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Technique of Percutaneous Nephrolithotomy

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Abstract

According to the latest American and European Urological Association guidelines, percutaneous nephrolithotomy (PNL) is the current gold standard treatment for patients presenting with symptomatic large or complex renal stones ≥2 cm. This review chapter and accompanying videos will review the latest literature on indications, preoperative preparations, different patient positions, in addition to step by step explanations for the technique of PNL. Postoperative care and troubleshooting tips are provided. Furthermore, latest reported outcomes are reviewed.

Keywords: percutaneous nephrolithotomy, surgical technique, positioning, outcomes

Indications/Contraindications

As open renal stone surgery has decreased in utilization, percutaneous nephrolithotomy (PNL) has increased over recent years.[1] According to the 2016 American Urological Association Surgical Management of Stones Guidelines, PNL should be offered as first-line therapy to patients with over 20 mm of total renal stone burden due to the improved stone-free rates and outcomes in these patients.[2] Additionally, patients with stones in the lower pole of the kidney that are greater than 10 mm in size have improved stone-free rates with PNL compared to other surgical options.[2] In addition, stones greater than 10 mm in size that are known (either by history or imaging) to be very hard or complex in shape may be better suited to PNL.

Additionally, relative indications for PNL over other surgical options include abnormal collecting system anatomy, such as a stone within a calyceal diverticulum, as these cannot often be easily reached ureteroscopically. Similarly, kidneys that cannot be easily accessed in a retrograde fashion, including transplant kidneys and those in patients with lower urinary tract diversions, usually require percutaneous stone removal and as such this is a relative indication. Lastly, infected struvite stones have a tendency to recur without complete removal and, as such, percutaneous extraction may improve stone-free rates in these patients and become the method of choice.[2]

A major contraindication for PNL is active urinary infection and it is recommended that patients undergoing percutaneous stone removal have their urine sterilized or treated before instrumentation.[2] Given the direct puncture and dilation of a tract through the kidney and minimal tamponade abilities, uncorrected coagulopathy is a contraindication for this procedure. Pregnancy and the inability to tolerate the operative position of choice are also contraindications for PNL.

Preoperative Preparation

The initial step in preoperative preparation of the PNL patient is a full history and physical to ensure the need for the procedure and determine any medical reasons for a variation in typical surgical planning. In addition to standard anesthesia clearance, routine laboratory work should include complete blood count, platelet count, creatinine, and urinalysis. It has been suggested that screening coagulation studies are not required for the typical patient, although type and screen should be performed.[3] While the specifics of preoperative antibiotics will be discussed later, all patients with clinical, historical, or laboratory signs of urinary infection should undergo urine culture with appropriate treatment before instrumentation.

Preoperative imaging is required before instrumentation. Most guidelines suggest that a noncontrast CT scan be performed as the cross-sectional imaging allows evaluation of the stone burden and renal anatomy, nearby organs, and body habitus in relation to the kidney.[2] Low dose noncontrast CT is sufficient in this setting for most patients.[4] In most cases, contrasted imaging is not required, although it may be beneficial in cases with complicated anatomy; pre-PNL retrograde pyelography may suffice to provide a map of the collecting system in many cases. Of note, in patients with suspected decrease of function in the affected kidney, functional imaging (e.g., renal scan) should be performed to determine whether renal salvage is feasible.[2]

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As stated in the contraindications, it is recommended to avoid percutaneous stone removal in a setting of active urinary infection. Despite this, there is no defined standard perioperative antibiotic regimen. It is suggested that preoperative positive urine cultures should be treated before surgery, but in the absence of obvious infection there is a variety of suggested options for preoperative antibiosis. Some practitioners recommend a single perioperative dose of IV or oral coverage while others routinely give a week of preoperative ciprofloxacin or nitrofurantoin and document decreased septic episodes.[5–7] These inconsistencies are based on the fact that, possibly due to occult positive stone cultures and retained endotoxin within the calculi, patients with sterile preoperative urine occasionally still experience infectious complications. A recent consensus panel suggests administration of a single perioperative dose of antibiotics in patients without risk factors, although patients with sterile preoperative urine and risk factors will receive a week of preoperative antibiotics; these risk factors include hydronephrosis, preoperative tube drainage, complex stone burden, diabetes/immunosuppression, or history of recurrent infections.[8]

