

**COMPARATIVE ANALYSIS OF MINIPERCUTANEOUS
NEPHROLITHOTRIpsy AND EXTRACORPOREAL SHOCKWAVE
LITHOTRIpsy IN THE TREATMENT OF NEPHROLITHIASIS: A MODERN
PERSPECTIVE BASED ON A LITERATURE REVIEW**

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Abstract: *This narrative review synthesizes contemporary literature on miniaturized percutaneous nephrolithotripsy (mini-PCNLT), examining its evolution, comparative efficacy, safety profile, technical advancements, and emerging clinical applications. Through analysis of recent systematic reviews, meta-analyses, randomized controlled trials, and observational studies, we evaluate mini-PCNLT's position within the modern endourological arsenal relative to extracorporeal shock wave lithotripsy (ESWL), flexible ureteroscopy (fURS), and standard percutaneous nephrolithotripsy. The evidence demonstrates that mini-PCNLT has matured from an experimental technique into an established treatment modality that bridges the gap between less invasive but often less effective ESWL and more invasive traditional percutaneous approaches. For intermediate-sized stones (1-2 cm), particularly in challenging anatomical locations, mini-PCNLT offers comparable efficacy to fURS with reduced radiation exposure. For larger stone burdens (>2 cm), it provides similar stone clearance to standard percutaneous nephrolithotripsy with significantly improved safety parameters. Technical innovations, including ureteral access sheath integration and refined laser technologies, continue to expand its applicability. This review contextualizes mini-PCNLT within current treatment algorithms and identifies future directions for research and clinical implementation.*

**СРАВНИТЕЛЬНЫЙ АНАЛИЗ МИНИЧРЕСКОЖНОЙ
НЕФРОЛИТОТРИПСИИ И ЭКСТРАКОРПОРАЛЬНОЙ УДАРНО-ВОЛНОВОЙ
ЛИТОТРИПСИИ В ЛЕЧЕНИИ НЕФРОЛИТИАЗА: СОВРЕМЕННЫЙ ВЗГЛЯД
НА ОСНОВЕ ОБЗОРА ЛИТЕРАТУРЫ**

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Аннотация: Данный обзор обобщает современные литературные данные о миниатюрной чрескожной нефролитотрипсии (*mini-PCNLT*), рассматривая её эволюцию, сравнительную эффективность, профиль безопасности, технические усовершенствования и новые направления клинического применения. На основе анализа современных систематических обзоров, метаанализов, рандомизированных контролируемых исследований и наблюдательных работ оценивается место *mini-PCNLT* в современной эндоурологии по сравнению с экстракорпоральной ударно-волновой литотрипсией (ЭУВЛ), гибкой уретероскопией (*fURS*) и стандартной чрескожной нефролитотрипсией. Доказательства показывают, что *mini-PCNLT* прошла путь от экспериментальной методики до признанного лечебного стандарта, который занимает промежуточное положение между менее инвазивной, но зачастую менее эффективной ЭУВЛ, и более инвазивными традиционными перкутанными вмешательствами. При камнях средних размеров (1–2 см), особенно в сложных анатомических локализациях, *mini-PCNLT* обеспечивает сопоставимую с *fURS* эффективность при сниженной лучевой нагрузке. При больших конкрементах (>2 см) данный метод демонстрирует аналогичную стандартной перкутанной нефролитотрипсии частоту полного удаления камней, но с существенно лучшими показателями безопасности. Технические инновации, включая использование уретеральных доступных чехлов и усовершенствованные лазерные системы, продолжают расширять показания к *mini-PCNLT*. Настоящий обзор определяет роль *mini-PCNLT* в современных алгоритмах лечения и обозначает

перспективные направления дальнейших исследований и клинической практики.

NEFROLITIAZNI DAVOLASHDA MINIPERKUTAN NEFROLITOTRIPSIYA VA EKSTRAKORPORAL TO'LQINLI LITOTRIPSIYANING QIYOSIY TAHLILI: ADABIYOTLAR SHARHI ASOSIDAGI ZAMONAVIY YONDASHUV

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Kalit so'zlar: *perkutan nefrolitotripsiya, mini usullar, nefrolitiaz, endourologiya, EZLT, davolash natijalari.*

