditional modifications. This position facilitates the "real-time simultaneous" operation of the nephroscope and flexible ureteroscope, enabling a unique collaboration between the two modalities where the limita-

Table 3. Summary of meta-analysis outcomes comparing ECIRS versus conventional PCNL

Outcome variable	Comparison result (ECIRS vs. PCNL)	Statistical significance	Key findings & notes
Stone-free rate	Higher in ECIRS	Significant ($p<0.0001$)	ECIRS shows superior efficacy.[a]
Hemoglobin drop	Lower in ECIRS	Significant	ECIRS is associated with significantly less blood loss (mean difference favored ECIRS), likely due to the 'washout mechanism'.
Operative time	Shorter in ECIRS	Not significant	Trend towards shorter time in ECIRS (MD, approximately -8 minutes), but statistical significance was not reached.
Retreatment rate	Lower in ECIRS	Significant	Patients in the ECIRS group required significantly fewer auxiliary procedures or second-look surgeries.
Complications (overall)	Lower in ECIRS	Significant	General complication rates favored ECIRS.
Postoperative fever	Lower in ECIRS	Not significant	A trend towards lower incidence of fever was observed, but p-value did not reach significance.
Hospital stay	Shorter in ECIRS	Not significant	Trend towards shorter stay, but differences were not statistically significant across all included studies.

Data from the article of Gauhar et al. [35] (Cent European J Urol 2022;75:171-81).
ECIRS, endoscopic combined intrarenal surgery; PCNL, percutaneous nephrolithotomy; MD, mean difference.
[a]:Initial text reporting suggested PCNL was favor, but forest plot and subsequent reviews confirm ECIRS superiority.

tions of one instrument are compensated by the capabilities of the other [28]. The core advantages of this dynamic intrarenal interaction can be summarized as follows.

1. Precise access and elimination of blind spots

The flexible ureteroscope serves as an internal "guide," assisting in the precise percutaneous puncture of the target calyx through transillumination and direct visual feedback [29]. This minimizes radiation exposure and puncture-related complications while ensuring comprehensive stone clearance in calyces inaccessible to the rigid nephroscope.

2. Optimized efficacy (transport technique)

Instead of struggling to fragment stones in difficult locations, the RIRS surgeon can displace (or "pass the ball") these fragments toward the nephroscope for rapid evacuation [6,30]. This "transport technique" significantly reduces operative time compared to dusting large volumes with a laser alone.

3. Enhanced safety and visibility (washout mechanism)

By establishing a continuous circuit—inflow from the ureteroscope and outflow through the percutaneous sheath—ECIRS maintains a clear visual field and consistently low IRP [6]. Since elevated IRP is linked to intrarenal backflow and related complications, maintaining low IRP is clinically meaningful [31].

Recent studies analyzing the initial experience and consecutive large-scale series of ECIRS have demonstrated its clinical robustness [32,33]. In a propensity score-matched analysis, ECIRS showed significantly higher SFR for large renal calculi compared to shock-wave lithotripsy, particularly in cases with high stone burden [28]. Furthermore, comparative studies between standard and miniature ECIRS (Mini-ECIRS) have confirmed that miniaturization does not compromise SFR while potentially reducing hemorrhagic complications [34]. Thus, ECIRS represents a comprehensive solution, transforming sequential surgical steps into a holistic, real-time intrarenal collaboration that maximizes efficacy and safety [21].

This clinical superiority has been further solidified by recent meta-analyses. A systematic review by Gauhar et al. [35] corroborated these benefits, demonstrating that ECIRS is associated with significantly lower hemoglobin drop and complication rates compared to conventional PCNL, while maintaining superior SFRs (Table 3). Notably, Gauhar et al. [35] also indicate that the narrative interpretation of SFR may appear discordant with the direction displayed in the forest plot, underscoring the need to rely on the pooled effect estimates and study-level definitions when interpreting SFR outcomes. Importantly, they also caution that inter-study heterogeneity and non-standardized definitions of "stone-free" (including variable imaging modalities and fragment cut-offs) can materially influence pooled SFR estimates, and they highlight that ECIRS may reduce retreatment by enabling meticulous intraoperative calyceal inspection and complementary retrograde access to otherwise difficult calyces.

