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Review

Present indications and techniques of percutaneous nephrolithotomy: What the future holds?

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Abstract The purpose of the review was to present the latest updates on percutaneous nephrolithotomy (PCNL) procedure in terms of indications and evolving techniques, and to identify the advantages and disadvantages of each modality. The data for this review were collected after a thorough PubMed search in core clinical journals in English language. The key words included "PCNL" and "PNL" in combination with "indications", "techniques", "review" and "miniaturized PCNL". Publications relevant to the subject were retrieved and critically reviewed. Current European and American Urology Association Nephrolithiasis Guidelines were included as well. The indications for standard PCNL have been changed through the past decade. Despite evolution of the procedure, innovations and the development of new technical approaches, the indications for miniaturized PCNL have not been standardized yet. There is a need for well-constructed randomized trials to explore the indications, complications and results for each evolving approach. A continuous reduction of tract size is not the only revolution of the last years. There is constant ongoing interest in developing new efficient miniature instruments, intracorporeal lithotripters and sophisticated tract creation methods. We can summarize that, PCNL represents a valuable well-known tool in the field of endourology. We should be open minded to future changes in surgical approaches and technological improvements.

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1. Introduction

Percutaneous nephrolithotomy (PCNL) was originally introduced back at 1976 by Fernström and Johansson [1]. Since then it has gradually evolved to be one of the main endourologic treatment options. With the introduction of other treatment modalities such as extracorporeal shock wave lithotripsy (SWL) [2] and ureterorenscopy [3], the indications for percutaneous stone surgery have changed. Initially, patients unfit for open surgery were referred for the percutaneous approach. Later on, with the advancements in energy delivery and intraoperative visibility, the indications expanded to specific cases, such as ureteral [4] and calyceal diverticular [5] stones. In an effort to reduce the morbidity without compromising stone-free rates and efficacy of the procedure, miniaturized instruments were introduced [6]. The changes in PCNL techniques included not only decrease of the working instruments diameter but also improvement of patient positioning, safer and more accurate tract creation techniques, new imaging modalities, evolvement of intracorporeal lithotripters and incorporation of flexible instruments for efficient collecting system screening. Urinary stone disease management constitutes today more than a third of the surgical volume of a contemporary urological department [7]. Reviewing and updating PCNL indications, techniques, and current practices are of a tremendous value. The aim of this review is to outline the current indications and describe the techniques of modern PCNL.

2. Evidence acquisition

For this literature review we conducted a thorough PubMed search using the keywords "PCNL" and "PNL" in combination with the terms "innovation", "indications", "new techniques" and "urinary stones" published between 2012 till present. Both prospective and retrospective studies and reviews and meta-analyses referring to PCNL indications and techniques written in English language were reviewed. Relevant and important review articles were further explored for reference list completion. Animal studies and other series were added in case a new technique was described. The manual selection was performed by two authors (I.M.S and I.K.) and the two other authors reviewed (M.D. and O.N.G.) the final common list. Articles with valuable information were evaluated and processed. The selected studies are summarised in Table 1.

3. Indications

3.1. The European Association of Urology (EAU) & American Urological Association (AUA) guidelines

According to EAU guidelines, PCNL still remains the standard procedure for large and complex renal calculi. In comparison to other treatment modalities, PCNL success rates are independent of stone size. PCNL is the gold

Table 1 Characteristics of studies included in the review.

