Comparison of Stone-Free Rate, Length of Hospital Stay, Operative Time, and Complications between Minimally Invasive Percutaneous Nephrolithotomy and Retrograde Intrarenal Surgery for Renal Stones: A Systematic Review and Meta-Analysis

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Abstract

Background: Minimally Invasive Percutaneous Nephrolithotomy (mini-PCNL) and Retrograde Intrarenal Surgery (RIRS) are widely used treatment modalities for renal stones measuring 10–20 mm. While mini-PCNL is associated with high stone clearance rates, RIRS offers a less invasive approach with faster postoperative recovery. Current evidence comparing the effectiveness and safety of these procedures remains inconsistent.
Methods: A systematic review and meta-analysis was conducted according to PRISMA guidelines. Electronic databases were searched for comparative studies evaluating mini-PCNL and RIRS in patients with renal calculi. Outcomes of interest included stone-free rate (SFR), length of hospital stay (LOS), operative time, and overall complications. Pooled analyses were performed using random-effects models and reported as risk ratios (RRs) or mean differences (MDs) with 95% confidence intervals (CIs).
Results: Thirteen studies involving 1,694 patients met the inclusion criteria. Meta-analysis demonstrated a significantly higher stone-free rate with mini-PCNL compared with RIRS (RR=0.95; 95% CI 0.92–0.98; p=0.001). Conversely, RIRS was associated with a significantly shorter hospital stay (MD=-2.05 days; 95% CI -2.72 to -1.38; p<0.00001) and a lower overall complication rate (RR=0.75; 95% CI 0.62–0.92; p=0.005). No significant difference was observed in operative time between the two procedures (MD=2.98 minutes; 95% CI -13.24 to 19.19; p=0.72).
Conclusion: Mini-PCNL achieves superior stone-free outcomes compared with RIRS. However, RIRS provides advantages in terms of shorter hospitalization and lower complication rates. Treatment selection should therefore be individualized according to the balance between maximizing stone clearance and minimizing perioperative morbidity.

Keywords: kidney stones, mini-PCNL, retrograde intrarenal surgery, stone-free rate, complications, meta-analysis.

Introduction

Nephrolithiasis is one of the most common urological disorders and its prevalence continues to increase worldwide. A recent global meta-analysis involving more than 1.2 million participants estimated the prevalence of urolithiasis at 10.85%, indicating that approximately one in ten adults is affected by the disease (1). Beyond causing severe renal colic, nephrolithiasis is associated with urinary tract obstruction, infection, impaired renal function, high recurrence rates, and increased healthcare utilization, including hospitalization and surgical intervention (1,2).

Stone size is a major determinant in treatment selection. Renal calculi measuring 10–20 mm have a low likelihood of spontaneous passage and frequently require active intervention to achieve optimal clinical outcomes (2,3). Current guidelines from the European Association

of Urology (EAU) and the American Urological Association (AUA) recommend several treatment options for stones within this size range, including Retrograde Intrarenal Surgery (RIRS) and Minimally Invasive Percutaneous Nephrolithotomy (mini-PCNL), with treatment decisions guided by stone characteristics, renal anatomy, patient factors, and surgeon expertise (2,3).

Mini-PCNL was developed as a modification of conventional percutaneous nephrolithotomy using a smaller access tract to reduce procedure-related morbidity while maintaining effective stone clearance. Its principal advantage lies in providing direct access to the pelvicalyceal system, allowing efficient stone fragmentation and evacuation within a single procedure (4,5). Several meta-analyses have demonstrated higher stone-free rates with mini-PCNL compared with RIRS, particularly in patients with larger or more complex renal stones (5,6).

In contrast, RIRS has evolved substantially with advances in flexible ureteroscopy, ureteral access sheaths, and laser lithotripsy technologies. By utilizing the natural urinary tract without the need for percutaneous access, RIRS offers a less invasive approach associated with reduced blood loss, less postoperative pain, and shorter hospital stays compared with percutaneous procedures (3,7). However, these advantages may come at the expense of lower single-session stone-free rates and a greater likelihood of requiring auxiliary procedures or staged interventions to achieve outcomes comparable to mini-PCNL (6,8).

