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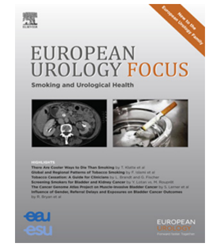

Review – Stone Disease

A Critical Review of Miniaturised Percutaneous Nephrolithotomy: Is Smaller Better?

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Abstract

Context: In an effort to reduce morbidity related to percutaneous nephrolithotomy (PCNL), some investigators have progressively introduced miniaturised approaches. The development of miniaturised nephroscopes facilitated widespread dissemination of these techniques and a significant expansion of the role of PCNL in endourology.
Objective: To discuss the different techniques comprising modern PCNL and identify the pros and cons of each of them.
Evidence acquisition: Data for this review were identified through a search of PubMed, including studies published in the last 20 yr in core clinical journals in English. The search terms included "urolithiasis", "nephrolithiasis", or "urinary stones" in combination with "miniaturised PCNL", "mini-PCNL", "micro-PCNL", "minimally invasive PCNL", and "ultra-mini PCNL". Publications relevant to the subject were retrieved and critically appraised.
Evidence synthesis: The indications for miniaturised PCNL have not been standardised yet. Even though data in the literature reveal limitations and conflicting results, these techniques seem promising in terms of effectiveness and safety for the treatment of renal stones. The development of miniaturised scopes facilitated knowledge of the physics behind the vacuum cleaner effect generated during procedures, and greater efficacy of holmium laser generators and surgeon skill have led to progressive expansion of the indications for miniaturised techniques. Well-designed, randomised, multi-institutional studies are needed to better understand the indications for these miniaturised techniques before considering them a standard procedure for potential replacement of conventional PCNL.
Conclusions: Miniaturised PCNL represents a valuable new tool in the armamentarium of modern endourologists, capable of offering good outcomes with lower complications rates compared to the standard technique and higher cost effectiveness compared to flexible ureteroscopy.
Patient summary: Miniaturised percutaneous nephrolithotomy represents a safe and effective alternative to standard techniques for the treatment of renal stones. Each patient needs to be considered individually and tailored surgical treatment has to be offered.

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1. Introduction

After decades in which open surgery was the only solution for treating renal stones, Fernstrom and Johansson [1] achieved a breakthrough in 1976, when the carried out percutaneous nephrolithotomy (PCNL) in the prone position for the first time in three patients with renal stones who were unfit for open surgery.

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Since then, relentless advances in the endourology armamentarium, downsizing of instrumentation, refinement of different lithotripters, progress in imaging techniques, and increasing requests for minimally invasive procedures have made PCNL one of the mainstays of modern endourology, even after the advent of other competitive and less invasive treatment modalities such has shock wave lithotripsy and, more recently, flexible ureteroscopy (fURS). This was possible because PCNL underwent relentless evolution over the years, aimed at reducing its invasiveness and complication rates and improving outcomes [2–7].

Despite these advances, PCNL remains a challenging procedure with associated morbidity. Postoperative sepsis (2%), fever (10–16%), blood transfusion (3–6%), significant bleeding (8%), and perforation of adjacent organs (0.4%) are still important complications after PCNL [8,9]. In an effort to reduce this morbidity, paralleling what happened in paediatric endourology [4], some investigators have progressively introduced miniaturised instruments. After initial scepticism regarding its potential [10], the development of dedicated miniaturised nephroscopes facilitated widespread dissemination of the technique and significant expansion of the role of PCNL in endourology. But the question then arises as to whether smaller is better.

The aim of this review is to discuss the different techniques comprising modern PCNL and identify the pros and cons of each of them.

2. Evidence acquisition

Data for this nonsystematic review were identified through a search of PubMed, including studies published in the last 20 yr in core clinical journals in English. The search terms included "urolithiasis", "nephrolithiasis", or "urinary stones" in combination with the terms "miniaturised PCNL", "mini-PCNL", "micro-PCNL", "minimally invasive PCNL", and "ultra-mini PCNL".

