Preoperative Patient Preparation and Imaging in PCNL

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Abstract The decision to proceed to percutaneous nephrolithotomy (PCNL) is always undertaken after due consideration of the individual circumstances of the patient. This includes a detailed assessment of previous medical history and concurrent pharmaceutical therapy, in particular anticoagulant use, plus optimal imaging of the stone burden and location in order to determine the most appropriate positioning of the patient and puncture site. Contingency plans should also be developed in case of intraoperative difficulty achieving complete stone clearance, and these will usually be based upon evaluation of cross sectional imaging studies using contrast agents. Such PCNL complexity can be graded preoperatively using nephrolithotomy scores.

Keywords PCNL · Opiods · Fusion imaging · Nephrolithometry · CT imaging

1 Introduction

A thorough preoperative patient evaluation is necessary to reduce operative risks and potential complications of surgical intervention for urolithiasis. Initial assessment starts with a complete history and physical to ensure patients are appropriately selected for percutaneous nephrolithotomy (PCNL). This evaluation should include prior medical and surgical history, age, stone characteristics, renal anatomy, and patient preference.

Patients with high-risk medical co-morbidities and/or prior surgical history may pose a higher perioperative surgical risk. On physical exam, special attention should be paid to anatomic factors that may require intraoperative modification including obesity, surgical scars, contractures and scoliosis. Appropriate preoperative laboratory and radiographic studies can be used to mitigate risk. Complex patients or

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J. D. Denstedt and E. N. Liatsikos (eds.), *Percutaneous Renal Surgery*,
https://doi.org/10.1007/978-3-031-40542-6_4

those with significant risk factors may benefit from evaluation by internal medicine, cardiology and/or anesthesia for optimization prior to surgery.

Finally, the patient and surgical team must engage in shared decision making to obtain informed consent. This discussion should cover the risks, benefits and alternatives to PCNL and the patient and family members should be given ample opportunity to ask clarifying questions.

2 Patient History

2.1 Anticoagulation

PCNL is contraindicated in patients unable to hold anticoagulants and antiplatelet agents, other than low dose aspirin, or who have an uncorrectable bleeding disorder or coagulopathy. The reported incidence of blood transfusion after PCNL ranges from 3 to 24% (Ganpule et al. 2014; MacDonald et al. 2022; Tayeb et al. 2015; Nasseh et al. 2022; Said et al. 2017; Rosette et al. 2011). Therefore, it is important to identify which patients are at increased risk of bleeding prior to undergoing surgery. Several scoring systems have been developed. The HAS-BLED score, for example, takes into account risk factors in atrial fibrillation patients such as age over 65, chronic kidney disease, stroke, hypertension, liver dysfunction, coagulation disorders, history of bleeding or high alcohol and drug use. A HAS-BLED score greater than three is predictive of future bleeding events (Doherty et al. 2017).

Perioperative management of anticoagulation should be a shared decision between the surgeon and prescribing provider. The American College of Cardiology published perioperative management guidelines for anticoagulation use in nonvalvular atrial fibrillation patients (Doherty et al. 2017). For vitamin K antagonists (VKA) like warfarin, the guidelines recommend checking an INR 5–7 days preoperatively. For most patients, VKAs can be held 5 days preoperatively for patients with normal INR who are undergoing low risk surgery. For patients at a high risk of VTE, such as those with CHADSVASC score >7, consideration should be given to bridging with low molecular weight heparin. While patients with a low risk of postoperative bleeding can restart VKAs after 24 h, patients with a higher risk of bleeding, including PCNL, should restart after 48–72 h without the need for bridging. In contrast, direct-acting oral anticoagulation (DOACs) can be held for shorter periods due to shorter drug half-lives. Newer reversible agents are also now available. DOACs should be held for 4–5 half-lives and adjusted for a patient's renal function. For surgeries with low bleeding risk, DOACs can be held for 24 h preoperatively and held for 48 h for higher risk surgeries. Longer intervals may be needed for patients with impaired renal function. DOACs can typically be restarted 24 h after surgery for low-risk surgeries and, after higher risk surgery like PCNL, they can be restarted after 48–72 h or at the surgeon's discretion.

Antiplatelet agents should also be held prior to surgery. Due to the irreversible binding to platelets, P2Y12 inhibitors like clopidogrel should be held for five days to allow bleeding time and platelet aggregation to return to normal (Muluk UpToDate). However, continuing low dose aspirin (81 mg) perioperatively is not associated with an increase in complications, difference in hemoglobin or higher transfusion rate after PCNL (Pan et al. 2022). Therefore, low dose aspirin (81 mg) may be able to be safely continued perioperatively.

2.2 Contrast Allergies

There are no formal guidelines for management of patients with allergies to iodinated intravenous contrast. A large retrospective study by Blackwell et al. reported very low rates of adverse reactions with intraluminal contrast (0.48%), however, 3–4% of surveyed urologists have seen a serious reaction with contrast use during PCNL (Blackwell et al. 2017; Dai et al. 2018). Perioperative management of contrast allergies is variable among surveyed urologists and up to a third of respondents premedicate patients prior to PCNL with steroids or antihistamines (Dai et al. 2018; Mohapatra et al. 2019). With the lack of supporting evidence to guide practice patterns, urologists should be cautious with patients who have a history of anaphylaxis to iodinated contrast and could consider premedicating prior to PCNL. In addition, maintaining low intrarenal pressure to prevent pyelovenous backflow is prudent.