Despite numerous comparative studies, the available evidence remains inconsistent. Differences in stone size and location, definitions of stone-free status, surgical techniques, operator experience, and rapidly evolving instrumentation contribute substantially to heterogeneity among studies (9,10). Furthermore, several previous meta-analyses combined various percutaneous and ureteroscopic techniques into broad categories, potentially limiting the applicability of their findings to contemporary mini-PCNL and modern RIRS procedures (10,11).

Therefore, an updated synthesis of the evidence is warranted to evaluate the comparative efficacy and safety of these treatment modalities. This systematic review and meta-analysis aimed to compare stone-free rate, length of hospital stay, operative time, and complications between mini-PCNL and RIRS. The findings are expected to provide stronger evidence to guide clinical decision-making in the management of patients with renal stones measuring 10–20 mm.

Methods

Study Design

This study was conducted as a systematic review and meta-analysis to compare the efficacy and safety of Minimally Invasive Percutaneous Nephrolithotomy (mini-PCNL) and Retrograde Intrarenal Surgery (RIRS) in patients with renal stones. The review was designed and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

Literature Search Strategy

A comprehensive literature search was performed using the PubMed, Scopus, ScienceDirect, Cochrane Library, and Google Scholar databases from inception to the most recent search date. Search terms included a combination of Medical Subject Headings (MeSH) and free-text keywords such as “mini-percutaneous nephrolithotomy”, “mini-PCNL”, “retrograde intrarenal surgery”, “RIRS”, “kidney stone”, “renal stone”, “urolithiasis”, and “nephrolithiasis”, combined using Boolean operators (“AND” and “OR”). Reference lists of eligible studies were also manually screened to identify additional relevant publications.

Eligibility Criteria

Studies were included if they directly compared mini-PCNL and RIRS in patients with renal stones, reported at least one predefined outcome of interest, and were available as full-text articles in English. Both randomized controlled trials and comparative observational studies were considered eligible.

Studies were excluded if they were case reports, review articles, editorials, letters to the editor, conference abstracts without complete data, animal studies, or publications lacking extractable outcome data for quantitative synthesis.

Study Selection and Data Extraction

All retrieved articles were independently screened by two reviewers. Duplicate records were removed before title and abstract screening. Potentially eligible studies underwent full-text assessment according to the predefined inclusion and exclusion criteria. Disagreements between reviewers were resolved through discussion until consensus was reached. Data extracted from each study included author name, year of publication, country of origin, study design, sample size, patient characteristics, stone size, and outcomes of interest, including stone-free rate (SFR), length of hospital stay, operative time, and postoperative complications.

Quality Assessment

Methodological quality assessment was performed using appropriate tools according to study design. Quality evaluation was conducted independently by two reviewers to minimize selection and interpretation bias. Any discrepancies were resolved through consensus discussion.

Outcomes

The primary outcome was stone-free rate (SFR). Secondary outcomes included length of hospital stay, operative time, and postoperative complications.

Statistical Analysis

Meta-analysis was performed using appropriate statistical software. Dichotomous outcomes were analyzed using risk ratios (RRs), whereas continuous outcomes were analyzed using mean differences (MDs), both reported with 95% confidence intervals (95% CIs). Statistical heterogeneity was assessed using the Chi-square test and I^2 statistic. An I^2 value greater than 50% was considered indicative of substantial heterogeneity, and a random-effects model was applied. Otherwise, a fixed-effects model was used. A p-value of less than 0.05 was considered statistically significant.

Results

Study Selection and Characteristics

The literature search identified potentially relevant studies from multiple electronic databases. Following duplicate removal, title and abstract screening, and full-text eligibility assessment, 13 studies met the inclusion criteria and were included in the quantitative synthesis. A total of 1,694 patients were analyzed, comprising 898 patients in the RIRS group and 796 patients in the mini-PCNL group. Included studies consisted of randomized controlled trials and comparative observational studies evaluating the efficacy and safety of both procedures for renal stones measuring 10–20 mm.

