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GUIDELINES

International Alliance of Urolithiasis (IAU) Guideline on percutaneous nephrolithotomy

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ABSTRACT

The International Alliance of Urolithiasis (IAU) would like to release the latest guideline on percutaneous nephrolithotomy (PCNL) and to provide a clinical framework for surgeons performing PCNLs. These recommendations were collected and appraised from a systematic review and assessment of the literature covering all aspects of PCNLs from the PubMed database between January 1, 1976, and July 31, 2021. Each generated recommendation was graded using a modified GRADE methodology. The quality of the evidence was graded using a classification system modified from the Oxford Center for Evidence-Based Medicine Levels of Evidence. Forty-seven recommendations were summarized and graded, which covered the following issues, indications and contraindications, stone complexity evaluation, preoperative imaging, antibiotic strategy, management of antithrombotic therapy, anesthesia, position, puncture, tracts, dilation, lithotripsy, intraoperative evaluation of residual stones, exit strategy, postoperative imaging and stone-free status evaluation, complications. The present guideline on PCNL was the first in the IAU series of urolithiasis management guidelines. The recommendations, tips and tricks across the PCNL procedures would provide adequate guidance for urologists performing PCNLs to ensure safety and efficiency in PCNLs.

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Introduction

Percutaneous nephrolithotomy (PCNL) has been applied as a well-established procedure in the management of upper urinary tract stones for decades.[1] However, its applicability in the routine daily practice is challenging particularly in unexperienced hands because of a long learning curve, the potential of severe complications which are more frequently noted compared to other less invasive endoluminal stone removal modalities.[2] Exactly, different International Associations have proposed their own guidelines on urolithiasis, but their focus is primarily on surgical principle rather than surgical technique-based aspects. Therefore, a standardized approach rather than individual experience-based applications is certainly needed with the aim of rendering PCNLs safer and more widespread utilized.

As a non-profit-making academic Institution, the International Alliance of Urolithiasis (IAU) has always adhered to academic and techniques promotion principles worldwide. Now, IAU would like to release the latest guideline on PCNL and provide a clinical framework for PCNLs including perioperative evaluation, intraoperative procedural tips and tricks, and postoperative follow-up.

Panel and future goals

The IAU Guideline on PCNL Panel consists of an international group of faculty members with particular expertise in PCNL applications. None of the panel members declared any potential conflict of interest. A serial of urolithiasis management guidelines will be released step by step in the upcoming years. Both the panel as well as the released guidelines are planned to be updated regularly at specific time intervals.

Literature search

Data identification

For 2021 IAU guideline on PCNL, all recommendations and conclusions are collated and appraised from the systematic review and assessment of the available literature. The comprehensive searching covering all aspects of PCNL was performed from the PubMed database. The searching terms include "percutaneous nephrolithotomy," "PCNL," "PNL" or "percutaneous lithotripsy," publication date ranges from January 1, 1976, to July 31, 2021. The studies with high levels of evidence, *i.e.*, randomized controlled trials (RCTs), prospective non-randomized comparative studies, and meta-analysis (MA) were preferred for further evaluation and referred.

LE and GR

Each recommendation was graded in a modified GRADE (GR) methodology.[3] The body of evidence is assigned a strength rating of A (high-quality evidence; high certainty), B (moderate-quality evidence; moderate certainty), or C (low-quality evidence; low certainty) according to the evidence that existed.

The quality of the evidence was graded according to a classification system modified from the Oxford Center for Evidence-Based Medicine Levels of Evidence.[4] Level (LE) 1 was the highest level, and level 5 was the least, assigned according to the study nature and homogeneity.

Guideline results

Indications and contraindications

Indications

- Renal stones ≥2 cm (LE: 1, GR: A);
- stones in the upper urinary tract of any size unsuitable for or that have failed shock wave lithotripsy (SWL) or retrograde intrarenal surgery (RIRS) (LE: 2, GR: B).

