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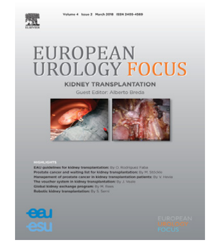

Review – Stone Disease

European Association of Urology Section of Urolithiasis and International Alliance of Urolithiasis Joint Consensus on Percutaneous Nephrolithotomy

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Abstract

Context: Although percutaneous nephrolithotomy (PCNL) has been performed for decades and has gone through many refinements, there are still concerns regarding its more widespread utilization because of the long learning curve and the potential risk of severe complications. Many technical details are not included in the guidelines because of their nature and research protocol.
Objective: To achieve an expert consensus viewpoint on PCNL indications, preoperative patient preparation, surgical strategy, management and prevention of severe complications, postoperative management, and follow-up.
Evidence acquisition: An international panel of experts from the Urolithiasis Section of the European Association of Urology, International Alliance of Urolithiasis, and other urology associations was enrolled, and a prospectively conducted study, incorporating literature review, discussion on research gaps (RGs), and questionnaires and following data analysis, was performed to reach a consensus on PCNL.
Evidence synthesis: The expert panel consisted of 36 specialists in PCNL from 20 countries all around the world. A consensus on PCNL was developed. The expert panel was not as large as expected, and the discussion on RGs did not bring in more supportive evidence in the present consensus.
Conclusions: Adequate preoperative preparation, especially elimination of urinary tract infection prior to PCNL, accurate puncture with guidance of fluoroscopy and/or ultrasonography or a combination, keeping a low intrarenal pressure, and shortening of operation time during PCNL are important technical requirements to ensure safety and efficiency in PCNL.
Patient summary: Percutaneous nephrolithotomy (PCNL) has been a well-established procedure for the management of upper urinary tract stones. However, according to an expert panel consensus, core technical aspects, as well as the urologist's experience, are critical to the safety and effectiveness of PCNL.

1. Introduction

Urolithiasis is one of the most common diseases in benign urological conditions. The prevalence of urolithiasis ranges from 1% to 20% worldwide according to the most recent epidemiological surveys [1,2].

Percutaneous nephrolithotomy (PCNL) has been a well-established procedure in the management of upper urinary tract stones >2 cm [3–5]. Although PCNL has been performed for decades and has gone through many refinements, there are still concerns regarding more widespread utilization because of the long learning curve and the potential risk of severe complications. Several urological associations, including American Urological Association (AUA), European Association of Urology (EAU), and Chinese Urology Association, have released corresponding guidelines [6,7], but many technical details of PCNL are not included in the guidelines because of their nature and research protocol.

Given the safety and effectiveness of PCNL, a global consensus on indications, preoperative patient preparation, surgical strategy, prevention and management of severe complications, postoperative management, and follow-up is certainly desirable [8]. In order to standardize the procedure and make it more acceptable, the Urolithiasis Section of the EAU (EULIS) and the International Alliance of Urolithiasis (IAU) present a joint consensus on PCNL.

2. Evidence acquisition

2.1. Study design and participants

A prospectively conducted study incorporating literature review, discussion on research gaps (RGs), and questionnaire and following data analysis was carried out during the coronavirus 2019 (COVID-19) outbreak in 2020.

Expert representatives, with expertise in PCNL, from the EULIS, the IAU, and other urology associations all around the world were invited to form an international panel for PCNL consensus drafting.

2.2. Literature review

The Medline, Embase, and PubMed databases were searched for a systematic review of the literature from 2010 to present. The keywords and medical subject heading (MeSH) terms for search strategy were as follows: "percutaneous nephrolithotomy," "PCNL," "PNL," "urolithiasis," and "urinary tract stones," either alone or in combination. Potentially relevant articles were screened, and further evaluation was required to select the exact studies focused on PCNL. The enrollment criteria were the following: (1) articles published in English and (2) PCNL-related studies, either prospective or retrospective. Repeated published materials were excluded.

Official guidelines on stone management from the EAU, AUA, and other associations were also enrolled.

2.3. RG evaluation and consensus developing

A core group summarized RGs from the above selected studies, mainly in the following four aspects: (1) preoperative evaluation and preparation, (2) intraoperative tips and tricks of PCNL procedure, (3) management and prevention of severe complications, and (4) postoperative evaluation.

The initial draft was completed and reviewed by all the experts, and a modified Delphi survey was then conducted in the way as reported [9]. The aim of the first survey was to reach consensus, defined as 70% agreement by experts [10]. As these RGs did not reach a consensus, another round of survey with questionnaires on key RGs was required.

