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Invited Review

Minimally invasive percutaneous nephrolithotomy (PCNL): Techniques and outcomes

Panagiotis Kallidonis, Arman Tsaturyan, Marco Lattarulo, Evangelos Liatsikos

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ABSTRACT

Minimally invasive percutaneous nephrolithotomy (PCNL) was introduced to decrease the morbidity of the standard PCNL (sPCNL). Thereafter, many modifications and techniques have been presented with the introduction of different miniaturized PCNL (mPCNL) techniques, such as micro-PCNL and ultra-mini-PCNL (UMP). As of present, none of the techniques has displaced the sPCNL. Nonetheless, mini-PCNL has continuously widening indications and has been proposed to have significant advantages over sPCNL. In the current review, each technique is presented while discussing the advantages and disadvantages of each approach. A comprehensive review of the current literature has been performed. Articles related to the topic were retrieved and critically analyzed. Less peri-operative bleeding and shorter hospital stay were the most important advantages advocated for mini-PCNL. Although the performance of mini-PCNL is safe, the utilization of micro-PCNL and UMP should be done with caution.

Keywords: Minimally invasive PCNL; nephrolithiasis; percutaneous nephrolithotomy; review.

ORCID IDs of the authors:
P.K. 0000-0002-6854-4501;
A.T. 0000-0002-2499-7015;
M.L. 0000-0002-3574-9228;
E.L. 0000-0002-5544-9636

Department of Urology, University Hospital of Patras, Patras, Greece

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Corresponding Author:
Panagiotis Kallidonis
E-mail:
pkallidonis@yahoo.com

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Introduction

Percutaneous nephrolithotomy (PCNL) is considered a first-choice treatment for renal stones >2 cm. The treatment modality results in the best stone-free rate (SFR) compared with other minimally invasive techniques, such as shock wave lithotripsy and retrograde intrarenal surgery (RIRS). Nonetheless, PCNL is associated with several complications and requires a steep learning curve.[1] The proper understanding of each step of the procedure, available instruments, techniques, and associated complications are essential for providing a high quality of care to the patients.

Standard PCNL (sPCNL) is performed with the use of 24–30 Fr instrumentation. Over the past decade, continuous technological advancement has led to the miniaturization of endoscopic instrumentation. These instruments aim to decrease the intraoperative blood loss, the incidence of intraoperative and postoperative complications, as well as the hospital stay.[2] Despite a wide variety of devices in the market, the understanding of when a specific instrument should be used is limited. This paper presents a discussion of all the techniques of minimally invasive PCNL (MIP) separately and provides an overview of the contemporary outcomes of mini-PCNL.

Terminology in mPCNL

In terms of access tract size, miniaturized PCNL (mPCNL) has not been well-defined since the introduction of the technique. Practically, the term mPCNL requires a universally accepted definition. Furthermore, several new PCNL terms, such as mini PCNL (<22 Fr)[3], MIP[4], ultra-mini PCNL[5], super-mini PCNL[6], and micro-PCNL[7], have emerged in the literature from different groups of investigators and contribute to the current confusion regarding terminology. The presence of a single reporting nomenclature eases the documentation and comparison of existing techniques. It is accepted that PCNLs smaller than 24 Fr should be considered miniaturized approaches. Schilling et al.[8] proposed a categorization of PCNL based on the diameter of the outer sheath. Any diameter >25 Fr was considered to be XL size, 20–24 Fr as L size, 15–19 Fr as M size, 10–14

as S size, 5–9 Fr as XS size, and finally <5 Fr XXS size. Similarly, Tepeler et al.[9] proposed labeling based on the size of the access tract. PCNL techniques were categorized as PCNL^{+30}, PCNL^{+20}, and PCNL^{+12} (Table 1).

Mini-PCNL

In 1998, Jackman et al.[3] were the first to report the use of the miniaturized technique for PCNL in adult patients with a stone burden <2 cm^3. The technique was translated to the adult population after successful initial outcomes in children.[10] In the described technique, after obtaining fluoroscopic-guided percutaneous access with the use of an 18-gauge needle, a guidewire was passed to the ureter. An additional working wire was introduced using an 8/10 Fr guidewire introducer set. Thereafter, dilation to 13 Fr (outer sheath) was performed on the working wire under fluoroscopic guidance. The used endoscopes included a 6.9 Fr rigid ureteroscope, a 7.2 Fr flexible ureteroscope, and a 7.7 Fr pediatric cystoscope. The fragmentation was achieved with a holmium laser or ultrasonic lithotripter. Thereafter, the generated stone pieces were removed with the help of forceps or baskets. Nine patients were subjected to the technique, and stone-free status was achieved in 8 patients (89%). Furthermore, the patients had favorable outcomes with a mean estimated blood loss of 83 mL.[3]