PCNL is recommended as the primary treatment option for stones >20 mm, including staghorn stones.[5-7] However, it is also feasible for smaller stones (<20 mm) that are unsuitable for or after failed SWL or RIRS,[8-11] regardless location in lower pole, ureteropelvic junction (UPJ) or upper ureter,[12-15] stones in patients with urinary diversion,[16, 17] and symptomatic calyceal stones or diverticular stones.[18-20]

Contraindication

- Untreated acute urinary tract infection (UTI) (LE: 1, GR: A);
- patients with anticoagulant/antithrombotic

therapy which cannot be temporarily discontinued, and uncorrected coagulopathies (LE: 1, GR: A);

• inaccessible kidney in puncture (LE: 1, GR: A).

Untreated acute UTI is the risk factor of postoperative urosepsis and septic shock, with a high risk of consequent death.[21-23] Therefore, untreated acute UTI should be the absolute contraindication of PCNL.

Coagulation disorders and anticoagulant/antithrombotic therapy could significantly increase the risk of postoperative bleeding. PCNL is a high-risk bleeding procedure, therefore it should not be performed in patients with clotting disorders.[24, 25] Although it has been reported that continuing aspirin therapy during PCNL seems not to increase the risk of postoperative hemorrhagic complications,[26, 27] there is very low evidence level to support this statement as it has been derived from small cohort retrospective studies.

Another contraindication is the inaccessible kidney due to interposition of other organs (retro-renal colon, spleen, liver, etc.) or tumor.[1, 28]

Stone complexity evaluation

• There are four generally used scoring systems evaluating stone complexity (Guy's Stone Score [GSS]),[29] STONE nephrolithometry,[30] CROES nomogram,[31] S-ReSC score[32]) and they have comparable predictive accuracy for SFR[33-38] (LE: 2, GR: A).

• Moreover, patients can be easily stratified into risk groups with the STONE nephrolithometry and S-ReSC score[39] (LE: 5, GR: C).

• The GSS is the only stone scoring system able to predict complications after PCNL[34] (LE: 3, GR: B).

• As the score is determined by using computed tomography (CT) findings, subjectivity caused by the clinician assigning the STONE nephrolithometry score is minimized[40] (LE: 5, GR: C).

Although it has an equal predictive power as GSS and CROES nomograms, STONE nephrolithometry seems to be overall superior, with better applicability in daily practice and more accurate risk stratification ability when compared to other scoring systems.

When CT evaluation is not available, GSS is the most reasonable alternative to STONE nephrolithometry.[39]

For children undergoing mini-PCNL, the CROES nomogram is the best to predict SFR.[30, 40]

Preoperative images

• Non-contrast computed tomography (NCCT) should be performed before PCNL[41] (LE: 2, GR: A);

• a contrast study (IVU or CT urography) is recommended if the anatomy of the renal collecting system needs to be well assessed[42-44] (LE: 4, GR: B);

• a functional imaging study (MAG-3 or DTPA) can be performed to evaluate the split renal function of the both renal units[45-47] (LE: 4, GR: C).

Successful PCNL relies on meticulous preoperative planning and optimal percutaneous access.

NCCT provides highly valuable information about stone characteristics, pelvi-caliceal anatomy of the involved kidney and perirenal organs, thus has gained widespread acceptance as a very helpful tool in treatment decision making.[48-51] CTU and IVU are helpful for an accurate definition of the calyceal anatomy or clarify abnormal findings in the precontrast study.[42, 44] In patients with retrorenal colon, NCCT in prone position seems to be more appropriate to plan the ideal access during PCNL.[51, 52]

In case of any suspect on renal functional deterioration, a functional imaging study (DTPA or MAG-3) is advisable.[53] Nuclear renogram evaluation is helpful as it can provide the split renal function values and assessing the presence of any urinary tract obstruction. The diagnosis of a deteriorated renal function may lead to other rational therapeutic options, ranging from observation to nephrectomy. Furthermore, establishing the baseline renal function of the treated unit can help to follow and exclude possible changes caused by PCNL procedure.[42, 54]