Study selection was based on an independent review process by two authors (S.P., G.G.) after the structured data search. The list of articles was augmented with significant manuscripts not previously found in this search or outside the time period of the initial search and identified via extensive cross-checking of the reference lists from the selected articles and from previous reviews. Publications relevant to the subject were retrieved and critically appraised.

3. Evidence synthesis

The indications for miniaturised PCNL have not been standardised yet. Even though data in the literature show limitations and conflicting results, these techniques seem promising in terms of both effectiveness and safety for the treatment of renal stones.

The development of dedicated miniaturised scopes facilitated knowledge of the physics behind the vacuum cleaner effect generated during procedures, and the greater efficacy of holmium laser generators and surgeon skill have led to progressive expansion of the indications for miniaturised techniques. Well-designed, randomised, multi-institutional studies are needed to better understand the indications for these miniaturised techniques before considering them a standardised procedure with potential to replace conventional PCNL.

3.1. *Terminology in PCNL and miniaturised PCNL*

Despite the growing role of miniaturised PCNL, terminology in this field is not yet standardised, and the semantics of different acronyms can be confounding for endourologists. Terminologies recommended by different groups over the years are shown in Table 1 [11–17].

3.2. *Indications for miniaturised PCNL*

The indications for miniaturised PCNL have not been standardised yet. First used in a paediatric population, mini-PCNL has progressively become the procedure of choice in this subset of patients as a safe and effective alternative to standard PCNL [4]. The potential of miniaturised PCNL in adults was then recognised and the approach gained in popularity as an appealing middle ground between standard PCNL and fURS.

Traditionally, medium-sized (1.5–3 cm) and hard stones (>1000 Hounsfield units [HU]) is the ideal indication for mini-PCNL [11,12,18].

It is noteworthy that the development of dedicated miniaturised scopes facilitate knowledge of the physics behind the vacuum cleaner effect generated during procedures [19], and increased efficacy of modern holmium laser generators and surgeon skill led to progressive expansion of the indications for miniaturised techniques. As a consequence, some Chinese authors reported that miniaturised PCNL is comparable to standard PCNL in treating staghorn stones and proximal ureteral stones, yielding similar

Table 1 – Terminologies for PCNL and miniaturised PCNL.

Procedure	Sheath outer diameter (F)	Study
Conventional categorisation		
Standard PCNL	>22	Knoll et al [11]
Mini-PCNL	≤22	Jackman et al [4]
Minimally invasive PCNL (MIP)	9.5–26	Nagele et al [12]
Ultra-mini PCNL (UMP)	11–13	Desai et al [13]
Super-mini PCNL (SMP)	10–14	Zeng et al [14]
Mini-micro PCNL	8	Desai et al [15]
Micro-PCNL	<5	Desai et al [15]
Schilling [16] categorisation		
XL	≥25	
L	20 to <25	
M	15 to <20	
S	10 to <15	
XS	5 to <10	
XXS	<5	
Tepeler [17] categorisation		
Named according to tract size	PCNL $^{+size}$	

PCNL = percutaneous nephrolithotomy.

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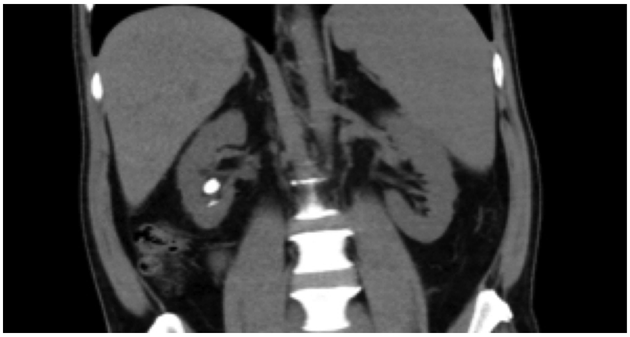

Fig. 1 – A 1.2-cm stone in the right lower calyx (1500 Hounsfield units) treated with mini-percutaneous nephrolithotomy.

Fig. 2 – A stone in a calyceal diverticulum of the left middle calyx (1300 Hounsfield units) treated with mini percutaneous nephrolithotomy.