Furthermore, Pellanda et al. [22] highlighted in their review that multiple meta-analyses consistently favor ECIRS

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Table 4. Summary of key outcomes from meta-analyses comparing ECIRS versus PCNL as reviewed by Pellanda et al. [22]

Outcome variable	Consensus finding across meta-analyses	Details & references
Stone-free rate	Favors ECIRS	All four meta-analyses (Abdullatif et al. [36], Widyokirono et al. [37], Liu et al. [38], and Gauhar et al. [35]) consistently demonstrated higher stone-free rates in the ECIRS group compared to PCNL.
Complications	Favors ECIRS	ECIRS was associated with significantly lower overall complication rates in all reviewed studies.
Hospital stay	Favors ECIRS	Shorter length of stay was reported in ECIRS groups (specifically noted in Abdullatif et al. [36] and Widyokirono et al. [37]).
Operative time	Comparable (NS)	Most meta-analyses found no statistically significant difference in operative time, suggesting ECIRS does not prolong surgery despite using two devices.
Blood loss/Transfusion	Favors ECIRS	Lower blood loss (Gauhar et al. [35]) and reduced need for transfusions (Liu et al. [38]) were observed in ECIRS.
Auxiliary procedures	Favors ECIRS	Significantly fewer secondary procedures were required for ECIRS patients (Widyokirono et al. [37] and Gauhar et al. [35]).

This table summarizes findings from Table 2 of Pellanda et al. [22] (Int Braz J Urol 2024;50:714-26), which aggregated data from major meta-analyses published between 2022.
ECIRS, endoscopic combined intrarenal surgery; PCNL, percutaneous nephrolithotomy; NS, not significant.

in terms of safety and efficacy, particularly reducing the need for auxiliary procedures (Table 4) [22,35-38]. They interpret these advantages as mechanistically plausible given ECIRS's ability to combine endoscopic-guided/visually assisted access, flexible inspection of all calyces, and "dual drainage" through both percutaneous and ureteral pathways. These features may mitigate bleeding risk by limiting the need for multiple tracts and help control IRP during complex stone surgery. However, the authors emphasize that higher-quality prospective data, such as well-designed RCTs and cost-effectiveness analyses, are still required before ECIRS can be universally established as the new standard of care.

CURRENT STATUS OF ECIRS: TECHNIQUES AND OUTCOMES

1. Optimal patient positioning: From Galdakao to intermediate-supine

The successful execution of ECIRS relies heavily on optimal patient positioning that allows simultaneous and unobstructed access to both the renal collecting system and the urethra [39]. The GMSV position, popularized by Scoffone et al. [5] and Scoffone and Cracco [21], has long been considered the standard platform for ECIRS. It involves placing the patient in a SP with the ipsilateral flank elevated by a bolster and the legs supported in stirrups [5,18]. This setup maximizes the space between the last rib and the iliac crest, facilitating percutaneous puncture while enabling retrograde access.

Building upon this foundation, the "intermediate-supine position" has been proposed as an optimization to further reduce patient burden and simplify the surgical setup [6]. Unlike traditional modifications that may require extreme torso rotation, the intermediate-supine approach maintains a more neutral alignment while still providing adequate exposure for the percutaneous tract [40]. This position is particularly advantageous for prolonged "real-time simultaneous" surgeries, as it minimizes musculoskeletal stress on the patient and offers a superior ergonomic environment where the retrograde surgeon can operate comfortably in a seated position [6,18]. This ergonomic stability is crucial for performing delicate tasks such as the transport technique without fatigue [41].

Beyond ECIRS, multiple systematic reviews comparing supine versus prone PCNL report broadly comparable stone-free outcomes, while suggesting that the SP may shorten operative time and reduce overall complications in selected analyses [16,42,43]. A recent meta-analysis similarly found no major differences in SFR between supine and prone PCNL, but noted shorter operative time and fewer complications favoring the supine approach [16]. While the supine approach is the cornerstone of modern ECIRS, the concept has also been adapted to the PP, known as prone ECIRS or the prone split-leg technique [44,45]. In this configuration, the patient is placed prone with the legs abducted to allow ureteroscopic access from below [44]. This approach may be preferred by surgeons who are strictly trained in conventional prone PCNL or in specific anatomical scenarios, such as the presence of a retrorenal colon that precludes safe supine puncture [46,47]. However, prone ECIRS poses significant ergonomic challenges for the retrograde surgeon, who must often operate in an awkward standing position with invert-