Preoperative antibiotic strategy

• Urine culture and urinary microscopy should be performed before PCNL (LE: 4, GR: A);

• in patients with a positive preoperative mid-

stream urine culture (MSU), an antibiotic should be administered according to antibiogram findings for a period of 5 days, while repeated MSU is not required after having completed the antibiotic cycle (LE: 3, GR: A);

• in patients with a negative MSU and urinalysis, a standard antibiotic prophylaxis according to the prevalent local antibiogram should be administered before PCNL (LE: 1, GR: A).

Currently, despite the universal agreement on the application of antibiotic prophylaxis and treatment of UTI prior to PCNL,[55] the optimum administration period of antibiotics remains controversial in patients with negative MSU. Notably, it is reported that 36.8-52.4% of patients suffering from post-PCNL urosepsis were found to have preoperative negative MSU.[21, 56] Urine test positive for leukocytes and/or nitrites is considered as an independent risk factor of postoperative urosepsis.[56, 57] Well-designed multicenter RCTs are required to evaluate the preoperative administration of antibiotics in patients with negative MSU but positive urinalysis for leukocytes and/or nitrites.

Perioperative management of antithrombotic therapy

• Interruption of antithrombotic therapy is required to minimize postoperative bleeding in patients receiving PCNL (LE: 4, GR: A).

Since PCNL is categorized as a procedure with a high-risk of bleeding,[58] discontinuation of antithrombotic therapy is required to minimize postoperative bleeding. However, the risk of thromboembolism should also be considered.

In patients receiving anticoagulant (a mechanical heart valve, atrial fibrillation, or venous thromboembolism) or antiplatelet therapy, the contradiction between antithrombotic therapy and bleeding risk in PCNL should be balanced, which varies and depends on the time to intervention, disease presentation, the patient's clinical characteristics, and the treatment received.[59-62] The temporary discontinuation or bridging of antithrombotic therapy should be discussed with the internist in cases of doubts or complex situations.

In patients receiving anticoagulant therapy, oral anticoagulants should be withdrawn before PCNL, furthermore, bridging is needed for patients with high thromboembolic risk.[59, 60] Timing of anticoagulant therapy cessation is largely determined by the INR values for vitamin K antagonists (warfarin, acenocoumarol, etc.) and renal function for direct oral anticoagulants (dabigatran, rivaroxaban, apixaban, edoxaban, etc.) (Table I).[63-67] Reintroduction of oral anticoagulant therapy should be postponed for 48-72 hours only in patients with a high risk of postoperative bleeding.[60]

In patients undergoing antiplatelet therapy for primary prevention or those with low thrombotic risk, antiplatelet therapy should be withdrawn before surgery (aspirin 7-10 days, ticagrelor 3-5 days, clopidogrel 5 days and prasugrel 7 days, respectively).[59, 68] Antiplatelet therapy should be restarted at 48-72 hours.[60] However, in patients with moderate-high thrombotic risk, PCNL should be postponed until thrombotic risk is low.[60]

TABLE I.—*Time to discontinue anticoagulation therapy before PCNL.*

VKAs	Renal function (CrCl, ml/min)	Timing of anticoagulation interruption before surgery (days)
Dabigatran	CrCl<50	4 d
	CrCl 50-79	3 d
	CrCl≥80	2 d
Rivaroxaban, apixaban, edoxaban	CrCl 15-30	3 d
	CrCl≥30	2 d
DOACs	INR	Timing of anticoagulation interruption before surgery
Acenocoumarol	INR<2	2 d
	INR 2-3	3 d
	INR>3	4 d
Warfarin	INR<2	4 d
	INR 2-3	5 d
	INR>3	6 d

VKAs: vitamin K antagonists; DOACs: direct oral anticoagulants; CrCl: creatinine clearance; INR: international normalized ratio.

