Renal Imaging Used in Percutaneous Nephrolithotomy in Children

Aon Allah Elaref Ali Gashgesh [1]*, Mohamed Salah El din El dereey [2], Ahmed Sakr [2], Ehab Elsayed [2].

[1]Department of Urology, Faculty of Medicine, Tripoli University, Libya
[2]Department of Urology, Faculty of Medicine, Zagazig University, Egypt

***Corresponding author:** Aon Allah Elaref Ali Gashgesh, **E-mail:** aonallaha86@gmail.com

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Abstract:

Pediatric urolithiasis is an important kidney disorder encountered in clinical practice . There has been considerable regional variability in the reported incidences of urolithiasis, A perfect puncture is a crucial step to avoid post percutaneous nephrolithotomy bleeding.

Keywords: PNL, prone, stone.

Introduction:

Percutaneous extraction of renal stone, properly termed PNL, had been invented over 3 decades ago. Fernström and Johansson, first reported the formation of a percutaneous track for the specific purpose of subsequently removing an intrarenal stone **(1).** This technique was rapidly taken up by other centers, with **Alken et al., and Wickham and Kellet,** who further demonstrating the effectiveness and safety of the procedure in disintegrating and clearing not just small stones in renal pelvis **(2).** The term PNL can be in short for nephro-lithotomy or nephrolithotripsy: 'lithotomy' meaning removal of stone, and 'lithotripsy' meaning shearing or fragmentation of stone. Different urologists may have their own preferences and variations of the basic operative technique the standered methode should be one that has been most researched and tested, that can be safely applied under all circumstances, that consistently produces optimal and reproducible results, and of paramount importance, that can be taught and learnt easily **(3).**

Clinical Applications:

Indications:

Percutaneous nephrolithotomy can practically be applied to most, if not all, renal stones. It is the preferred treatment for obstructive stones that have long been impacted or stones that are deemed too big (>1.5 cm) to be optimal for SWL, because percutaneous removal has less infective and obstructive complications and more effective stone clearance **(4).**

In a prospective randomized trial of SWL versus PNL for lower pole nephrolithiasis, **Albala et al.,** suggested that lower pole calyceal stones larger than 1 cm are better treated by primary PNL, as this offers the best chance of rendering patient stone-free after one single procedure**(5).**

PNL can also be applied to stones in calyceal diverticulum, horseshoe kidney, transplanted kidney, and in children, though these are challenging situations where substantial technical difficulty would be expected **(4).**

The European Association of Urology (EAU) guidelines recommend PNL for the treatment of renal stones ≥2 cm and lower pole stones ≥1.5 cm. The American Urological Association (AUA) guidelines recommend PNL as the first-line treatment for staghorn calculi (**6).**

Contraindications:

Percutaneous nephrolithotomy is contraindicated if patient has uncorrectable coagulopathy. Antiplatelet medications like aspirin should be discontinued 7 days before operation **(7).**

Urine sterility is mandatory for all elective procedures. This should be achieved by urine culture followed by sensitivity-specific antibiotics for 5 to 7 days before the procedure. Documented follow-up sterile urine is preferable but may not always be feasible (e.g., indwelling nephrostomy or urethral catheter, struvite stone). Consideration should be given for 1 to 2 days or more of pre-operative intravenous antibiotics in select patients with a history of urosepsis, struvite calculi, or indwelling tubes. Percutaneous entry in the setting of untreated urinary tract infection risks sepsis and death and a temporary percutaneous nephrostomy can be inserted to drain an obstructed and infected P/C system beforehand **(7).**

Preoperative Preparation:

A detailed medical history of the patient must be obtained pre-operatively. Specific questions must include any history of previous surgery, bleeding disorders, antibiotic treatments, immunosuppression, or other risk factors for infectious complications. Radiologic definition of the stone size and the anatomy of the collecting system enable the assessment of the indications for a proper PNL. Laboratory checks must include coagulation parameters and electrolytes. A preoperative urine evaluation by urine culture is strongly recommended **(8).**

Patient Positioning:

Careful positioning of patient during PNL facilitates correct puncture of the collecting system, while at the same time protects the anaesthetized patient from inadvertent injury. The correct position of the patient during a PNL has always been a debated issue, as the precise access to the kidney is facilitated by a careful positioning of the patient and can reduce intraoperative complications. In the past 3 decades, PNL has been performed with the patient in various positions **(9).** Many PNL positions were described, with the patient placed prone, lateral or supine in various modifications.