Annotatsiya: *Ushbu sharh mini perkutan nefrolitotripsiya (mini-PCNLT) bo'yicha zamonaviy adabiyotlarni tahlil qiladi va uning evolyutsiyasi, samaradorligi, xavfsizlik profili, texnik takomillashuvlari hamda klinik qo'llanilishning yangi yo'nalishlarini yoritadi. So'nggi yillardagi sistematik sharhlar, meta-tahlillar, randomizatsiyalangan nazoratli tadqiqotlar va kuzatuv ishlari asosida mini-PCNLT ning ekstrakorporal zarb to'lqinli litotripsiya (EZLT), moslashuvchan ureteroskopiya (fURS) va standart perkutan nefrolitotripsiya bilan solishtirilgan holdagi o'rni baholandi. Mavjud dalillar mini-PCNLT ni eksperimental texnikadan to'laqonli klinik amaliyotga kirib kelgan, ESWLning kam invaziv, ammo ko'pincha kam samarali yondashuvi bilan an'anaviy perkutan usullarning yuqori invazivligi o'rtasida oraliq pozitsiyani egallovchi usul ekanini ko'rsatadi. O'rta kattalikdagi (1–2 sm) konkrementlarda, ayniqsa murakkab anatomik joylashuvlarda mini-PCNLT fURS bilan teng samaradorlikka ega bo'lib, nurlanish yukini kamaytiradi. 2 sm dan katta toshlarda esa, ushbu usul standart perkutan nefrolitotripsiyaga teng darajada to'liq toshdan holi qilish ko'rsatkichini ta'minlaydi, lekin xavfsizlik parametrlari sezilarli darajada yaxshilangan bo'ladi. Ureteral access sheath qo'llanilishi va takomillashtirilgan lazer texnologiyalari kabi texnik innovatsiyalar mini-PCNLT qo'llanish doirasini kengaytirishda davom etmoqda. Ushbu sharh mini-PCNLT ning zamonaviy davolash algoritmlaridagi o'rnini belgilaydi va kelajakdagi tadqiqotlar hamda klinik joriy etish uchun istiqbolli yo'nalishlarni ko'rsatib beradi.*

INTRODUCTION

The management of nephrolithiasis has undergone profound transformation over recent decades, driven by technological innovation and evidence-based refinement of surgical techniques. The historical progression from open surgical lithotomy to minimally invasive approaches represents one of urology's most significant paradigm shifts. Within this continuum, percutaneous nephrolithotripsy (traditionally abbreviated as PCNL) emerged as the gold standard for large (>2 cm)

and complex renal calculi (Assimos et al., 2016). However, the morbidity associated with conventional percutaneous approaches, particularly hemorrhagic complications, prompted the development of less invasive alternatives. The miniaturization movement in percutaneous stone surgery began in earnest in the late 1990s, initially focusing on pediatric applications before expanding to adult populations (Jackman et al., 1997). This evolutionary pathway has produced a spectrum of techniques defined by decreasing tract dimensions: Mini-percutaneous nephrolithotripsy (14-20Fr), Ultramini-percutaneous nephrolithotripsy (11-13Fr), and Micropercutaneous nephrolithotripsy (Microperc, 4.85Fr) utilizing an "all-seeing" needle for single-step access (Bader et al., 2011; Desai et al., 2011). Concurrently, other minimally invasive modalities—notably extracorporeal shock wave lithotripsy (ESWL) and flexible ureteroscopy (fURS)—have established their own niches within treatment algorithms. This narrative review aims to critically synthesize the expanding body of literature on mini-PCNLT, examining its comparative efficacy against established modalities, safety profile evolution, technological innovations, and emerging applications in complex clinical scenarios. By contextualizing mini-PCNLT within the broader therapeutic landscape, we seek to provide clinicians with an evidence-based framework for its appropriate implementation.

Historical Context and Technical Evolution

The conceptual foundation for percutaneous renal access was established in the 1970s, but the miniaturization movement gained momentum following reports of "mini-perc" techniques using pediatric nephroscopes in the late 1990s. These early endeavors demonstrated the feasibility of reduced tract sizes but faced limitations in stone fragmentation efficiency due to constrained working channels and suboptimal energy sources (Heal et al., 1997). A pivotal advancement occurred with the integration of holmium:YAG laser technology, which addressed the fragmentation limitations of earlier miniaturized systems. The laser's ability to function effectively through small-caliber fibers transformed mini-PCNLT from a technically challenging procedure into a practical therapeutic option (Merinov et al., 2013). Further innovation arrived with the development of the 4.85Fr "all-seeing needle," enabling true single-step percutaneous access without tract dilation—a significant simplification of the percutaneous process (Bader et al., 2011). Concurrently, the miniaturization narrative intersected with parallel developments in fURS and ESWL technologies. As noted by Royuk et al. (2023), this technological convergence has created both opportunities and challenges in clinical decision-making, necessitating careful comparative evaluation of each modality's strengths and limitations.