The minimally invasive PCNL (MIP)

The successful initial experience with mini-PCNL led to an increased interest in this field. After the presentation of new miniaturized instruments by different companies, further modification of the technique took place. Nagele et al.[4], as a similar approach, introduced the MIP. The technique possessed the same principles as that of mini-PCNL, with several technical changes. The puncture to the kidney was performed under ultrasound guidance, after the placement of a balloon ureteral catheter. A single step 16 Fr dilation using a metal dilator and insertion of an 18 Fr metal sheath followed. The 12 Fr nephroscope utilized in this technique was produced by the Karl Storz (Karl Storz GmbH & Co. KG, Tuttlingen, Germany) company. A ballistic lithotripter was used to fragment the stones. The difference in sheath and nephroscope sizes ensured low-pressure irrigation in the collecting system and eased the evacuation of stone fragments. The latter phenomenon was called "the vacuum cleaner effect." In addition, the authors performed a tubeless procedure.

Main Points:

- Miniaturized PCNL techniques are associated with less bleeding and shorter hospital stay compared with standard PCNL.
- Increased inrarenal pressure and operative time are the drawbacks of mPCNL techniques.
- Higher stone-free rate and shorter operative time are observed in mPCNL techniques compared with RIRS.

In a series of 57 patients, SFR was reported to be 92.9%. None of the patients experienced bleeding requiring transfusion or had sepsis.[4]

Ultra-Mini-PCNL

The technique was developed and introduced by Desai in 2013.[5] The instruments include a 13 Fr outer sheath and a 6 Fr nephroscope. The access is obtained under ultrasound guidance and then dilated to 8 Fr and 11 Fr using fluoroscopic guidance. The stone disintegration is performed with the use of a 365 μm laser fiber. The instrumentation allows irrigation outflow and provides low pressure in the collecting system. The technique generates stone fragments of 2 mm in size, which are evacuated through the working sheath.[5]

Super-mini-PCNL (SMP)

SMP represents one of the latest modifications of PCNL. It was introduced in 2015 by Zeng et al.[6] The puncture and dilation of the access tract are done under fluoroscopic guidance in a prone position. The technique utilizes a 7 Fr nephroscope with a modifiable 10–14 Fr outer sheath. In addition, a suction–evacuation sheath is inserted before introducing the nephroscope. A

Table 1. Classifications of PCNL

PCNL classification according to different investigating groups	
Procedure	**Sheath outer diameter**
Standard PCNL (2)	>22 Fr
Mini-PCNL (3)	≤22 Fr
MIP (4)	18 Fr
UMP (5)	13 Fr
SMP (6)	10–14 Fr
Superperc (11)	10–12 Fr
Micro-PCNL (7)	<5 Fr
Mini-micro PCNL (13)	8 Fr
PCNL classification proposed by Schilling et al.[8]	
Size	**Sheath outer diameter**
XL	≥25 Fr
L	20–24 Fr
M	15–19 Fr
S	10–14 Fr
XS	5–9 Fr
XXS	<5 Fr
PCNL categorization proposed by Tepeler et al.[9]	
Size of percutaneous access indicated as superscript: e.g., PCNL+30, PCNL+20, and PCNL+12	

PCNL: percutaneous nephrolithotomy; MIP: minimally invasive PCNL; UMP: ultra-mini PCNL; SMP: super-mini-PCNL

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pump mechanism is used to push the irrigation fluid through the working channel. Laser energy and pneumatic lithotripter are considered for stone fragmentation. The 3.5 Fr working channel is designed to accommodate the 365-µm laser fiber or the 0.8 mm pneumatic probe. SMP was successfully performed in 141 patients. With the mean stone size of 2.2 cm, a 90.1% STF was reported. No major complications were observed, and 72.3% of patients were free of urine drainage catheters.[6]

Superperc

Superperc is the recent modification of SMP described by Shah et al.[11]. The authors designed a specific 10/12 Fr sheath (Shah sheath) with an integrated suction. This modification allowed the authors to actively aspirate small stone fragments while having only input irrigation. A 4.5/6 Fr pediatric ureteroscope was used for nephroscopy. Complete stone fragmentation was achieved using holmium laser energy with a 365-µm laser fiber. In 52 patients with 19.1 mm mean stone size, 96.1% stone clearance rate was documented. Blood transfusion was not required in any of the cases.[11]