2.3 Anatomic Considerations

Certain anatomic factors may require additional preoperative evaluation or modification of operative technique. Prior intrarenal surgery, for example, can cause scar tissue in the collecting system, renal parenchyma, or perirenal fascia of the retroperitoneum that can increase the difficulty of percutaneous renal access and tract dilation. In these situations, specialty equipment may be necessary such as the use of a high-pressure balloon dilator or fascial incising needle. Prior abdominal surgery may cause scar tissue or adhesions around the kidney that can alter the location of adjacent organs. Specifically, the position of the colon can be variable and move with changes in position. Colon injury can be a serious complication with a reported incidence of 0.3% of cases (El-Nahas et al. 2006). Avoiding this complication begins with identifying higher risk patients based on patient demographics, access site and colon anatomy. El-Nahas et al. reported complicated lower pole access, especially in older patients, was associated with colon injury (El-Nahas et al. 2006). With respect to the kidney, a posterolateral colon extends beyond the posterior calyceal border and a retrorenal colon is completely posterior to the kidney. A colon in one of these orientations is also at higher risk of injury during percutaneous renal access. However, anatomy may be hard to predict because patients are often in different positions during imaging studies versus in the operating room. For example, Hur et al. demonstrated 15% of patients had posterolateral or retrorenal colons when imaged supine but increased to 25% of patients when they were imaged prone (Hur et al. 2021). Retrorenal colon is more common with older age and lower BMI with decreased perirenal fat. Intraoperative adjuncts like ultrasound guidance during access can help locate adjacent structures to decrease the risk of injury.

Complex renal and patient anatomy related to obesity, spinal cord injury and spina bifida may complicate intraoperative positioning and renal access. Malrotated, horseshoe, ectopic or transplanted kidneys increases complexity of percutaneous renal access. Positioning spina bifida patients is challenging due to severe spinal curvature, contractures of upper and lower extremities and restricted joint movement. In particular, the concave aspect of spinal curvature can limit the distance between the ribs and iliac crest, limiting renal access and altering the anatomic relationships of adjacent structures. In these patients, additional preoperative contrasted CT imaging may be needed to provide detailed renal and ureteral anatomy and to better define the collecting system (Assimos et al. 2016). It may also be beneficial to use a combination of ultrasound and fluoroscopic guidance and, in some cases, may require interventional radiology consultation for CT guided access.

Obese or morbidly obese patients present several intraoperative challenges. Special consideration must be given to patient positioning to avoid injuries. Prone positioning can increase intrathoracic pressure which can lead to decreased tidal volumes and difficult ventilation. Truncal obesity can make it difficult to identify bony landmarks and, as tissues shift once in the prone or supine position, there may be an increase in the skin to stone distance. Operative teams need access to extra-long PCNL equipment if proceeding with surgery in patients with an increased skin to stone distance. However, despite these considerations, overall outcomes, complications and stone free rates are comparable in morbidly obese and lower BMI patients after PCNL (Torrecilla Ortiz et al. 2014; Zhou et al. 2017).

3 Laboratory and Radiographic Evaluation

3.1 Urinalysis and Urine Culture

Preoperative urinalysis is mandated by the AUA guidelines prior to proceeding with stone surgery and urine cultures are, at a minimum, required for clinical or laboratory signs of infection (Assimos et al. 2016). Untreated urinary tract infection is an absolute contraindication to PCNL. Thirty percent of patients have a positive preoperative midstream urine culture (Liu et al. 2021) and have a higher rate of SIRS (12%) and urosepsis (5%) postoperatively, even when treated prior to surgery (Tang et al. 2021). Culture speciation and sensitivity results should be used to select perioperative antibiotics. The ideal timing between obtaining urine culture and surgery is not completely clear. In a retrospective study, Akkas et al. did not find increased rates of postoperative sepsis when urine cultures were collected more than ten days prior to surgery compared to within ten days (Akkas et al. 2021). Adequate antibiotic coverage based on urine culture results is imperative, therefore, a minimum of 10 days is recommended to allow for culture results and treatment of a positive culture.

Intraoperative renal pelvis and stone cultures are recommended as patients with positive cultures are four times more likely to have postoperative sepsis (Mariappan et al. 2006). Stone and renal pelvis cultures are more reliable than midstream urine in predicting postoperative sepsis as well as the causative organism to direct postoperative antibiotic therapy (Liu et al. 2021; Castellani et al. 2022). Midstream urine cultures have been shown to have poor diagnostic accuracy in predicting renal pelvis or stone cultures (Castellani et al. 2022). Mariappan et al. found that, in patients with negative preoperative midstream cultures, 11% of patients had positive intraoperative bladder urine cultures, 20% had positive renal pelvis cultures and 35% had positive stone cultures. Only 5.6% of patients had positive bladder cultures with positive upper tract cultures (Mariappan et al. 2005). Similarly, Korets et al. reported 33% of patients with a positive intraoperative renal pelvis culture and 48% of patients with a positive stone culture had negative preoperative midstream urine cultures (Korets et al. 2011). In addition, positive midstream cultures have been reported to be discordant in 55% of patients with positive renal pelvis cultures and 30% of stone cultures, complicating antibiotic selection (Korets et al. 2011). This data underscores the benefit of renal pelvis and stone cultures in the management of patients undergoing PCNL.