A. Prone Position:

(1) The Classic Prone Position:

When PNL was initially described in 1976 the PP was chosen because it was believed that this would be the safest way to avoid damage to the colon and visceral organs. The technique was standardized over the following years as a two-stage procedure. The first part is with the patient supine, to give anesthesia and gain retrograde access to the upper urinary tract. Then the patient is repositioned prone for the main part of the procedure. Rolled supports are placed under the thorax and the upper abdomen or on both sides, extending from shoulder to hip, to facilitate ventilation **(10).** Padding is placed under all pressure points (knees, feet, forehead, eyes, elbows, fingers) and the shoulders, and the elbows are carefully positioned to prevent brachial plexus injury **(7).**

The main advantage of the PP is that it exposes completely the lumbar area. This gives the surgeon ample room to place the puncture, allows several accesses/tracts, and provides enough space for manipulation with the instruments. Upper-pole puncture is facilitated in the PP because of the posteromedial location of the upper pole, which is closer to the posterior abdominal wall **(11).**

Percutaneous nephrolithotomy with the patient prone has several disadvantages. First, the patient must be repositioned after the first stage. This increases the operating time, and could cause injury to the patient and jeopardise the airway access. It is very difficult or almost impossible for the anesthetist to manage an eventual cardio-respiratory emergency. Lying on the abdomen creates further anesthesiological difficulties by reducing lung compliance as a result of the abdominal compression, and by reducing COP **(12).**

The patient is bedded uncomfortably with the risk of creating pressure lesions. The PP is generally associated with an increased rate of ophthalmological complications, as seen mostly from spinal operations. Direct compression might cause injury to the orbit and corneal abrasions. Also, intraocular pressure is raised during the operation and is suspected to lead to the rare complication of post-operative visual loss due to ischemic oculopathy **(13).** For patients with ankylosing spondylitis or other spinal or lower limb deformities, the PP might not be possible. Finally, there is a theoretically greater risk of radiation exposure for the surgeon when the patient is prone, because the surgeon stands close to the patient, working with the instruments in perpendicular direction **(14).**

Various supporting equipment have been developed to minimize the risk of pressure injury, reduce the risk of position-related complications, and improve the ventilation and circulation of the patient. For example, the rolled supports can be replaced by the Cloward surgical saddle (Cloward Instruments Corp., Honolulu, Hawaii) **(10)** or the Montreal mattress (Teasdale Hospital Equipment, Manchester, UK) **(15),** embedding the patient in a more comfortable, slightly flexed posture with less pressure on the abdomen. To better position the head, the Prone-view protective helmet system (Dupaco, Oceanside, CA, USA) was developed, which protects the critical cephalic pressure points and the airways**(12).**

(2) The Reverse Lithotomy Position:

To allow simultaneous retrograde access to the upper urinary tract during PNL, a modification of the classic prone position became necessary. In 1988, Lehman and Bagley, reported successful results with this combined approach in three female patients. According to the initial description, the patient is placed prone with the legs abducted at the hips, and the thighs and knees fixed in plastic cradles specifically modified for this purpose. The caudal end of the operating table is lowered as far as possible. The operator approaching from the caudal end of the table has access to the urethra, bladder and ureter with flexible instruments **(16).**

(3) The Split-leg Prone Position:

The same group of authors, who described the reverse lithotomy position, three years later, reported the split-leg PP that allowed easier simultaneous percutaneous and transurethral access both in female and male patients. The patient is anesthetized while supine and then turned prone on a standard endourological table with split-leg adapters. The patient's legs are appropriately padded, secured independently and solely abducted at the hips without being flexed. The genitalia are positioned at the bottom of the operating table, making room for retrograde access. The flank and the genital area are separately prepared and draped. Using flexible instruments, the bladder and upper urinary tract are accessed, although this can be challenging. The authors report that many endourological procedures, including intracorporeal lithotripsy, can be performed in this position **(17, 18).**