Table 1. General Characteristics of Included Studies

Characteristic	Value
Number of studies	13
Total patients	1,694
RIRS group	898
Mini-PCNL group	796
Study design	Randomized controlled trials and comparative observational studies
Population	Patients with renal stones measuring 10–20 mm
Primary outcomes	Stone-free rate, complications
Secondary outcomes	Length of stay, operative time

The included studies provided sufficient data for quantitative comparison of efficacy and safety outcomes between mini-PCNL and RIRS, with stone-free rate, hospital stay, operative time, and complications being the most consistently reported endpoints.

Table 2. Meta-analysis of Stone-Free Rate

Outcome	Effect Size	95% CI	p-value	I^2
Stone-Free Rate	RR = 0.95	0.92–0.98	0.001	31%

Meta-analysis demonstrated a significantly higher stone-free rate with mini-PCNL compared with RIRS (RR=0.95; 95%CI 0.92–0.98; p=0.001). The relatively low heterogeneity (I^2=31%) suggests good consistency among included studies.

Figure 1. Forest Plot of Stone-Free Rate

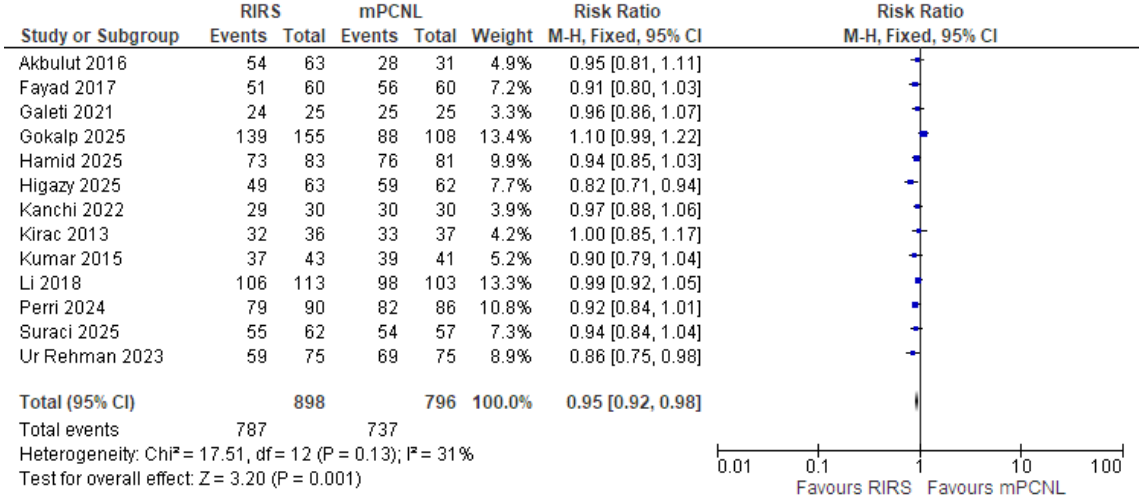

Table 3. Meta-analysis of Length of Hospital Stay

Outcome	Effect Size	95% CI	p-value	I^2
Length of Stay	MD = -2.05 days	-2.72 to -1.38	<0.00001	97%

RIRS was associated with a significantly shorter hospital stay than mini-PCNL (MD=-2.05 days; 95%CI -2.72 to -1.38; p<0.00001). However, substantial heterogeneity was observed across studies (I^2=97%).