A draft manuscript was produced and reviewed by all experts; several disagreements were eliminated after three rounds of discussion before the manuscript was finalized.

3. Evidence synthesis

The expert panel consisted of 36 specialists in PCNL from 20 countries all around the world. A total of 120 studies were cited as references. The consensus on PCNL was reached, which is described in the following sections.

3.1. Indications and contraindications for PCNL

Indications for renal stones are as follows [3–8]:

1. Renal stones $\geq$2 cm
2. Lower pole stones $\geq$1.5 cm
3. Stones in calyceal diverticulum
4. Stones of any size unsuitable for or that have failed after shock wave lithotripsy (SWL) or retrograde intrarenal surgery (RIRS)

Indications for ureteric stones are the following:

1. Stones $\geq$1.5 cm in upper ureter
2. Stones of any size if retrograde access is not possible or not available (ureteral stricture, urinary diversions, ureteral reimplantation, etc.).

The following are relative contraindications:

1. Pregnancy
2. Patients unfit for general anesthesia (severe heart disease, pulmonary insufficiency, etc.)
3. Stones in the kidney with tumor in the vicinity of the proposed PCNL tract
4. Severe spinal deformities precluding patient positioning and access to the desired calyx
5. Inaccessible collecting system due to interposition of other organs (retrorenal colon, pleura, lung, etc.)
6. Patients on anticoagulant therapy that cannot be discontinued temporarily

Absolute contraindications are as follows:

1. Patients with uncorrected coagulopathies
2. Untreated acute urinary tract infection

3.2. Patient evaluation and preparation

3.2.1. Routine examination before operation

Standard evaluation includes the following [7,8]:

1. Detailed medical history
2. Physical examination
3. Laboratory tests: full blood count, blood group, coagulation function, renal function, serum electrolytes, urinalysis, midstream urine culture, and antibiogram
4. Imaging: plain X-ray film of the kidney, ureter and bladder (KUB) and a non–contrast-enhanced computed tomography scan (NCCT; preferably a low-dose computed tomography [CT]) are recommended to evaluate the stone location and characteristics, which are fundamental to planning optimal access and determining the ideal number of tracts. A contrast study of intravenous urogram or contrast CT is required only in selected cases for whom further anatomic details are advisable [11,12]. If necessary, a CT scan of the abdomen with three-dimensional reconstruction can be considered [13–15]. Functional imaging (emission CT) may be indicated to evaluate the split renal function.

3.2.2. Preoperative workup

3.2.2.1. Evaluation of urinary tract infection. In patients with a positive preoperative midstream urine culture (MSU), an antibiotic should be administered according to antibiogram findings for a period of 3–7 d [6,7,16].

In patients with negative MSU but positive urinalysis for leukocytes and/or nitrites, no empirical antibiotic treatment is required [17–19]; however, prophylaxis antibiotics according to the local prevalent antibiogram should be administered 30 min prior to PCNL in these patients, as well as in patients with negative MSU and negative urinalysis [6,7,16–20].

In patients with resistant (intractable) urinary tract infection due to obstruction, staged operations might be considered, by which the placement of a percutaneous nephrostomy tube or ureteric stent is performed first and definitive stone management (PCNL) is performed at a later date, after treatment with appropriate antibiotics [21,22].

3.2.2.2. Anticoagulants and antiplatelet drugs. In patients under anticoagulant/antiplatelet management, the risk of thromboembolism with discontinuation of therapy is determined according to the underlying pathology (atrial fibrillation, artificial heart valves, arteriovenous embolism within 3 mo, etc.) [23]. Referral to a hematologist/cardiologist may be advisable.

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Anticoagulant (warfarin, dabigatran, rivaroxaban, or apixaban) should be discontinued 5 d prior to PCNL, with bridging therapy utilized according to the recommendations of the cardiologist or hematologist [23,24].

Antiplatelet drugs, including aspirin, clopidogrel, and thienopyridine agents (P2Y12 receptor inhibitors), should be discontinued 5–7 d before PCNL. Thienopyridine agents should be resumed with a loading dose within 24–72 h after PCNL in patients with a high risk of thromboembolism. Bridging therapy with glycoprotein IIb/IIIa inhibitors is recommended in patients receiving thienopyridine agents [23–27].