Study	Type of study	Levels of evidence	Number of patients	Objective of the study
Kruck et al. [2]	Retrospective	3b	482	Mini-PCNL
De et al. [3]	Meta-analysis	1a	727	PCNL, mini-PCNL, micro-PCNL
Kirac et al. [4]	Retrospective	3b	37	Mini-PCNL
Prakash et al. [11]	Retrospective	3b	86	PCNL
Purkait et al. [13]	Retrospective	3b	44	PCNL
Waingankar et al. [17]	Review	4	221	PCNL
Srivastava et al. [18]	Retrospective	3b	44	PCNL
Gücük and Üyetürk [19]	Review	4	259	PCNL
Zhang et al. [20]	Meta-analysis	1a	2142	PCNL
Siev et al. [22]	Retrospective	3b	101	PCNL
Yuan et al. [24]	Meta-analysis	1a	6881	PCNL
Derisavifard et al. [26]	Review	4	NA	PCNL
Hatipoglu et al. [29]	Retrospective	3b	200	PCNL
Sharma et al. [30]	Review	4	NA	Access technique
Sorensen et al. [31]	Prospective	3b	18	Ultrasound detection
Li et al. [32]	Prospective	3b	NA	Access technique
Rodrigues et al. [33]	Review	4	NA	Puncture technique
Isac et al. [35]	Retrospective	3b	159	Access technique
Ritter et al. [39]	Prospective	3b	27	Puncture technique
Tepeler et al. [42]	Prospective	3b	20	Microperc, PCNL
Gao et al. [43]	Meta-analysis	1a	1279	Mini-PCNL, ultramini-PCNL, micro-PCNL
Ruhayel et al. [44]	Systematic review	3a	NA	Mini-PCNL, PCNL
Schilling et al. [45]	Review	4	NA	Nomenclature proposal
Sabnis et al. [46]	Randomized controlled trial	2b	35	Microperc
Wang et al. [47]	Retrospective	3b	216	Mini-PCNL, PCNL
York et al. [51]	Randomized controlled trial	2b	201	PCNL
El-Nahas et al. [50]	Randomized controlled trial	2b	70	PCNL

PCNL, percutaneous nephrolithotomy.
NA, no available number of patients in the studies.

standard and the first choice for renal stones larger than 20 mm. It may also be an alternative to retrograde intrarenal surgery (RIRS) for the treatment of stones measuring between 10 mm and 20 mm due to better stone-free rates achieved by single procedure. Moreover, PCNL together with RIRS is an alternative option to SWL for lower pole stones measuring less than 10 mm. For lower pole stones 10—20 mm, PCNL is the first option together with RIRS in case of unfavorable factors for SWL. Large impacted proximal ureteric stones can also be treated by percutaneous ureterorenoscopy, especially in situations when the retrograde approach is not feasible or SWL has failed. The stone composition is another important factor that influences the treatment options. SWL-resistant stones such as brushite, calcium oxalate monohydrate and cystine should be alternatively treated by PCNL or RIRS. Contraindications for PCNL treatment according to EAU guidelines include ongoing anticoagulant therapy, untreated urinary tract infection (UTI), tumor in the presumptive access tract area, potential malignant renal tumor and pregnancy [8].

According to AUA guidelines percutaneous approach is indicated for the treatment of renal stones larger than 2 cm achieving better stone-free rates in a single procedure. PCNL offers the highest stone free rates for staghorn stones. PCNL can be suggested for large ureteral stones that SWL has failed or that is unlikely to have successful outcome. For lower pole stones measuring more than 10 mm, PCNL has a higher stone-free rates but with higher morbidity. PCNL also should be one of the main options for the treatment of symptomatic calyceal diverticular stones [9].

3.2. PCNL indications in the actual practice—the Clinical Research Office of the Endourological Society (CROES) study group

An observational study of PCNL initiated by the CROES, outlined the actual indications, strategies, complications, and outcomes of the procedure all around the globe [10]. This study included 5803 procedures. Forty-seven percent of cases were primary stone treatment without previous intervention in the same renal unit. Staghorn calculus was found in 1466 (25.3%) patients. Stones in upper calix, middle calix, lower calyx and renal pelvis were treated in 940 (16%), 956 (16%), 2603 (45%) and 1350 (23%) patients respectively. Almost 400 (7%) patients with anatomic kidney anomalies were treated in this cohort—the largest published number today. This includes a single functioning kidney, horseshoe kidney, malrotated and ectopic kidney.

