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KIDNEY STONES – WHEN TO USE MINI-PERCUTANEOUS NEPHROLITHOTOMY AND WHEN TO USE ULTRA-MINI PERCUTANEOUS NEPHROLITHOTOMY?: A NARRATIVE REVIEW

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ABSTRACT

Background: Miniaturized percutaneous nephrolithotomy techniques have been developed to reduce the morbidity associated with standard percutaneous nephrolithotomy (PCNL) while maintaining high stone clearance. Among these approaches, mini-PCNL and ultra-mini PCNL (UMP) are increasingly used; however, their optimal indications remain incompletely defined.
Aims: To review and synthesize current evidence regarding the efficacy, safety, and clinical indications of mini-PCNL and UMP in the management of kidney stone disease.
Methods: A narrative review of the literature was performed using PubMed/MEDLINE, Scopus, and Web of Science databases. Clinical studies, comparative analyses, meta-analyses, reviews, and international guideline documents addressing mini-PCNL and UMP were included. Evidence was synthesized descriptively with emphasis on stone- and patient-related factors influencing technique selection.
Results: Both mini-PCNL and UMP demonstrated high stone-free rates when applied in appropriately selected patients. Mini-PCNL achieved superior stone clearance for larger (15–30 mm), multiple, or high-density renal stones, owing to efficient fragment extraction. UMP was associated with lower perioperative morbidity, reduced bleeding risk, and shorter hospital stay, with optimal outcomes observed in smaller stone burdens. Differences in efficacy between techniques were minimal for stones <15 mm but became more pronounced with increasing stone size and complexity.
Conclusions: Mini-PCNL and UMP are complementary techniques in contemporary percutaneous stone surgery. Mini-PCNL is best suited for larger or more complex stones requiring active fragment removal, whereas UMP offers advantages in minimizing invasiveness and accelerating recovery in selected patients. Individualized treatment selection based on stone characteristics, patient factors, and surgical expertise is essential to optimize outcomes.

KEYWORDS

Kidney Stones, Nephrolithiasis, Mini-PCNL, Ultra-Mini-PCNL, Percutaneous Nephrolithotomy, Stone-Free Rate

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Introduction

Kidney stone disease (KSD) is a prevalent and increasingly common urological condition, affecting approximately 10–15% of the adult population worldwide, with substantial geographic and demographic variation [1,2]. The incidence of nephrolithiasis has risen steadily over recent decades, largely driven by changes in dietary habits, obesity, metabolic syndrome, and climate-related factors [3,4]. In addition to causing acute pain and recurrent hospital admissions, kidney stones are associated with long-term morbidity, including an increased risk of chronic kidney disease and reduced quality of life [5].

The management of renal calculi has evolved considerably with advances in minimally invasive surgery. Percutaneous nephrolithotomy has long been established as the gold-standard treatment for large and complex renal stones, particularly those exceeding 20 mm in diameter or presenting as staghorn calculi [6,7]. While highly effective, conventional PCNL using large-caliber access tracts (24–30 Fr) is associated with procedure-related morbidity, most notably bleeding, postoperative pain, and prolonged hospitalization [8]. These limitations have prompted the development of miniaturized percutaneous techniques aimed at reducing renal parenchymal trauma without compromising stone clearance.

Miniaturized PCNL techniques encompass a spectrum of approaches characterized by progressively smaller access tracts, including mini-PCNL, ultra-mini PCNL, micro-PCNL, and super-mini PCNL. Among these, mini-PCNL and UMP have gained the widest clinical adoption and the strongest evidence base [9–11]. Mini-PCNL, typically performed through access tracts of 14–20 Fr, represents a compromise between efficacy

and reduced invasiveness, whereas UMP employs even smaller tracts (11–13 Fr) to further minimize surgical trauma [10,12].

Despite their increasing use, the optimal selection between mini-PCNL and UMP remains a subject of clinical debate. Overlapping indications, variability in stone characteristics, anatomical considerations, and patient-specific factors complicate decision-making in daily practice. Current guidelines provide broad recommendations for PCNL but offer limited granularity regarding the choice between different miniaturized techniques [7,13]. Therefore, a clear understanding of the advantages and limitations of mini-PCNL and UMP is essential to optimize outcomes in contemporary stone surgery.