If anticoagulation/antiplatelet therapy cannot be discontinued before PCNL, other less invasive treatment procedures (insertion of ureteric stent) should be considered for an obstructed kidney [27].

3.2.2.3. Evaluation of obstructive nephropathy. A preliminary nephrostomy tube/ureteric stent insertion should be considered in patients with significant renal dysfunction secondary to acute obstruction when the patient condition is not well enough to tolerate the PCNL procedure [28,29].

In patients with chronic renal failure, if severe metabolic acidosis and/or hyperkalemia is noted, hemodialysis is recommended to optimize the patient.

3.3. PCNL procedure

3.3.1. Anesthesia and patient positioning

The PCNL procedure can be performed under general anesthesia, spinal anesthesia, epidural anesthesia, paravertebral block, or local infiltration anesthesia [30–32]. The choice of anesthesia may be decided by assessment of patients' comorbidities (cardiopulmonary function, coagulation function, spinal diseases, etc.) and urologists' preference, and also the local hospital conditions.

Patient positioning also depends on patients' comorbidities and urologists' preference. Available options are the prone, supine, lateral, or modified positions [33–35]. Prone PCNL is the most traditional and widely utilized position at present, while supine positioning is considered equally acceptable [36–38]. Modified positions are also available for endoscopic combined intrarenal surgery or other alternative procedures [39].

3.3.2. Retrograde ureteric catheterization

The PCNL procedure can be assisted with an open-ended ureteric catheter or balloon catheter, to allow retrograde injection of saline or contrast during renal access and to prevent migration of stone fragments down to the ureter. Furthermore, by injecting methylene blue or inserting a guidewire retrogradely, it can help better identify the ureteropelvic junction or establish through-and-through access [40,41].

In cases of failed retrograde ureteric catheterization, ultrasound-guided puncture is required, and percutaneous anterograde radiography would further elucidate the anatomy of the renal collecting system.

3.3.3. Type of imaging

Fluoroscopy and ultrasound guidance alone or in combination are widely used to gain access to the desired calyx during PCNL [42]. Ultrasound guidance generally provides a clear understanding of renal position, configuration of the calices, and location of adjacent organs in real time, thereby facilitating safe and effective puncture [42–46]. However, positioning of the guidewire, tract dilation, and identification of residual stone fragments are more easily monitored by fluoroscopy than by ultrasound [47,48].

When fluoroscopy is utilized, precise puncture is achieved using the triangulation technique, the bulls-eye technique, or a hybrid of these systems [49]. However, fluoroscopy increases radiation exposure to both the patient and the medical staff. Adherence to the ALARA (as low as reasonably achievable) rule may reduce radiation exposure [50], including the use of pulsed fluoroscopy, low-dose emission, and Endovision. A combination of ultrasound and pulsed fluoroscopy provides the advantages of both imaging modalities by reducing radiation exposure without compromising the safety and efficacy of the procedure [42].

3.3.4. Selection of the puncture site

The optimal puncture should be planned preoperatively according to the stone characteristics, collecting system anatomy, and the location of adjacent organs [51,52]. The general principle is to create efficient access to the largest stone burden. A papillary puncture is traditionally performed with the aim of minimizing the risk of bleeding respecting the anatomy of the intrarenal vascularization [53]. Recent studies have also reported that nonpapillary punctures might also be a feasible alternative in expert hands [54].

3.3.5. Selection of the tract size

The selection of tract size depends on stone characteristics, surgeon's preference, and available instruments. Compared with mini-PCNL, standard PCNL allows for quicker stone removal, but are associated with a higher risk of bleeding [55,56]. A small tract is believed to decrease tract-related bleeding, but stone extraction is more time consuming [57,58]. With 18Fr suction sheath, mini-PCNL and enhanced super-mini-PCNL could be equally effective for managing staghorn calculi [59,60], while super-mini-PCNL, ultra-mini-PCNL, and Microperc are recommended for small stone burden [61–63]. When multitract PCNL is performed, the combination of large and small tracts may improve stone clearance, while minimizing the risk of hemorrhagic complications [64].

3.3.6. Percutaneous tract dilatation

The general principle for tract dilation is to "prefer shallow to deep", as too deep dilatation may increase the risks of perforation of the collecting system and bleeding. Fluoroscopy guided tract dilation is most commonly performed. Sequential fascial dilators, balloon dilators, and other dilators have their own pros and cons, but all are considered acceptable and depend on the surgeon's preference [65].