3.3. PCNL in anatomic abnormalities

In cases of renal abnormalities, PCNL is a challenging procedure because of collecting system architecture and vascular differences [11]. During PCNL in anatomically normal kidney, the pelvis is found medially while the calyces are located posteriorly. However, in a malrotated kidney, the pelvis rotates anteriorly, and the calyces are found postero-laterally so the puncture becomes challenging. In the ectopic pelvic kidney, as bowel is surrounding the kidney hindering a safe access, laparoscopic assistance is required. In a duplex system, stones located in upper calyx cannot be managed by accessing a lower calyx and *vice versa*. All these aggravating factors make PCNL quite difficult. In a recent study of 86 cases, the authors conclude that the chance of stone clearance by PCNL is about 84% but still higher in comparison to extracorporeal shock wave lithotripsy (ESWL) [11].

3.4. Horseshoe kidney (HSK)

HSK is the most common renal fusion abnormality with an incidence of about 1/400 [12]. This anatomic anomaly is challenging for retrograde or extracorporeal treatment modalities because of malrotation of the kidney and collecting system complexity. In these cases, an even smaller stone volume can be better treated percutaneously. The optimal anatomic point of renal puncture for HSKs is through a posterior upper calix, which is typically in a more medial and caudal location than the normal kidney and enables infra-costal approach. PCNL in HSK is safe and effective with success rates of about 92%. Auxiliary procedures may be needed in order to achieve this stone free rates [13].

3.5. Calyceal diverticulum

A calyceal diverticulum is a non-secretory outpouching of the collecting system in the renal parenchyma and is lined by transitional cell epithelium communicating with the main collecting system via a narrow channel. It was first described in 1841 by Rayer [14]. It contains stones in up to 50% of cases with an average size of 12 mm and ranges from 1 mm to 30 mm. The vast majority of patients with calyceal diverticulum are asymptomatic. Indications for intervention include chronic pain, recurrent urinary tract infection, gross hematuria, or deterioration of renal function [15]. PCNL has been suggested to have high success rates in calyceal diverticular stone (CDS) treatment and has produced worldwide better results than those achieved by SWL. Percutaneous approach offers improved access to larger, more complex, and posteriorly located stones. Moreover, it allows the surgeon to manage the diverticulum with fulguration or incision of the diverticular neck [16]. In a review, Waingankar et al. [17] concluded that percutaneous access through a posteriorly located mid- to lower-pole calyx for the management of diverticular stones, offers simultaneously the ability to directly ablate the diverticulum. PCNL remains effective in the management of upper-pole diverticula but carries the risk of pulmonary complications. In another study, it was reported that among management options for CDS, the most versatile approach with maximum stone-free and symptom-free rates is PCNL [18]. In this study, the stone clearance was more than 90% and the conclusion was that PCNL can clear calculi from calyceal diverticula in most cases with minimal morbidity. After stone retrieval, the diverticula may be drained into the collecting system or fulgurated [18].

3.6. Stone composition

As mentioned previously, one of the indications for the percutaneous approach is stone density. SWL and RIRS results could be compromised as the treated stone becomes harder. Intracorporeal lithotripters used in PCNL such as ultrasonic devices or larger laser fibers may be more efficient than retrograde or extracorporeal approaches. Gücük and Üyetürk [19] reported that Hounsfield Units play a vital role in the selection of the appropriate treatment modality contributing to improved success rates. The authors conclude that both stone size and hardness are important parameters for PCNL selection.

3.7. Stone location, lower pole stones

The lower pole calculi management can be a challenging procedure. The indications for percutaneous, extracorporeal or retrograde lithotripsy choice are controversial. Several factors should be considered before treating lower pole stones. These include stone size, anatomy of the lower pole, associated morbidity, cost, hospital stay, and of course the efficacy and recurrence rates of each method.

In a recent systematic review and meta-analysis Zhang et al. [20] found that PCNL provided a significantly higher stone-free rate compared to RIRS and SWL. No statistically significant difference was found when PCNL was compared to RIRS and SWL in regards to complication rates. PCNL had a longer hospital stay whereas SWL was associated with significantly higher retreatment rates. However, there were no significant differences in auxiliary procedures rates among the three treatment modalities. The authors concluded that stones of 1.5—2 cm located in the lower pole should be treated percutaneously.

