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**REVIEW ARTIKEL**

# Comparative Outcomes of Endourological Procedures in Urolithiasis: A Narrative Literature Review of PCNL, URS, and ESWL

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## *ABSTRACT*

*Urolithiasis remains a recurrent and resource-intensive condition, where endourological interventions are selected based on stone burden, location, anatomy, patient preference, stone-free rate, safety, retreatment, recovery, and cost. This narrative review assesses percutaneous nephrolithotomy (PCNL), ureteroscopy or retrograde intrarenal surgery (URS/RIRS), and extracorporeal shock wave lithotripsy (ESWL/SWL). PCNL consistently has the best chance of getting rid of stones, especially for bigger stones, stones in the lower pole, or complicated kidney stone burdens. However, these benefits come with more invasive procedures, longer hospital stays, and more bleeding-related illnesses. ESWL is still the least invasive and often the least expensive option, but the results depend more on the size, density, position, and the gap between the stone and the skin, as well as the need for repeat sessions. Recent evidence suggests that treatment selection should not be limited to a single efficacy hierarchy: PCNL, URS, and ESWL each serve distinct therapeutic functions, and optimal decision-making requires the alignment of procedural benefits with stone- and patient-specific priorities.*

***Keywords:*** *urolithiasis, PCNL, ureteroscopy, retrograde intrarenal surgery, ESWL.*

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## INTRODUCTION

Urolithiasis is a frequent and recurrent condition. Recent studies show that kidney stone disease affects a large number of adults and puts a lot of stress on healthcare systems because patients need to have treatments, imaging, and follow-up visits over and over again (Terro et al., 2026). The primary objective of active kidney stone treatment is the definitive elimination of stones with minimal collateral damage, as residual fragments may lead to symptom recurrence, infections, obstructions, re-interventions, and continuous surveillance (Assimos et al., 2016).

The three main types of modern endourological treatments are PCNL, URS/RIRS, and ESWL. Each has its own way of getting to the stones, how much anesthesia it needs, how invasive it is, what technical needs it has, and what kind of retreatment it is likely to need (Akram et al., 2024). PCNL usually has the highest stone-free rates when effectiveness is the only thing that matters. These rankings might not be clinically comprehensive when patients prioritize outpatient treatment, evasion of percutaneous access, accelerated recovery, or diminished initial procedure costs (Chung et al., 2019).

The rapid advancement of URS/RIRS is attributed to the introduction of flexible ureteroscopes, access sheaths, and laser lithotripsy, enabling retrograde treatment of numerous kidney stones that were previously addressed with ESWL or PCNL (Geraghty et al., 2017). ESWL is still important because it doesn't require surgery and can be done without an endoscope. Nonetheless, its effectiveness is more contingent upon stone and patient variables in comparison to the efficacy of endoscopic treatments (Lee et al., 2019)

## METHODS OF THE NARRATIVE REVIEW

This article employs a narrative literature review methodology instead of a formal systematic review, with the objective of synthesizing the comparative clinical implications of PCNL, URS/RIRS, and ESWL across various study designs and stone locations (Setthawong et al., 2023). We only used peer-reviewed journal articles that were published between 2016 and 2026. We focused on studies that were relevant to the endourological treatment of renal or ureteral calculi (Akram et al., 2024). The review focused on outcomes that generally affect the choice of clinical settings: stone-free rate, need for retreatment or further procedures, complications, length of hospital stay, radiation exposure, expenses, and quality of life (Terro et al., 2026).

The review considered the stone-free rate as a comparative endpoint rather than an absolute one, owing to the variability in definitions of stone-free status across studies. It prioritized studies that specified the imaging modality, follow-up duration, and residual fragment threshold (Chung et al., 2019). All cited references were integrated into the manuscript text or comparative tables, and no uncited sources were present in the final reference list.

## TECHNICAL OVERVIEW OF PCNL, URS/RIRS, AND ESWL

### *Percutaneous Nephrolithotomy*

PCNL gets rid of stones through the percutaneous renal route, which lets the nephroscope watch as the stones are broken up and removed (Assimos et al., 2016). Its main advantage over other treatments is that it can clear stones quickly, especially those that are larger than 2 cm, in a

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single session. This is especially true for stones that are at the lower pole, have bad drainage, are staghorn calculi, or are very dense (Chung et al., 2019).

Miniature PCNL variants reduce tract size and may mitigate postoperative bleeding or discomfort. However, the relative benefit depends on how big the stone is, how long the surgery takes, how much pressure the irrigation has, and the need to remove all the pieces (Qin et al., 2022). PCNL is more invasive than ESWL and many URS procedures, which means there is a greater risk of bleeding, a prolonged hospital stay, the requirement for percutaneous access, and more resources needed during the treatment (Tzelves et al., 2022).