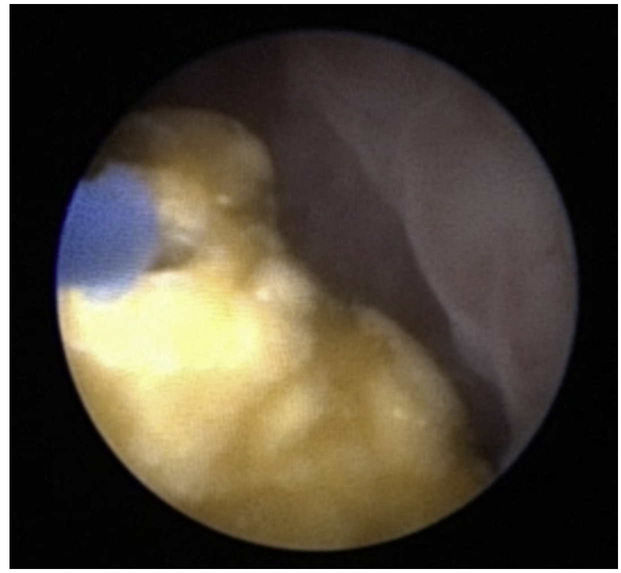

Fig. 3 – Lithotripsy for removing stone fragments during mini percutaneous nephrolithotomy.

outcomes with lesser invasiveness, especially from hemorrhagic point of view [20,21].

Moreover, a degree of superiority of miniaturised PCNL over modern fURS has been demonstrated for stones located in a difficult target calyx with a long or narrow infundibulum or inside a calyceal diverticulum and for impacted stones [22,23] (Figs. 1 and 2) for which the durability of costly newest-generation fURS is frequently challenged.

In addition, these techniques could represent a good tool for percutaneous surgery. In fact, during the initial phase of the PCNL learning curve, the smaller dilatation diameter for a non-ideal puncture may prevent major bleeding.

Finally, economic factors may play a role in determining the final indication. For cases for which both fURS and mini-PCNL might represent a viable treatment option, reimbursement for miniaturised PCNL is much greater than for fURS in some countries, inevitably favouring the percutaneous approach.

3.3. *Techniques and instrumentation*

The main characteristics of each technique are reported in Table 2. Figs. 3 and 4 show lithotripsy and the vacuum cleaner effect, respectively, for removing stone fragments during mini-PCNL.

Table 2 – Main characteristics of different percutaneous nephrolithotomy techniques.

PCNL	Equipment	Outer sheath size (F)	Tract dilatation	Working channel (F)	Fragmentation device	Stone removal
Conventional	Reusable	≥24	MS, SS, balloon	– [a]	Ballistic, US, laser	Grasper, basket
Mini-PCNL	Reusable	11–20	MS, SS, balloon	– [a]	Ballistic, US, laser	Grasper, basket
Miniperc (Lahme)	Reusable	15–20	SS	6	Ballistic, US, laser	Grasper, basket, AWO
MIP L	Reusable	24–26	MS, SS, balloon	12.4	Ballistic, US, laser	Grasper, basket, AWO, VCE
MIP M	Reusable	16–22	SS	6.7	Ballistic, US, laser	Grasper, basket, VCE
MIP S	Reusable	12	SS	2	Laser	Basket, VCE, PE
MIP XS	Reusable	9.5	SS	2	Laser	Basket, AWO, VCE, PE
UMP	Reusable	11–13	MS or SS	–	Laser	AWO, VCE
SMP	Reusable	10–14	MS	3	Ballistic, laser	Grasper, basket, AWO, suction evacuation, PE, VCE
Micro-PCNL	Disposable	4.85	SS	–	Laser	PWO, PE
Mini-micro PCNL	Reusable [b]	8	SS	–	US, laser, suction	PWO, suction

SS = single step; MS = multistep; US = ultrasonic; AWO = active washout; VCE = vacuum cleaner effect; PE = purging effect; PWO = passive washout.
[a] Depends on the manufacturer.
[b] The sheath is available as disposable and reusable models.