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3.3.7. Stone fragmentation and extraction techniques

The optimal choice of energy source to fragment stones is determined by the stone characteristics and tract size. Ultrasonic-based lithotripters can fragment and aspirate stone fragments simultaneously, thereby reducing stone extraction time and maintaining low renal pelvic pressure [66]. However, effectiveness may be reduced with very hard stones such as calcium oxalate monohydrate or uric acid stones. Ballistic lithotripters are useful for harder stones. Lithotripsy with Ho:YAG laser is suitable for stones of all compositions, but high energy is required for large stone burden [67–69]. With the advent of thulium fiber lasers, this situation might be changed in the very near future [70].

During PCNL, excessive/inappropriate torqueing of the nephroscope can tear the renal parenchyma and lead to bleeding complications. The use of flexible nephroscopy to search for residual fragments/stones in difficult calyces should be utilized in lieu of torqueing of the rigid nephroscope. If necessary, a multitract PCNL can be considered to minimize renal manipulation [71].

Blood loss and infectious complication increase with the operation time [72]. Setting a time limit for PCNL is common practice and varies from 1 to 4 h, but should take into account the condition of the patient intraoperatively. Simultaneous bilateral PCNL can be used to treat moderate bilateral stone burdens, especially after proficiency has been achieved for unilateral PCNL [73].

3.3.8. Staged PCNL and second-look PCNL

Occasionally, the operation may require two stages for completion. If purulent fluid is obtained at the time of renal puncture, the operation should be stopped immediately. In this case, a nephrostomy tube should be inserted to allow for infection to clear with drainage and antibiotics [21,22,74]. If the calyceal system is occupied completely by stones, not allowing enough room to place a nephrostomy tube, limited stone fragmentation that is enough to allow for nephrostomy tube placement may be performed. Careful attention to maintain low renal pelvic pressure is essential.

The presence of residual stones following PCNL should be re-evaluated by postoperative imaging (KUB and/or NCCT). Retreatment options include second-look PCNL, antegrade flexible nephroscopy, RIRS, SWL, or a combination of modalities [74].

3.3.9. Exit strategy

3.3.9.1. Indications for indwelling nephrostomy tube. Placement of a nephrostomy tube is indicated in the case of residual stones, urinary extravasation, severe bleeding, ureteric obstruction, pyonephrosis, or subsequent planned stone chemolysis. Generally, an 8–10Fr nephrostomy tube is recommended to maintain access and provide drainage. The nephrostomy tube can generally be removed within 1–2 d after assuring adequate antegrade drainage, when the urine is relatively clear and residual fragments have been cleared [75,76].

3.3.9.2. Indications for ureteric stent placement. Indications for ureteral stent placement include residual stones to be treated ureteroscopically at a later date, urinary extravasation, ureteric obstruction, or iatrogenic ureteric injury. The stent can safely be removed after 1–2 wk if no residual ureteric fragments are noted [75].

3.3.9.3. Indications for totally tubeless PCNL. Totally tubeless PCNL is feasible in selected cases with no expectation of residual stones, no signs of sepsis, no collecting system perforation, no ureteric obstruction, and no severe bleeding during the PCNL procedure [77–80].

3.3.10. PCNL in special cases

Serial reports have verified the feasibility of PCNL in selected special cases, such as stones in horseshoe kidney, transplanted kidney, and ectopic kidney [81–83]. Owing to the abnormal anatomy of the kidney and/or renal collecting system, puncture of the desired calyx and access to different calyxes are challenging in these cases. A three-dimensional CT reconstruction would help in preoperative case selection and evaluation; intraoperative real-time ultrasonography guidance is critical in puncture, while fluoroscopy is required in tract establishment [84]. Although PCNL in children is similar to that in adults, mini tracts are more expected owing to the nature of the narrow renal collecting system and small stone burden in children [85].

3.4. Prevention and management of complications

3.4.1. Hemorrhage

In case of poor visibility due to severe intraoperative bleeding, the operation should be terminated and a nephrostomy tube should be placed. The patient should be placed in the supine position as soon as possible, as bleeding may stop as a result of the pressure of abdominal contents over the kidney. If the bleeding fails to cease, the nephrostomy tube can be clamped to allow clots in the collecting system to tamponade the bleeding. In general, venous bleeding should cease within 30 min of clamping the tube [86–88].

In case of severe loin pain, gross hematuria from the Foley catheter, significant hemoglobin drop, or hemodynamic instability, arterial bleeding is suspected and an arteriogram with selective renal artery embolization should be considered [89,90].

