REVIEW

Recent advances in percutaneous lithotripsy techniques

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Purpose of review
To describe and critically discuss the most recent evidence regarding the percutaneous nephrolithotomy (PCNL) techniques.

Recent findings
Three-dimensional printing and virtual reality are promising tools to improve surgeon experience and operative performance. Totally ultrasound-guided PCNL is feasible and can reduce the radiological risk. Growing evidence highlights the safety and advantages of the use of miniaturized instrumentations, although some related limitations place the mini PCNL (mPCNL) in direct challenge with the retrograde intrarenal surgery. LithoClast Trilogy and ClearPetra system can improve the stone clearance. Thulium laser is a new source of energy with growing expectations and promising in-vitro results.

Summary
Significant advances have recently been recorded in PCNL techniques. Thulium fiber laser, LithoClast Trilogy, new suction devices, and the development of novel technologies for teaching and planning procedures may overcome mPCNL drawbacks. Further studies are needed to confirm the promising preliminary results available on the topic.

Keywords
lithotripsy, percutaneous nephrolithotomy, percutaneous, stone

INTRODUCTION

From the publication by Alken in 1981 of the first clinical series [1], percutaneous nephrolithotomy (PCNL) irrupted in the urological surgical scenario. The procedure was suddenly standardized, and to date we still follow the same steps and use the same accessories and lithotripsy devices specifically designed at that time. Later on, PCNL was flanked by extracorporeal shock wave lithotripsy (ESWL) first and retrograde intrarenal surgery (RIRS) thereafter in the treatment of nephrolithiasis. Current European Association of Urology guidelines identify PCNL as surgical treatment of choice for more than 2 cm renal stones, leaving free choice among PCNL, ESWL, and RIRS for smaller stones based on patient and surgeon preference [2]. Chung *et al.* studying patients with nephrolithiasis who received any surgical treatment in the United States from 2007 to 2014 observed an increase in the number and costs of each treatment. An increase in the number of RIRS and to a lesser extent of PCNL have been observed while ESWL showed a percentage decrease. In 2014 ESWL, RIRS, PCNL, and open surgery accounted respectively for 77.83, 14.71, 7.24, and 0.22% of all treatment modalities; RIRS was the least expensive form of therapy with the cost of a single procedure which was about half that of PCNL (5412 vs. 11 730 $) [3].

The high cost is certainly not the main factor affecting the diffusion of PCNL among urologist. PCNL is a complex invasive procedure with a steep learning curve, in which, unlike RIRS, a natural access to the kidney is not available. The accurate diagnostic evaluation and the consequent planning of the procedure are crucial to gain good access to

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Curr Opin Urol 2021, 31:24–28

DOI:10.1097/MOU.0000000000000829

KEY POINTS

- Three-dimensional-printed models and virtual reality are promising tools to improve to improve PCNL teaching and planning.
- Ultrasound-guided PCNL is feasible and can reduce the radiological risk.
- Growing evidence highlights the advantages and safety of mPCNL, placing this technique in direct challenge with the retrograde intrarenal surgery.
- Thulium fiber laser, LithoClast Trilogy, ClearPetra system, three-dimensional-printed models, and virtual reality may overcome mPCNL drawbacks.

the pelvicalyceal system. This is the key point of PCNL, influencing the following steps of tract dilatation, lithotripsy, fragments evacuation, upper urinary system drainage, and therefore ultimately the outcomes of surgery.

The major advantage of PCNL compared with ESWL and RIRS was the possibility to remove stone fragments avoiding spontaneous expulsion with its inherent complications, allowing a faster stone-free rate (SFR) status, and reducing repeated treatments as well as ancillary maneuvers. This is still true when large instruments (24–30 Fr) are used to perform the so-called standard PCNL (sPCNL). In the last decade a large number of miniaturized endoscopes, in which optical fibers replaced rigid lens, were introduced on the market. The terminology in this field is not yet standardized, however, generally, the procedure is considered a mini PCNL (mPCNL) when the sheath diameter is 14–22 Fr [4]. The working channel of miniaturized instruments in most cases allows only the passage of a laser fiber; therefore, the direct stone removal is less efficient than sPCNL, challenging the results of the less invasive RIRS. To give PCNL the opportunity to be competitive with RIRS it is mandatory the improvement of existing devices, the development of new technologies, as well as the optimization of teaching and treatment planning.