Anesthesia

• Both general anesthesia and regional anesthesia are effective techniques for PCNL[69] (LE: 1, GR: A);

• local anesthesia is effective and safe in selected patients[70] (LE: 4, GR: C).

PCNL procedure can be safely carried out under both general anesthesia and regional anesthesia, including spinal anesthesia, combined spinal-epidural anesthesia, and epidural anesthesia. The advantages of general anesthesia include a better access and control of airways. It is also necessary to control tidal volume during puncture to minimize injury to the pleura and lungs. A prolonged anesthesia can bring minimal patient discomfort, especially in cases with large stone burden.[71] The advantages of regional anesthesia include less postoperative pain and early recovery which results in reduced hospital stay. It is reported that PCNL is also feasible under local anesthesia in carefully selected patients with dilated upper urinary tract and a stone with small\ modest stone burden.[70] However, high-level evidence is still required to validate these conclusions.

The choice of the anesthesia depends on physician's preference, patient's position, surgical expertise, and expected operation time. The anesthetist should be informed of all the possible complications occurring peri-operatively. A multidisciplinary approach is therefore advisable to formulate a correct perioperative planning for patient safety.

Intraoperative position

• Both prone and supine positions are equally safe and effective (LE: 1, GR: A);

• the supine position in PCNL provides an optimal cardiovascular and airway control, it also facilitates a Combined Intra-Renal Surgery (ECIRS) (LE: 3, GR: A);

• the prone position provides a broader surface area for percutaneous puncture and is more convenient for upper pole and multiple accesses (LE:3, GR: A).

Although prone position and its modifications are the most widely used positions for PCNL, various supine positions have been proposed and assessed for PCNL applications over the last two decades.[72-75] Data have not shown any significant superiority of either approach with respect to the SFR's, complications or operation time.[76-78] Each position has its own advantages and limitations.[76-78] Prone position has drawbacks related to increased cardiopulmonary risks.[79-82] There is not sufficient data investigating anesthetic risk in patients with very complex stones and specific body related factors (obese, age, high-risk patients, etc.), limiting the chance of making strong recommendations on the superiority of each position to the other.

Puncture

• Fluoroscopy, ultrasound, and combined guidance are the mostly frequently used techniques for percutaneous renal access (LE: 1, GR: A);

• the use of ultrasound guidance in puncture reduces the risk of radiation exposure[83] (LE: 1, GR: A);

• fluoroscopic or combined guidance is more effective for complex stones[84] (LE: 2, GR: B);

• CT-guided percutaneous access is a good alternative for a successful renal access in cases with body (spinal deformities), or renal abnormalities (ectopic kidneys etc.)[85](LE: 4, GR: C);

• by using endovision images ECIRS may give the chance of enhancement of renal access but costs and surgeon's experience have to be taken into account[86](LE: 3, GR: C).

Although fluoroscopy guidance has been used commonly in the past, increasing experience with ultrasound applications has enabled urologists to use this approach more and more often, with particular advantages in preventing perirenal organs injury and limiting the radiation exposure. However, blood clots, urine extravasation and air in the caliceal system may render puncture and dilation under ultrasound guidance more challenging. Therefore, a totally ultrasound guided PCNL is feasible in experienced hands.

Fluoroscopy may be advantageous in cases with small size stone in undilated collecting systems. Consequently, for complex stones requiring multiple tracts, it is prudent to perform PCNL under fluoroscopy or combined guidance.[84] In extremely complex but rare cases, CT-guided

percutaneous access can be a good alternative.[87] The "endovision technique" during ECIRS and "all-seeing needle" optical puncture systems have also been introduced for an accurate access.[88, 89]

Tract size and number of tracts

• Conventionally, PCNL being performed with 24-30 Fr sheath size is considered "standard PCNL," while PCNL performed with tract sizes less than 18 Fr is named "mini-PCNL"(LE: 1, GR: A);

• mini-PCNL has equal SFR, less bleeding, longer operative time compared to standard PCNL, mini-PCNLs with active suction can shorten the operative time (LE: 1, GR: A);

• multiple-tract PCNL is a feasible option, but it is associated with a higher risk of bleeding. ECIRS could reduce the risk of hemorrhagic complications (LE: 1, GR: A).