4. Techniques

Modern PCNL is a complicated staged procedure where each step is technically demanding and should be completed with precision. The main steps are positioning of the patient, renal access, safe tract dilatation, intracorporeal lithotripsy, fragments evacuation and upper system drainage. Updated techniques of each step are brought in this part of the review.

4.1. Patient positioning

Patient positioning influences not only the endourological approaches but also the cardiovascular and ventilation status of the patient during the procedure. Three main options exist—prone, supine and lateral decubitus position. The *pros and cons* of prone versus supine PCNL are in debate. Prone position is still considered as the standard approach. The advantages are easier identification of renal anatomy and selection of the appropriate puncture site. It also provides a wider surface area for percutaneous access with a low risk of abdominal visceral injuries [21]. The main concern with the prone position is anesthesiological safety affecting patient's cardiovascular status, especially in cases of obese patients. The supine position has been introduced to deal with these drawbacks. With regards to the advantages, cardiovascular and respiratory risks are diminished, easier for the anesthesiologist to manage the patient, no need to reposition the patient following initial retrograde ureter catheter insertion [21]. However, Siev et al. [22] addressed the ventilatory issues and concluded that obese patients have higher baseline peak inspiratory pressure regardless of position and that prone positioning does not impact peak inspiratory pressure and remains a safe and viable option. The disadvantages of the supine position are a limited surface area for puncture, increased skin to kidney distance and potential risk for visceral and vascular injuries [23]. In a recent meta-analysis which included 5881 patients from 13 randomized controlled trial (RCT) and non-RCT studies, several advantages of supine over prone positioning were proposed. Alongside safety concerns, stone-free rates were lower in supine group. An obvious advantage was the reduction of the mean operative time. No effect on the average length of hospital stay was observed. The authors outlined the retrospective nature of the majority of the studies and concluded that there is a need for prospective, multi-center RCTs [24]. The lateral decubitus position [25] might overcome these disadvantages and still preserve most of the benefits of the supine position that were noted. In such approach, the endourologist can still use all familiar potential puncture sites as in prone position avoiding its main disadvantages.

4.2. Access

Performing the renal access during PCNL is the most crucial step of the procedure with the steepest learning curve. It can be performed by an interventional radiologist (IR) prior to planned operation or by the endourologist during the procedure. The ultimate goal is to remove the entire stone burden in a single procedure [26]. The experience of the endourologist plays an important role in decision making but generally, the access may be safely obtained both by the endourologist and IR. However, when the endourologist performs the access during the surgery, the actual stone location can be observed and the ideal access to the collecting system can be selected. Previous studies have shown lower stone-free rate and a higher complication rate in cases that the access was performed by radiologist [27]. There are several guidance options for renal puncture during PCNL.

4.2.1. Fluoroscopy-guided access

The "bull's eye" or "the eye of the needle" technique for renal access gaining is an established, well-known technique that is widely applied. It incorporates alignment of C-arm fluoroscopy image with an imaginary line to the desired calyx. C-arm rotation confirms the proper depth of the needle and its secure advancement to the fornix of the preferred calyx. Another technique is the "triangulation" using two known points of reference to locate a third unknown point and guided by biplanar fluoroscopy [28]. Most updates of access techniques that are discussed in our review are focusing on two main principles: Increasing target accuracy and decreasing radiation exposure of the patient and the medical staff. In accordance with that goal, a mono-planar access technique was described [29]. It is different from the biplanar method in the fact that only fluoroscopic projections maintained on a vertical plane are utilized. In this study of 200 patients, apart from one case with an injury to the colon, no severe complications were observed. The stone-free rate was approximately 80% after a single procedure. The authors concluded that this type of fluoroscopy access is faster, safe, and effective [29]. Another puncture method is performed using the mathematical principle to determine the angle and depth of the puncture in the prone position. In more than 150 cases with accesses to various calyces, more than 95% success in the first attempt was described with this mathematically based technique and no pleural, visceral or hemorrhagic complications occurred [30].