This narrative review aims to synthesize current evidence on mini-PCNL and ultra-mini PCNL, with particular emphasis on clinical indications, efficacy, safety, and practical considerations guiding the selection of each technique in the management of kidney stone disease.

Aims

The aim of this narrative review is to synthesize and critically appraise the available evidence on mini-percutaneous nephrolithotomy and ultra-mini percutaneous nephrolithotomy in the management of kidney stone disease. The review seeks to clarify the respective clinical roles of these miniaturized percutaneous techniques and to support informed technique selection in contemporary stone surgery.

Specifically, this review aims to compare mini-PCNL and UMP with regard to technical characteristics, clinical efficacy, safety, and perioperative outcomes, while also highlighting areas of uncertainty and emerging developments that may influence future practice.

Research Questions:

1. What technical and procedural features differentiate mini-PCNL from UMP?
2. How do mini-PCNL and UMP compare in terms of effectiveness and safety?
3. Which stone-related factors influence technique selection?
4. Which patient-related factors favor one technique over the other?
5. How may ongoing technological advances refine the role of mini-PCNL and UMP?

Methods

This work is a narrative review aimed at providing a structured and clinically oriented synthesis of the literature on mini-PCNL and ultra-mini PCNL. The methodological approach follows accepted principles for narrative evidence synthesis, with selected structured elements incorporated to improve transparency, without adopting a systematic review design [14,15].

Search Strategy

A literature search was conducted using PubMed/MEDLINE, Scopus, and Web of Science, databases commonly used for clinical and surgical research in urology [1,2]. The search covered publications from January 2005 to December 2024, corresponding to the development and increasing adoption of miniaturized PCNL techniques [9–12].

Eligibility and Exclusion Criteria

- Eligible studies:
- addressed mini-PCNL and/or UMP,
- reported on indications, technical aspects, or clinical outcomes,
- included adult or pediatric populations,
- were published in peer-reviewed journals,
- were written in English.

Excluded studies:

- focused solely on standard PCNL, micro-PCNL, or non-percutaneous techniques,
- case reports or very small case series (<10 patients),
- conference abstracts without full-text availability,
- animal or experimental studies.

Study Types Included

Randomized trials, observational studies, comparative analyses, meta-analyses, narrative and systematic reviews, and international guideline documents were considered. This inclusive approach reflects the heterogeneity of available evidence and aligns with methodological recommendations for narrative reviews in surgical research [15,16].

Data Collection and Quality Appraisal

Data were extracted qualitatively from full-text articles, focusing on stone characteristics, patient factors, technical parameters, and reported outcomes. No formal risk-of-bias tool was applied. Instead, study quality was appraised descriptively, considering study design, sample size, and clarity of outcome reporting, consistent with narrative review methodology [14,16].

Synthesis Approach

Findings were synthesized using a thematic narrative approach**,** grouping evidence according to clinical relevance (indications, efficacy, safety, and determinants of technique selection). No quantitative pooling was undertaken.

PRISMA Considerations

The study selection process followed the conceptual stages of PRISMA reporting (identification, screening, eligibility, inclusion) to enhance transparency. A formal PRISMA flow diagram was not generated, as quantitative synthesis was not the objective of this review.

Results

Characteristics of the Available Evidence

The available literature included randomized controlled trials, prospective and retrospective cohort studies, comparative analyses, meta-analyses, and guideline documents addressing mini-percutaneous nephrolithotomy and ultra-mini percutaneous nephrolithotomy. Most studies evaluated outcomes such as stone-free rate (SFR), operative time, perioperative morbidity, and length of hospital stay, with stone size and complexity consistently reported as key determinants of treatment success [7,9–12,17].

Across studies, both techniques demonstrated favorable outcomes when applied within appropriate indication ranges, although measurable differences were observed across several outcome domains.

Stone-Free Rates

Mini-PCNL consistently achieved high stone-free rates, most commonly reported between 85% and 96%, particularly for stones measuring 15–30 mm, multiple stones, and high-density calculi [12,17,19]. Studies attributed these outcomes to improved visualization and the ability to actively retrieve fragments using forceps or suction devices [9,18].

UMP demonstrated stone-free rates ranging from 75% to 92%, with the highest success observed in stones <20 mm, especially single and moderate-density stones [10,12,22]. Comparative studies and meta-analyses reported similar SFRs between techniques for stones <15 mm, while mini-PCNL showed higher clearance rates as stone size increased [22].