Table 5. Comparison of renal access guidance strategies in percutaneous stone surgery

Guidance strategy	Radiation exposure[a]	Visceral injury risk[b]	Targeting confidence[c]	Workflow complexity[d]	Best indication
FG	High	Moderate	High (skeleton/stone)	Low (standard)	Standard PCNL, radio-opaque stones
UG	None	Low	High (parenchyma/fluid)	Moderate (learning curve)	Radiolucent stones, pediatric/pregnant, anatomical anomalies
CG	Low-moderate	Low	Very high	Moderate	Complex anatomy, non-dilated collecting systems
Endoscopic-assisted (ECIRS)	Minimal/None	Lowest	Highest (direct vision)	High (requires 2 surgeons)	Complex stones, parallel calyces, minimizing tract number

FG, fluoroscopy-guided; UG, ultrasound-guided; CG, combined guidance (typically ultrasound for puncture and fluoroscopy for tract dilation); ECIRS, endoscopic combined intrarenal surgery; PCNL, percutaneous nephrolithotomy.

[a]:Radiation exposure: While standard ECIRS may use fluoroscopy for safety checks, the primary reliance on endoscopic and ultrasound guidance significantly minimizes or potentially eliminates radiation exposure compared to pure FG-PCNL.

[b]:Visceral injury risk: Graded as "lowest" for ECIRS because the flexible ureteroscope allows for real-time internal visualization of the needle entry (papillary puncture), ensuring the tract does not traverse adjacent organs or the renal infundibulum.

[c]:Targeting confidence: "direct vision" in ECIRS refers to the visualization of the "bull's-eye" sign or transillumination from the ureteroscope, which provides absolute confirmation of the target calyx compared to the two-dimensional planar images of fluoroscopy or ultrasound.

[d]:Workflow complexity: Marked as "high" for ECIRS due to the requirement for simultaneous retrograde access, specialized patient positioning (e.g., Galdakao-modified or intermediate-supine), and the coordination of two surgeons ("four-hand technique").

ed endoscopic orientation [44,45]. Furthermore, it retains the anesthetic limitations inherent to the PP, such as restricted airway access and cardiovascular implications [48,49]. Therefore, while feasible, prone ECIRS is generally reserved for select cases rather than routine practice [45].

Ultimately, the SP—particularly with streamlined optimizations like the intermediate-supine approach—is widely regarded as the preferred platform for ECIRS [40,50]. By harmonizing anesthetic safety, superior ergonomics for simultaneous endoscopy, and patient comfort, it aligns perfectly with the trajectory of minimally invasive stone management [11,12,48,51]. While prone ECIRS serves as a useful alternative for specific anatomical constraints, the supine approach represents the logical mainstream and a progressively adopted framework for the future of combined intrarenal surgery [52-54].

2. Optimizing renal access: Ultrasound, fluoroscopy, and endoscopic guidance

Obtaining precise and safe renal access is the most critical step in percutaneous stone surgery. While fluoroscopy has traditionally been the standard for guiding percutaneous puncture, it entails radiation exposure for both the patient and the surgical team and lacks the ability to directly visualize surrounding visceral organs. Consequently, ultrasound guidance has gained prominence as a radiation-free alternative that allows for real-time visualization of the renal parenchyma and adjacent structures, significantly reducing the risk of visceral injury [55-58].

Comparative studies and pooled evidence support this shift. Systematic reviews and meta-analyses comparing ultrasound-guided (UG) versus fluoroscopy-guided (FG) PCNL consistently report markedly reduced radiation exposure with UG access while maintaining broadly comparable stone-free and complication outcomes in appropriately selected patients [55,56]. Furthermore, randomized data directly comparing FG, total UG, and combined guidance (CG) show that total UG can achieve similar safety and efficacy without radiation in lower-complexity stones, while CG may be more effective in higher complexity settings [59]. Complementary evidence also suggests that combining ultasound with fluoroscopy can significantly reduce fluoroscopy time compared with standard fluoroscopy-only workflows [60]. Table 5 summarizes the practical trade-offs among these access strategies, highlighting how each modality balances targeting confidence, radiation burden, and workflow complexity [55-57,59,60].

