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Prone Percutaneous Access: *Case Discussion—Caliceal Diverticular Calculi*

John D. Denstedt and Andrew Fuller

Abbreviations

CD	Caliceal diverticulum
CT	Computed tomography
PCNL	Percutaneous nephrolithotomy
SFR	Stone-free rate
SWL	Shock wave lithotripsy
TDPN	Transdiverticular puncture and neoinfundibulotomy
UPJ	Ureteropelvic junction
URS	Ureteroscopy
US	Ultrasound
UTI	Urinary tract infection

Since its initial description by Fernstrom and Johansson in 1976, percutaneous nephrolithotomy (PCNL) has evolved with improvements in technique and equipment to become the gold standard form of management for large stones in the upper urinary tract. It has now largely replaced open surgery in this context. Although alternatives such as supine patient positioning have emerged in the last decade, the vast majority of PCNL cases worldwide continue to be performed prone, with high stone-free rates (SFR) and a low incidence of major complications [1, 2].

The ability to safely and efficiently achieve percutaneous renal access depends on a number of factors including appropriate training, careful preoperative planning, recognition of anatomical variation, interpretation of radiological investigations, reproducible technique, and the availability of specialized instrumentation to effectively delineate and negotiate the urinary tract. Tract placement by the treating urologist without the involvement of an interventional radiologist in routine cases has been shown to be associated with excellent outcomes [3–5]. Additionally, such an approach allows PCNL to be performed as a one-stage procedure with the opportunity to place additional tracts as dictated by intraoperative findings.

This chapter summarizes what we believe to be a series of safe and effective strategies when performing percutaneous renal access. In presenting the chapter, we acknowledge that there are many effective alternate approaches to PCNL, some of which may not have been incorporated into this work. Many cases require the endourologist to safely apply a range of techniques in combination to achieve the desired outcome.

J.D. Denstedt, M.D., F.R.C.S.C., F.A.C.S. (✉)
Department of Surgery, Western University, London, ON, Canada
e-mail: john.denstedt@sjhc.london.on.ca

A. Fuller, M.B.B.S., F.R.A.C.S.
Division of Urology, Department of Surgery, Western University, London, ON, Canada
e-mail: afuller@sturology.com.au

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Preoperative Planning

Indications

The advent of extracorporeal shock wave lithotripsy and flexible ureteroscopy has expanded the treatment options available for stones within the upper urinary tract. Despite the emergence of these technologies, PCNL remains the most appropriate and effective form of management for most large renal calculi [6]. As with any form of surgical intervention, appropriate patient selection is crucial. Table 1.1 summarizes the contemporary indications for PCNL.

While there are few absolute contraindications to PCNL, each patient scheduled for PCNL should undergo a thorough evaluation incorporating history, physical examination, and review of preoperative laboratory and radiological investigations.

History and examination should be focused to identify factors that may have implications from a surgical or anesthetic perspective. In particular, one should identify the presence of bleeding diathesis, anticoagulant therapy, recurrent urinary tract infection (UTI), chronic obstructive pulmonary disease, and morbid obesity, all of which may significantly increase the risk of perioperative complications. The presence of spinal deformity and limb contractures may complicate patient positioning and percutaneous access. In the case of morbid obesity, special equipment may be required. In high-risk patients, preoperative anesthetic assessment is mandatory prior to any contemplated intervention.

Laboratory investigations should include complete blood count, group/reserve, electrolytes, creatinine, and urinalysis/culture. Even in the context of a negative preoperative urine culture, there is evidence to support the routine administration of prophylactic oral fluoroquinolone antibiotics in reducing the risk of septic complications in the perioperative period [7].