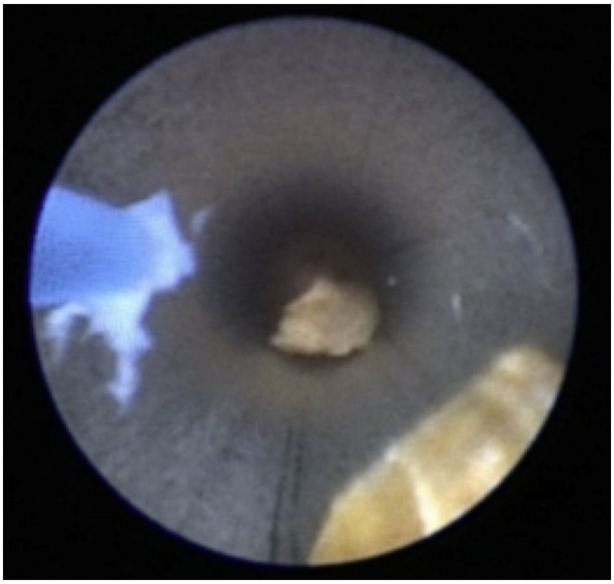

Fig. 4 – The vacuum cleaner effect for removing stone fragments during mini percutaneous nephrolithotomy.

3.4. *Comparative outcomes*

3.4.1. *PCNL vs miniaturised PCNL*

Pioneers of miniaturised PCNL initially postulated that potential nephron sparing was one of the major advantages. On the contrary, Traxer et al [24] refuted this hypothesis, demonstrating that there was no difference in the amount of scar tissue after standard (30F) and miniaturised percutaneous (13–15F) approaches. Of note, this was the study that basically prevented dissemination of the Miniperc approach in North America, where this technique has not still gained acceptance among the majority of urologists.

The scientific evidence that reduced bleeding is the most important advantage of PCNL miniaturisation quickly grew: bleeding rates are significantly lower, although data on the need for blood transfusion are anedoctal [25–27]. It has been demonstrated that the size and number of PCNL tracts and the dilatation method are important factors in causing intraoperative bleeding [15].

A single-centre randomised study comparing mini-PCNL to conventional PCNL demonstrated no difference in stone-free rate (SFR) between the two procedures for staghorn and single renal pelvis stones, whereas the SFR was higher for mini-PCNL than for PCNL for multiple calyceal stones ($p < 0.05$), probably because of the better manoeuvrability of the smaller flexible scope in accessing the calyces. However, the standard PCNL group had a higher transfusion rate compared to the mini-PCNL group (10.4% vs 1.4%; $p < 0.05$) [27].

Similarly, a meta-analysis on miniaturised versus standard PCNL revealed no difference in SFR; the operative time was longer for mini-PCNL and the transfusion rate was higher for standard PCNL. There were no differences in the rates of other complications [28]. A limitation to the validity of these results is that the majority of the studies included were single-centre and nonrandomised trials, with significant heterogeneity in inclusion criteria and reported outcomes and no standardised procedure.

Another recent systematic review demonstrated that smaller tracts used in miniaturised PCNL tended to be associated with significantly lower blood loss or need for blood transfusion, at the cost of a significantly longer procedure compared to standard PCNL [29]. The major disadvantage of small instruments is that smaller stone fragments that fit through the narrower sheaths must be obtained, leading to longer operative times [29]. There is an inverse relationship between tract size for percutaneous access and operative time and between tract size, bleeding, and consequent intraoperative visibility during the procedure [30].

A comparative study of mini-PNCL versus microperc for medium-sized lower calyx stones revealed similar SFRs, whereas blood loss and fluoroscopy and hospitalisation times were lower and tubeless procedures were higher for microperc compared to mini-PCNL. However, these results should be weighted by the retrospective nature of the study and the small size of the groups [31].