Micro-PCNL

Micro-PCNL is the further miniaturization of mini-PCNL. It was introduced by Bader et al.[7] in 2011. The particularity of the technique is that the access to the kidney is obtained under direct vision with a so-called "all seeing needle." Small 0.9 mm and 0.6 mm micro-optic cameras were inserted into a 4.85 Fr puncture cannula. The aforementioned puncture before proceeding to standard PCNL was performed in 15 patients. Those patients did not experience any significant complications. The 0.9-mm optic had superior visibility compared with the 0.6-mm optic.[7] The technique was further elaborated on 10 patients subjected only to micro-PCNL. A 16-gauge needle with a three-way connector accommodated the irrigation, micro-optic, and 200-µm laser fiber. A pumping mechanism was required for irrigation. Holmium laser was used to perform the disintegration of the stone. Apparently, the smaller diameter of the cannula does not allow to retrieve any of the stone fragments. Therefore, stone clearance was achieved in an antegrade fashion through the ureter. SFR of 88.9% was observed in those patients with the mean stone diameter of 14.3 mm.[12]

Mini-Micro PCNL

To overcome the limitations of micro-PCNL, an additional technical modification on micro-PCNL was further proposed.[13] The main difference in this technique was the utilization of a bigger 8 Fr metallic sheath. The latter restricts the bending of the sheath in the collecting system and provides the possibility to accommodate a 1.6-mm ultrasonic lithotripter probe.[13]

Kidney puncture and mPCNL

The success and complication rates of the procedure do not solely depend on PCNL size and utilized instruments. Regardless of any technique used for the PCNL, the initial step of gaining access to the kidney is universal and critical for the whole procedure. To achieve successful dilation of the tract, fluoroscopic and ultrasound-guided techniques or a combination of the two approaches can be used.[14] A recently published prospective randomized trial investigated the safety and efficacy of three approaches in obtaining mPCNL access. Overall, 450 patients were included and divided into 3 groups, each having 150 patients. Although no statistical differences were observed between the approaches in simple kidney stones [size, topography, obstruction, number of stones present, evaluation of hounsfield unit (S.T.O.N.E.) scores 5–6], fluoroscopic guided and combined access led to significantly better outcomes in more complex stones (S.T.O.N.E. scores 7–8) and in cases requiring multiple tracts.[14] Regarding the puncture site, it is generally recommended that the puncture is performed through the papilla. Anatomical studies on cadaveric kidneys propose the papillary puncture as safe with 7%–8% probability of vessel injury.[15-17] In contrast, clinical studies prove no inferiority of non-papillary PCNL approach in terms of perioperative bleeding complications.[18,19] In fact, several advantages have been proposed for the non-papillary approach, namely, the easier passage of the guidewire to the ureter and the better mobility of the nephroscope in the collecting system.[19] No comparative data exist regarding the puncture site of different mPCNL techniques.

Mini-PCNL versus standard PCNL

The PCNL is the most often performed procedure worldwide for stones >2 cm with a high SFR and acceptable complication rate.[20] Therefore, the success and effectiveness of miniaturized techniques should be viewed under the prism of the established outcomes of sPCNL. Current literature includes four randomized control trials undertaken by different research groups comparing the mPCNL techniques to conventional ones (Table 2).[21-24] A statistically significant difference in favor of mPCNL was documented in one earlier study, whereas the most recent ones did not find any significant differences between the groups.[21-24] The main advantage of mPCNL, apart from SFR, was the reduced bleeding. Three studies reported a lower drop in hemoglobin level, which led to a decreased rate of blood transfusion in two of them. In addition, mPCNL was associated with decreased duration of nephrostomy and shorter hospital stay.[22,23] Nonetheless, operation time was universally reported to be longer in patients with mini-PCNL, ranging between 89.2 and 134.3 min.[21-24] Another drawback of miniaturized techniques, though not discussed in those studies, is the increased intrarenal pressure (IRP).[25] In a porcine model, Loftus et al.[26] evaluated the impact of sheath size on IRP and infectious complications. The standard arm utilized a 26 Fr nephroscope inserted through a 30 Fr sheath and a 9.8 Fr semi-rigid ureteroscope through a 14/16 Fr sheath for the miniaturized approach arm. Higher mean intrapelvic pressure and significantly longer period of pressure above