(4) The Prone-flexed Position:

A modification of the prone position was described which incorporates a flexed position of the patient during the procedure **(14).** After the patient is turned to prone the table is flexed 30 - 40^o to open the space between the 12th rib and the posterior iliac crest. This flexion prevents the exaggeration of the anterior lordosis that occurs in the classic prone position. More working space is created, potential interference from the buttock with the nephroscope during rigid nephroscopy through the lower pole is minimized, and the kidneys are displaced inferiorly in the retroperitoneum. As a result, the puncture can be made more caudally. However, this position impairs even more the patient's respiration and circulation. Airway pressures are increased, the cardiac index is decreased and the inferior vena cava can be transiently obstructed **(19).**

Surgical Technique:

The standard operative technique of PNL consists of three main steps:

A. Renal access.

B. Formation of the track.

C. Fragmentation and/or removal of stone.

A. Renal Access:

The first description of percutaneous renal access was by Goodwin et al in 1955 **(20).** This cleared the way for the first removal of stones through PNL by Fernstrom and Johansson in 1976 **(1).** Even now, gaining renal access and formation of the track are still the most challenging parts of the operation; they have a long learning curve **(21),** and are deemed as the most critical factor for blood loss in PNL **(22)**. Renal access is divided into two main parts:

(1) Puncture of the collecting system.

(2) Formation of the track.

Percutaneous nephrolithotomy can also be performed as a two-stage procedure, with the puncture in a first step and track dilation with stone extraction in a second step. As early reports approved PNL as a safe single stage procedure **(2),** the two-stage procedure might take place for organizational reasons or in patients with increased anesthesiologic risk factors to reduce the stress on the patient **(8).** For both the puncture and the track dilation, different techniques are discussed in the current literature review.

(1) Percutaneous Puncture of the Collecting System:

After induction of anesthesia, cystoscopy can be performed with the patient in lithotomy or prone position with spreader bars for placement of a ureteral catheter. Bladder drainage should be provided by means of an indwelling urethral catheter. Options for ureteral catheterization include a 5- or 6-Fr open-ended catheter, an occlusion balloon catheter, a dual-lumen catheter, or a ureteral access sheath **(23).**

It is important that whenever possible the access is carried out in the operating room (OR) at time of surgery, in order to eliminate transfer of the patient between different departments. The urologist alone can do the access. According to the published data, most urologists puncture the collecting system themselves (90.1%). Sixty-two percent of the punctures are performed with radiographic guidance alone, 10.1% with ultrasound guidance alone, 14.6% use the combination of both, and 10.8% use other techniques like CT-guided access, endoscopic guidance, or any combination of the mentioned techniques**(24)**.

If the access is performed by an interventional uroradiologist, it should preferably be done in collaboration with the endourologist in a one-stage setting in the OR for selection of the optimal tract based on intrarenal anatomy and the ability to make secondary tracks **(25).**

Also, placement of a ureteral catheter for contrast injection provides the ability to create a dilated system and presents intrarenal anatomic details, which improves the chances of getting ‘the perfect puncture’ through the cup of the desired calyx. Fewer access-related complications and higher stone-free rates can be achieved in this manner **(26).**

Which Pole to Puncture?