4.2.2. The ultrasonography (US) guided access

US is a safe and effective method of imaging guidance during percutaneous access in PCNL. It is versatile, enables real-time image acquisition, cost-effective and can be used in both supine and prone positions [31]. Two-dimensional US cone has sometimes a compromised image quality. Technologic advancement led to the introduction of combined three-dimensional (3D) US images, which provided a complete view of the needle length and its alignment with the targeted calyx [32]. In a recent manuscript, the authors described the Interactive Closest Points algorithm of intraoperative US images and preoperative magnetic resonance (MR) images combination. This technique does not allow real-time imaging, demands experienced technicians and are insufficient at the identification of small calculi. Nevertheless, it can be successfully used in preoperative planning [33].

4.2.3. Endoscopic guided access (EGA)

EGA is rare and was first reported in 1995 in a series of nine patients [34]. It involves endoscopic retrograde assistance to percutaneous access by flexible ureteroscope. The advantages seem to be lower transfusion rates, precise calyx targeting, shorter operative time and lower radiation exposure [34]. Recently various studies have described the results of this technique. In a comparison study of standard imaging and EGA in 159 cases, patients undergoing EGA had shorter fluoroscopy time (3.2 *vs.* 16.8 min, $p < 0.001$). EGA group also needed lower number of punctures required for access (1.03 *vs.* 1.22 $p = 0.002$). There was no significant difference in blood transfusion rate, operative time, or intraoperative complications between the groups [35]. Procedures were aborted due to bleeding more commonly in standard (8%) than in the EGA group (0%), $p = 0.02$ [35]. Another endoscopic method is a needle with 1.6 mm diameter and micro-optics with light that is used during the puncture or in the sheath of the puncture needle. "Under vision" puncture contributed to the avoidance of adjacent organs and helped in the decrease of the time needed to puncture and as a result of the decrease of radiation exposure [36]. In the same concept of utilizing ureteroscopy to gain renal access, a nephrostomy puncture wire that was advanced retrogradely through a ureteroscope to achieve access to the collecting system was described (UARN). A success rate of 77% was reported using this technique [37].

4.2.4. iPad guided access

Technology advancements in electronics and computers also brought innovation to surgical "navigation" techniques. iPad-assisted puncture employing a marker-based tracking system was invented [38]. Based on preoperative computed tomography (CT) scan images a 3D renal and surrounding tissues model is translated to the virtual anatomy on the iPad and is correlated with the real anatomy driven by 3D CT images. The ideal position and pattern for needle puncture are then recognized [38]. Advantages are feasibility, safety, and efficacy of the technique, but puncture time, learning curve and radiation exposure are still need to be further evaluated.

4.2.5. Combined CT guided access

In this method, digital angiography unit produces sliced images. 3D reconstruction of the kidney and collecting system is performed and a laser guide (syngo iGuide) marks the area of a puncture on the patient's surface and provides the trajectory for needle insertion. In 27 complex access cases, 24 patients had successful percutaneous access obtained using this technique, without major complications. However, the radiation exposure and time required for puncture were higher compared to standard approach [39].

4.2.6. Electromagnetic tracking (EMT) access

EMT enables a new level of precision of renal calyx access. It uses an endoscopically targeted ferromagnetic sensor tip adjusted at the end of a ureteral catheter introduced retrogradely to the desired site in collecting system combined to AURORA tracking system (Waterloo, Canada) and open source Medical Imaging Interaction Toolkit. Then a three-dimension puncture is feasible with 100% success rates as described in a feasibility study on 6 porcine units and 90 renal tracts performed without calyx location affecting the results [40]. A novel, combined US and EMT device for renal puncture navigation, the technique was also proposed [41]. Using a mobile lightweight electromagnetic field generator that is combined with a conventional US probe into one compact apparatus, porcine kidneys were punctured with 100% success [41]. In this report, the authors noted that navigated punctures are superior compared to conventional sonographic ones.