Patient Positioning

Appropriate patient positioning is mandatory to facilitate PNL and avoid complications. Initially, PNL was performed in the prone position, which allows a large field, namely the back, to puncture the kidney (Fig. 1). Prone position provides access to all of the calyces including the upper pole calyces. Ideally, posterior calyces are punctured through Brodel's avascular plane without significant parenchymal bleeding.[9] Prone position could be modified to oblique prone position with the affected side tilted 30° up, so that the posterior lower pole calyx is directed posteriorly on the vertical sagittal plane. However, the prone position potentially increases abdominal pressure, which in turn decreases end expiratory lung volume and lung capacity, reducing the ability of patients to tolerate prolonged surgery. Therefore, ventilating could be challenging in morbidly obese patients and in individuals with respiratory diseases.[10] Another modification of the prone position is the prone-flexed position to expand the space between the hip and the costal margin.[11]

Supine position was first reported by Valdivia Uria and colleagues.[12] Variations of this position include completely supine, supine with the ipsilateral side elevated, and supine combined with ipsilateral flank elevation and asymmetric lithotomy position.[13] The potential advantages of the supine position include shorter operating time, possibility of simultaneous retrograde transurethral manipulation, and easier anesthesia, especially for morbidly obese patients. The major disadvantage of the supine position is that the kidney is more easily pushed forward by the puncture needle and dilators, leading to a longer tract.[14] Clinical Research Office of the Endourological Society (CROES) data have shown that supine position is currently used in about 20% of centers worldwide.[9]

Alternative Approaches

The antegrade approach to percutaneous access into the upper urinary tract collecting system is still the most common approach. There are two well-described methods: the ''Bull's eye'' technique and the ''triangulation'' technique. Retrograde approach was originally described by Lawson and Hunter-Hawkins using a needle stylet directed through a catheter to puncture the desired calyx.[15,16] The retrograde approach was later modified by Grasso such that a ureteroscope is used to identify the calyx to be punctured percutaneously.[17] This approach is limited by inability to bypass impacted stones and long percutaneous tract that was not straight. Currently, flexible ureteroscopy is used to assist in gaining access (Endoscopic guided PNL). Figure 2 demonstrates innovations in PNL techniques over time.

Recent techniques

Miniaturized PNL (micro PNL; mini PNL; minimally invasive PNL; ultra mini PNL). Traditionally, standard PNL is performed with a 30F Amplatz sheath. Recently, there is a trend toward miniaturizing instruments used for PNL. This has led to different techniques and instruments, and eventually generated confusion in the terminology of PNL. Some authors also call for better labeling of PNL, in relation to the size of the tract (i.e., PNL^{+20}, PNL^{+30}, PNL^{+12}) whereas others suggested using XL, L, M, S, XS, and XSS to identify

FIG. 1. Position of the patient for PNL. PNL = percutaneous nephrolithotomy.