Whichever imaging modality is used the urologist has to select a pole for puncture which provides the straightest path along the stone axis and would provide maximum or complete stone clearance. A useful adjunct to make this decision would be to make an “outline-o-gram”. There is a complete stag horn calculus. The “outline-o-gram” as shown indicates that most of the calculus can be cleared by a lower pole puncture. The mid pole calculus would need a separate puncture or use of a flexible nephroscope. Thus an “outline-o-gram” can serve as a guide to determine which pole to puncture and also to decide whether multiple tracks will be needed **(23).**

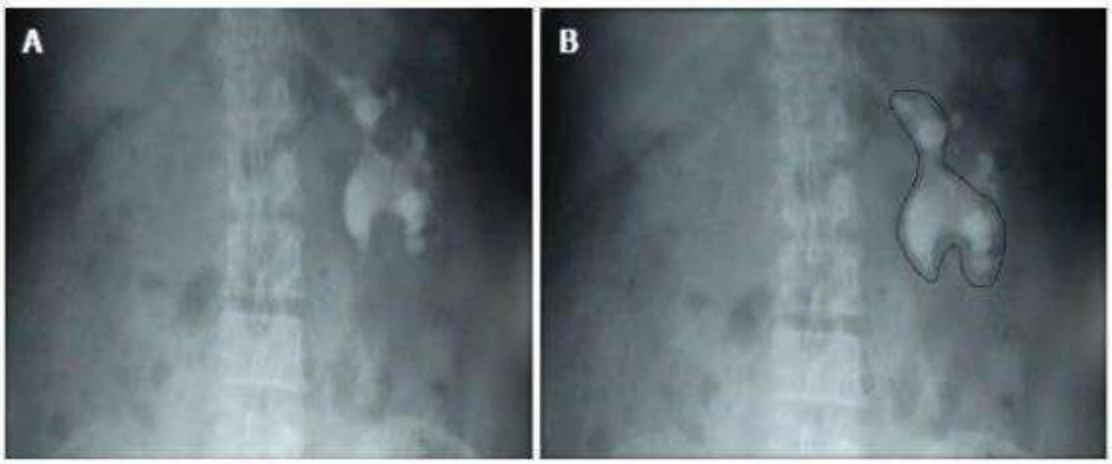


Figure (1): Outline-o-gram. (A), KUB showing a Left staghorn calculus; (B), Outline- o-gram.

Which Calyx to Puncture?

The literature is clear about the fact that it should always be the posterior calyx which should be punctured for a safe and complication free access **(27).**

Why to Puncture the Posterior Calyx?

Puncture of a posterior calyx will traverse the relatively avascular Brodel's line. Also, if the patient is prone, it will provide the direct path to the renal pelvis **(28).**

If an anterior calyx is punctured, there is increased risk of bleeding as it does not traverse through the Brodel's line. More parenchyma is traversed to reach the calyx, resulting in more renal damage. Also, as there will be an acute angle between the line of puncture and the infundibulum, entry in the renal pelvis will be difficult, associated with more torque and thus increased bleeding and damage to the renal parenchyma **(27).**

Fluoroscopy?

On account of the unreliability of the antero-posterior radiography to determine the optimal posterior calyx for entry additional maneuvers are needed **(29).** With the patient in Prone Position, diluted contrast when instilled will fill the dependent anterior calices first. Thus the posterior calices will be filled later and would appear less dense **(25).** Injection of 5-10 mL of air via the ureteric catheter also helps to identify the posterior calices as air will preferentially enter these calices when the patient is prone **(30).**

Despite these maneuvers if there is dilemma in identifying the posterior calyx, movement of the C-arm can help to identify the posterior calyx. In the PP, the posterior calyces move in the opposite direction to the image intensifier on the Carm. If the C-arm is rotated towards the surgeon then the posterior calices move away and shorten. *Vice versa*, if the C-arm is rotated away from the surgeon then the posterior calices appear elongated. Thus by moving the C arm way from the surgeon one can identify the laterally placed calices as posterior and by moving the C-arm towards the surgeon the posterior calices appear more medially placed and appear end on **(14).**

What should be the Trajectory of the Needle?