Table 2. Comparative studies between mini-PCNL and standard PCNL

Mini-PCNL versus Standard-PCNL: comparison

Authors	Study design	Number of cases		Stone free rate (%)		Operative time (min)		Hospital stay (days)		Drop in Hb (g/dL)		Blood transfusion (%)		Nephrostomy stay (hours)	
		Mini	STD	Mini	STD	Mini	STD	Mini	STD	Mini	STD	Mini	STD	Mini	STD
Cheng et al.[21]	Randomized	72	115	*72.2 **92.6	*75.9 **91.3	*134.3 **89.4	*118.9 **77	7.3	7.5	0.53	0.97	1.4	10.4	/	/
Guler et al.[22]	Randomized	51	46	76.5	71.7	89.2	74.7	2.0	2.8	1.35	2.07	2	15.2	35.3	72
Kandemir et al.[23]	Randomized	76	72	75	72.2	106.9	91.2	2.7	3.2	0.7	1.4	2.6	5.6	47.8	61.8
Zhong et al.[24]	Randomized	29	25	82.8	56	116	103	9.8	7.1	3.2	3.5	3.4	12	/	/

*Results for staghorn stones. **Results for simple renal pelvis stones. PCNL: percutaneous nephrolithotomy; Mini: mini-PCNL; STD: standard PCNL

Table 3. Comparative studies between mini-PCNL/micro-PCNL and RIRS

Mini-PCNL versus RIRS: comparison

Authors	Study design	Number of cases		SFR (%)		Operative time (min)		Hospital stay (days)		Drop in Hb (g/dL)		Blood transfusion (%)	
		Mini	RIRS	Mini	RIRS	Mini	RIRS	Mini	RIRS	Mini	RIRS	Mini	RIRS
Fayad et al.[27]	Randomized	60	60	92.7	84.3	71.7	109.7	2.2	2.1	0.28	0.13	0	0
Xiao-Jian et al.[28]	Randomized	30	29	100	89.7	/	/	4.6	1.9	/	/	0	0
Kumar et al.[29]	Randomized	41	43	95.1	86.1	61.1	47.5	3.1	1.3	/	/	12.9	0
Lee et al.[30]	Randomized	35	33	85.7	97	76.1	99.6	1.6	1.5	0.69	0.38	0	0

Micro-PCNL versus RIRS: comparison

Authors	Study design	Number of cases		SFR (%)		Operative time (min)		Hospital stay (days)		Drop in Hb (g/dL)		Blood transfusion (%)	
		Micro	RIRS	Micro	RIRS	Micro	RIRS	Micro	RIRS	Micro	RIRS	Micro	RIRS
Jiang et al.[31]	Randomized	58	58	84.5	79.3	54	60.3	3.2	3.2	3.0	2.3	0	0

Statistically significant values are expressed in bold. PCNL: percutaneous nephrolithotomy; RIRS: retrograde intrarenal surgery; SFR: Stone-free rate; Mini: mini-PCNL; Micro: micro-PCNL.

30 mmHg were found in the miniaturized approach arm. With the retrograde instillation of *E. coli* 10^9 for 1 h, the miniaturized arm demonstrated higher positive spleen and liver tissue cultures. Thus, the authors concluded that 1-h long mPCNL led to increased IRP and a higher possibility of bacterial seeding.[26] Although the "vacuum cleaner" and "purging" effects reduce IRP in mini-PCNL, IRP may be at high levels in ultra-mini PCNL and micro-PCNL.[25]

Mini-PCNL versus RIRS

PCNL and particularly mini-PCNL together with RIRS are the treatment of choice for 1–2 cm diameter renal stones. Five randomized controlled studies have investigated the differences between RIRS and mPCNL (Table 3).[27-31] The mPCNL appeared to possess a higher SFR compared with RIRS.[27,28,30] In addition, it was associated with shorter operative time and less postoperative pain.[27,29,31] Nevertheless, patients with mPCNL more often experienced bleeding complications and required blood transfusion.[28,30] From a psychological perspective, RIRS patients reported higher anxiety and depression scores with similar stone-free and complications rates.[32]

In conclusion, the interest in mPCNL among urolo-

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gists is increasing. The appealing advantages of less bleeding and shorter hospital stay compared with sPCNL cannot be overridden. However, increased operative time and possible increased IRP, especially for micro- and UMPs, should be always kept in mind for the operative planning of any of these techniques. In contrast, mPCNL might be preferred over RIRS considering higher SFR, shorter operative time, and better acceptance of the technique by the patients (less postoperative pain, less anxiety, and depression). Nevertheless, the preference and expertise of the surgeons probably remain the most decisive factors for the routine performance of either of the techniques.

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