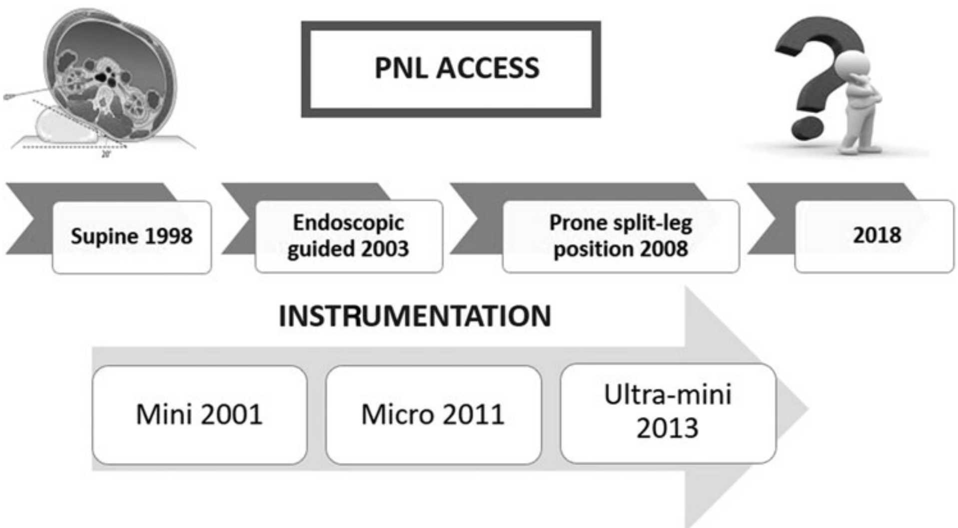

FIG. 2. Innovations in PNL techniques timeline (adapted from Ghani et al.[30]).

tract sizes.[18–20] Table 1, summarizes the terminology on the miniaturized PNL.

Some authors reported improvement in outcomes with miniaturized PNL when compared with the standard PNL and retrograde intrarenal surgery (RIRS). They have used ≤22F sheath instead of 30F sheath that yielded significant improvement in intraoperative blood loss, reducing the rate of blood transfusions such that the rate of transfusions was similar to that of mini PNL.[21–23] In addition, small caliber sheaths may help with spontaneous drainage of fragments.[23,24] The potential advantages of the miniaturized PNL reported in the literature were lower bleeding rate and decreased hospital stay. Nevertheless, miniaturized PNL still need to be proven more advantageous than the conventional PNL.[20]

Desai and colleagues further developed modification on micro PNL, which was reported by several studies.[24–26] They have demonstrated the feasibility of miniaturized PNL in their initial series with no postoperative complications. They have used specific micro-optical system (0.9 and 0.6 mm in diameter) inserted through a specific puncture needle (all seeing needle) to confirm the location of the chosen access.[27,28] However, this technique still requires high level of evidence for it to be accepted and validated.

Outcomes

While extracorporeal shockwave lithotripsy decreased, and RIRS increased, utilization of PNL remained constant over 20 twenty-year from 1991.[29] The rate of PNL among endourologic procedures, ranged from 3.5% to 6% worldwide. The use of PNL was affected by patient and surgeon preferences, availability, and logistic institutional issues.[30]

Although PNL is generally safe, the outcomes of PNL procedure can be affected by some factors. For instance, patient age and obesity are associated with unsatisfactory outcomes. Okeke and colleagues reported higher risk of complications for older patients ≥70 years when compared with younger patients.[31] PNL in obese patients was also associated with significantly lower stone-free rate and longer operative time.[32] Furthermore, PNL outcomes can also be affected by other factors such as stone configuration and location, surgeon experience, and case load volume. CROES data revealed that high-volume centers have significantly less complications and better stone-free rates.[32,33]

Different scoring systems have been previously tested to improve the quality of reporting perioperative complications of PNL. These include Guy's stone score, Nephrolithometric nomogram, STONE nephrolithometry and Modified Clavien Classification (MCC) system.[34–37] Recently, the European Association of Urology (EAU) recommended MCC system as the standardized system for grading PNL complications. The CROES data have shown that the MCC system is more objective to describe minor complications (1 and 2).[37] However, there is still no consensus regarding the best classification. Table 2 summarizes outcomes of randomized clinical trials comparing different PNL approaches. The steps of PNL can be seen in Video S1 (Supplementary Data are available online at www.liebertpub.com/end)

Table 1. Terminology Proposed for Different Percutaneous Nephrolithotomy Techniques

Procedure	*Sheath outer diameter*
Standard PNL	>22F
Mini-PNL	≤22F
The minimally invasive PNL	18F
Ultra-mini PNL	11–13F
Mini-micro PNL	8F
Micro-PNL	<7F
Super mini-PNL	7F

PNL = percutaneous nephrolithotomy.