Renal pelvis should not be punctured directly as there is very high risk of injuring a retro pelvic vessel (artery and/or vein). Studies by Sampaio have proved beyond doubt that puncture through the infundibulum of a calyx is associated with a significant risk of significant bleeding from interlobar vessels. There is an added risk of through and through puncture of the collecting system. The risk of injury to a major arterial vessel is maximum in the upper pole where puncture of the upper pole infundibulum may cause damage to posterior segmental artery, which is related to the posterior surface of upper pole infundibulum in 57% of cases. Damage to this artery may lead to loss of up to 50% of the renal parenchyma as well as serious hemorrhage **(28, 29).**

The trajectory of the needle during puncture should be such that it aims at the fornix and not at the infundibula. In other words, we should aim for the center of the calyx posterolaterally via the renal parenchyma. When puncture is made through a fornix, no arterial injury occurs and venous injury occurs in less than 8% cases **(28).**

Confirmation of Puncture of the Posterior Calyx:

If air has been instilled during opacification of the P/C system, air will be aspirated followed by a free flow saline especially if it is instilled through the ureteric catheter. After this when the glide wire is passed, while maintaining the angle of the needle, it enters the pelvis easily. No manipulation is needed. On the contrary if the anterior calyx has been punctured than the glide wire will be coiled in the calyx, will not enter the pelvis easily or will do so only after much manipulation **(23).**

Criteria for Good Puncture:

Percutaneous renal access through a calyx must meet five conditions that guarantee safe access and avoids complications **(31).**

a. Access should be performed from a posterolateral aspect.
b. Access should be through the renal parenchyma.
c. Access should be towards the center of a calyx posterolaterally.
d. Access should be towards the center of the renal pelvis as a result of these 4 conditions
e. The trajectory does not damage any major blood vessels.

Postoperative Care:

An accurate estimate of irrigation and output is imperative during and following the procedure. Generally, 20 mg furosemide is given intravenously at the termination of the percutaneous procedure. Vital signs are monitored closely and serial blood counts are obtained as determined by the course of the procedure. For approximately 24 hours postoperatively, intravenous fluids are administered at a rate that ensures a sustained diuresis. For those patients with documented urinary infection associated with the stone disease, specific antibiotic therapy is continued intravenously for at least 48 to 72 hours in the hospital, and then orally at least until the first follow-up visit. In those patients with sterile urine initially, prophylactic antibiotic coverage can be discontinued within 48 hours of uncomplicated stone extraction **(4).**

A nephrostogram is generally obtained 48 hours following stone removal. Any residual fragments seen on this study that appear accessible to the percutaneous tract can be managed by repeat nephroscopy that can often be performed with light intravenous sedation **(32).**

If there are no residual stones, and no obstruction or extravasation are noted on the nephrostogram, the pyeloureteral catheter is removed. The nephrostomy tube is then clamped for 12 to 24 hours and removed if there has been no flank pain, fever or significant drainage around the tube. The patient can then be discharged with a light dressing and allowed to return to full pre-hospitalization activity and employment 10 days following the procedure **(31).**

In those cases where extravasation or obstruction is noted on the initial nephrostogram, the nephrostomy tube is left to drainage and serial studies obtained until the problem resolves. Ureteral obstruction noted at this time is usually the result of blood clots that will lyse, or edema that should subside spontaneously. Occasionally, obstruction can result from small stone fragments in the ureter that will often pass spontaneously, or may be managed with antegrade or retrograde manipulation **(31).**

Modified biplanar technique

1st step, identifying the calyx to puncture: With the C-arm at 0 degrees (Anteroposterior projection), the calyx to be punctured is selected, moving the needle from head to toes. When having the needle at the tip of the papillae, a visual landmark is placed over the patients' skin at this selected point (Verified by fluoroscopic control); we called this: point A. The landmark marked on the skin can follow all the trajectory of the needle (Line A), which will be the actual trajectory when performing the puncture.

2nd step Then entry point along this line in the safety zone is determined: (between the last rib superiorly, paravertebral line medially and posterior axillary line laterally). The puncture needle will be introduced under C arm guidance just near to the desired calyx.

3rd step, identifying the depth of the calyx: the C-arm has to be rotated under the surgical table (90º about the patient position), achieving a complete lateral view of the kidney. It will allow knowing which calyces are anterior or posterior. For this, a good trick is to have the vertebral column as a reference point, seeing the vertebral column body as anterior and the spinous process as posterior. The needle will be moved in anterior or posterior direction to face the desired calyx.

4th step, the C arm: rotate again in zero position and the needle advanced to reach the desired calyx.