Cross-sectional imaging with computed tomography (CT) affords the opportunity to assess the renal collecting system and plan appropriate sites of access prior to PCNL. Additionally, one may evaluate the relationship of the planned site of access to surrounding structures including colon, liver, spleen, and pleura. This is particularly important in the context of previous abdominal surgery, where the risk of retrorenal colon (Fig. 1.1) is higher [8]. Patel and colleagues [9] demonstrated the value of multiplanar CT reconstructions in defining the morphology of the intrarenal collecting system, calyceal orientation, stone location, and anatomical variants such as caliceal diverticulum.

Table 1.1 Indications for PCNL

Indications for PCNL
Staghorn calculi
Stones >2 cm in size
Lower pole stones >1 cm
Cystine stones
Failure of other treatments
Associated anatomical anomalies (UPJ obstruction, Caliceal diverticulum, horseshoe kidney)

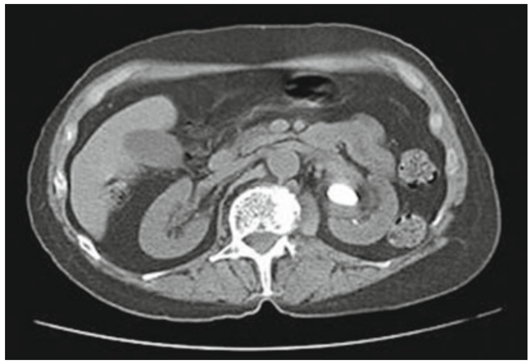

Fig. 1.1 CT demonstrating retrorenal colon. *Reproduced from Ko R, et al. Percutaneous nephrolithotomy made easier: a practical guide, tips and tricks. BJU Int 2007;101:535–539 (Figure 1)*

Technique of PCNL

Anatomical Considerations

A detailed understanding of the intrarenal vascular anatomy, calyceal orientation, and perirenal visceral relationships is essential in minimizing the likelihood of morbidity related to PCNL.

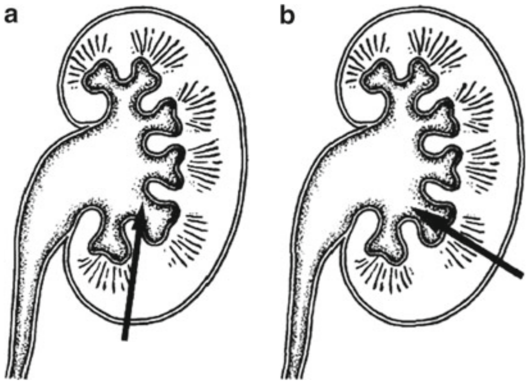

Fig. 1.2 (**a**, **b**) Puncture into the infundibulum (*left*) risks injury to the interlobar and arcuate branches of the renal artery. *Reproduced from Sampaio FJB. Renal Anatomy. Urol Clin North Am 2000*;*27*(*4*):*585–607 with permission* (*Figures 17a*, *18a*)

After arising from the lateral aspect of the aorta at a level between the first and second lumbar vertebrae, the main renal artery divides into anterior and posterior divisions. The renal parenchyma supplied by each of these branches is separated on the lateral aspect of the kidney by Brodel's line. This location represents the optimal location to traverse the kidney during percutaneous access. The anterior division branches into 4 segmental arteries which supply the anterior and polar aspects of the kidney. The posterior division supplies the reminder of the kidney. Segmental arteries divide further into interlobar (infundibular), arcuate, and interlobular vessels. Entering the caliceal fornix in the correct orientation (end on rather than side on) as demonstrated in Fig. 1.2 serves to minimize the risk of inadvertent vascular injury by avoiding the interlobar and arcuate vessels which run in proximity to the caliceal infundibulum and medullary pyramids respectively [10].

Access via a posterior calix is desirable as it facilitates direct access to the collecting system to allow initial passage of guidewires with subsequent nephroscopy and stone removal. The posterior calices are at a 30° oblique angle to the vertical plane with the patient positioned prone. Additionally, the upper and lower pole calices adopt a 10° offset in the cranial and caudal plane respectively. This has particular implications when positioning the fluoroscopic unit during access which will be discussed in more detail later.