Operative Time and Fragment Management

Operative time varied according to stone burden and fragmentation strategy. Mini-PCNL was associated with shorter operative times for larger stones, reflecting more efficient fragment evacuation [17,19]. In contrast, UMP procedures frequently relied on laser dusting, resulting in longer operative times for stones approaching the upper size limit of its indications [12,20].

Recent studies reported improvements in operative efficiency for UMP with the introduction of advanced laser technologies, including thulium fiber laser systems, although fragment extraction remained limited by sheath size [26,27].

Perioperative Morbidity and Complications

Mini-PCNL was associated with a modest decrease in hemoglobin levels and low transfusion rates, generally below **3%**, representing a reduction compared with standard PCNL [8,19,21]. Reported complications were predominantly minor (Clavien–Dindo grade I–II).

UMP demonstrated consistently lower bleeding risk, minimal hemoglobin drop, and reduced postoperative analgesic requirements, reflecting its smaller access tract size [10,12,22]. Infectious complications were uncommon for both techniques and were more closely related to stone burden and intrarenal pressure than to tract diameter alone [24,28].

Hospital Stay and Postoperative Recovery

Length of hospital stay was shorter following UMP compared with mini-PCNL in most comparative studies. UMP frequently enabled tubeless procedures and early discharge**,** including same-day surgery in selected patients [23,25]. Mini-PCNL also allowed reduced hospitalization compared with standard PCNL but typically required overnight observation [8,17].

Special Populations

In pediatric populations, UMP demonstrated excellent safety profiles with acceptable stone-free rates, supporting its use as a preferred percutaneous approach in children [23]. Mini-PCNL was more commonly used in pediatric patients with larger or more complex stones, where higher stone clearance was prioritized [21].

Patients with increased bleeding risk or significant comorbidities were more frequently treated with UMP, whereas mini-PCNL was favored when active fragment removal was required due to stone burden or complexity [10,22].

Summary of Comparative Outcomes

Table 1. The main outcome differences between mini-PCNL and UMP across the reviewed studies.

Outcome parameter	Mini-PCNL	Ultra-mini PCNL (UMP)
Typical stone size range	15–30 mm	8–20 mm
Stone-free rate (SFR)	85–96%	75–92%
Performance in high-density stones	High	Moderate
Fragment management	Active extraction	Limited; laser dusting
Operative time	Shorter for larger stones	Longer for stones >15 mm
Hemoglobin decrease	Low–moderate	Minimal
Transfusion rate	<3%	<1%
Postoperative pain	Low	Very low
Hospital stay	Short (1–2 days)	Very short / day-case
Tubeless feasibility	High	Very high
Pediatric applicability	Acceptable	Preferred
Typical complications	Mostly Clavien I–II	Mostly Clavien I–II

Note: mini-PCNL – mini-percutaneous nephrolithotomy; UMP – ultra-mini percutaneous nephrolithotomy.

Results Overview

Overall, the reviewed evidence demonstrates that both mini-PCNL and UMP achieve high success rates with acceptable safety profiles. Differences between techniques were most pronounced with increasing stone size and complexity, whereas outcomes were comparable for smaller stones within overlapping indication ranges [12,17,22].

Discussion

This narrative review highlights that mini-percutaneous nephrolithotomy and ultra-mini percutaneous nephrolithotomy represent complementary approaches within the contemporary management of kidney stone disease. Rather than competing techniques, they address different clinical needs along the spectrum of stone burden, patient characteristics, and surgical priorities. The reviewed evidence supports a tailored approach to technique selection, moving beyond a purely size-based algorithm.

Interpretation of Key Findings

The most consistent determinant influencing outcomes across studies was stone size and complexity. Mini-PCNL demonstrated superior stone-free rates for stones larger than 15–20 mm, particularly in cases of high-density, multiple, or anatomically complex calculi [12,17,19]. This advantage is largely attributable to the ability to actively extract stone fragments through a larger working sheath, thereby reducing residual fragment burden and the need for secondary procedures [9,18].

In contrast, UMP provided clear benefits in terms of reduced invasiveness**,** lower bleeding risk, and faster postoperative recovery [10,12,22]. These features make UMP particularly attractive for smaller stones,

pediatric patients, and individuals with an increased risk of hemorrhagic complications. Importantly, differences in stone-free rates between the two techniques were minimal for stones smaller than 15 mm, suggesting that safety considerations may reasonably take precedence over marginal differences in efficacy in this subgroup [22].