3.2 Laboratory Data

AUA stone guidelines recommend obtaining serum electrolytes and creatinine if there is a concern for reduced renal function (Assimos et al. 2016). Renal function can dictate choice and dosage of perioperative medications. There is no evidence that PCNL worsens renal function long term and often improves renal function after treating obstructing stones (Reeves et al. 2020). When a chronically obstructed kidney is suspected to be nonfunctional, nuclear renogram should be considered prior to PCNL (Assimos et al. 2016).

Hematologic evaluation including CBC, coagulation panel and type and screen should be obtained before surgeries where there is a significant risk of bleeding or in patients with a history of anemia or coagulopathies (Assimos et al. 2016). The reported incidence of postoperative blood transfusion ranges from 3 to 24% and reported incidence of embolization ranges 0.5–1.8% (Ganpule et al. 2014; MacDonald et al. 2022; Tayeb et al. 2015; Nasseh et al. 2022; Said et al. 2017; Rosette et al. 2011). Given this, an updated type and screen and consent for blood products should be completed prior to surgery. An elevated white blood cell count, abnormal coagulation studies or low platelet count may require further hematologic investigation to minimize complications.

Platelet lymphocyte ratio (PLR) and neutrophil lymphocyte ratio (NLR) can be helpful adjuncts as they are easily calculated from routine CBC and have been shown to be independent risk factors for postoperative sepsis (Kriplani et al. 2022). PLR and NLR have been utilized in other inflammatory, cardiovascular and metabolic conditions as a marker of systemic inflammation. It has also been shown to be elevated in some stone formers (Tang et al. 2021). Proinflammatory molecules found in the renal papilla of stone formers is thought to promote crystallization through oxidative stress and release of reactive oxygen species (Tang et al. 2021; Kriplani et al. 2022; Khan et al. 2021). The inflammatory immune response can promote Randall's plaque and calcium stone formation (Khan et al. 2021). Increased neutrophils triggered by inflammation leads to an exaggerated inflammatory response that suppresses the immune response of lymphocytes, T cells and NK cells (Tang et al. 2021). Platelets can also release proinflammatory agents that can perpetuate inflammatory conditions and reactions (Gasparyan et al. 2019). Therefore, NLR and PLR can be used as markers of an ongoing inflammatory reaction and, thus, can be used as predictors of postoperative sepsis following PCNL (Tang et al. 2021; Kriplani et al. 2022). PLR is calculated by dividing the absolute platelet count by the absolute lymphocyte count. Similarly, NLR is calculated by dividing the absolute neutrophil count by the absolute lymphocyte count. Special consideration should be given to patients with preoperative PLR (>110) and NLR (>2.03) as they may be at higher risk for postoperative sepsis (Tang et al. 2021; Kriplani et al. 2022; Sen et al. 2016).

3.3 Electrocardiogram and Chest X-Ray

The American Academy of Family Practice preoperative guidelines recommend an electrocardiogram (EKG) for high-risk surgery or for intermediate risk surgery with patient risk factors such as cardiac history, chronic kidney disease or diabetes (Preoperative 2002). Chest x-rays are not routinely indicated but may be needed for symptomatic patients. Most patients do not require routine EKG or chest x-ray prior to PCNL unless significant risk factors or symptoms are present.

4 Patient Preparation

4.1 Antibiotics

Historic reported incidence of postoperative sepsis after PCNL ranges from 0.8 to 3% and SIRS occurs in as high as 30% of cases (O'Keeffe et al. 1993; Bag et al. 2011; Segura 1984). AUA perioperative antibiotic guidelines recommend antibiotic coverage for gram negative bacteria, enterococci and skin flora including S. aureus (Lai and Assimos 2016). First line antibiotics should be first or second generation cephalosporins followed by an aminoglycoside with metronidazole or clindamycin and continued for less than 24 h postoperatively. However, the AUA guidelines do not specifically address the role of empiric or directed preoperative antibiotics.

Preoperative antibiotic regimens should be tailored according to patient risk factors and preoperative cultures. Risk factors include stone size, hydronephrosis, foreign bodies, indwelling drainage tubes, recurrent UTI, struvite stone formers, and or urinary diversion. For low-risk patients with negative urine cultures, Zeng et al. reported no difference in sepsis rates based on preoperative antibiotic duration (Zeng et al. 2020). These findings were confirmed by a prospective multi-institutional randomized controlled trial (RCT) conducted by the Endourology Disease Group for Excellence (EDGE) Consortium. Sepsis rates were similar between low-risk patients with negative preoperative cultures who received seven days of nitrofurantoin versus patients who just received perioperative antibiotics (Chew et al. 2018).

Patients with risk factors may develop postoperative sepsis even with a negative preoperative urine culture. Specifically, patients with hydronephrosis and stones over 2cm in size are more likely to have postoperative sepsis even with negative midstream urine cultures (Mariappan et al. 2005). When these patients were treated with one week of preoperative antibiotics (ciprofloxacin 250 mg twice daily), they were three times less likely to have postoperative SIRS compared to no empiric antibiotics (Mariappan et al. 2006). Bag et al. also reported decreased postoperative SIRS (19% vs. 49%) in these patients when treated with one week of nitrofurantoin (100 mg twice daily) preoperatively (Bag et al. 2011).

Positive urine cultures should be treated preoperatively but antibiotic management is highly variable. Decreased SIRS rates (21% vs. 40%) have been reported when patients are treated with greater than 7 days of preoperative antibiotics compared to less than six days (Zeng et al. 2020; Xu et al. 2022). To elucidate this further, the EDGE Consortium prospectively compared 2 days versus 7 days of antibiotics for high-risk patients defined as either positive urine culture or presence of indwelling drainage tube. Patients treated for 7 days preoperatively had decreased rates of sepsis compared to those treated for a shorter duration (Chew et al. 2018). The AUA guidelines do not recommend the routine use of antibiotics postoperatively as they have not been shown to decrease sepsis rates (Yu et al. 2020).