Figure 2. Forest Plot of Length of Hospital Stay

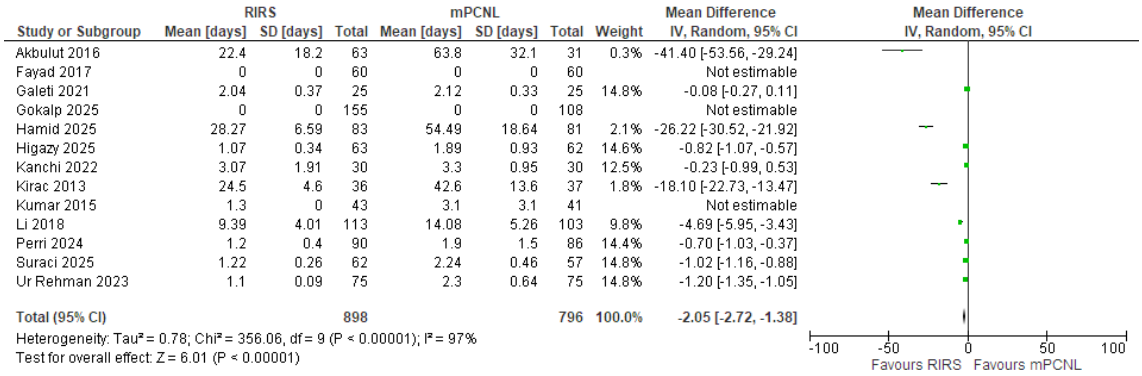

Table 4. Meta-analysis of Operative Time

Outcome	Effect Size	95% CI	p-value
Operative Time	MD = 2.98 min	-13.24 to 19.19	0.72

No significant difference in operative time was observed between mini-PCNL and RIRS. Operative duration appeared to be influenced by multiple factors beyond procedure type alone.

Figure 4. Forest Plot of Operative Time

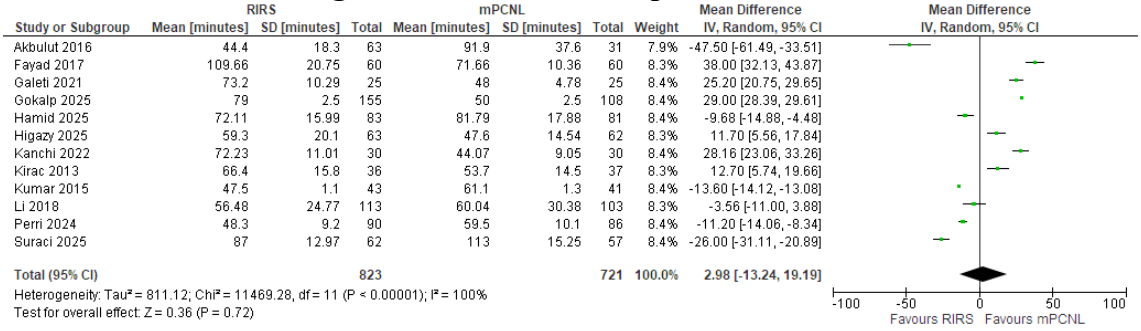

Table 5. Meta-analysis of Overall Complications

Outcome	Effect Size	95% CI	p-value	I^2
Overall Complications	RR = 0.75	0.62–0.92	0.005	31%

RIRS demonstrated a significantly lower risk of postoperative complications than mini-PCNL (RR=0.75; 95%CI 0.62–0.92; p=0.005), with low-to-moderate heterogeneity across studies (I^2=31%).

Discussion

This meta-analysis compared the efficacy and safety of Minimally Invasive Percutaneous Nephrolithotomy (mini-PCNL) and Retrograde Intrarenal Surgery (RIRS) in patients with renal stones measuring 10–20 mm. The findings demonstrated that mini-PCNL achieved a significantly higher stone-free rate, whereas RIRS was associated with a shorter hospital stay and lower complication rates. No significant difference was observed in operative time. These findings highlight the ongoing trade-off between maximal stone clearance and procedural invasiveness in the management of medium-sized renal calculi.

The principal finding of this study was the significantly higher stone-free rate achieved with mini-PCNL compared with RIRS. This result is consistent with previous comparative studies and meta-analyses demonstrating the superiority of percutaneous approaches in achieving complete stone clearance (12–16).

The advantage of mini-PCNL is largely attributable to its direct access to the pelvicalyceal system, allowing both stone fragmentation and active extraction of residual fragments. In contrast, RIRS relies primarily on laser fragmentation and spontaneous passage of stone debris. Consequently, mini-PCNL provides a greater likelihood of complete stone removal within a single session. The present findings reinforce previous evidence suggesting that mini-PCNL remains one of the most effective interventions for achieving stone-free status in patients with renal stones measuring 10–20 mm. Nevertheless, differences in stone-free definitions and imaging modalities across studies should be considered when interpreting pooled estimates.