Irrigation and consequent intrarenal pressure is a major issue in miniaturised PCNL. It is well known that a key point for successful miniaturised procedures is being able to take advantage of the so-called *vacuum cleaner effect*, which, if properly managed, greatly facilitates stone removal. The vacuum cleaner effect occurs when a round-shaped nephroscope is used and depends on the relation between the nephroscope diameter and inner sheath diameter; it does not develop when an oval or crescent-shaped nephroscope is used. A slipstream is generated in front of the distal end of the round-shaped nephroscope, induced by the excursive change in width of the fluid flow in the outlet of the flushing channel. This allows take-up of a stone fragment into the eddy while the fluid flow is circulating around the stone [32].

It has been shown that intrapelvic pressure during mini-PCNL lower than the backflow level (30 mm Hg) via a 14–18F access sheath. Any factors that lead to poor drainage, such as a smaller diameter between the endoscope and the sheath compared to standard PCNL, can result in temporary elevation of intrarenal pressure with a cumulative effect, which can generate enough backflow to induce fever [33]. This finding is even more evident when using super-miniaturised nephroscopes; it is advisable that the intrarenal pressure should be controlled via combined suction using a transurethral mono-J catheter.

3.4.2. *Miniaturised PCNL versus fURS*

Several studies reported a higher SFR and shorter operative time for miniaturised PCNL over fURS, whereas a longer hospital stay and greater analgesic requirements were described [34,35]. A meta-analysis confirmed these results, showing that overall, PCNL yields a significantly higher SFR than fURS at the expense of higher complication rates and blood loss and longer stay [36]. Thus, although fURS has a lower SFR, it offers less morbidity. The meta-analysis was limited by including only a few studies, the majority of which were nonrandomised, with variations in the inclusion criteria, the outcomes studied, and the complications reported.

Sabnis et al [37] showed that mini-PCNL and fURS had no significant difference in SFR at 1-mo follow-up; stone clearance rates were high and complications were low for both modalities. However, fURS required a longer operative time, although it was associated with favourable pain scores and a lower decrease in haemoglobin.

Another randomised study or the treatment of 1.5-cm renal calculi demonstrated that microperc is an effective and safe alternative to fURS for small renal stones, with similar SFRs and complication rates [38]. Microperc was associated with higher haemoglobin loss and analgesic requirements, whereas fURS required higher JJ ureteral stenting. Only one concern should always be kept in mind when dealing with microperc: it is the only percutaneous procedure without outflow from the nephroscope itself, inevitably leading to potential peaks in intrarenal pressure if drainage of the collecting system is impaired [39].

Moreover, miniaturised PCNL is more cost effective than fURS, since the acquisition and maintenance costs of equipment such as flexible ureteroscopes and disposable devices are significantly higher. This is particularly evident in developing countries, even though, somewhat surprisingly, Pan et al [40] showed that the overall costs of these two techniques were comparable.

At present, all the miniaturised PCNL techniques are already a useful tool that endourologists should be familiar with to be able to always deliver tailored therapy for each patient and stone. Only by doing this can we offer our patients the best care with the lowest complication rates, avoiding the mistake of choosing one treatment option not because it is the best for an individual case but only because it is the only one available.

4. Conclusions

Even though neither the American Urological Association nor the European Association of Urology guidelines give recommendations on indications for miniaturised PCNL techniques, and the data in literature have shown limitations and conflicting results, after initial scepticism, it has been demonstrated that these techniques are capable of offering similar outcomes to standard PCNL, with lower complication rates in the case of medium-sized and hard renal stones and collecting systems with challenging anatomy of. In this subset of patients, fURS is the major competitor, yielding similar outcomes but at the expense of higher retreatment rates and much higher acquisition and maintenance costs for delicate, flexible ureteroscopes.

Well-designed, randomised, multi-institutional studies are certainly needed to better understand the indications for these miniaturised techniques before considering them a standardised procedure with potential for replacing conventional PCNL.

Author contributions: Silvia Proietti had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study concept and design: Proietti, Giusti.
Acquisition of data: Proietti, Giusti.
Analysis and interpretation of data: Proietti, Giusti.
Drafting of the manuscript: Proietti, Giusti.
Critical revision of the manuscript for important intellectual content: Proietti, Giusti, Desai, Ganpule.
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