Patients at higher risk for infectious complications such as those with struvite nephrolithiasis, positive stone culture, chronic indwelling catheters urinary diversion, hydronephrosis or large stone burden should be treated with an antibiotic regimen that is individually tailored to cover risk factors.

4.2 Anesthesia

The majority of PCNL cases are completed under a general anesthetic. This allows for continuous airway protection during positioning, improved pain control intraoperatively and allows for adjunctive measures such as breath holding during access. In select cases, PCNL can be successfully performed under regional anesthesia.

Selection of an anesthetic approach depends on patient anatomy, comorbidities and planned surgical approach and should be a discussion between the urology and anesthesia teams. Spinal anesthesia involves injecting anesthetic medication into the intrathecal space to create motor and sensory blockade. For patients who are appropriate candidates, a spinal is commonly placed at L4 and then the patient is placed in Trendelenburg position until the anesthetic reaches the T6-T7 level. Conversion to a general anesthetic occurs in 5–10% of cases due to incomplete spinal blockade (Mehrabi et al. 2013). In a prospective RCT, patients who underwent PCNL under a spinal anesthetic had a shorter operative time and decreased narcotic requirement postoperatively (Mehrabi et al. 2013).

In addition, the anesthesia team can be consulted for perioperative nerve blocks. Intercostal, paravertebral and peritubular nerve blocks have all been proposed as analgesic adjuncts. Intercostal nerve blocks are performed by injecting local anesthetic at the inferior margin of the 10th, 11th and 12th ribs at the posterior axillary line. With this technique, care must be taken to avoid injury to the neurovascular bundle during needle placement. The peritubular nerve block involves injecting local anesthetic along the nephrostomy tube if left at the end of the case. Proposed technique by Jonnavithula et al. involves image guidance of the needle into the renal capsule adjacent to the nephrostomy tube and then local anesthetic infiltration along the nephrostomy tract as the needle is removed (Jonnavithula et al. 2017). The paravertebral block can be completed by visualizing the T10 paravertebral space under ultrasound guidance and instilling local anesthetic into this space. This can create a nerve block along the T7-L1 dermatomes (Baldea et al. 2020). Paravertebral nerve blocks have been shown to improve subjective pain scores and significantly decreased opioid use postoperatively (Baldea et al. 2020; Borle et al. 2014) Comparative studies between peritubular and intercostal nerve blocks found that intercostal nerve blocks were superior and had lower pain scores and decreased PACU opioid requirements (Jonnavithula et al. 2017).

4.3 Tranexamic Acid

Tranexamic acid is a synthetic derivative of lysine and inhibits fibrinolysis by blocking the conversion of plasminogen to plasmin. Intraoperative use of TXA has been shown to decrease perioperative blood loss in gynecology, orthopedic and general surgery cases with minimal complications (Tanaka et al. 2001; Gungorduk et al. 2011; Massicotte et al. 2011). TXA has also been adapted to urologic cases, including PCNL. Several prospective randomized controlled trials have uniformly reported decreased change in hemoglobin, decreased intraoperative blood loss and decreased transfusion rates (Mokhtari et al. 2021; Batagello et al. 2022; Kumar et al. 2013; Siddiq 2017; Bansal and Arora 2017). Several different TXA regimens have been proposed. The majority of protocols include 1g given intravenously at induction (Mokhtari et al. 2021; Siddiq 2017) and some give an additional dose of 500 mg three times over the following 24 h (Kumar et al. 2013). Bansal et al. also propose adding

TXA in the irrigant fluid in lieu of giving it intravenously. Currently, there are no comparative studies to identify the optimal dosing regimen but a meta-analysis found decreased blood loss, decreased transfusion rates and shorter operative times across all dosing regimens. Patients who have a higher risk of VTE should be excluded from use including active smokers, known coagulopathies, uses of oral contraceptives, use of anticoagulation or antiplatelets, history of VTE or impaired renal function. With an established favorable safety profile and low cost, TXA should be considered during PCNL for eligible patients.

5 Imaging

The development of Percutaneous Nephrolithotomy (PCNL) enabled for the first time the successful treatment of large, complex renal calculi in a minimally invasive manner. Even very large, very hard and very complex calculi can be treated with very high stone clearance rates. However over time the expectations of outcomes from such surgery have increased substantially, and now the goal of achieving a stone free, complication free patient with minimal intervention has become the standard to which all endourologists aspire. An essential component of such an outcome is the appropriate imaging and evaluation of the patient prior to surgery being undertaken. This should be undertaken with the lowest radiation dose and the least invasiveness possible, but with the utilization of more complex investigation whenever likely to be required.

5.1 CT Imaging

CT imaging, also known as computed tomography, is the best practice imaging methodology in the preoperative assessment and planning of treatment of urinary calculi by PCNL (Lipkin and Ackerman 2016). This technology utilizes X-rays and computer algorithms to generate detailed cross-sectional images and of the body that can then be reconstructed into any plane. CT imaging provides excellent visualization of urinary stones, allowing for precise assessment of stone size, location, and composition. It also enables evaluation of surrounding structures, such as the renal parenchyma, collecting system, vasculature and adjacent organs, aiding in treatment planning and identification of potential complications (see Fig. 1).