Surgical Steps

In the holding area, sequential compression boots and thigh-high antiembolic stockings are applied. The compression device is activated before induction. Following administration of culture-specific antibiotics and induction of general anesthesia, patients are positioned for flexible cystoscopy portion of PNL. Female patients are placed in the frog-leg position and male patients are placed in the supine position. Flexible cystoscopy is performed to identify the ureteral orifice and cannulate it with a hybrid nitinol-PTFE guidewire under fluoroscopic guidance. This guidewire is used

Table 2. Relevant Studies Demonstrating Outcomes of Different Percutaneous Nephrolithotomy Approaches

Relevant randomized controlled studies comparing supine versus prone PNL

Refs.	*Year of publication*	N		*Stone-free rate %*		*Opertive time (min)*		*Hospital stay (day)*		*Complication rate %*	
		PP	*SP*	*PP*	*SP*	*PP*	*SP*	*PP*	*SP*	*PP*	*SP*
Al-Dessoukey et al.[38]	2014	102	101	87.3	88.1	111.7	86.2	3.4	2.1	15.7	9.9
Wang et al.[39]	2013	62	60	88.7	73.3	78	88	8.2	8.4	32.3	28.3
Karami et al.[40]	2013	50	50	92	86	78.7	54.2	2.6	2.9	20	24
Basiri et al.[41]	2013	46	43	65.2	79	113.3	110.2	3	2.5	19.7	18.9
Falahatkar et al.[13]	2008	40	40	77.5	80	106	74.7	3.1	3.3	30	27.5

Summary of randomized controlled studies comparing tubeless versus standard PNL

		N		*Stone-free rate %*		*Operative time (min)*		*Hospital stay (day)*		*Complication rate %*	
		TT	*ST*	*TT*	*ST*	*TT*	*ST*	*TT*	*ST*	*TT*	*ST*
Agrawal et al.[42]	2008	101	101	100	100	NA	NA	2.9	3	54.5	18.2
Cormio et al.[43]	2012	50	50	87.8	87.2	83.7	88.4	2.8	5.2	2	25.5
Shoma and Elshal[44]	2012	50	50	92	84	60	overall	2.7	3.3	14	20
Chang et al.[45]	2011	58	60	NA	NA	31.7	33.1	3.4	4.2	8.3	5.6
Marchant et al.[46]	2011	45	40	—	—	—	—	3.2	5	5	2.2
Kara et al.[47]	2010	30	30	86	83	41	45	1.5	3.2	13.3	13.3

PP = prone position; SP = supine position; TT = tubeless technique; ST = standard technique; *N* = number of patients; NA = not available.

to bypass any obstructing renal stones. The flexible cystoscope is then removed and a 5F ureteral catheter is inserted over the guidewire into the upper pole. An 18F Foley catheter is placed in the bladder carefully without displacing the ureteral catheter, which is secured to the Foley catheter with a silk suture. The patient is then positioned to the prone position with foam padding of pressure points, including the face, elbows, and abdomen. In addition, a gel pad is used as a chest role. The feet are elevated over a pillow to remove pressure from the toes. In addition, the patient is secured to the operating room table with a towel and tape over the hips.

Once the patient's prone position is secured, the silk suture attaching the ureteral catheter to the Foley catheter is cut using a blade. A warm-air blanket is placed over the patient's head and shoulders to maintain the patient's temperature intraoperatively. At this point, the patient's back is prepped and draped with sterile covers. Retrograde pyelography is then performed to opacify the pelvicalyceal system and choose the desired calyx to obtain renal access.[48] Using ''bull's eye'' or triangulation techniques under fluoroscopic guidance an 18-gauge diamond-tipped needle is inserted into the desired renal calyx. Once urine is aspirated, a hybrid nitinol-PTFE guidewire is introduced into the pelvicalyceal system through the puncture needle. For extra security, this guidewire could be down the ureter. The skin is then incised to 10 mm and the 8/10 co-axial dilator is used to dilate the tract to 10F and insert a safety guidewire, which is then stapled to the skin to avoid misplacement during the procedure.[49,50] The tract is then dilated to 30F using a balloon dilator and a 30F Amplatz sheath is placed. A rigid indirect nephroscope is used to visualize stones. If available, a digital nephroscope may be used. If needed, an atraumatic grasper is used to removed clots within the tract. A dual pneumatic and ultrasonic intracorporeal lithotripter is then used, and fragments are removed using the atraumatic grasper.