This technique will allow that always the puncture site in the safety area. IED Clavien Dindo grading system.

Renal Imaging Used in Percutaneous nephrolithotomy

[1] Preoperative imaging:

Importance of pre-op imaging:

1. Defining Stone burden and renal anatomy.
2. Relationship of the Kidney to Adjacent Organs.
3. Estimation of Stone Fragility.

(1) Defining stone burden and renal anatomy:

Plain Abdominal Radiography (KUB):

KUB (kidney-ureter-bladder plain radiography) is readily available and inexpensive.With regard to detection of upper urinary tract stones, it has however a rather low sensitivity and specificity both with regard to renal (58 and 62 %, respectively) and ureteral (67 and 69 %, respectively) calculi **(33).**

Intravenous Urography (IVU):

Traditionally, IVU was the preferred imaging modality for both diagnosis of the stone disease and planning of treatment including access in PNL. With use of both anterior-posterior (AP) and oblique views, IVU presents the anatomy of the collecting system as well as its relationship to the ribs, there by predicting the need for asupracostal access **(33).**

Computerized Tomography (CT):

Standard CT urography, has been proposed as the 'catch-all' diagnostic procedure for all renal tract anomalies (Nolte-*Emsting* and Cowan, 2006). Non-contrast CT (NCCT or CT KUB) unequivocally performs significantly better than IVU in the evaluation of acute flank pain and the diagnosis of urolithiasis **(34).** Both sensitivity and specificity of NCCT in the evaluation of renal and ureteral calculi approach 100 % **(35).**

A 3-D CT not only presents exact volume, orientation and location of stone(s) in relation to the collecting system, there by facilitating selection of the optimal calyx for percutaneous access and , it also provides excellent perirenal organ mapping in combination with the CT images used for the 3-D reconstruction, thereby presenting the optimal plane of access in order to avoid injury of adjacent organs such as the liver, spleen, colon and pleura, which is of special value in patients with unusual body habitus and renal anomalies. A 3-D CT demonstrates accurately the presence of parallel calculus-bearing calyces, and it displays calyceal orientation, thickness of narrowed calyces or the neck of a calyceal diverticulum **(36).**

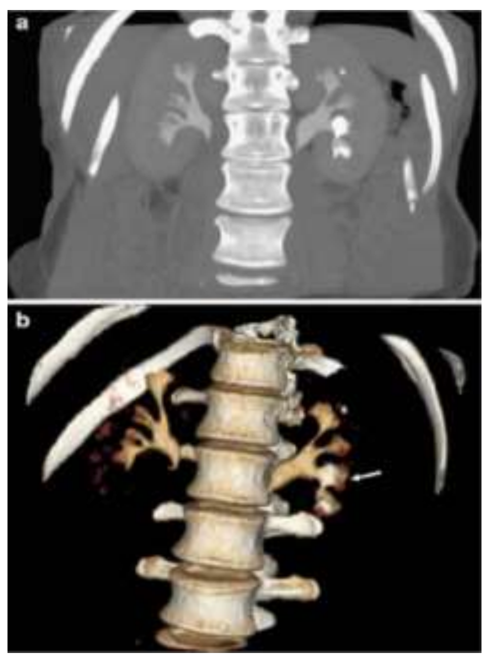


Figure (2): CT demonstrates stone shape and size thickness of narrowedcalyces **(36).**

Guy’s scoring system (GSS):

GSS categorizes PCNL cases into four grades of complexity (Grade 1, 2, 3, and 4) depending on patients’ past medical history and non-contrast computed tomography (NCCT) **(37,38).**

GSS is easy to use and reproducible. In their original study. assessed 100 patients and showed that GSS was the only factor that significantly and independently predicted the stone-free rate. None of the other factors tested, including stone burden, operating surgeon, patient weight, age and comorbidity, were correlated with the stone-free rate **(39**).