In the context of ECIRS, the concept of renal access evolves further through "endoscopic-assisted puncture." Unlike standard PCNL, where the surgeon relies solely on external imaging, ECIRS enables the retrograde surgeon to position the flexible ureteroscope directly into the target calyx. By identifying the specific papilla and creating "transillumination" or a "bull's-eye" sign, the ureteroscope provides a distinct visual target for the percutaneous surgeon. Furthermore, the retrograde view allows for real-time confirmation of the needle entry, ensuring that the puncture is strictly through the papilla (papillary puncture) rather than the

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infundibulum, thereby minimizing the risk of significant bleeding [29,61-63].

This "triangulated" guidance—combining external (UG/fluoroscopy) and internal (endoscopic) views—maximizes puncture accuracy. This precision often renders a "single puncture" sufficient even for complex stones, as the flexible ureteroscope can manage stone burdens in calyces not accessible by the rigid nephroscope, negating the need for multiple potentially hazardous percutaneous tracts [22,63]. Finally, contemporary data reflect this clinical convergence: a recent prospective randomized trial reported that a UG ECIRS approach yielded comparable efficacy with fewer complications and less blood loss compared to combined UG+fluoroscopy PCNL [64]. Thus, contemporary supine ECIRS increasingly aligns with radiation-sparing access and endoscopic confirmation as the definitive direction for safe and efficient intrarenal surgery [22,55-57,59,60,63,64].

3. Integrated surgical strategy: "single puncture" and "real-time" collaboration

Once renal access is established, the true synergy of ECIRS is realized through the integrated "four-hand" technique [65]. Traditionally, in conventional PCNL for staghorn or multiple calculi, surgeons often resorted to creating multiple percutaneous tracts to access disparate calyces [66]. While effective for stone clearance, multiple tracts are significantly associated with increased risks of bleeding, renal parenchymal injury, and postoperative pain [67-69]. ECIRS fundamentally challenges this necessity, advocating for a "single puncture" strategy even in complex cases [70].

In the ECIRS framework, the rigid nephroscope and the flexible ureteroscope operate simultaneously, covering complementary territories [6]. The rigid nephroscope is primarily responsible for debulking large stone burdens through the single percutaneous tract [71]. Concurrently, the flexible ureteroscope acts as a versatile "roving" instrument, accessing parallel calyces or the ureter—areas that are mechanically inaccessible to the rigid scope without excessive torque [22]. By managing these peripheral stones via the retrograde route, the need for additional percutaneous punctures is largely eliminated, thereby preserving renal function and minimizing morbidity [25].

The hallmark of this strategy is the "real-time collaboration" between the antegrade and retrograde surgeons, which manifests in two key mechanisms.

1) The transport technique ("passing the ball")

Instead of spending excessive time dusting stones in difficult-to-reach calyces with a flexible—which can be slow and thermally hazardous due to the potential rise in intraluminal temperature during laser lithotripsy [72]—the retrograde surgeon mobilizes these stones and "passes" them toward the renal pelvis or the percutaneous tract [30]. The antegrade surgeon then efficiently extracts these fragments using the rigid nephroscope and a lithotripter [22]. This coordinated maneuver significantly expedites the procedure, overcoming the "time-consuming" limitation of RIRS monotherapy [30].

2) The washout mechanism

ECIRS establishes an efficient fluid dynamic circuit. Irrigation fluid instilled through the flexible ureteroscope flushes out through the percutaneous sheath [6]. Spontaneously evacuating stone dust and preventing the "snowstorm" effect during lithotripsy. Traditionally, this mechanism was highly emphasized for uniquely maintaining consistently low IRP, thereby protecting the kidney from pyelovenous backflow and sepsis [27]. However, it is important to acknowledge that recent advancements in flexible and navigable suction (FANS) ureteral access sheaths have enabled active IRP modulation and continuous fragment evacuation even in purely retrograde procedures [26]. While IRP control is thus no longer exclusive to ECIRS, the dual-lumen outflow of the combined approach remains exceptionally advantageous for managing massive stone burdens.

By seamlessly integrating these techniques, ECIRS transforms the surgery from a sequential set of procedures into a fluid, continuous operation. The result is a highly efficient workflow that achieves maximum stone clearance with minimal parenchymal invasiveness [21].