To reach calyces inaccessible through an indirect nephroscope, a flexible cystoscope serves as a flexible nephroscope to examine and remove stones. Holmium laser lithotripsy is used when flexible nephroscopy identifies stone fragments that are too large to be removed by a stone basket. The stone-free status is confirmed using both fluoroscopy and endoscopic examination with flexible nephroscopy. Routine flexible nephroscopy and high-resolution fluoroscopy has been shown to improve stone-free rate and reduce significant residual fragments.[51] In addition, the renal pelvis is inspected for perforation and hemorrhage, and any blood clots are removed. As an exit strategy, we have been routinely placing a 6F indwelling ureteral stent antegradely under fluoroscopic guidance to minimize risk of ureteral edema and fragments causing postoperative ureteral obstruction. If required, a 20F Council-tip catheter is inserted as a nephrostomy tube and the balloon inflated to 3 cc. A nephrostogram is then performed to confirm the correct positioning of the nephrostomy tube. The Amplatz sheath is then removed, and gentle pressure is applied to the wound.

In absence of any significant bleeding, the skin is infiltrated with 5 mL of 0.25% bupivacaine without epinephrine for immediate postoperative pain control. The nephrostomy tube is secured to the skin with absorbable sutures. The safety wire is removed, and a pressure dressing is applied. Before the patient is awakened from anesthesia, 1.3 g of an acetaminophen suppository is administered, and the patient is then turned to supine position, extubated, and transferred to the recovery room. Stone fragments are sent for biochemical analysis. Some authors also recommend sending the stones for microbiological examination.

Surgical Steps of Prone Split-Leg PNL

1. Prone split leg position
   a. The patient is intubated in a supine fashion on the stretcher and the patient is moved to the prone position on the operating table on two foam rolls (chest and hips). The arms are outstretched toward the head and all pressure points are padded. The legs of the table are then split and taped in position. The flank and genitals are then prepped and draped.
2. Prone cystoscopy
   a. Prone cystoscopy is performed with a flexible cystoscope and the ureteral orifice of interest is cannulated with two access wires in a retrograde fashion. An access sheath is passed up into the proximal ureter.
3. Ureteroscopy
   a. Ureteroscopy is performed through the access sheath to choose the posterior, access calyx for percutaneous entry
4. Needle access
   a. Utilizing a combination of fluoroscopy, the retrograde ureteroscope, and an air pyelogram, the posterior calyx of interest is punctured with an access needle. An antegrade wire is passed down through the needle and out the ureteral access sheath.
5. Replacement of access sheath
   a. The access sheath is then removed and replaced over the safety wire, such that the antegrade through-and-through wire is alongside the sheath.
6. Ureteroscopic visualization of dilation and sheath placement
   a. The ureteroscope is replaced into the access sheath and the balloon dilation and sheath placement is performed over the through-and-through wire under direct ureteroscopic visualization, ensuring safe access.
7. Intracorporeal lithotripsy
   a. Intracorporeal lithotripsy is performed in standard fashion utilizing a combination ultrasonic/impactor device through a rigid nephroscope. Flexible nephroscopy and antegrade ureteroscopy is performed to ensure stone-free status.
8. Retrograde stent placement
   a. Utilizing the through-and-through wire, after removal of the ureteral access sheath a stent (or open-ended catheter) can be placed in a retrograde fashion and, if desired, left on a string for easy patient removal. A Foley catheter is placed in the bladder and left to drainage.
9. Closure of access site
   a. After removal of the PNL sheath, the access tract is closed with absorbable suture and the wound is dressed. The patient is then returned back to the supine position and awoken from anesthesia.