***Ureteroscopy and Retrograde Intrarenal Surgery***

URS treats ureteral and renal stones by going backwards, while RIRS is flexible intrarenal ureteroscopic lithotripsy that happens in the renal collecting system (Geraghty et al., 2017). The best thing about URS/RIRS is that it is more balanced than other methods. It is more invasive than ESWL but less invasive than PCNL, and for many lower-pole, solid, or larger stones, it can get rid of more stones than ESWL (MacLennan et al., 2025).

The efficacy of URS/RIRS is contingent upon ureteral access, visibility, lower pole anatomy, laser parameters, fragment retrieval techniques, surgeon proficiency, and stent associated complications (Croghan et al., 2023). Modern cost analyses increasingly favor URS over repeat ESWL in specific scenarios, as superior primary clearance may compensate for the elevated initial utilization of endoscopic resources (Nedbal et al., 2025).

***Extracorporeal Shock Wave Lithotripsy***

ESWL utilizes shock waves generated externally to fragment stones, rendering it the least invasive technique, as it circumvents intrarenal percutaneous and endoscopic approaches (Lee et al., 2019). This method works best for small kidney stones, people with good kidney anatomy, stones that aren't too dense, stones that are close to the skin, and people who want to be treated as outpatient or with as little pain as possible (Wagenius et al., 2022).

The primary issues with ESWL are its propensity to leave residual fragments and necessitate additional sessions when the stone is larger, more calcified, situated in the lower pole, or presents anatomical challenges (Bai et al., 2023).Although ESWL is often the least expensive option at first, its economic benefits may be lessened or eliminated when considering repeat treatments, extra imaging, emergency consultations, and delayed definitive clearance (Geraghty et al., 2018).

## COMPARATIVE CLINICAL OUTCOMES

***Stone free rate***

The stone-free rate is the most common endpoint and the clearest difference between the three procedures. A network meta-analysis of 35 research showed that PCNL had the highest stone-free rate, RIRS situated in the middle of PCNL and SWL, and SWL had the lowest chance of becoming stone-free (Chung et al., 2019). Recent randomized studies demonstrate that flexible ureteroscopy flexible ureteroscopy works better than ESWL for getting rid of lower-pole renal stones. Simultaneously, PCNL demonstrates a minor yet statistically significant superiority over flexible ureteroscopy (MacLennan et al., 2025).

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Prospective comparative research on hard lower-pole renal stones measuring up to 2 cm revealed that FURS achieved a stone-free rate of 90.2% at two weeks, surpassing ESWL's rate of 61.5% in the same report (Zeinelabden et al., 2024).

A propensity-matched prospective comparison for non-lower-pole stones up to 20 mm demonstrated that SWL and F-URS exhibited comparable short-term clearance, indicating that ESWL remains a viable option when stone positioning and patient selection are appropriately managed (Bai et al., 2023). So, the most logical

explanation is that PCNL has the best chance of complete clearance, URS/RIRS is usually more reliable than ESWL in difficult stone cases, and ESWL is okay when the stone's anatomy and characteristics make it easier for fragments to pass on their own (Kallidonis et al., 2020).

***Retreatment and auxiliary procedures***

Retreatment is a crucial endpoint, as procedures with a lower initial burden may lose their appeal if multiple sessions are required to attain similar clearance (Geraghty et al., 2017). According to population-based comparative effectiveness data, ureteroscopy and shockwave lithotripsy exhibit markedly different retreatment patterns; the stone's location and the initial treatment type can influence the likelihood of requiring additional procedures (Bowen et al., 2020).

Systematic cost-effectiveness literature indicates that URS may exhibit greater cost effectiveness than ESWL when higher initial success rates and lower retreatment rates are factored into long-term models (Nedbal et al., 2025). PCNL may reduce the need for phased treatment in patients with significant kidney stone burdens. However, additional flexible endoscopy, repeated nephroscopy, or integrated methodologies may still be necessary in complex collecting duct anatomy (Ates et al., 2025).

***Complications, hospitalization, and radiation exposure***

Complication profiles differ due to the unique injury mechanisms linked to these procedures: tract-related hemorrhage and visceral access risk in PCNL, ureteral trauma and stent morbidity in URS, and colic or Steinstrasse following ESWL. A systematic comparison of SWL complications employing the modified Clavien-Dindo system validated that the majority of complications are mild; however, clinically significant adverse events persist and must be acknowledged during counseling (Tzelves et al., 2022).

Mini-PCNL and outpatient PCNL strategies aim to preserve the stone-free advantages of PCNL while minimizing morbidity; however, evidence is contingent upon tract size, surgeon proficiency, and case selection (Shabana et al., 2021). Ultrasound-guided PCNL techniques or reduced fluoroscopy are increasingly being investigated due to radiation exposure posing a significant procedural risk for both the patient and the surgical team (Yang et al., 2019). During ureteroscopy, high pressure in the upper urinary tract is a safety concern because it can cause infections and make recovery harder (Croghan et al., 2023).