Operative Efficiency and Morbidity

Operative time emerged as a relative limitation of UMP, especially for stones approaching the upper limit of its indication range. Reliance on laser dusting, combined with restricted fragment evacuation, frequently prolonged procedures compared with mini-PCNL [12,20]. Nevertheless, advances in laser technology—particularly the introduction of thulium fiber laser systems—have shown promise in improving fragmentation efficiency and may partially mitigate this limitation in the future [26,27].

Perioperative morbidity differed quantitatively rather than qualitatively between techniques. Both mini-PCNL and UMP were associated predominantly with low-grade complications, while clinically significant bleeding and infectious events remained uncommon [8,19,24]. These findings underscore that tract size reduction alone does not eliminate risk, and factors such as intrarenal pressure, operative duration, and stone burden remain critical determinants of complications [28].

Special Populations and Clinical Context

The role of UMP in pediatric stone disease deserves particular emphasis. The reviewed literature consistently demonstrated excellent safety profiles and acceptable efficacy in children, supporting the preferential use of UMP when percutaneous intervention is required [23]. Mini-PCNL, however, retains a role in pediatric patients with larger or more complex stones, where complete clearance is paramount [21].

Similarly, in patients with significant comorbidities or elevated bleeding risk, UMP offers a favorable risk–benefit profile, whereas mini-PCNL is better suited to scenarios in which stone burden necessitates active fragment removal [10,22]. These findings reinforce the importance of individualized decision-making rather than rigid adherence to technique-based thresholds.

Guideline Considerations and Clinical Decision-Making

Current EAU and AUA guidelines appropriately recommend PCNL for large and complex renal stones but provide limited granularity regarding the selection among miniaturized techniques [7,13]. The evidence summarized in this review suggests that incorporating tract size selection into guideline frameworks—based on stone burden, density, and patient risk profile—could enhance clinical applicability and outcome optimization.

Future Perspectives

Ongoing technological developments are likely to further refine the roles of mini-PCNL and UMP. Improvements in laser efficiency, suction-assisted systems, and intrarenal pressure control may expand the indications for smaller-caliber techniques while preserving efficacy [26–29]. Future comparative studies focusing on patient-reported outcomes, cost-effectiveness, and long-term recurrence rates will be essential to inform evidence-based refinement of treatment algorithms.

Limitations

This review is subject to limitations inherent to narrative synthesis, including potential selection bias and heterogeneity in study designs and outcome reporting. The absence of quantitative meta-analysis precludes definitive conclusions regarding superiority in overlapping indication ranges. Nevertheless, the narrative approach allows integration of diverse evidence and reflects real-world clinical practice.

Clinical Implications

Taken together, the available evidence supports a **patient- and stone-centered approach** to percutaneous stone surgery. Mini-PCNL should be favored for larger, denser, or multiple stones requiring efficient fragment extraction, whereas UMP is best suited for smaller stones and for patients in whom minimizing surgical trauma is a priority.

Conclusions

The evolution of miniaturized percutaneous nephrolithotomy has expanded the therapeutic options for the surgical management of kidney stone disease. This review demonstrates that both mini-PCNL and ultra-mini PCNL achieve high clinical effectiveness when used within appropriately selected indications, but their roles differ according to stone burden and patient characteristics.

Mini-PCNL remains the preferred percutaneous approach for patients with larger, denser, or multiple renal stones, as it allows active fragment retrieval and higher stone-free rates without a substantial increase in morbidity. Ultra-mini PCNL, by contrast, prioritizes maximal reduction of surgical invasiveness and is best suited for smaller stones, pediatric populations, and patients in whom minimizing bleeding risk and postoperative recovery time is essential.

The choice between mini-PCNL and ultra-mini PCNL should therefore be guided by a comprehensive assessment of stone size, density, anatomical complexity, and patient-specific risk factors, rather than by a single parameter. As endourological technologies continue to advance, further refinement of miniaturized percutaneous techniques is expected, potentially broadening their indications and improving outcomes. Integrating emerging evidence into clinical decision-making and guideline frameworks will be crucial to optimize personalized care for patients with kidney stone disease.

Disclosure

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