Radiation Exposure and Safety During PNL

As low as reasonably achievable principles of minimizing fluoroscopy time (FT), maximizing distance and always using shields should be considered during PNL procedure. Bush et al. reported average radiation dose per case: urologist: 0.10 mSv (nondominant hand the most); surgical nurse: 0.04 mSv; radiology technologist: 0.04 mSv; anesthesiologist: 0.03 mSv. This highlights the importance of shielding gear for all operating room personnel and not just the surgeon.[52] Hellawell et al. reported that fluoroscopically guided PNL is associated with the highest radiation exposure among all endourological procedures.[53] Factors associated with increased effective radiation dose (ERD) during PNL are increased body mass index (BMI), higher stone burden, and a greater number of percutaneous access tracts.[54] Obese patients with higher BMI had a greater than threefold in mean ERD when compared with normal weight patients. Out of all organs exposed, the skin was exposed to the greatest amount of radiation; 0.24 to 0.26 mGy/s.[55]

Surgeon behavior is one of the modifiable factors that impacts radiation exposure. Surgeons reduced 55% of their median FT after being informed about their fluoroscopy usage.[56] There are several modifications of the original fluoroscopy-guided PNL to reduce radiation to patients and operative personnel. Pulsed fluoroscopy at 4 frames per second (fps) during PNL was associated with a 65% reduction in FT compared with those performed using standard fluoroscopy (SF) at 30 fps.[57]

Recently, air has been used instead of contrast to decrease radiation. Radiation exposure significantly decreased when using air rather than contrast during retrograde pyelography, where the mean adjusted ERD decreased by nearly twofold.[55] This is because the air has a lower density and require less radiation to penetrate and produce an image. Therefore, these maneuvers could be used for radiation safety during PNL procedure. Recently, complete PNL procedure sing only ultrasound has been described.[58]

Troubleshooting

Different operative scenarios could be encountered throughout the entire PNL procedure. Table 3 illustrates troubleshooting to different clinical scenarios from intraoperative up to late postoperative complications.

Postoperative Care

Within the first 24 hours postoperatively, the patient is kept under strict observation for clinical assessment of vital signs, abdominal rigidity, and any postoperative abnormalities. Complete blood count in addition to serum electrolytes and creatinine are obtained in the recovery room and daily thereafter. In addition, an inspiratory and expiratory chest X-ray is obtained to rule out hemothorax or pneumothorax, especially if supra-costal access is obtained.

Nephrostomy tube is left open for 3–6 hours postoperatively. A low dose abdominal CT scan may be obtained to verify stone-free status. Once urine is clear, nephrostomy tube is clamped. If the patient remains afebrile without any flank pain, the nephrostomy tube is removed and the patient is discharged home. The nephrostomy tube is kept in place if a second PNL session is planned. If there are significant residual fragments, a second-look nephroscopy could be performed to remove residual fragments. A second session of PNL was found to be cost-effective in cases of significant accessible residual stones ≥4 mm when compared with observational strategy.[59] An alternative to leaving a nephrostomy tube is to perform tubeless PNL (without a nephrostomy tube) if the patient is stone-free and there were no intra-operative complications. Randomized clinical trials have shown that tubeless PNL is associated with lower postoperative pain, and urinary leakage when compared with