While non-contrast CT scans are the most common study in preoperative assessment of urinary stone disease, contrast-enhanced CT urography is routinely utilized for evaluating upper urinary tract stone burden and renal collecting system anatomy. Such CT imaging also assists in determining stone complexity and composition, guiding surgical planning including nephrostomy placement and choice of equipment based on the post-processing determination of Hounsfield density of the calculus.

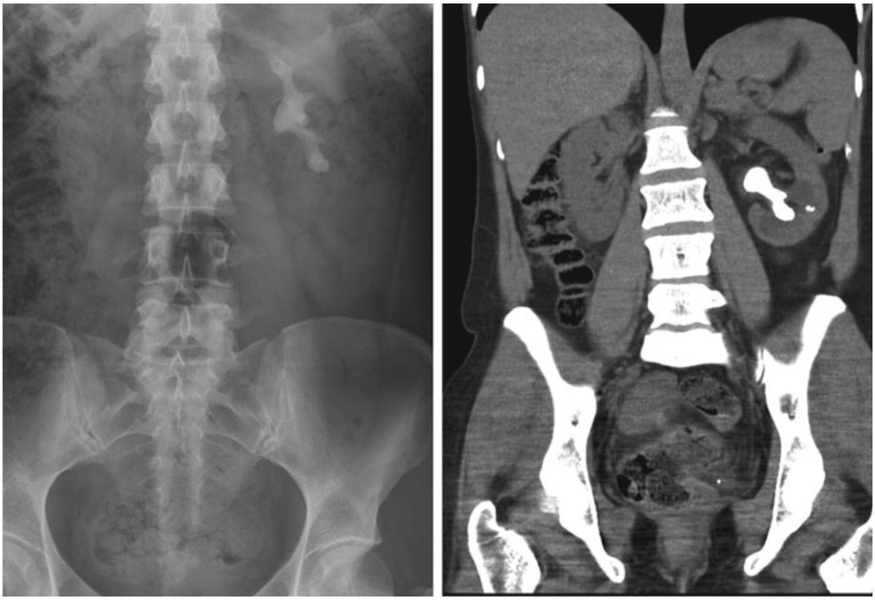

Fig. 1 Comparison of respective images from plain abdominal X ray (left) and CT KUB (right) reconstruction, showing greater detail of lower pole calyceal anatomy for where puncture is planned, including additional fragment separate to main calculus which will also require extraction

While CT imaging provides valuable diagnostic information, radiation exposure is a concern, particularly in younger patients or those requiring repeated imaging studies. Radiation reduction techniques, such as low-dose protocols, iterative reconstruction algorithms, and dose modulation, should be employed wherever possible to minimize radiation exposure without compromising image quality (Lipkin and Ackerman 2016).

Traditional CT imaging does however entertain specific limitations. A major disadvantage is its inability to provide real-time imaging, limiting its use during dynamic procedures. Additionally the use of iodinated contrast agents can pose risks to patients with renal insufficiency or contrast allergies. Moreover technical considerations such as beam hardening or patient motion may affect image quality and interpretation. These limitations highlight the importance of a multidisciplinary approach, considering other imaging modalities and clinical data to make informed decisions.

5.2 Ultrasound Imaging

Ultrasound imaging utilizes high-frequency sound waves to generate real-time images of the body's structures, and is widely used in urology due to its safety, cost-effectiveness, portability, and ability to provide dynamic imaging. Ultrasound imaging does not involve ionizing radiation or contrast agents, making it ideal for repeated evaluations, pediatric patients, pregnant patients, and individuals with contraindications to other imaging modalities.

In preoperative assessment of patients prior to PCNL, ultrasound aids in the evaluation of renal size, shape, and stone location, identifying abnormalities such as hydronephrosis, concurrent renal masses, or cysts. Doppler ultrasound can assess renal blood flow and detect vascular abnormalities. Most importantly in patients due to undergo ultrasound guided puncture of the collecting system it enables familiarity with what will be apparent at the time of surgery.

The sensitivity and specificity of ultrasonography is lower than CT imaging for urolithiasis (Ray et al. 2010). This is particularly apparent in situations such as obese patients or in patients with bowel gas interference. Its operator-dependent nature can also lead to variability in image quality and interpretation. Additionally, ultrasound is not as effective as CT imaging in evaluating stone composition or complex stone burden.

5.3 Fusion Imaging

Fusion imaging combines different imaging modalities such as CT or MRI with real-time ultrasound imaging, providing a comprehensive and detailed visualization of the urinary tract. It combines the strengths of each modality, such as the anatomical information from CT or MRI and the real-time guidance of ultrasound. Fusion imaging may potentially enhance the accuracy of stone localization, aid in needle guidance during procedures, and improve outcomes by allowing for precise targeting and minimizing damage to surrounding structures.

There are various techniques for fusion imaging, including software-based registration of preoperative CT or MRI images with real-time ultrasound, or hardware-based systems that use electromagnetic or mechanical tracking to merge the imaging data. In percutaneous nephrolithotomy this technology has been reported to facilitate more precise needle placement and reduced procedure time. Like routine ultrasound, fusion imaging also enables real-time monitoring during interventions, enhancing safety and minimizing complications.

Despite these advantages, fusion imaging also has certain limitations and challenges. The registration accuracy between different imaging modalities can be affected by organ deformation, patient movement or technical limitations. The complexity and cost of fusion imaging systems may limit their widespread use. Operator expertise and training are crucial to ensure optimal image fusion and interpretation. Ongoing advancements in technology and further research are necessary to address these limitations and expand their clinical utility.