Particularly in the context of large stones at the ureteropelvic junction (UPJ), staghorn calculi and stones located in the upper pole calix, supracostal access and upper pole puncture may be the optimal approach for efficient stone removal [11–13]. When performing such access it is essential to appreciate the proximity of the pleural reflection and lung base to the trajectory of the planned access. The pleura is attached to the medial half of the 12th rib and medial three quarters of the 11th rib [14]. The lower border of the lung lies at the 10th intercostal space. Irrespective of the phase of respiration, the likelihood of intrathoracic complications is much higher with a supra-11th rib approach [15, 16]. Where possible, supra-12th puncture should be used as the approach to the upper pole due to the lower risk of pleural and pulmonary complications [17]. To avoid damage to the intercostal neurovascular structures in a supracostal approach, one should remain as close as possible to the upper border of the rib.

Patient Positioning

Many of the challenges associated with prone positioning can be managed with appropriate attention to detail and planning. One should be aware of the risk of peripheral nerve compression injuries and brachial plexus traction injuries in this position [18]. The patient's upper limbs should be positioned on arm boards with the shoulders abducted to 90° and the elbows flexed to 90°. The cervical spine should be in a neutral position. Padding should be placed to support the chest to assist with ventilatory function. In consultation with the anesthetic staff, the surgeon should confirm that the face and eyes are padded appropriately.

Fluoroscopic access techniques require the placement of a ureteral catheter through which contrast may be injected to outline the collecting

Table 1.2 Instrument list for prone PCNL

• Flexible cystoscope
• 0.035″ Guidewire
• 5 Fr ureteric catheter
• Contrast media
• Access needle
• Fascial incising needle
• 0.035″ Hydrophilic tip guidewire
• Kumpe catheter
• 0.038″ Extra stiff guidewire
• Balloon dilator
• 30 Fr Amplatz working sheath
• Rigid nephroscope
• Rigid graspers
• Lithoclast/Ultrasonic device
• Flexible nephroscope
• 2.4 Fr Nitinol basket
• 18 Fr Councill catheter

system. In most cases, flexible cystoscopy and cannulation of the ureteric orifice can easily be achieved with the patient prone. This approach offers several advantages over cystoscopy in the supine or dorsal lithotomy position. In particular, one avoids the need for a second patient transfer and the associated risk of ureteral catheter displacement.

Equipment

Preoperative planning, particularly with regard to ensuring the availability of specialized equipment is essential to the successful performance of PCNL. Before gaining access, one should confirm the availability of all necessary equipment (Table 1.2). A number of patient factors may necessitate specialized equipment. In particular, when treating obese patients, it may be necessary to use a longer access needle, working sheath, and/or rigid nephroscope. A larger skin incision is also occasionally required to facilitate access to the working sheath. Commercially available balloon dilation devices range in length from 12 to 15 cm. When this is insufficient, the use of serial Amplatz dilators is a useful means of gaining additional length.