4. Miniaturization of ECIRS: Balancing efficacy and morbidity

As the paradigm of percutaneous stone surgery shifts toward minimizing invasiveness, the integration of miniaturized tracts (15–18 Fr) into the ECIRS platform—termed "Mini-ECIRS"—has emerged as a pivotal advancement [33]. While standard ECIRS (24–30 Fr) allows for rapid stone removal, larger tracts are intrinsically linked to a higher risk of renal parenchymal bleeding [73]. Mini-ECIRS aims to mitigate this morbidity without compromising stone-free outcomes, leveraging the "four-hand" synergy to compensate for the smaller outflow tract [22].

A comparative study by Moon et al. [33], analyzing 200 consecutive cases, provided early robust evidence for this approach. The study demonstrated that Mini-ECIRS achieved comparable SFRs to standard ECIRS while significantly reducing hemoglobin drop and transfusion requirements [33].

This suggests that the "transport technique" and "washout mechanism" effectively offset the limitations of a smaller sheath, allowing for efficient stone clearance even with reduced tract size [6].

Recent high-level evidence further solidifies the role of Mini-ECIRS. A 2025 RCT comparing Mini-ECIRS versus conventional PCNL for complex nephrolithiasis (Guy's Stone Score III/IV) revealed that Mini-ECIRS offered superior outcomes. The Mini-ECIRS group demonstrated a significantly higher single-session SFR (51% vs. 32.6%, p=0.0275) and a lower overall complication rate (14.3% vs. 38.8%, p=0.006) compared to the PCNL group, alongside shorter operative times and hospital stays [74]. These findings underscore that the combination of flexible endoscopy and miniaturized percutaneous access is not merely an alternative but a highly effective therapeutic option for complex stones.

Technical refinements within the Mini-ECIRS framework continue to evolve. A recent retrospective analysis highlighted the advantages of "upper calyx puncture" (UCP) in Mini-ECIRS. Accessing the upper pole, facilitated by endoscopic guidance, was associated with improved intraoperative visibility, shorter fluoroscopy times, and a reduced need for postoperative ureteral stenting compared to non-UCP approaches, without increasing thoracic complications [75].

Furthermore, the safety profile of Mini-ECIRS extends to vulnerable populations [76]. A multicenter matched-pair analysis in 2025 investigated the outcomes of Mini-ECIRS in geriatric patients (≥75 years). The study found no significant differences in SFR, complications, or hospitalization duration compared to younger cohorts, confirming that Mini-ECIRS is a safe and viable option even for frail, elderly patients who require maximal renal preservation and minimal surgical stress [77].

Collectively, these data suggest that Mini-ECIRS effectively balances the "efficacy" of combined surgery with the "safety" of miniaturization, making it a versatile solution for a broad spectrum of patients ranging from those with complex staghorn calculi to the fragile geriatric population [74].

5. Clinical outcomes in complex scenarios (staghorn & high burden)

The management of staghorn and high-burden renal calculi remains one of the most challenging frontiers in endourology [78]. While PCNL has been the gold standard, complete stone clearance often necessitates multiple percutaneous tracts, which are intrinsically linked to higher rates of bleeding, renal functional loss, and postoperative pain [67,69,79]. ECIRS has fundamentally altered this landscape by offering a "single-tract" solution even for the most complex stone configurations [70].

1) Efficacy in complete staghorn stones

Recent comparative evidence highlights the superiority of ECIRS over conventional PCNL in managing complete staghorn calculi. A 2023 study comparing the two modalities found that ECIRS was associated with significantly reduced fluoroscopy time, shorter operative duration, and a shorter hospital stay. Crucially, the ECIRS group demonstrated a significantly lower drop in hemoglobin levels and required fewer access tracts to achieve comparable or superior SFRs (64.4% vs. 48.5%) [80]. This confirms that the retrograde flexible ureteroscope can effectively clear stone burden in parallel calyces that would otherwise require additional punctures in a standard PCNL setting.

2) The "pain-free" advantage of Mini-ECIRS

For high-burden stones, the morbidity of multiple tracts is a major concern. A study comparing Mini-ECIRS (single tract) versus Multi-tract Mini-PCNL for staghorn stones revealed a striking difference in patient quality of life. While both techniques achieved comparable SFRs, Mini-ECIRS resulted in significantly less postoperative pain (visual analog scale score 0 vs. 2.7, p<0.001) [81]. This suggests that leveraging the "four-hand" technique to minimize the number of tracts is a direct pathway to reducing patient suffering and narcotic requirements.