The aim of this review was to describe and critically discuss the most recent evidence regarding the percutaneous lithotripsy techniques.

REVIEW

Teaching and preoperative assessment

The widespread diffusion of PCNL was limited by its steep learning curve. Renal puncture is undoubtedly the most demanding part of the procedure and correct calyx selection is considered the cornerstone of the surgery as it strongly influences its results and complications.

Three-dimensional printing and virtual reality are promising tools to improve surgeon experience and operative performance. They can accurately reproduce the anatomy of the kidney and the exact location of the stones. These technologies only require dedicated software and a three-dimensional printer or virtual reality glasses, so they are potentially available anywhere. The costs are still high, but they are expected to decrease in the near future.

Ali *et al.* investigated the teaching effectiveness of a three-dimensional-printed model compared with the URO Mentor (Simbionix, Lod, Israel) surgical simulator in a group of 40 urology residents who never performed percutaneous procedures. The use of three-dimensional-printed simulator was associated with significantly better performance of residents; however, radiograph-guided puncture of the pelvicalyceal system was improved but not significantly. The authors concluded that the three-dimensional-printed model could facilitate urological training [5▪].

To assess the optimal calyx for a puncture, Xu *et al.* printed three identical three-dimensional models for each of 12 patients with staghorn stone. Three simulations of PCNL were performed in each model through a lower, middle, and upper preselected calyx, then the procedure was translated to the patient using the calyx which led to maximum SFR in the model. After surgery, the authors compared the SFR of patients and models reporting similar results. The three-dimensional-printed models showed to be useful in the procedure planning, especially in the selection of optimal access to the pelvicalyceal system [6].

Parkhomenko *et al.* tested an immersive virtual reality technology assuming that a three-dimensional-printed model may have several limitations as it is time-consuming, expensive, and not universally available, besides, it only provides a surface representation of structures. Four differently experienced surgeon tested the system before the PCNL of 25 patients reporting an improvement in the understanding of renal anatomy, characteristics of urolithiasis, and treatment planning compared with computed tomography alone. The author also compared this cohort with retrospectively matched cases reporting a significant improvement in blood loss and fluoroscopy time [7▪].

Limitation of radiation exposure

Radiation exposure represents a relevant safety issue for urologists performing PCNL and every effort should be made to limit the associated risks. Balaji *et al.* demonstrated that radiation exposure was significantly associated with stone volume, number of the tracts, sheath size, and mode of access. As expected, fluoroscopic-guided access strongly correlated with radiation exposure [8]. Based on the evidence, we should open our minds by increasing the ultrasound-guided PCNL, without losing sight of the concept that patient safety is our primary aim.

Many groups investigated the feasibility of a total radiograph-free tract dilatation under ultrasound guidance. Wang *et al.* assessed the tract dilation monitored by the ultrasound in 24-Fr PCNL in a retrospective study. Six hundred eighteen cases, 207 with balloon and 411 with sequential dilation, were completed with one access. Balloon dilatation was significantly faster (4.4 vs. 6.0 min; $P<0.001$) but failed at the first attempt in 24 (11.6%) patients. All procedures were successfully completed without major intraoperative complications, and no significant differences in the rate of minor complications were found between the two groups [9▪]. Conversely, Pakmanesh *et al.* [10] in a randomized trial on a small cohort of 66 patients undergoing ultrasound-guided PCNL found a higher rate of short dilation in the Amplatz dilation group compared with the Ballon group (57.6 vs. 36.4%; $P=0.08$). The use of ultrasound-guided dilation could increase with the spread of mPCNL, since the sheath introduction of these instruments is largely a single-shot technique. Simayi *et al.* [11▪] reported in 104 patients undergoing ultrasound-guided super-mPCNL a 98% SFR with only 5 Clavien I and 4 Clavien II complications.