***Cost, quality of life, and patient-centered outcomes***

Cost comparisons should be viewed with caution, as the expenses associated with equipment, the accessibility of lithotripters, inpatient regulations, reimbursement practices, reimaging protocols, and readmission trends vary among health systems (Wymer et al., 2021).

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A systematic analysis of cost and effectiveness suggested that URS might be more cost effective than SWL when factoring in readmission costs (Geraghty et al., 2017).

A 2026 EAU systematic review of endourology indicated that ESWL was typically the least costly initial method, PCNL the most costly and invasive, and URS the method exhibiting the most equitable balance of efficacy, safety, and cost. Quality-of-life data are less comprehensive than stone-free and complication data, and comparative reviews have not consistently demonstrated a sustained difference in quality of life among PCNL, URS, and ESWL (Terro et al., 2026).

As a result, patient-centered decision-making should take into account the estimated number of sessions, temporary stent symptoms, recovery time, need for anesthesia, risk of residual fragments, and the possibility that a less invasive

initial procedure may not be the best way to get complete care (Nedbal et al., 2025).

## CLINICAL SYNTHESIS AND DECISION-MAKING IMPLICATIONS

Evidence supports a multilevel decision-making model rather than a universal procedural hierarchy (Tran et al., 2022). For large kidney stone burdens, especially stones larger than 2 cm or complex lower pole disease, PCNL should usually be considered when the clinical priority is maximal clearance in as few sessions as possible (Kang et al., 2017). For small -making small-to medium-sized stones, when patients prefer a less invasive yet definitive endoscopic approach, URS/RIRS offers a practical compromise between stone free rate and morbidity (MacLennan et al., 2025). For small renal stones outside the lower pole with favorable density and anatomy, ESWL remains the preferred choice small-choice, as selected contemporary cohorts demonstrate competitive clearance with lower hospitalization and costs (Bai et al., 2023).

For stones at the lower pole, especially those that have unfavorable infundibular anatomy or high density, the balance shifts towards URS/RIRS or PCNL because passive fragment clearance after ESWL is less predictable (Kallidonis et al., 2020). For hard kidney stones in the lower pole up to 2 cm, direct comparative evidence supports FURS or mini-PCNL over ESWL when the desired outcome is stone-free status as early as possible (Zeinelabden et al., 2024).

Cost-sensitive decision-making should include direct procedural costs and downstream costs resulting from residual fragments, repeat ESWL, emergency presentations, stent placement, and additional endoscopies (Wymer et al., 2021). In practice, shared decision making must translate statistical differences into specific patient expectations: the probability of cleaning in a

single session, the likelihood of needing another procedure, the expected recovery interval, and an acceptable balance between invasiveness and the certainty of cleaning (Nedbal et al., 2025).

## LIMITATIONS OF THE EVIDENCE BASE

Heterogeneous definitions of stone-free status limit the comparability of literature, as some studies used plain radiography or ultrasonography, while others used computed tomography (Chung et al., 2019). The intervals for follow-up differ among research, potentially

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leading to an overestimation of the stone-free rate in the initial phases or an under-detection of spontaneous passing of fragments in the subsequent phases following ESWL (Wagenius et al., 2022). The comparison between PCNL and URS/RIRS is also influenced by technological developments, such as miniaturized PCNL, thulium fiber lasers, disposable ureteroscopes, and improved access sheaths can alter operative time, costs, and complications (Perri et al., 2022).

Many studies are single-center or heavily dependent on operator expertise, which limits generalizability to institutions with different case volumes, equipment, and postoperative pathways (Ates et al., 2025). Outcomes related to costs and quality of life have been reported less consistently than stone-free outcomes, limiting the ability to draw confident conclusions about value-based selection across countries and payment systems (Terro et al., 2026).

## CONCLUSION

PCNL, URS/RIRS, and ESWL should be considered complementary rather than interchangeable procedures for urolithiasis (Akram et al., 2024). PCNL offers the most robust stone-free rate, especially for high-burden or complex kidney stones, but is more invasive and

associated with greater morbidity (Chung et al., 2019). URS/RIRS provides the most balanced profile for many contemporary patient's choice, as it often improves clearance relative to ESWL while avoiding the morbidity of the percutaneous route (MacLennan et al., 2025).

ESWL remains valuable for easily managed kidney stones and patients who prioritize noninvasive treatment, bupatients,treatment but requires careful counseling regarding residual fragments and repeat procedures (Lee et al., 2019). The best choice of procedure is achieved when stone characteristics, patient preferences, institutional expertise, and the full burden of care are integrated into a shared decision, rather than when the stone-free rate alone is used as the sole determining factor (Terro et al., 2026).

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