A solitary kidney, multiple tracts, diabetes, large stone burden, and the experience of the urologists have been shown to be independent risk factors for severe bleeding following PCNL [91–93]. Precise renal puncture, careful tract dilation, fewer accesses, smaller tracts, and avoidance of torqueing in the kidney are the key factors for avoiding significant bleeding complications.

3.4.2. Postoperative infections

Post-PCNL infections can fall into a wide spectrum of severity. Systemic inflammatory response syndrome (SIRS), sepsis due to urinary source, and septic shock reflect varying severity of infection where fever, leukocytosis, or hemodynamic instability may be the presenting signs [94].

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Generally, simple postoperative fever resolves within a few days without requiring a change in the antibiotic regimen, while severe infection, sepsis, or septic shock is potentially life threatening and constitutes the most dangerous post-PCNL complication. Thus, early and rapid identification of patients with sepsis is imperative in order to initiate prompt treatment and minimize morbidity and mortality [95].

When postoperative fever and/or chills occur, blood tests including procalcitonin may be performed to determine the infection status. A very low or very high white blood cell count ($\leq 3 \times 10^9$/l or $\geq 20 \times 10^9$/l) or a progressive decrease in platelet count can indicate impending sepsis [95–97].

The sensitivity and specificity of SIRS criteria in determining the severity of infection have recently been questioned. A new definition of sepsis, Sepsis-3.0, requires the quick sequential organ failure assessment (qSOFA) for the prediction of mortality in sepsis. The qSOFA criteria consist of low blood pressure (systolic blood pressure $\leq$100 mmHg), increased respiratory rate ($\geq$22 bpm), and altered mental status (Glasgow Coma Scale $\leq$14). The qSOFA score is a simple but very useful tool to evaluate sepsis status that requires a thorough evaluation of respiratory, neurological, cardiovascular, coagulation, and renal functions [98].

The treatment principles of sepsis include initiation of early appropriate antibiotic therapy, resuscitation support, and management of complication in other systems [99]. Early use of broad-spectrum antibiotics along with fluid replacement can significantly improve survival rates. At the same time, blood clotting, and liver and kidney function status should be monitored carefully. Fluid resuscitation, transfusion with blood products, and pressor support may be required to maintain circulation. Intubation and mechanical ventilation are used to correct serve respiratory acidosis or in case of respiratory failure [99].

The key points in the prevention of post-PCNL severe infections are effective treatment of preoperative urinary tract infections, maintenance of low intraoperative renal pelvic pressure, and minimization of operative time [100–103].

3.4.3. *Organ injuries*

Supracostal punctures increase the risk of pleural injury, with the potential for hydrothorax, pneumothorax, or hemothorax. If the patient complains of shortness of breath or pain radiating to the shoulder, or if blood oxygen desaturation is noted, pleural injury should be suspected [104]. The diagnosis can be made by chest x-ray or CT scan. While a small pneumothorax or hydrothorax can be treated conservatively, larger fluid collections require percutaneous pleural aspiration or drainage. Liver and spleen injuries following PCNL are very rare; however, the majority of splenic injuries cause severe bleeding. In these cases, ultrasound or CT imaging can make the diagnosis. These complications can be managed by leaving the nephrostomy tube in place for a prolonged period of time, but in case of uncontrolled bleeding, arterial embolization or laparotomy may be required [105,106].

Intraperitoneal bowel injury should be considered if the patient develops symptoms of peritonitis. These cases may require an exploratory laparotomy. In case of extraperitoneal colonic injury without peritonitis, the initial management can be conservative, by repositioning the nephrostomy tube into the injured colon or in its close vicinity to provide free and effective outside drainage to leaking colonic contents, along with placing a ureteral stent. A contrast study through the colostomy tube should be performed in 5–10 d or as soon as infection is controlled, to ensure that there is no further communication between the kidney and the colon. Once this has healed, the nephrostomy tube can be removed from the colon, and the ureteral stent can be removed within 7–30 d after that [107–109].

3.4.4. *Fluid extravasation*

During PCNL, extravasation of fluid, generally irrigation, should be suspected when there is progressive abdominal distension, oxygen desaturation, or an unexplained increase in inspiratory peak airway pressure [110]. The PCNL procedure should be terminated promptly and nephrostomy tube should be placed.

Mild fluid extravasation can generally be managed with conservative treatment, while severe extravasation requires immediate management. Ultrasonography can detect the ascites or pelvic effusion, and guide the placement of a drainage tube [104,110].