5.4 *Advanced Imaging Modalities: Virtual Image Guidance, 3D Imaging and 3D Printed Modelling*

Newer software and processing techniques have allowed reconstruction of CT images into 3D models of the renal stone (Hubert et al. 1997; Li et al. Dec 2013) or the renal pelvis (Durutović et al. 2022). 3D models may be used to plan for the puncture trajectory. More recently virtual image guidance has been piloted, where the 3D model was translated on the skin of the lumbar area to enable the planned puncture trajectory. This technique was able to reduce the duration of fluoroscopy time required to obtain a successful puncture (Durutović et al. 2022) and may also reduce the number of puncture attempts. While promising, the major limitation to the utility of these techniques lies in the lack of supporting research to this point.

Syngo Dyna-CT (Siemens), also called the C-arm CT, is a form of imaging comprising a mounted biplanar X-ray system and a carbon-based operating table. It was initially used in angiography and supported vascular interventions. With adjusted protocols specific for urology, real time acquisition of cross-sectional imaging of the renal pelvis and calyces can be achieved. The images obtained can further undergo 3-dimensional reconstruction allowing for accurate visualisation of the collecting system.

There are major advantages in the utility of Dyna-CT for PCNLs. Firstly, the 3-dimensional image reconstructions may improve accuracy during puncture planning. Further guidance is provided with a laser crosshair on the detector, which can aid in planning trajectory fluoroscopic needle provide further control of the puncture process (Ritter et al. Nov 2015). Secondly, at the conclusion of the treatment, an on-table scan may be performed to examine for any missed stones or to confirm stone clearance (Ritter et al. Nov 2015). This is particularly helpful in avoiding repeated treatments after an incomplete PCNL.

Consideration needs to be given to radiation dose. Dyna-CT is currently used uncommonly in urology, and as such there is limited research on radiation doses. It has been shown to have mildly less radiation than a non-contrast multi-slice CT (7.04 mSv vs. 8.23 mSv) (Bai et al. Nov 2012). There are no studies comparing Dyna-CT with the more commonly used fluoroscopic images intraoperatively. However, this comparison using the C-arm CT system has previously been examined in neurosurgical intervention, with results demonstrating that a single 3-dimensional CT scan can equate to up to 132 fluoroscopic images' worth of radiation exposure (Naseri et al. 2020). As such, strict radiation safety protocols need to accompany Dyna-CT use. As an extension of the 3D reconstructed images, printed 3D models show promise in preparation for complex cases. 3D printed models of patient kidneys have been used as part of doctor–patient communication in addition to surgical planning, and have been demonstrated to improve both the patient experience and stone clearance rates (Liu et al. 2022; Cui et al. 2022).

Finally, a pilot study for the 3D printing of a patient specific needle access guide to aid puncture has demonstrated 100% success rate with a single puncture (Keyu et al. 2021). Despite positive results to date, barriers still exist to the wider adoption of 3D printing in PCNL planning. 3D printing imposes an additional financial burden to the healthcare system, plus clinicians often lack the technical skills to process radiology images and render 3D printing files (Manning et al. Apr 2018), and outsourcing of this task may be required.

5.5 Skin-to-Stone Distance (SSD)

Skin-to-stone distance (SSD) is the measurement from the skin surface to the location of a urinary stone within the body, and is the key parameter in the planning and execution of percutaneous puncture of the collecting system prior to PCNL. SSD helps determine the optimal puncture site and approach, influencing the success and safety of the procedure, and should be considered before any percutaneous puncture is undertaken (see Fig. 2).

SSD can be measured using either ultrasound or CT. It is influenced by several factors, including patient body habitus, the position of the kidney, and the location and size of the stone. The position of the kidney, whether it is ectopic in a lower

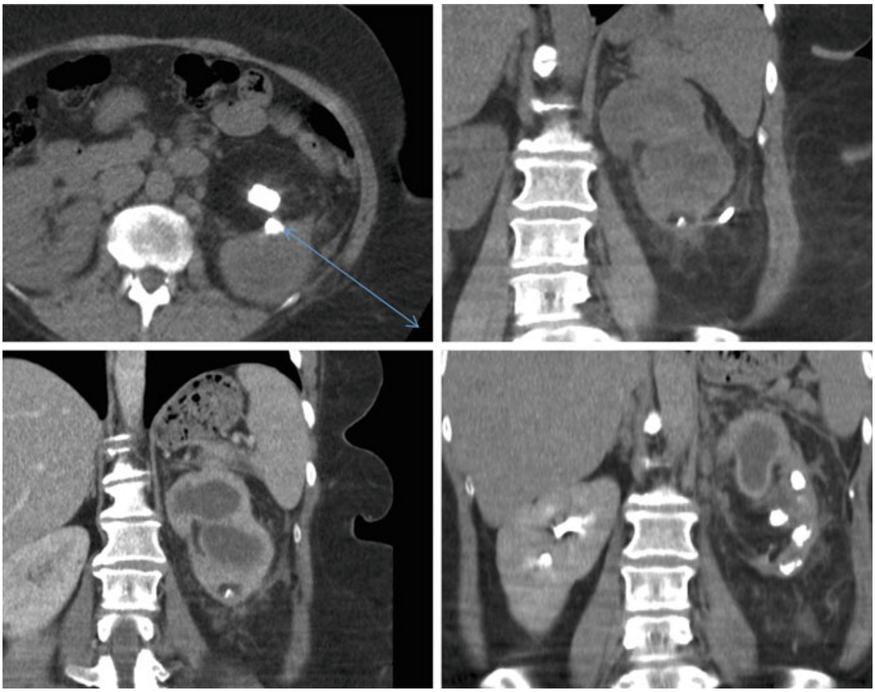

Fig. 2 Multiplanar CT demonstrating extensive abdominal wall adipose tissue with skin stone distance 19.1 cm with patient lying supine. Accordingly decision was made to treat the patient prone

or higher position, also affects SSD. The size and location of the stone within the kidney determine the optimal calyx for puncture, and consequent needle trajectory.