Standard vs. miniaturized instrumentation

Since standard 24–30-Fr PCNL has been performed successfully for almost 40 years, many urologists are not prone to change their surgical behavior in favor of small instruments. However, growing evidence from well designed studies highlights the safety and advantages of percutaneous procedures performed with the new generation of miniaturized nephroscopes. It is necessary to underline that a great confusion derives from the nomenclature of the instruments which is not standardized and often misleading. It would be more scientifically appropriate to classify the instruments according to the sheath size, to make it easier to compare the results of the different studies and their interpretation.

In a randomized trial, Raja Sekhar *et al.* compared super-mPCNL (sheath size: 14 Fr) to sPCNL (sheath size: 22–30 Fr) in 150 patients with less than 2 cm renal stones. SFR was not statistically different (97.33 vs. 98.66%; $P=0.56$) but at the price of significantly longer operative time in the super-mPCNL group (36.40 vs. 23.12 min; $P<0.0001$). Hemoglobin decrease, pain score, and hospital stay were significantly lower in the super-mPCNL group. More complications were observed in the sPCNL group [12▪].

Bozzini *et al.* in a multicenter prospective randomized study compared standard (sheath size: 30 Fr) with mini (sheath size: 19.5 Fr) and ultra-mini (sheath size: 13 Fr) PCNL for a single 1–2 cm lower calyx stone in 132 patients. SFR was significantly higher for sPCNL and mPCNL (86.3 vs. 82.9 vs. 78%; $P<0.02$). Complication rate (13.6 vs. 4.2 vs. 2.4%; $P<0.001$) and hospital stay (3.7 ± 1.5 vs. 2.7 ± 2.1 vs. 2.2 ± 2.1 days; $P<0.04$) were significantly higher for sPCNL compared with the other two groups. No significant differences were observed for the operative time [13▪].

In another randomized trial, Kandemir *et al.* compared standard (sheath size: 30 Fr) and mini (sheath size: 16.5/20 Fr) secondary PCNL in 148 patients with residual stones. Operative time (91.2 ± 33.2 vs. 106.9 ± 38.8 min; $P<0.016$) was significantly shorter for sPCNL, while fluoroscopy time (5.3 ± 3.1 vs. 4.4 ± 3.2 min; $P<0.021$) and hospital stay (75.5 ± 34.0 vs. 64.3 ± 36.5 h; $P<0.005$) were significantly shorter for mPCNL. Success and complication rate were not statistically different. One patient in each group required angioembolization [14].

In these three articles, it is evident how different terminologies are used for identical sheath sizes. Their results are quite contradictory; this may depend on the different classification of the instruments as well as on the different populations under examination, being the second article focused on lower pole stone and the third on secondary stones. The standardization of the nomenclature and further large cohort studies are needed to draw solid conclusions.

A meta-analysis in the topic by Deng *et al.* assessed nine randomized clinical trials (RCTs) and five non-RCTs of high-medium quality. A total of 1980 patients, 897 sPCNL and 1083 mPCNL, were included in the analysis. SFR was similar between the two groups (87.6 vs. 87.8%; $P=0.57$), but sPCNL showed significantly shorter operative time and significantly greater blood loss and transfusion ($P<0.00001$) [15▪].

Suction and lithotripsy devices

sPCNL can ablate and remove a large volume of stones in a short time, while mPCNL has the main limitation of a narrow working channel that does not allow the introduction of effective lithotripsy devices and stone removal tools but only the passage of a laser fiber. The results of mPCNL are similar to RIRS, but with greater invasiveness and complications rate. Intrapelvic pressure plays an essential role in the onset of complications, favoring the absorption of bacteria and toxin from the irrigation fluid. Higher intrapelvic pressures and consequently higher infections rate were documented in mPCNL compared with sPCNL [16].