Mini-PCNL has been shown to have equal SFR, less blood loss and transfusion rates, better postoperative recovery, less postoperative pain, and shorter hospital stay when compared to standard PCNL.[90, 91] However, small tracts are believed to bring prolonged operative time and the potential increased renal pelvic pressure.[92] Suctioning sheath would facilitate stone extraction and the maintenance of a low renal pelvic pressure.[93, 94]

For multiple calyceal stones and branched staghorn calculi, multiple-tract PCNL is feasible, but at a higher risk of bleeding and kidney function deterioration. ECIRS could reduce the risk of bleeding due to a reduced need of multiple tracts.[95-97]

Percutaneous tract dilation

• Fascial amplatz dilation, telescopic metal dilation, balloon dilation, and one-shot dilation are all available, the selection depends on the surgeon's preference and experience[98] (LE: 1, GR: A).

Fascial amplatz dilation and metal telescopic dilation are cumbersome and time consuming, while balloon dilation and one-shot dilation require shorter access and fluoroscopy time, and also less hemoglobin decrease.[98-100] However, balloon is much more costly, and one-shot dilation is more frequently failed.[101, 102] It is reported that fascial dilators with scale marker are associated with shorter access and fluoroscopy time.[103] The choice of the dilation technique depends on the surgeon's preference and experience.

Lithotripsy techniques

• The ultrasonic, pneumatic, combined pneumatic and ultrasonic, and Holmium laser lithotripter are associated with similar SFR (LE: 1; GR: A);

• the stone fragmentation and removal time (SFRT) for hard stones are shorter using pneumatic lithotripsy, while ultrasonic lithotripsy provides a shorter SFRT for soft stones (LE: 1; GR: B);

• more stone clearance time is required for Holmium laser in PCNL; however, Holmium laser is associated with fewer complication rates (LE: 1; GR: B).

Four commonly used lithotripsy techniques for PCNL include ultrasonic, pneumatic, Ho:YAG laser and combination.[104-108]

The stone clearance time is similar for ultrasonic and pneumatic lithotripters during PCNL, and the combination is not superior to monotherapy.[105, 109] Taking into account the stone composition, the pneumatic lithotripsy is more efficient for harder stones (either pure or a mixture of cystine, calcium oxalate monohydrate, and calcium phosphate). In contrast, ultrasonic lithotripsy is more efficient for soft stones (struvite and uric acid).[104, 106] Shockpulse© (Boston Scientific, Marlborough, MA, USA) and Trilogy© (Boston Scientific) are the most recent lithotripters, combining ultrasonic and mechanical vibration lithotripsy. The clinical efficiency needs to be further verified.[110] The Ho:YAG laser can handle almost all stones components, despite their hardness. On the other hand, Ho:YAG laser seems to be associated with less complications but longest stone clearance time when compared to other lithotripters.[105, 107, 108]

All these devices provide excellent outcomes in standard PCNL, no significant difference in SFR has been noted.[104-108] However, for suction mini PCNLs, the Ho:YAG laser is the most commonly used lithotripter,[111] and the high-power laser is associated with shorter stone clearance time, if compared with low-power ones.[112] More

recently, thulium fiber laser (TFL) has been shown to dust stones swiftly and is also preferred in mini-PCNLs with active suction.[113]

The selection of the type of lithotripsy depends on the stone density, stone burden, intraoperative real-time lithotripsy efficiency, availability and also surgeon's preference.