SSD plays a significant role in the success and safety of PCNL. A shorter SSD allows for a more direct access to the stone, usually reducing the need for multiple puncture attempts and minimizing the risk of injury to adjacent structures. However, a very short SSD may increase the risk of complications such as bowel injury or pleural injury if the kidney is unusually high or lateral. For this reason SSD is best calculated in conjunction with careful appraisal of individual anatomy with the patient in the orientation in which their procedure will be undertaken eg. with the CT scan being undertaken in the prone position for a patient having a prone PCNL and in the supine position for a supine puncture. The integration of SSD measurement with other imaging parameters and clinical data ensures the optimal needle tract and the best possible patient outcomes.

5.6 Grading PCNL Complexity and Outcomes

Four prognosticating tools have been reported in literature aiming to predict stone free rates after a PCNL, and pre-operative imaging is necessary to use these tools. These are the Guy's stone score, CROES nomogram, S.T.O.N.E nephrolithometry score and the Seoul National University Renal Stone Complexity (S-ReSC) score.

The Guy's stone score was first described in 2011 and comprises four grades of increasing anatomical and renal calculi related complexities (Thomas et al. 2011). The major advantage of this score include it being the only one aiming to predict for complications as well as stone free rates. In addition, its simplicity lends to ease of use. However multiple other patient factors and surgeon factors are not taken into consideration.

The CROES (Clinical Research Office of the Endourological Society) nomogram resulted from multinational data. It accounts for the number of stones, stone position, stone volume, prior treatment, and surgeon experience to predict stone free rates after PCNL (Smith et al. 2013). It is the only scoring system accounting for surgeon experience, however this metric has been subjectively rather than objectively assessed (Wu and Okeke 2017).

The S.T.O.N.E. nephrolithometry score was developed using variables identified in literature reviews that can affect PCNL outcomes. The acronym S.T.O.N.E. represents these factors: stone **s**ize, **t**ract length, degree of **o**bstruction, **n**umber of involved calyces, and stone **e**ssence (i.e. density) (Okhunov et al. 2013). On the basis of these factors, a score of 5–13 may be calculated, with increasing scores representing decreasing stone free rates. A strength of this particular score is that factors are chosen solely based on published data, whereas the remainder were based at least in part on expert opinion.

The S-ReSC score was first presented in 2013, where cases were assigned scores from 1 to 9 based on the number of sites involved: in the renal pelvis (#1), superior major calyceal groups (#2), inferior major calyceal group (#3), anterior and posterior minor calyceal groups of the superior (#4–5), middle (#6–7), and inferior calyx (#8–9) (Jeong et al. 2013). The S-ReSC score takes into account the anatomy of the patient and the renal calculi, and like Guy's stone score it is simple to use. The authors also demonstrated a relationship between the S-ReSC score and complication rates; however, the correlation failed to reach statistically significance.

With several scoring systems available, the question of whether any single system is superior to another often falls to operator preference. Several comparison studies have been performed; however no single score has consistently proven more accurate in predicting outcomes after PCNL (Withington et al. Jan 2016; Jaipuria et al. 2016; Kumar et al. 2016; Noureldin et al. 2015).

5.7 Imaging Considerations for Supine Versus Prone Percutaneous Nephrolithotomy (PCNL)

Traditionally PCNL was performed with the patient in the prone position, which provided excellent access to the renal collecting system. In recent years there has been a shift toward performing PCNL in the supine position due to potential advantages such as improved patient comfort (Goumas-Kartalas and Montanari Jul 2010), shorter operative times (Yuan et al. 2016; Liu et al. 2010), and suggested easier access to lower pole stones. The choice between supine and prone PCNL depends on several factors, including stone characteristics, patient anatomy, and surgeon preference.

For both approaches to PCNL the puncture is usually performed using fluoroscopic guidance based on preoperative imaging. Choice of approach should be individualised, and based on the use of contrast enhanced imaging to optimize access to all calyces. Ideally the pre-operative contrast CT should have been performed with the patient in the position proposed for the puncture.

5.8 Imaging Considerations for Size of the PCNL Tract

There can be considerable morbidity associated with the PCNL tract, including urine extravasation, renal haemorrhage and need for transfusions, renal parenchymal loss and post-operative pain (Michel et al. 2007; Tailly and Denstedt Dec 2016). In attempt to reduce these risks, there has been a trend towards smaller tract sizes. Standard PCNL utilises outer sheath sizes of 24Fr or greater (Kallidonis et al. Jan 2021), while mini-PCNL utilises outer sheath sizes of 22 Fr or smaller (DiBianco and Ghani 2021).