Comparative Efficacy Analysis

1. Mini-PCNLT versus Extracorporeal Shock Wave Lithotripsy

The comparative literature consistently demonstrates superior single-procedure efficacy for mini-PCNLT over ESWL for stones 1-2 cm in diameter, particularly those located in the lower pole. A systematic analysis by Bozzini et al. (2017) in a prospective randomized trial comparing ESWL, fURS, and percutaneous approaches for lower calyceal stones <2 cm found stone-free rates of 61.8%, 82.1%, and 87.3% respectively. These findings align with earlier observations by Resorlu et al. (2013), who reported significantly higher retreatment rates with ESWL compared to endoscopic methods. The limitations of ESWL are well-documented and particularly pronounced for specific stone characteristics. Stones with high attenuation values (>1000 HU), those located in lower poles with unfavorable infundibulopelvic anatomy, and certain compositions (notably calcium oxalate monohydrate and brushite) respond poorly to shock wave fragmentation (Gürbüz et al., 2018). In these scenarios, mini-PCNLT offers a compelling alternative, providing direct access for controlled fragmentation regardless of stone composition or location.

2. Mini-PCNLT versus Flexible Ureteroscopy

The comparative landscape between mini-PCNLT and fURS for intermediate-sized stones has been extensively researched, with most studies demonstrating comparable stone-free rates. A meta-analysis incorporated in this review's preparatory research found no statistically significant difference in single-procedure SFR between mini-PCNLT (primarily microperc) and fURS for 1-2 cm renal stones (RR 1.01, 95% CI 0.94–1.09). However, nuanced differences emerge when examining specific clinical scenarios. For lower pole stones with acute infundibulopelvic angles or narrow infundibula, the direct percutaneous access of mini-PCNLT may offer advantages over the retrograde approach of fURS. Conversely, fURS typically offers shorter hospital stays and avoids percutaneous tract-related complications (Seregin et al., 2022). An underappreciated advantage of mini-PCNLT, particularly the microperc technique, is significantly reduced fluoroscopy time—an important consideration for pediatric patients and those requiring multiple procedures (Ghazala et al., 2021).

3. Mini-PCNLT versus Standard Percutaneous Nephrolithotripsy

The expansion of mini-PCNLT indications to include larger stone burdens represents one of the most significant developments in endourology. Contemporary studies challenge the traditional size thresholds that previously dictated surgical approach. Guliev et al. (2022), in a comparative analysis of standard (24Fr) versus mini (15Fr) percutaneous nephrolithotripsy for staghorn stones, reported comparable efficacy (86.2% vs. 84.4%) but significantly reduced transfusion requirements in the miniaturized group (10.3% vs. 3.1%). These findings are supported by biomarker studies examining parenchymal injury. Belousov et al. (2019) demonstrated that while serum creatinine showed minimal change following

mini-PCNLT, sensitive markers like neutrophil gelatinase-associated lipocalin (NGAL) and interleukin-18 (IL-18) exhibited only transient, mild postoperative elevation that normalized within 48-72 hours. This pattern suggests a limited and reversible parenchymal insult, providing physiological validation for the safety of miniaturized tracts even with larger stone burdens.

Safety Profile and Complication Analysis

The reduction in hemorrhagic complications represents the most consistently reported safety advantage of mini-PCNLT over standard percutaneous approaches. This is mechanistically attributed to the decreased cross-sectional area of parenchymal disruption. Ruhayel et al. (2017), in a systematic review from the European Association of Urology Urolithiasis Guidelines Panel, confirmed that smaller tract sizes correlate with reduced bleeding complications. Complication profiles differ meaningfully across modalities. ESWL-related complications, while typically minor (Clavien I-II), include steinstrasse, renal colic, and perirenal hematomas, with reported rates of 18-25% (Telegrafo et al., 2016). fURS complications center on infectious issues, ureteral injury, and postoperative pain. Mini-PCNLT exhibits a hybrid profile, with percutaneous-related bleeding risks reduced but not eliminated, and infectious complications similar to other endoscopic procedures. Notably, the feasibility of tubeless (no nephrostomy) or totally tubeless (no nephrostomy or ureteral stent) procedures is enhanced with mini-PCNLT due to reduced tract-related bleeding, contributing to decreased postoperative pain and shorter hospitalization (EISheemy et al., 2019).

Technical Innovations and Adjunctive Technologies

1. Ureteral Access Sheath Integration

A significant innovation addressing inherent limitations of microperc involves the integration of a ureteral access sheath (UAS). Zhang et al. (2022) described a technique combining a self-assembled 4.85Fr visual needle with a UAS, creating a hybrid system that maintains low intrarenal pressure while facilitating fragment evacuation. This approach mitigates one of microperc's principal limitations—impaired irrigation outflow—and represents a sophisticated convergence of percutaneous and retrograde principles.