• Broader evidence and meta-analysis: These findings are corroborated by a systematic review and meta-analysis focusing on large and complex renal stones. The analysis by Widyokirono et al. [37] confirmed that ECIRS consistently yields a higher one-step SFR and a lower complication rate compared to PCNL alone, mainly by reducing the need for auxiliary procedures and minimizing blood loss.

3) Versatility in anomalous anatomy

The adaptability of ECIRS extends to patients with complex renal anatomy, where standard percutaneous access is hazardous or mechanically limited.

(1) Renal ectopia: A case report of a staghorn calculus in a crossed fused renal ectopia demonstrated that ECIRS could safely achieve complete clearance in a single session, a feat nearly impossible with rigid nephroscopy alone due to the aberrant calyceal orientation [82].

(2) Difficult access: In scenarios where patient positioning is restricted (e.g., severe skeletal deformities) or standard ECIRS is challenging, modified approaches such as "PCNL combined with antegrade flexible ureteroscopy" have proven to be effective alternatives. This technique allows for the

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clearance of residual fragments in difficult-to-reach calyces through the nephrostomy tract, further exemplifying the utility of combining flexible and rigid instrumentation [83].

In conclusion, for complex scenarios ranging from complete staghorn stones to anomalous kidneys, ECIRS provides a "maximal clearance, minimal invasion" strategy [37,38]. By substituting multiple percutaneous tracts with flexible retrograde (or antegrade) navigation, it significantly reduces hemorrhagic risks and postoperative pain, solidifying its role as the preferred treatment modality for high-complexity urolithiasis [25,37,38,81].

6. Limitations, practical challenges, and contraindications of ECIRS

Despite its profound clinical advantages, ECIRS possesses inherent limitations and practical challenges, and specific contraindications that must be acknowledged [22]. Primarily, the procedure is highly resource-intensive [84]. The simultaneous "four-hand" approach mandates the presence of two skilled endourologists, which significantly increases procedural expenses and manpower burdens, making it difficult to adopt in resource-limited settings or smaller community hospitals [36]. Furthermore, the operating room setup is complex and costly, requiring two separate endoscopic video towers and potentially two lithotripsy or laser systems operating simultaneously [84], although recent advancements like laser splitters are attempting to mitigate this equipment redundancy. Moreover, ECIRS involves a steep learning curve and high team dependency [85]. The success of the procedure relies heavily on seamless communication and synchronized movements between the antegrade and retrograde surgeons, further limiting its routine applicability in low-volume centers where such coordinated teams are not readily available.

Clinically, it is crucial to recognize that while ECIRS reduces the need for multiple percutaneous tracts—thereby lowering major hemorrhagic risks—the procedure-specific complications are not entirely eliminated but rather additive [36]. In essence, the complication profile of ECIRS is the sum of its parts (1+1) [22]. Patients are exposed to the inherent risks of both approaches concurrently; for instance, the parenchymal bleeding and adjacent organ injury risks of PCNL are combined with the risks of ureteral mucosal injury, ureteral stricture, or prolonged stenting associated with the retrograde deployment of ureteral access sheaths and flexible ureteroscopes [3].

Finally, specific contraindications must be respected. Alongside standard PCNL contraindications—such as uncorrected coagulopathy or untreated urinary tract infections—ECIRS cannot be performed in patients where retrograde ureteral access is impossible (e.g., due to severe untreated urethral strictures) or where the SP is medically prohibited [86]. Therefore, careful patient selection and a thorough cost-benefit analysis remain imperative before proceeding with ECIRS [2].

From a health economics perspective, the cost-effectiveness and reimbursement of ECIRS remain subjects of ongoing debate [87]. The upfront costs of ECIRS are undeniably higher than monotherapies due to the requirement for dual endoscopic towers, two primary surgeons, and potentially two laser systems [84]. However, these initial financial burdens may be offset by significant reductions in downstream costs [37]. By achieving a higher single-session SFR, ECIRS decreases the need for multiple percutaneous tracts, shortens hospital stays, and reduces the frequency of auxiliary procedures or retreatments. Despite these potential long-term savings, current reimbursement models in many healthcare systems often fail to adequately compensate for the concurrent use of two distinct surgical modalities and the presence of two surgeons in a single session [84]. Consequently, for ECIRS to achieve broader adoption and definitive guideline-level impact, formal, large-scale cost-effectiveness analyses are urgently required to justify these upfront institutional investments [88].