Despite these trends and research, mini-PCNL did not show the anticipated improvements in the observed complication domains. The positive outcomes favouring mini-PCNL were reduced blood loss and reduced blood transfusion rates (Giusti et al. 2007). Additionally, mini-PCNL equipment has been used to gain access in cases where standard PCNL access was unable to be achieved (Hennessey et al. May 2017). Parenchymal loss has been examined (Traxer et al. May 2001), and mini-PCNL made no statistically significant improvement. Furthermore, higher intrarenal pressures are demonstrated in mini-PCNL (Tepeler et al. Jun 2014), and this has been associated with higher rates of bacteraemia and septic complications (Loftus et al. Apr 2018). Finally, mini-PCNL operative time has been reported as significantly longer than standard PCNL at 155.5 vs 106.6 min respectively (Giusti et al. 2007). As such standard PCNL with standard tract sizes remains the mainstay of percutaneous management of urolithiasis in many departments.

5.9 Calyceal Diverticula

Calyceal diverticula are pouch-like cavities arising from the calyces of the collecting system within the kidney. They are often congenital and can be classified as either true diverticula, which involve all layers of the calyx, or false diverticula, which only involve the mucosal layer. Calyceal diverticula are typically located in the upper or lower pole of the kidney and can vary in size and shape. They may be asymptomatic or present with symptoms such as recurrent urinary tract infections, hematuria, or stone formation.

Where calculi are present and requiring of treatment in calyceal diverticulae, delayed phase imaging (Stunell et al. Oct 2010) on CT or even magnetic resonance urography (MRU) can provide more detailed information regarding the size, location, orientation and characteristics of the diverticula. Detailed assessment of the calyceal anatomy can assist in determining whether marsupialization is an appropriate option for consideration in association with stone extraction.

5.10 Ectopic Kidney

An ectopic kidney is a congenital condition in which the kidney is located in an abnormal position instead of the normal retroperitoneal space due to a developmental anomaly. The prevalence of ectopic kidneys is relatively rare, estimated to occur in approximately 1 in 1000 live births (Chavis et al. Nov 1992), and where PCNL is contemplated these kidneys are usually located in the pelvis or across the midline of the abdomen.

Imaging techniques play a crucial role in identifying and characterizing ectopic kidneys. CT scans or MRI with intravenous contrast are commonly employed, because almost by definition the vascular supply will be anomalous. Visualization of the vascular supply is critical preoperatively in order to avoid injury to associated vessels during puncture and nephrostomy tract dilation. As the kidney's shape is often abnormal, and there is greater potential for additional associated congenital anomalies including ureteropelvic junction obstruction (Eid et al. 2018), CT urography is particularly valuable in evaluating the optimal approach to any calyx where a calculus may be present. Punctures for nephrostomy tube placement in such kidneys are often more vertical than normal due to failure of the kidney to lodge into the relatively deep renal fossa during arrestation of its development, and consequently it is essential to optimize preoperative imaging—often by the use of 3D reconstructions that can show the orientation of calyces and identify any overlying structures such as the colon. This is particularly pertinent to the presence of a Horseshoe kidney where the collecting system lies especially close to the midline of the abdomen.

5.11 Paediatric Stones

The incidence of paediatric stones varies across different regions and populations, but has been noted to increase over the past 2 decades. Various factors contribute to the formation of stones in children, including metabolic disorders, urinary tract abnormalities, dietary habits, genetic predisposition and inadequate fluid intake. The greater availability of ultrasonography has also no doubt made possible the more frequent diagnosis of this pathology (Jobs et al. 2018).

Imaging techniques based around ultrasound are more commonly used as initial diagnostic modalities due to the lack of radiation (Jobs et al. 2018). However the disadvantages of ultrasound in general remain applicable in the paediatric population, therefore, in complex cases CT scan or occasionally intravenous pyelography (IVP) may be necessary for more appropriate, detailed evaluation (Jobs et al. 2018) (Table 1).

Preoperative Checklist

- History and Physical
- Medical clearance
- Appropriate laboratory and radiographic testing
  - Urine Culture
  - CBC
  - BMP
  - Coagulation Panel
  - Type and Screen
  - Non contrasted CT abdomen and pelvis
- Discussion of anesthetic options and pain control adjuncts
- Obtain informed consent

Table 1 Perioperative antibiotic regimens

		Antibiotic regimen	Duration	Study findings
***Low risk**: Negative preoperative culture and no risk factors*				
Zeng et al. (2020)	Review	Guideline based	Single Dose	No difference in postop sepsis
Chew et al. (2018)	Prospective RCT	Nitrofurantoin 100 mg versus No antibiotics	7 days	No difference in postop sepsis (12% v 14%)
***Intermediate risk**: Negative urine cultures with risk factors (hydronephrosis and stones >2 cm)*				
Mariappan et al. (2006)	PCT	Ciprofloxacin 250 mg BID	7 days	3 times less likely to have SIRS (RR 2.9)
Bag et al. (2011)	PCT	Nitrofurantoin 100 mg BID	7 days	Decreased postoperative SIRS (19% v 49%)
***High risk**: Positive urine cultures, large stone size, hydronephrosis, foreign bodies, indwelling drainage tubes, recurrent UTI, struvite stone, and or urinary diversion*				
Xu et al. (2022)	Review	Culture specific	>7 days versus <6 days	Decreased SIRS (21% v 40%)
Zeng et al. (2020)	Review	Culture specific	>7 days versus <3 days	Decreased SIRS (8% v 28%)
Sur et al.	Prospective RCT	Culture specific	2 days versus 7 days	Decreased sepsis in the 7-day group

RCT Randomized controlled trial, *PCT* Prospective controlled trial, *SIRS* Systemic inflammatory response syndrome

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