4.3. Tract size

Undoubtedly, one of the most dramatic changes in modern endourology is the reduction of percutaneous tract size. It has a profound impact on the PCNL performance and outcomes. The new techniques demand novel approaches, a different way of thinking and new endourologic armamentarium. Miniaturized percutaneous nephrolithotomy (MPCNL) including mini-PCNL, ultra-mini PCNL, and micro-PCNL have been developed. Decreasing tract diameter to 16, 14 Fr and even less than that (micro-PCNL) may minimize renal parenchymal trauma leading to less bleeding, lower complication rates, and shorter hospital stay, and therefore to a cost-effective procedure. However, smaller stone fragments should be created in order to be evacuated from the smaller diameter tracts, which may increase the operation time of the MPCNL. Another vital issue is the intrarenal pelvic pressure which is significantly increased during the procedure compared to PCNL [42] and constitutes a risk factor for urosepsis. A recent meta-analysis concluded that for different stone sizes different channels should be chosen in order to achieve better stone free rates [43]. The EAU urolithiasis guidelines panel review showed non-inferiority of the procedure in comparison to PCNL in terms of efficacy. They concluded that up to date, there is not enough quality consistent data to outline precise indications for the procedure and further studies are needed for the evidence based recommendation [4]. The tract sizes of miniaturized procedures range from 4.8 Fr to 22 Fr including mini-PCNL (14–22 Fr), ultra-mini PCNL (11–13 Fr) and micro-PCNL (4.85–10 Fr). Due to heterogenicity and misleading definitions, Schilling et al. [45] proposed a new nomenclature for tract sizes in relation to the outer sheath size: XL > 25 Fr, L 20 to <25 Fr, M 15 to <20 Fr, S 10 to <15 Fr, XS 5 to <10 Fr and XXS <5 Fr. Using such small calibers of access sheaths, stone size is an important factor for the selection of the procedure. For example, microperc uses a 16 G "all seeing needle" and a 0.9 mm flexible microperc telescope. The main indications are the management of a single renal calculus or multiple renal calculi of relative small stone burden (<1.5 cm), which can be accessed through a single puncture. Additionally, the indications for microperc can include difficult to access ureteroscopically and lower pole stones that have poor clearance rates with ESWL. Microperc proved to be similar to RIRS in terms of stone clearance and complications [46]. The selection of microperc or retrograde intrarenal surgery finally depends exclusively upon surgeon preference in these cases. Combined, standard and mini tracts could be advised for staghorn, large burden or multiply located in the collecting system stones. In these cases, additional small tracts can improve anatomic approachability while decreasing renal trauma and bleeding and improving stone free rates [47,48].

4.4. Collecting system drainage and fragments extraction

One of "mini-techniques" main concerns is an increase of the collecting system pressure during lithotripsy. Increased intrapelvic pressure might exaggerate intravascular fluid overload, acidosis, extravasation, and cause sepsis. Retrogradely placed ureter-catheter (UC) drains the collecting system during lithotripsy and is one of the methods of decreasing the pressure. Another method is an irrigation pump that is combined with retrograde pressurized flushes of the collecting system through the UC. The time-dependent pump generates an intermittent pressure increase interrupted by rest which in total lowers intrarenal pressure. Repeated removal of the endoscope from the closed system further reduces the pressure and also creates a vacuum within the sheath, called a "vacuum cleaner effect". This effect forces out smaller fragments, and was described using Karl Storz Nagele minimally invasive PCNL (MIP) system [49].