The keys to prevent extravasation during PCNL are to avoid pelvicalyceal system perforation, maintain low intrarenal pressure, and minimize operation time [104]. If perforation of the pelvicalyceal system occurs, discontinue the procedure and provide drainage. Newer energy devices with simultaneous suction could reduce intrarenal pressure, and also irrigation with low pressure is recommended.

3.5. *Postoperative evaluation and follow-up*

3.5.1. *Evaluation of stone-free status*

Evaluation of stone-free status is generally assessed by NCCT obtained postoperatively between 1 d and 4 wk. NCCT is more accurate and sensitive than x-ray KUB, as the latter can be unreliable in case of small stone fragments, radiolucent stones, and bowel interposition [11,111,112]. Residual stones <2 mm may be considered acceptable with regard to long-term outcomes [113,114].

3.5.2. *Prevention of stone recurrence*

All patients should undergo stone analysis and basic metabolic evaluation. High-risk patients should undergo full metabolic evaluation. All patients should receive general dietary counseling and increased fluid intake, while high-risk patients should receive directed dietary and pharmacological therapy based on metabolic evaluation.

3.5.3. *Follow-up of residual stones*

Patients with stones $\geq$4 mm, diabetes mellitus, hyperuricemia, or non–lower calyceal stones are at a higher risk of having further stone growth and complications, requiring intervention. For fragments $\geq$4 mm, consideration should be given to preemptive treatment of these stones even if

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these are asymptomatic [115–117]. SWL or RIRS can be offered for treatment of residual stones >6 mm, while patients with residual fragments <5 mm might benefit from external physical vibration lithecbole and/or medical management with periodic follow-up [118]. The goal should be complete stone clearance, but all patients should be followed closely at regular intervals.

3.6. Training and practice

PCNL is currently the most complicated stone surgery technique to teach. The learning curve should evaluate surgical expertise and the number of procedures needed to gain competence; thus, the steep learning curve in PCNL is mainly related to obtaining percutaneous access. Competence at PCNL is reached after 60 cases and excellence is obtained at >100 cases [119,120].

The learning process should begin with the theoretical approach written in books and journals, and then continue, under mentor's supervision, with practice on animal models or surgical simulators (inanimate or VR simulators), and finally on patients. Besides the traditional stages and theoretical courses, master class workshops in PCNL offer training opportunities to residents and junior urologists and include intense real-life hands-on training by experts [119].

3.7. Discussion

Although PCNL has been a well-established procedure in the management of large stone burden, there are still concerns regarding more widespread utilization because of the long learning curve and the potential risk of severe complications. The tips and tricks of PCNL are available mostly in academic conferences or during training courses, rather than in guidelines, since the technical details are not included in the guidelines because of their nature and research protocols.

The present joint consensus on PCNL from the EULIS and the IAU presents series of technical details that cannot be obtained from guidelines. With the development of equipment and increasing experience, PCNL is also developing rapidly; technical aspects varies in different regions, such as the anesthesia, position, puncture guidance, tract size, sheath, nephroscope system, and so on. However, as presented in the consensus, the core technical aspects of the PCNL procedure are always coincident and will never change.

We acknowledge that the expert panel is not as large as expected; since the COVID-19 pandemic impacts us all, a face to face meeting is not available. However, extensive and positive communication through e-mails promotes team cooperation and consensus development. Second, the discussion on RGs does not bring in more supportive evidence in the present consensus; further analysis and evidence classification are required to enrich our statement.

4. Conclusions

Adequate preoperative preparation, especially elimination of urinary tract infection prior to PCNL, accurate puncture with guidance of fluoroscopy and/or ultrasonography or a combination, maintenance of low intrarenal pressure, and shortening of operation time during PCNL are important technical requirements to ensure the safety and efficiency of PCNL.

Author contributions: Zhangqun Ye 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: Zeng, Ye, Sarica.
Acquisition of data: Zhong, Pearle, Choong, Chew, Skolarikos, Liatsikos, Pal, Lahme, Durutovic, Farahat, Khadgi, M. Desai, Chi, Smith, Hoznek, Papatsoris, J. Desai, Mazzon, Somani, Eisner, Scoffone, Nguyen, Ferretti, Giusti, Saltirov, Maroccolo, Gökce, Straub, Bernardo, Lantin, Saulat, Gamal, Denstedt.
Analysis and interpretation of data: Zeng, Zhong, Ye, Sarica.
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