FUTURE PERSPECTIVES: ROBOTICS AND ARTIFICIAL INTELLIGENCE

While the current standard of ECIRS relies on human "four-hand" collaboration, robotic technologies are emerging to address its most technically demanding aspects.

1. Current clinical evidence

Initial clinical studies have validated the safety and feasibility of early robotic platforms as surgical adjuncts. For percutaneous access, systems like ANT-X and BotX utilize fluoroscopic triangulation to assist in needle targeting, demonstrating high accuracy and reduced radiation exposure in pilot cases [89-91]. Concurrently, robot-assisted retrograde manipulation using master-slave systems like the Avicenna Roboflex and Zamenix R has proven effective in early trials. These platforms offer superior ergonomics, scope stability, and high SFRs (over 93%) while reducing surgeon fatigue during prolonged lithotripsy [92-94].

2. Current limitations and unfeasible aspects

Despite these promising results, a clear distinction must be made between conceptual vision and current clinical reality. Currently, a "Fully Robotic ECIRS"—where both antegrade and retrograde arms are seamlessly integrated and autonomous—remains conceptually appealing but clinically unfeasible. Existing robotic systems are hindered by significant practical limitations, including the lack of haptic feedback, bulky equipment that exacerbates operating room crowding, prolonged docking times, and prohibitive costs [22,92].

Furthermore, while artificial intelligence (AI) holds conceptual potential for real-time stone recognition and optimal tract planning [95], fully autonomous robotic stone clearance is not yet attainable. Current AI algorithms lack the vast, standardized intraoperative datasets required for autonomous surgical decision-making in highly unpredictable intrarenal environments. Therefore, while robotic assistance is progressively maturing, these platforms are currently advanced tools rather than replacements for human surgical expertise. Future advancements must overcome these technological and economic barriers before "Fully Robotic ECIRS" can achieve widespread clinical adoption.

CONCLUSIONS

The evolution of renal stone surgery has been defined by a continuous pursuit of minimizing invasiveness while maximizing stone clearance [78]. As detailed in this review, ECIRS represents the culmination of this journey, transforming the treatment of complex urolithiasis from a choice between competing monotherapies into a synergistic alliance [21,22,96].

The shift from the prone to the SP was the pivotal catalyst that enabled this "four-hand" collaboration [21]. By integrating the versatile retrograde access of flexible ureteroscopy with the robust clearance capability of PCNL, ECIRS effectively overcomes the inherent limitations of each standalone technique [21,22,37]. The "transport technique" and "washout mechanism" described herein are not merely theoretical concepts but practical tools that translate into tangible clinical benefits: reduced operative times, lower IRPs, and the elimination of multiple hazardous percutaneous tracts [6,37,96].

Contemporary evidence, ranging from large-scale meta-analyses to RCTs, consistently supports the clinical superiority of ECIRS [37,74]. It has proven to be a robust solution across the entire spectrum of stone complexity, offering the high SFRs of PCNL with the safety profile of RIRS, even in vulnerable geriatric populations and challenging anatomical scenarios [37,77,82,83]. The Mini-ECIRS has further tilted the balance in favor of safety, making "single-puncture" clearance a reality for staghorn calculi [70,74,81,96].

Looking ahead, the horizon of ECIRS is expanding through the integration of robotic assistance and digital intelligence [89,93-95]. The emergence of robotic platforms for both percutaneous access and retrograde manipulation promises to democratize technical excellence, reducing the learning curve and standardizing outcomes [89-91,93,94]. As we stand on the cusp of the era of "Fully Robotic ECIRS," it is evident that this multimodal approach is not just a transient trend but a central framework for the future of endourology [89,93,94]. For the modern urologist facing the challenge of complex renal stones, ECIRS represents a strong candidate for broader adoption and may be considered a preferred modality in appropriately selected patients [22,37,74].

CONFLICTS OF INTEREST

The authors have nothing to disclose.

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