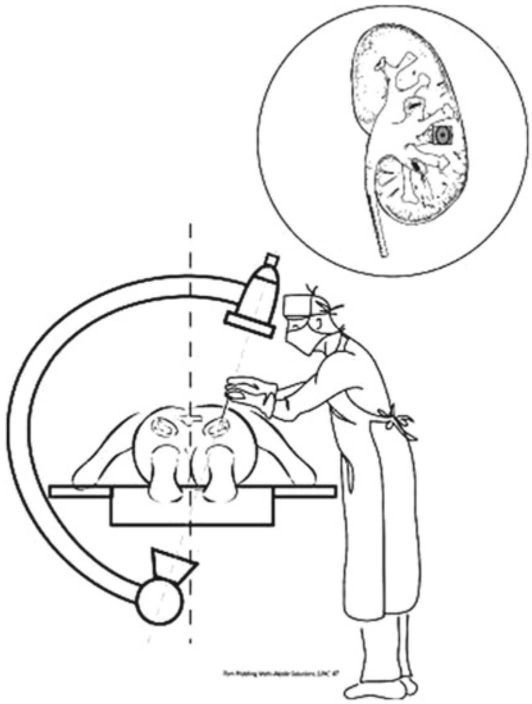

Fig. 1.3 The C-arm rotation toward the surgeon to align the needle tip with the desired entry calix. The *inset* shows the "bull's eye" appearance of the needle on the fluoroscopy monitor. *Reproduced from Ko R, et al. BJU Int 2007;101:535–539 with permission* (*Figure 3*)

Access Techniques

Several image-guided techniques have been described to facilitate antegrade renal access including biplanar fluoroscopy, ultrasound, and CT. In experienced hands, each technique provides safe and efficient access to the renal collecting system [19–24].

Fluoroscopy

Both the "bulls eye" and triangulation techniques represent effective means of achieving renal access.

When utilizing the "bulls-eye" technique, correct orientation of the C-arm is essential in order to visualize the targeted posterior calix end on. The C-arm is rotated approximately 20–30° from the vertical, towards the surgeon in the axial plane (Fig. 1.3). For upper and lower pole stones, it is then angled cranially or caudally respectively by approximately 10°. Although posterior calices generally appear less radio-opaque relative to anterior calices after contrast injection, if there is uncertainty, one can inject air with a 10 cc syringe through the ureteric catheter to identify preferential filling of the posterior calices.

A hemostat should then be used to localize the tip of the desired calix at the skin level. A 15 cm, 18 G needle is inserted at this point and advanced carefully under fluoroscopic guidance in expiration. The hemostat should be used to grasp the needle to maintain the surgeon's hands outside the field. An appropriate trajectory is confirmed by the appearance of the needle end-on (Fig. 1.3). Entry of the needle tip into the renal parenchyma may be confirmed by movement of the needle consistent with the phase of respiration. At this point, the C-arm should be rotated away from the surgeon at approximately 10° from the horizontal plane to provide depth perspective and to facilitate precise placement of the needle into the tip of the targeted calix (Fig. 1.4). Once the renal parenchyma has been entered, one should not alter the trajectory of the needle so as to avoid inadvertent cortical laceration.

Likewise, the triangulation technique relies on biplanar fluoroscopy to direct needle trajectory [20, 21]. As described by Miller and associates [21], the renal collecting system is opacified with contrast and the C-arm is moved between two positions parallel and oblique relative to the line of puncture. When the C-arm is aligned parallel, the needle trajectory may be adjusted in a medial or lateral direction. In the oblique plane, alterations in the craniocaudal axis should be made. Correct needle placement using this technique can only be achieved when the surgeon is able to maintain orientation in one plane whilst altering the other. When the needle appears to be in satisfactory alignment in both planes, the puncture is completed using the oblique view with the patient maintained by the anesthetist in the expiratory phase of respiration. The oblique view is advantageous in this scenario as it provides depth perspective to the operator.