Intraoperative evaluation of residual stones

• Fluoroscopy and flexible nephoscopy are the most common and valuable modalities to detect the residual fragments intraoperatively (LE: 2, GR: A);

• fluoroscopy is advantageous for radiopaque stones, while pyelography is required for radiolucent stones (LE: 2, GR: A);

• intraoperative use of CT scans for the detection of residual stones could improve the stone-free rate (LE: 4; GR: C).

Fluoroscopy combined with flexible nephoscopy allow sensitive and specific detection of residual stones, enabling immediate stone removal or planning of staged PCNL.[114] Fluoroscopy is preferred for radiopaque stones, while retrograde pyelography is required to detect radiolucent stones.[115] However, small stones overlying bony structures or intestinal artifact are hard to be identified, thus brings an overestimation of SFR.[115-118] Intraoperative CT scanning during PCNL is feasible and may provide a better estimation of residual stone fragments than fluoroscopy, however, it depends on available equipments.[119, 120] Ultrasound is much more prone to be affected by the blood clots and urine extravasation, therefore not the first line choice to detect residual stones.[121, 122]

Exit strategy

• The placement of a nephrostomy tube in uncomplicated and believed stone free PCNLs is optional (LE: 1, GR: A);

• tubeless PCNLs can bring less postoperative pain and analgesia requirement, reduced hospital stay, without affecting the complication rate (LE: 1, GR: A);

• tract sealing techniques have favorable outcomes in terms of safety and efficacy for bleeding (LE: 3, GR: B).

Nephrostomy tube is usually required in PCNL to promote hemostasis, drain urine to prevent extravasation, and allow for re-entry into the collecting system.

Tubeless PCNL is defined as PCNL without postoperative nephrostomy tube placement.[113-117] An internal double-J stent or external ureteral catheter was required in the early tubeless PCNL, while totally tubeless PCNL was introduced later, neither nephrostomy tube nor ureteral stent/catheter was indwelled.[123-127]

Tubeless PCNL is recommended in highly selected cases, including but not limited to uncomplicated stones, small stones, single-tract procedure, short operation time, normal renal function, complete stone removal, no collecting system perforation, and no active bleeding from the tract.[124, 126]

The meta-analysis showed that tubeless PCNL could result in similar stone-free and complication rates as standard PCNL, with advantages of reduced hospital stay and little need for postoperative analgesia.[127] However, there are still concerns associated with tract bleeding in tubeless PCNL. Tract sealing technique, such as electrocauterization of bleeding points,[128] applying fibrin glue,[129] and placement of hemostatic matrix into the tract,[130] have been reported, with favorable outcomes in terms of safety and efficacy for tract control. However, additional RCTs are required to define their clinical role.

Postoperative imaging and stone-free status evaluation

• Stone-free status should be defined as no residual stones detected on CT within postoperative four weeks (LE: 1, GR: A).

Generally, initial imaging is required on the postoperative first day or the first week before discharge to evaluate the initial stone free and tube status.[1] However, final SFR is should be evaluated at fourth postoperative week.[131]

A variety of imaging modalities are available to evaluate the presence of residual stones following PCNL, including KUB, IVU, US, and CT scans, each with its advantages and limitations. However, NCCT scan has the highest sensitivity and specificity for detecting residual fragments following PCNL compared to US, KUB, and IVU,

especially for lucent stones.[132-136] Plain radiography is recommended for the follow-up of radiopaque stones, with US and limited IVU reserved for radiolucent stones to minimize cumulative radiation exposure from repeated CT scans.[137]

Clinically insignificant residual fragments (CIRFs) are asymptomatic, non-obstructing residual fragments smaller than 4 mm.[138] However, CIRFs should be followed closely and be warned of the increasing likelihood of intervention and disease progression in years to come.[139]

PCNL aims to render the patient stone-free. If this cannot be achieved, then fragments should be as small as possible. Residual stones <2 mm may be considered acceptable concerning long-term outcomes.[140, 141]