4.5. Intra-corporeal lithotripsy devices

Intra-corporeal lithotripsy devices used in PCNL are divided into Holmium:YAG laser, pneumatic, ultrasonic or a combination of these. These instruments have their own distinct advantages, and all are considered to be safe, causing limited damage to the urothelium and structures of the collecting system. Because of the ability of powerful simultaneous fragmentation and clearance of the stone fragments and by utilizing reusable probes thus decreasing the costs, the ultrasonic technology is widely incorporated in PCNL. Pneumatic lithotripters are more efficient in fragmentation, but enable less control in stone retropulsion and fragmentation, making the procedure more time consuming [50].

Prior studies comparing lithotripter models have yielded variable results. A recent multicenter RCT compared the efficiency (stone fragmentation and removal time) of three current generation of lithotripters: Cyberwand (ACMI/Olympus, Center Valley, PA, USA), a dual probe ultrasonic device; Lithoclast Select (Boston Scientific, Marlborough, MA, USA), a combination of pneumatic and ultrasonic device; and StoneBreaker™ (Cook Medical, Bloomington, IN, USA), a portable pneumatic device. With the same baseline characteristics, 201 patients were divided into three groups according to the technology used. The results were similar concerning stone clearance rates in PCNL for stones >2 cm. The safety and efficacy were also comparable [51].

Laser lithotripsy is considered to be the least efficient for clearing stones in PCNL. Principally, the advantage of the laser is its flexibility in comparison to other lithotripters. This characteristic is less pronounced in PCNL where mostly rigid nephroscopes are used. In a study comparing high powered holmium laser (2 J, 20–30 Hz) and ultrasonic device for PCNL for the management of complete staghorn calculi showed that the use of the laser led to a significantly longer operative time (148 *vs.* 130 min, $p = 0.03$) with no change in post-operative complications or stone-free rates at 3 months of follow-up [52]. Miniaturization of access tracts in ultra-mini PCNL and the longer operation time has led to the increased demand for powerful laser lithotripsy devices. In contrast to standard approach where stone particles are cleared by ultrasonic suction or easily taken out through 30–32 Fr tracts by various forceps, improving the efficiency of stone dusting might avoid the need for additional intrarenal manipulations and decrease procedure duration. Holmium lasers and associated fibers effectively dust the stones of any composition or size through smallest tracts. One of the latest examples of the development of laser technology is Lumenis Pulse and VersaPulse® PowerSuite™. A 120 W maximal power is delivered through 200, 365, or 550-micron laser fibers at repetition rates up to 80 Hz and low energy pulses (0.2–0.6 J) enabling efficient and fast dusting. An additional limitation of laser lithotripsy is stone retropulsion. Moses technology, including the Moses™ D/F/L fibers, using pulse modulation resulting in improved energy transmission through water and reduced retropulsion. This new technology modulates the energy pulse that enables emission of a controlled portion of energy to create a bubble, known as the "Moses effect" while leaving a portion that travels through the bubble to the stone. Preclinical study comparing the Moses™ mode to the regular mode resulted in significantly higher ablation volume (160% higher, $p = 0.001$) and significant reduction in retropulsion by 50 times at 0.8 J and 10 Hz ($p = 0.01$) with significant reduction in procedure time (average 35% for fragmentation and 23% for dusting, $p = 0.01$) and longer lasering duration with shorter pauses indicating reduced need to reposition the fiber due to lack of retropulsion when using the Moses™ mode. The conclusion of the study was that Moses™ resulted in more efficient laser lithotripsy in addition to significantly reduced stone retropulsion resulting in significantly shorter procedural time and a greater margin of safety [53].

5. Conclusion

Percutaneous stone treatment is an important tool in the armamentarium of the contemporary endourologist. In this review, a variety of promising technologies and evolving techniques are presented. The majority of them require further study to assess their benefit and accept them as an alternative to current standards of care. PCNL is still the gold standard for the management of large and complex renal stones. New technologies enabled the use of smaller caliber instruments without compromising the outcomes. Well-designed randomized multi-institutional studies and careful approach are needed to understand the indications for new, miniaturized procedures and application of the novel technologies.

Author contributions

Study concept and design: Itay M. Sabler, Mordechai Duvdevani.
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Conflicts of interest

The authors declare no conflict of interest.

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