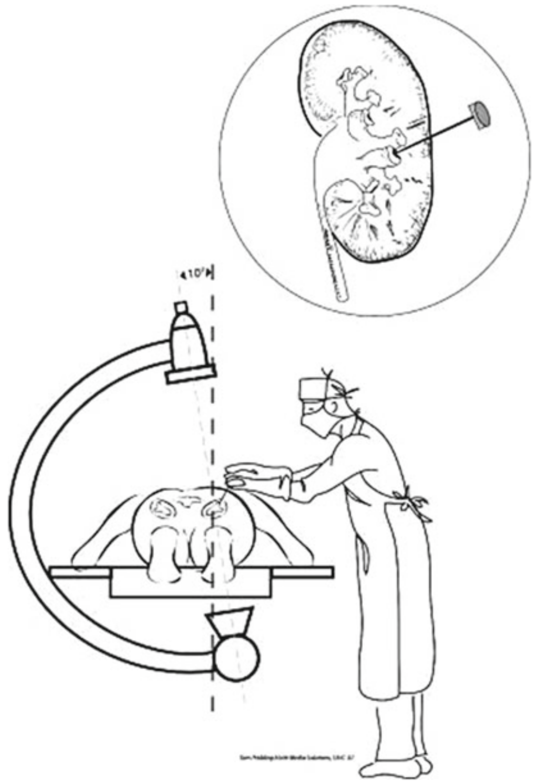

Fig. 1.4 C-arm rotation away from the surgeon to gauge the correct depth perception and to guide the needle tip into the entry calix. The *inset* shows the profile appearance of the needle on the fluoroscopy monitor. *Reproduced from Ko R, et al. BJU Int 2007;101:535–539 with permission (Figure 4)*

Ultrasound-Guided Puncture

Several investigators have demonstrated the feasibility of ultrasound (US)-guided access to the renal collecting system [22, 23]. Relative to fluoroscopy, this approach offers the advantage of no ionizing radiation and the ability to identify surrounding structures such as colon, liver, and spleen. In addition to standard B-mode ultrasonography, power Doppler US has been advocated as a means of defining and avoiding the renal vasculature, with resultant reductions in blood loss [25]. As with any form of percutaneous renal access, the use of ultrasound requires structured training, particularly in developing the skills to recognize the normal sonographic appearance of the renal collecting system and surrounding viscera.

Where access has been placed by ultrasound as a means of emergent drainage in a patient with sepsis, one should confirm placement of the tube at the tip of a posteriorly oriented calix prior to tract dilation to minimize the likelihood of segmental arterial injury. When the location of percutaneous renal access is deemed inadequate, one should have a low threshold to re-puncture in a more suitable location after opacifying the collecting system.

CT-Guided Access

The use of CT has been described in a number of clinical scenarios including hepatosplenomegaly, retrorenal colon, severe spinal deformity, urinary diversion, renal ectopia, and in cases where fluoroscopic and ultrasound-guided renal access has failed [26]. In these cases, the precise definition of surrounding structures provided by CT facilitates accurate and safe needle placement.

The patient is usually positioned prone and noncontrast images are taken to define the position of the targeted calculus as well as the position of the kidney relative to surrounding organs. Although contrast administration may be unnecessary in cases of moderate to severe hydronephrosis, it may assist in cases where the collecting system is not dilated. This procedure relies on the involvement of an interventional radiologist, however close collaboration with the referring urologist is useful, particularly when deciding upon the most suitable calix to expedite stone removal.

Dilation and Tract Placement

Once the tip of the needle has been placed into the renal collecting system, the stylet should be removed. An angled-tip 0.035 in. Sensor guidewire (Boston Scientific, Natick, MA) is passed through the needle and coiled within the renal pelvis. A 1cm incision is made at the level of the skin to allow for subsequent passage of a balloon dilation device. If possible, the wire should be directed down the ureter and coiled in the bladder. This process may be facilitated by an angled-tip angiographic catheter (Fig. 1.5—Kumpe catheter, Cook Urological, Bloomington, IN) which can be used to steer the guidewire down the ureter. The catheter may be advanced over the wire allowing exchange for a 0.038 in. extra stiff wire over which a balloon or serial Amplatz dilation may occur.