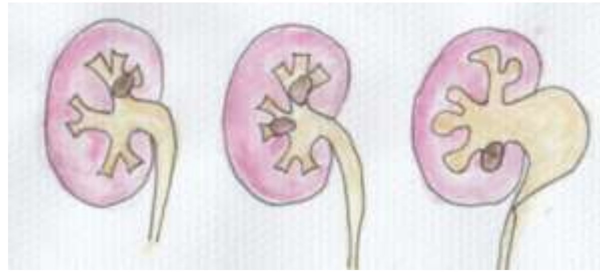
Published Guy's stone score (GSS), a simple method of stratifying renal calculus complexity, with high interobserver agreement and correlating well with success and complication rates. Guy’s stone score was developed to predict treatment outcomes **(40).**

They observed a final stone clearance rate of 97.73 % and stone clearance in GSS I and II was 100 % **(38).**

Grade 1

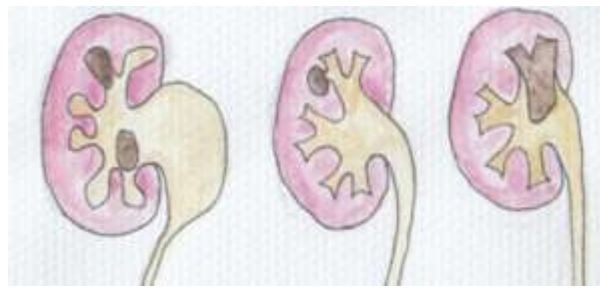
A solitary stone in the mid/lower pole with simple anatomy Or A solitary stone in the pelvis with simple anatomy

Grade 2



A solitary stone in the upper pole with simple anatomy Or Multiple stones in a patient with simple anatomy Or any solitary stone in a patient with abnormal anatomy

Grade 3



Multiple stones in a patient with abnormal anatomy Or Stones in a calyceal diverticulum Or Partial staghorn calculus**.**

Grade 4

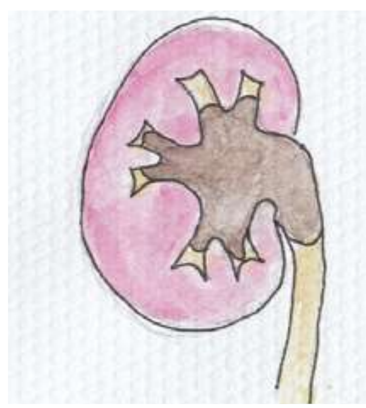


Figure (3): Grading of Guy’s scoring system. **(37, 38)**

Staghorn calculus

Any stone in a patient with Spina Bifida or Spinal Injury. The GSS provides a simple, intuitive and reproducible tool for predicting SFS following PCNL.

[2] Intraoperative imaging:

Fluoroscopy:

Traditionally, biplanar fluoroscopy with a rotating C-arm has been the most common imaging modality for obtaining percutaneous access in PNL, and regardless the imaging modality used for access guidance, intraoperative fluoroscopy complementary to endoscopy is considered indispensable for successful and safe stone removal.Tilting the C-arm towards the surgeon (20°–30°) and in the caudal or cranial direction depending on whether the lower or upper pole is being accessed presents the desired calyx – usually the posterior one – for end-on puncture **(33).**

[3] Postoperative imaging:

Evaluation of residual Stones:

Traditionally, KUB and/or nephrotomograms were used to determine whether the patient was stone free after a PNL**.** Using flexible nephroscopy as gold standard reference, NCCT had a sensitivity of 100 % and a specificity of 62 % compared with 46 and 82 %, respectively, for KUB**(41).**

Fowler et al. investigated the specificity and sensitivity of US in detecting renal calculi. They found an overall sensitivity of 24 % and a specificity of 93 %. The sensitivity was size dependent with the highest sensitivity (71 %) in stone sizes above 7 mm **(42).**

Evaluation of complications:

Intraoperative chest fluoroscopy seems to be sufficient to detect clinically significant pleural complications during PNL **(33).** Due to the fact that colonic perforation is most often retroperitoneal, colonic injury following PNL is often asymptomatic, and in these situations an antegrad enephrostogram before nephrostomy removal may reveal the presence of contrast in the colon **(43).**

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