RIRS demonstrated a significantly shorter hospital stay than mini-PCNL. This finding reflects the minimally invasive nature of RIRS, which avoids percutaneous access through the renal parenchyma and consequently reduces tissue trauma, postoperative pain, and recovery requirements. These results are consistent with previous studies and recent meta-analyses reporting shorter hospitalization among patients undergoing RIRS. However, the substantial heterogeneity observed indicates that hospital stay is influenced not only by the surgical procedure itself but also by discharge protocols, healthcare systems, patient characteristics, and institutional practices.

No significant difference in operative time was observed between mini-PCNL and RIRS. Operative duration is influenced by multiple variables including stone size and location, access complexity, fragmentation strategy, laser technology, surgeon expertise, and procedural workflow. The conflicting findings reported in previous studies further suggest that operative time is highly context-dependent and may not represent a reliable standalone criterion for selecting the optimal treatment modality.

The present analysis demonstrated a significantly lower complication rate with RIRS compared with mini-PCNL. This observation is biologically plausible because RIRS utilizes a natural orifice approach and avoids direct penetration of the renal parenchyma. Complications associated with mini-PCNL commonly include bleeding, hemoglobin decline, transfusion requirements, postoperative pain, and access-related adverse events. Although tract miniaturization has reduced morbidity relative to standard PCNL, procedural invasiveness remains greater than that of RIRS.

Conversely, complications following RIRS are generally mild and consist primarily of transient hematuria, urinary tract infection, fever, stent-related symptoms, and minor ureteral trauma. Major complications are relatively uncommon. These findings support the role of RIRS as a safer therapeutic option, particularly in patients with elevated surgical risk.

The findings of this study indicate that neither procedure is universally superior across all clinical outcomes. Mini-PCNL offers superior stone clearance, whereas RIRS provides faster recovery and improved perioperative safety. Therefore, treatment selection should be individualized according to stone characteristics, patient comorbidities, bleeding risk, anatomical considerations, healthcare resources, and patient preferences. Mini-PCNL may be preferred when achieving complete stone clearance in a single session is the primary objective, whereas RIRS may be favored when minimizing invasiveness, hospitalization, and complications is of greater importance.

Study Limitations

Several limitations should be acknowledged. First, significant heterogeneity was observed in some outcomes, particularly length of hospital stay and operative time. Second, definitions of stone-free status varied among studies, potentially affecting pooled estimates. Third, the analysis included both randomized controlled trials and observational studies, introducing methodological variability. Finally, subgroup analyses based on stone location, stone density, laser technology, and surgeon experience could not be performed because of

insufficient data. Despite these limitations, the large pooled sample size and consistency of findings across key outcomes provide robust evidence that mini-PCNL offers superior stone clearance, whereas RIRS provides advantages in postoperative recovery and perioperative safety.

Conclusion

This meta-analysis demonstrated that Minimally Invasive Percutaneous Nephrolithotomy (mini-PCNL) achieves a significantly higher stone-free rate than Retrograde Intrarenal Surgery (RIRS) in patients with renal stones measuring 10–20 mm. These findings indicate that mini-PCNL provides superior stone clearance and may be the preferred treatment option when complete stone removal in a single procedure is the primary therapeutic goal.

In contrast, RIRS was associated with a shorter hospital stay and lower overall complication rate compared with mini-PCNL, while no significant difference was observed in operative time between the two procedures. These results suggest that RIRS offers advantages in perioperative safety and postoperative recovery, making it an attractive option for patients who require a less invasive approach or have increased surgical risk.

Overall, both mini-PCNL and RIRS are effective and safe treatment modalities for renal stones measuring 10–20 mm. Treatment selection should be individualized according to stone characteristics, patient-related factors, risk of complications, and clinical priorities. While mini-PCNL provides superior stone clearance, RIRS offers benefits in terms of safety and faster recovery, supporting a patient-centered approach to surgical decision-making.

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