Table 3. Summary of Troubleshooting Problems

Problem	*Treatments*	*Prevention*
Intraoperative		
Unable to pass retrograde ureteral catheter retrograde	Attempt with PTFE or nitinol Glidewire® or hybrid nitinol-PTFE guidwire. Intravenous pyelogram if no allergy 22-Gauge needle blind access technique Intraoperative ultrasound if available Reschedule after CT-guided access or ultrasound-guided access	Preoperative check for history of ureteral reimplantation, bladder neck obstruction or ureteral stricture
Arterial puncture (pumping blood)	Withdraw needle into renal parenchyma, no other treatment required	Avoid medial punctures
Venous puncture (guidewire into inferior vena cava)	Withdraw guidewire and needle, and reestablish access to collecting system, no other treatment required	Avoid medial puncture Always use fluoroscopy to monitor guidewire and to avoid dilating renal vein
Parenchymal tears due to guidewire kinks	Place a 6F or 8F catheter over kink and advance kinked guidewire down ureter or exchange for a new one. Repeat puncture if access is lost	Do not change angle while dilating (observe same angle as needle under fluoroscopic new one guidance) Do not insert needle during deep inspiration or with excessive angulation Always dilate under fluoroscopic guidance Use balloon dilators instead of coaxial dilators.
Hemorrhage during dilation and procedure	Insert larger Amplatz sheath to tamponade Insert and clamp nephrostomy tube, and re-schedule the procedure	Avoid medial access through renal pelvis (posterolateral access through renal parenchyma tamponades bleeding) Avoid kinks in guidewire Ensure there are no burrs on Amplatz sheath Avoid torque during dilation Use balloon dilator instead of axial dilators
Loss of access	Reestablish access Inject saline to distend collecting system	Replace kinked guidewires Use safety wire Establish through and through access
Perforation of renal pelvis	Ensure good drainage of renal pelvis Place reentry nephrostomy tube or Double-J stent Perform nephrostogram before removal of stent and nephrostomy Antibiotic coverage	Avoid aggressive dilation of tract Avoid medial displacement of sheath
Stone displacement outside of the collecting system	No treatment required	Same as above, avoid mucosal tears with Amplatz sheath or forceps
Disruption of ureteropelvic junction	Insert endopyelotomy stent (14/7F) for 4 weeks	Same as above, avoid aggressive dilation Gentle use of lithotriptor Careful extraction of stones from the ureteropelvic junction (UPJ) Use an antegrade flexible ureteroscope to extract proximal ureteral stones

(*continued*)

TABLE 3. (CONTINUED)

Problem	*Treatments*	*Prevention*
Hemorrhage after removal of the sheath	Manual compression of nephrostomy site Insert large 24F nephrostomy tube and clamp or elevate Insert Council-tip catheter and inflate balloon in parenchyma Kaye tamponade balloon if available Crystalloids and transfusions to stabilize patient Angiography and super-selective embolization Rarely open exploration is required	Establish posterolateral access Gentle dilation and manipulation Avoid torque on Amplatz sheath Use atraumatic instruments Thrombin gel matrix (FloSeal) sealant into nephrostomy tract, cryoablation of tract
Immediate postoperative		
Displacement of nephrostomy	Observe for signs of obstruction If symptomatic, reinsert nephrostomy under fluoroscopy or insert indwelling ureteral stent in retrograde fashion	Use reentry nephrostomy for obese patients Secure nephrostomy to skin with 0 silk sutures May use cope loop catheter or Council-tip catheters
Gram-negative sepsis	Broad-spectrum antibiotics 24F nephrostomy and Foley catheter Intensive care unit consult and supportive care	Broad-spectrum antibiotics even if urine is negative Sterilize urine preoperatively Specific antibiotics to which original bacteria are sensitive Avoid over aggressive distension of collecting system with retrograde pyelogram (<10 cm H_2O) Avoid vascular punctures or mucosal perforation
Fluid overload	Mannitol or loop diuretics	Use saline irrigation Avoid mucosal perforation Use access sheath to maintain low pressure Measure inflow and outflow, if more than 500 cc discrepancy, then administer diuretics Avoid prolonged procedures, go back for second look
Colon perforation	If extraperitoneal and no peritonitis: insert indwelling ureteral stent, pull nephrostomy tube into the colon, antibiotics and contrast study in 2 weeks to confirm closure of tract If peritonitis or intraperitoneal: exploration, diverting colostomy and urinary drainage with antibiotics	Avoid access lateral to posterior axillary line Preoperative CT to rule out retrorenal colon in patients with horseshoe kidney and jejunoileal bypass
Pneumothorax/hemothorax/hydrothorax	Intraoperative decompression using small 8F catheter Underwater 32F chest tube drainage if not successful Thoracoscopy and decortication if not successful Check that nephrostomy tube is not going through pleura by performing nephrostogram, if so insert indwelling ureteral stent and remove nephrostomy tube Do not remove stent until chest problems have resolved	Avoid supracostal punctures Use triangulation technique or move kidney caudal using mid pole access sheath to establish upper pole access Perform intraoperative fluoroscopy of chest to monitor development of pneumothorax/hydrothorax
Perforation of the duodenum	Nephrostomy urinary drainage, nasogastric suction, somatostatin, and total parenteral nutrition	Make sure the floppy end of guidewire is used. Avoid aggressive medial dilation nutrition
Splenic or hepatic injury	CT scan to confirm diagnosis Crystalloids and transfusions to stabilize patient Explore if conservative therapy fails	Preoperative CT if splenomegaly or hepatomegaly suspected CT or ultrasound-guided access to collecting system if hepatosplenomegaly