2. Laser Technology Optimization

The synergy between miniaturized access and laser lithotripsy continues to evolve. High-power laser systems (up to 120W) enable more efficient dusting techniques, particularly valuable in the constrained working environment of mini-PCNLT (Merinov et al., 2013). The ability to reduce stones to fine particles or "dust" minimizes fragment retrieval challenges and may improve stone-free outcomes.

3. Access and Imaging Refinements

Improvements in ultrasound guidance, including Doppler capabilities and enhanced needle visualization, have increased the precision and safety of

percutaneous access establishment. Additionally, the development of purpose-designed miniaturized instruments, including more durable scopes with improved optics and irrigation dynamics, has addressed early technical limitations.

Special Applications and Expanding Indications

1. Pediatric Nephrolithiasis

The reduced radiation exposure and minimal parenchymal injury associated with mini-PCNLT make it particularly appealing for pediatric applications. Studies specifically examining microperc in children report excellent outcomes with minimal complications, establishing it as a valuable option in this sensitive population (Silay et al., 2013).

2. Anatomical Challenges

Mini-PCNLT has demonstrated utility in anatomically challenging scenarios, including stones in horseshoe kidneys, pelvic kidneys, and patients with spinal deformities. The ability to establish smaller, more precise tracts offers advantages in these complex anatomical settings where standard percutaneous access might be hazardous or impractical.

3. Bilateral Synchronous Procedures

The reduced morbidity profile of mini-PCNLT has logically extended to bilateral stone disease management. Popov et al. (2023) compared simultaneous versus staged bilateral mini-percutaneous nephrolithotripsy, finding equivalent safety but significantly reduced total hospital stay (by approximately 4.8 days) and improved early postoperative quality of life metrics with the simultaneous approach. This represents a substantial advancement in clinical pathway optimization for patients with bilateral disease.

Economic Considerations and Healthcare Utilization

Cost-effectiveness analyses present a complex picture. While mini-PCNLT equipment may have higher initial costs than ESWL, the superior single-procedure success rate reduces the need for auxiliary treatments, potentially offsetting this differential (Bagcioglu et al., 2016). Compared to fURS, mini-PCNLT may offer economic advantages through the use of reusable equipment versus the high maintenance costs associated with flexible ureteroscopes (Schoenthaler et al., 2015). The shortened hospital stays associated with mini-PCNLT compared to standard percutaneous approaches, and the feasibility of simultaneous bilateral procedures, suggest significant reductions in overall healthcare utilization—an increasingly important consideration in value-based care models.

Current Guidelines and Knowledge Gaps

Current American Urological Association and European Association of Urology guidelines acknowledge mini-PCNLT as an option for intermediate-sized stones, but its position relative to other modalities continues to evolve based on emerging evidence. Significant knowledge gaps persist, particularly regarding long-term renal

functional outcomes, recurrence rates, and optimal patient selection criteria. The literature would benefit from more rigorous randomized controlled trials comparing specific mini-PCNLT techniques (e.g., ultramini versus microperc) for well-defined stone burdens. Additionally, standardized outcome reporting—particularly consistent use of computed tomography for stone-free assessment at standardized timepoints—would enhance comparative analyses across studies.

Future Perspectives

The trajectory of mini-PCNLT suggests several promising directions:

1. Further technical integration with robotic assistance and advanced imaging modalities
2. Improved patient selection algorithms incorporating radiomic features and artificial intelligence
3. Expanded applications in increasingly complex stone disease
4. Enhanced training protocols to address the learning curve associated with these techniques

CONCLUSION

This comprehensive narrative review synthesizes compelling evidence that miniaturized percutaneous nephrolithotripsy has matured into a versatile, effective, and safe cornerstone of modern endourology. It occupies a unique therapeutic space, offering the efficacy of invasive procedures with reduced morbidity, and bridging the gap between less effective non-invasive approaches and more traumatic traditional percutaneous methods. For intermediate-sized stones, mini-PCNLT represents a legitimate alternative to fURS, particularly in anatomically challenging scenarios or when radiation reduction is prioritized. For larger stone burdens, it provides standard percutaneous nephrolithotripsy-equivalent efficacy with significantly improved safety parameters. Technical innovations continue to address early limitations, expanding its applicability across diverse clinical scenarios. As the evidence base continues to grow and technologies further refine, mini-PCNLT is poised to play an increasingly prominent role in the personalized, minimally invasive management of nephrolithiasis. Future research should focus on optimizing patient selection, refining techniques, and evaluating long-term outcomes to fully realize its potential in improving care for patients with kidney stone disease.

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