An interesting step forward in improving stone clearance is the ClearPetra device. It is a vacuum-assisted access sheath available in different size from 10 to 22 Fr. On the external edge of the sheath a Y-shaped sluice is connected to an aspiration system that constantly keeps low pressures inside the pelvicalyceal system and removes dust. Larger fragments of stones can be evacuated retracting the scope back to the sluice to let the fragments pass into the aspiration channel. Lai *et al.* tested an 18 Fr ClearPetra sheath on 75 single stone patients undergoing mPCNL and performed a matched-pair analysis with individuals undergoing mPCNL using a conventional sheath. Operative time (32.4 vs. 46.2 min; $P < 0.001$), immediate SFR (89.3 vs. 77.3%; $P < 0.049$), and complications rate (16 vs. 26.7%; $P < 0.046$) were significantly in favor of ClearPetra arm [17▪].

Significant advances have also been recorded for lithotripsy devices. The LithoClast Trilogy (EMS, Nyon, Switzerland) has recently been presented. It shows better suction properties due to the new design of the probe with a wider suction channel. Cannulas are available up to 1.1 mm and fit the working channel of mPCNL instruments. The evidence with this technology is still limited. Sabnis *et al.* reported their initial experience in 11 patients undergoing mPCNL with a 15 Fr scope and a 5.7 Fr probe. SFR and mean stone volume clearance ratios were 90.9% and 370.5 ± 171 μl/min, respectively. Only 1 Clavien I complication was reported [18▪].

Holmium : YAG (Ho : YAG) laser has been the best energy source for lithotripsy until now. The thulium fiber laser (TFL) is a new source of energy with growing expectations, mainly because smaller fibers down to 50 μm are available. It has been extensively studied in-vitro and compared with the Ho : YAG laser; however, clinical experiences are still limited. On artificial hard or soft stone phantoms in 'dusting' and 'fragmentation' modes with 272 μm fiber, the ablation rates with TFL compared with Ho : YAG laser were fourfold and two-fold higher against hard stones ($P < 0.05$), and three-fold and two-fold higher against soft stones ($P < 0.05$). Also the 150 μm thulium fibers worked better than the 272 μm holmium fibers [19]. 150 μm thulium fibers were also tested *in vitro* against real stones, resulting capable of dusting all composition stones in particles smaller than 500 μm [20]. Compared to Ho : YAG laser in different settings of frequency and power TFL showed superior fragmentation rate of calcium oxalate monohydrate stone samples [21▪]. In different pulse length settings, TFL showed a mean stone displacement lower than Ho : YAG laser and therefore a minor retropulsion effect [22]. Some doubts about the safety of the TFL have arisen from the potential damage of the thermal effect. Peng *et al.* [23] investigated the thermal effect of TFL in a tube filled with saline at different infusion rates measuring temperature rise at different power settings and documented potential heath injuries when the infusion was stopped. Animal studies are needed to assess the safety of TFL *in vivo*.

Enikeev *et al.* tested TFL in a clinical series of 120 patients with a minimum stone diameter of 12.5 mm (up to 30 mm) and a mean stone hardness of 1019 HU. Mean operative time was 23.4 ± 17.9 min. In two cases (1.7%) retropulsion interfered with the surgery, a noninterfering retropulsion was recorded in 13 cases (10.8%), whereas in 105 patients (87.5%) no retropulsion occurred. At 3 months, complete SFR was reported in 85% of patients and no anatomical modification of the urinary tract was documented [24▪▪].

CONCLUSION

PCNL was the first minimally invasive approach to kidney. Although more invasive than ESWL and RIRS, it allows the direct and fast removal of stone fragments. This statement became questionable following the introduction of the miniaturized instrumentation, whose recognized advantages are only faster access to the pelvicalyceal system and reduction in blood loss. mPCNL is still a complex procedure with a long-learning curve and several disadvantages such as high intrapelvic pressure and long operative time. However, Thulium fiber laser, LithoClast Trilogy, new suction devices, and the development of novel technologies for teaching and planning procedures may overcome mPCNL drawbacks.

Acknowledgements

None.

Financial support and sponsorship

None.

Conflicts of interest

There are no conflicts of interest.

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■ of special interest
■■ of outstanding interest

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