Complications

In literature, complication rates following PCNL may significantly vary, ranging from 8.1% to 19.6%.[142, 143] The Clavien-Dindo Classification system modified for PCNLs can be used to evaluate these events.[144] Most complications following PCNLs are mild, the Clavien 1, 2, 3, 4 and 5 complications are observed in 88.1%, 7%, 4.1%, 0.6% and 0.04% of cases, respectively.[28] Mini PCNL is reported to bear fewer complications when compared to standard PCNL and is at least as efficacious as standard PCNL.[91, 145, 146]

Bleeding

• Angiography and embolization are the first-line choice for the management of severe post-PCNL bleeding, if conservative treatment fails (LE: 4, GR: A).

Post-PCNL bleedings are common. The reported incidence of transfusions and embolizations following PCNL are 4.5-18.3%[142, 143] and 0.3-1.2%,[147, 148] respectively.

The presence of a mild hematuria is frequent and not significant, while lasting moderate or transient severe bleeding requires active interventions.[149] A massive intraoperative bleeding can cause poor visibility and a significant hemoglobin drop. A nephrostomy tube should be placed and clamped to tamponade and stop the bleeding.[150, 151] In case of severe loin pain, significant hematuria, and hemoglobin drop or hemodynamic instability, arterial bleeding should be suspected. A CT-angiogram, angiography and embolization are necessary in these cases.[151]

Incorrect puncture, solitary kidney, multiple tracts, significant stone burden, prolonged operation time, urinary tract infection, infected stones and diabetes mellitus are believed risk factors for postoperative hemorrhagic complications.[152-155] Although a precise renal puncture is important, an excessive kidney torque may lacerate the kidney, increasing the risk of bleeding. Ultrasound-assisted puncture is associated with a reduced risk of bleeding compared to fluoroscopy.[156] The utilization of hemostatic gels or electrocoagulation can help to seal the small blood vessels, especially in tubeless PCNLs.[157, 158]

Infections

• MSU and adequate antibiotics therapy are required before PCNL (LE:1, GR: A);

• intraoperative renal pelvic urine culture and stone culture are required in selected cases (LE:2, GR: A).

Post-PCNL infections vary according to the severity, including Systemic Inflammatory Response Syndrome (SIRS), urosepsis, and septic shock. Fever, increased heart rate, or hemodynamic instability are always the presenting signs. The reported postoperative fever rate ranges from 4.34-12.77%.[93]

Retroperitoneal irrigation fluid and bacterial endotoxins absorption play an important role in the pathogenesis of postoperative infections.[159] Risk factors include staghorn calculi, infected stones, preoperative urine test positive for nitrites, recurrent urinary tract infection, high renal pelvic pressure, prolonged operative time.[23, 57, 160] Thus, the control of these factors is crucial in the prevention of postoperative infectious complication. Intraoperatively, collecting a renal pelvic urine culture and stone culture is advisable as they have better sensitivity compared to MSU in predicting postoperative infections.[161-163]

Generally, simple postoperative fever resolves in few days following adequate sensitive antibiotics therapy, while urosepsis and septic shock are life-threatening. Hence, early and rapid identification of patients with urosepsis is imperative. A blood white cell counts less than 2.98×10^9/L

or 2.85×10^9/L can indicate impending urosepsis.[21, 164] IL-6, CRP, and PCT are other biomarkers to evaluate the infection status.[165, 166]

The treatment of urosepsis has to be prompt, it includes an early appropriate antibiotic therapy, resuscitation support, and complication management.[167] The early use of broad-spectrum antibiotics along with fluid resuscitation are crucial. The sequential organ failure assessment (SOFA) is a handy tool to evaluate organ function and thus to indicate the infection status.[168, 169] Transfusion or vasopressors are required to maintain the patient hemodynamically stable; intubation and mechanical ventilation are required to provide respiratory support and correct lung injury and hypoxemia.[167]

Perirenal organ injury

• Perirenal iatrogenic organ injuries during PCNL are rare, conservative management is usually feasible (LE: 2, GR: B);

• a preoperative NCCT and an ultrasound guided puncture are helpful to avoid perirenal organ injury (LE: 3, GR: A).