(*continued*)

TABLE 3. (CONTINUED)

Problem	*Treatments*	*Prevention*
	May try sealants before contemplating splenectomy	Laparoscopic access to collecting system
Hemorrhage through the nephrostomy tube	Elevate tube or clamp tube to allow clotting Bed rest, IV crystalloids, transfusions to stabilize Angiography and super-selective embolization	Previously mentioned intraoperative precautions
Hemorrhage after removal of the nephrostomy	Immediately reinsert 24F nephrostomy and clamp May use Council catheter or Kaye balloon if available Bed rest, IV crystalloids, transfusions to stabilize Angiography and super-selective embolization	Gently remove nephrostomy tube
Delayed postoperative		
Secondary (>5 days) hemorrhage	Bed rest, IV crystalloids, transfusions to stabilize Angiography and super-selective embolization	Minimize number of punctures intraoperatively
Ureteropelvic junction strictures	If short (<1 cm): endopyelotomy If long (>1 cm): laparoscopic or open pyeloplasty	Use gentle maneuvers as described above to prevent intraoperative UPJ disruption, use endopyelotomy stent when this occurs
Uro-cutaneous fistula	Indwelling ureteral stent insertion and antibiotics	Make sure there are no obstructing distal ureteral stones or damage to distal ureter by performing nephrostogram and observing contrast to bladder before removing nephrostomy tube
Urinoma	Percutaneous drainage of urinoma, indwelling ureteral stent placement and antibiotics	Avoid mucosal tears intraoperatively Ensure no distal obstruction with nephrostogram before tube removal
Perinephric hematoma or abscess	Angiography and embolization for hematoma Percutaneous drainage of liquefied hematoma and abscess in addition to antibiotics	Observe precautions to minimize bleeding as mentioned above

Adopted from Andonian et al., AUA update series.

standard PNL and tubeless PNL.[42,60] Finally, several centers have reported ambulatory tubeless PNL for highly selected patients.[48,61]

Future perspectives

iPad-guided percutaneous renal access. Rassweiller et al. reported obtaining renal access using an iPad-assisted navigation, which displays all relevant anatomical details using the iPad camera. Preoperative CT images are uploaded into the iPad, which is then used to guide the urologist in obtaining the desired renal access. This is done by overlaying the images from the iPad's camera on the preoperative CT images.[62]

Conclusions

In the proper patient with large stone burden, PNL is an excellent method for stone removal; the safety profile is such that it can be performed in a wide variety of patients and the stone-free rate is higher than other treatment methods. While it may be a more invasive endourologic treatment, significant advances have occurred in recent years to decrease tract size, increase confidence in calyceal targeting, and improve the rate of stone removal. There are multiple methods of patient positioning and access, but in all cases, there are a common set of steps utilized to decrease the risk of complications and safely remove large stones from a wide variety of patients.

Recommended Videos from Videourology

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Author Disclosure Statement

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Abbreviations Used

BMI = body mass index
CROES = Clinical Research Office of the Endourological Society
CT = computed tomography
ERD = effective radiation dose
Fps = frames per second
FT = fluoroscopy time
MCC = Modified Clavien Classification
PNL = percutaneous nephrolithotomy
RIRS = retrograde intrarenal surgery