Supra-costal punctures increase the risk of pleural injuries, hydrothorax, pneumothorax or hemothorax.[170] Shortness of breath, dyspnea, and decreased oxygen saturation are signs of pleural injury.[171] A chest x-ray or CT should be carried out in case of suspicion. Although mild pneumothorax or hydrothorax can be managed conservatively, a thoracic drainage tube is required in patients with severe hydrothorax or pneumothorax.[172]

Liver and spleen injuries following PCNL are infrequent; however, the risk increases in cases of supra-costal punctures and in patients with hepatosplenomegaly.[173] An ultrasound guided puncture can minimize this risk. However, an iatrogenic spleen or liver injury may cause severe bleeding, a CT scan should be carried out in case of suspect. Majority of liver/spleen injuries can be managed conservatively; a delayed removal of the nephrostomy tube may be beneficial in these scenarios. An urgent laparotomy is necessary in case of uncontrolled bleeding.[174, 175]

Intestinal injury during PCNL is a rare event, usually involving the large bowel. Iatrogenic duodenal injury has been described in very sporadic cases.[176] The presence of a retrorenal colon increases this risk, especially in case a left lower pole renal puncture is needed. Retrorenal colon is more frequently present in case of old patients, lower body mass index (BMI), thinner perirenal fat layer, left kidney and lower pole.[177, 178] Ultra-sonography guidance is required in these cases with posterolateral/retrorenal colon or other complex cases.[177-179] Duodenal injury mostly happens following renal collecting system perforation during a too deep tract dilation.[178] Peritonitis or bowel contents drainage from the nephrostomy tube indicates potential intestinal injury, a CT scan and fistulography are required. Duodenual injury and intraperitoneal colon injury need an urgent explorative laparotomy considering the risk of acute peritonitis. In the other cases a conservative management should be tried first. In case of an extraperitoneal colonic injury, the nephrostomy tube should be used as a percutaneous colostomy, withdrawing it from the kidney and relocated in the bowel. Subsequently, a double-J ureteral stent should be inserted, intravenous broad-spectrum antibiotics, bowel rest, and total parenteral nutrition should be started.[176, 178-181]

Urinary extravasation and leakage

• Significant urinary extravasation always occurs intraoperatively if a high intra-renal pressure is maintained (LE:3, GR: A);

• maintenance of low intrarenal pressure is highly recommended (LE: 2, GR: A).

Severe intraoperative urinary extravasation always originates from high-pressure irrigation, too much torquing of the nephoscope, perforation of the pelvicalyceal system in patients particularly with a thinner perirenal fat layer.[171] In addition, it would bring progressive abdominal distension, increased airway resistance for anesthesia ventilators, and oxygen desaturation.[182] Therefore, when identified, the lithotripsy should be promptly terminated, nephrostomy tube and double-J ureteral stent should be placed. What is necessary to be done next is the drainage of peritoneal effusion and pelvic effusion. Ultrasonography can help to detect effusion and guide proper puncturing. Do keep

a low renal pelvic pressure and discontinue the PCNL procedure if pelvicalyceal system perforation occurs.

The presence of urinary leakage alongside the nephrostomy tube may indicate inadequate drainage of the renal collecting system, for which the risk factors include residual ureteral stones and inadequate nephrostomy tube position.[182] A nephostogram should be performed at the end of the procedure to ensure that the urinary tract is unobstructed. A small-caliber nephrostomy tube or even placement of JJ stent would be helpful to decrease urinary leakage.[183, 184]

Conclusions

The present guideline on PCNL was the first in the IAU series of urolithiasis management guidelines. The recommendations, tips and tricks across the PCNL procedures would provide adequate guidance for urologists performing PCNLs to ensure safety and efficiency in PCNLs.

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