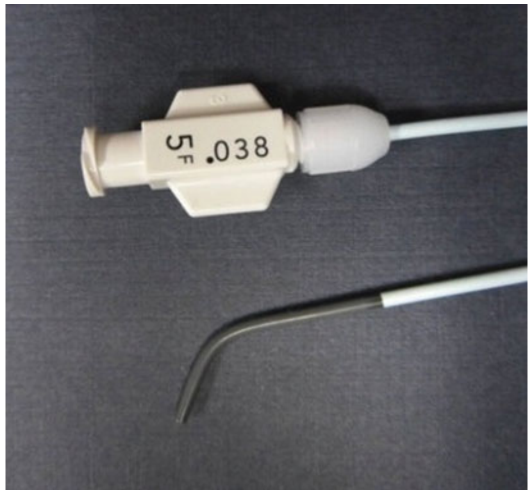

Fig. 1.5 Angled-tip angiographic catheter

Dilation can be safely achieved with either Amplatz serial dilators or a balloon device. One-stage balloon dilation is quicker than the use of Amplatz dilators, although it has been suggested by Lopes and colleagues [27] that this technique may pose a higher risk of hemorrhagic complications. In a follow up study conducted on behalf of the Clinical Research Office of the Endourological Society, no such association was found on multivariate analysis taking into consideration factors such as previous surgery, stone location, stone size, patient comorbidities, and the use of anticoagulant medications [28].

Particularly in patients who have undergone previous renal surgery or who have had recurrent pyelonephritis, there may be significant perinephric fibrosis. A fascial incising needle [Cook Medical, Bloomington, IN] is often useful in this situation to facilitate balloon dilation (Fig. 1.6) [19, 21]. An alternative approach is to use serial Amplatz dilators [19].

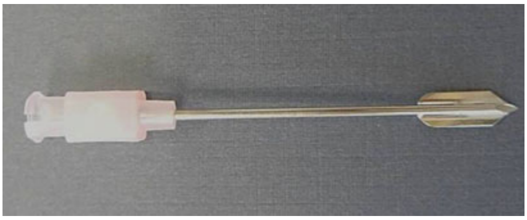

Fig. 1.6 Fascial incising needle

Once the tract has been dilated to 30 Fr, an Amplatz working sheath can be placed over the balloon. To avoid laceration of the collecting system, particular care should be taken when advancing the sheath to ensure the tip does not extend beyond the radiopaque marker on the distal aspect of the balloon. In the case of a supracostal puncture, it is essential that the working sheath remains within the renal collecting system for the duration of the procedure. Migration of the sheath out of the kidney risks considerable extravasation of irrigating fluid and hydrothorax. In such cases, a chest radiograph in recovery is useful to identify and preemptively manage intrathoracic complications.

Rigid Nephroscopy using 0.9 % saline as irrigation should be performed at this point to confirm the adequacy of sheath placement within the collecting system. If necessary, blood clot may be removed with rigid graspers. During stone fragmentation, one should avoid excessive torque on the working sheath as this is associated with a higher risk of intraoperative and postoperative hemorrhagic complications.

Case Discussion

Stones in a Caliceal Diverticulum

A 24-year-old female immigrant from Myanmar presented with a 3 year history of intermittent right sided flank pain. She was otherwise in good health and was prescribed no regular medications. There was no family history of urolithiasis.

After initially being diagnosed and treated with SWL for a presumed right lower pole renal calculus, she was referred with ongoing symptoms and residual stone for consideration of percutaneous stone removal. Noncontrast CT (Fig. 1.7) was arranged to provide further anatomical detail. This demonstrated a 12mm calculus at the lower aspect of the left kidney with minimal overlying parenchyma. An intravenous pyelogram (Fig. 1.8a, b) was performed and confirmed the presence of stone within a caliceal diverticulum (CD). The patient was counseled regarding the options for surgical management including retrograde ureteroscopic and antegrade percutaneous approaches. Although laparoscopic management has been described in this context [29, 30], this option was not felt appropriate in this scenario due to the location of the calculus in the posterior aspect of the renal parenchyma. The patient consented to PCNL.

Fig. 1.7 Low-dose noncontrast CT in coronal section demonstrating a peripherally located calculus with minimal overlying renal parenchyma

Procedure

Under general anesthesia, the patient was positioned prone on the operating table. Flexible cystoscopy was performed in the prone position. A 0.035 in. wire was inserted through the right

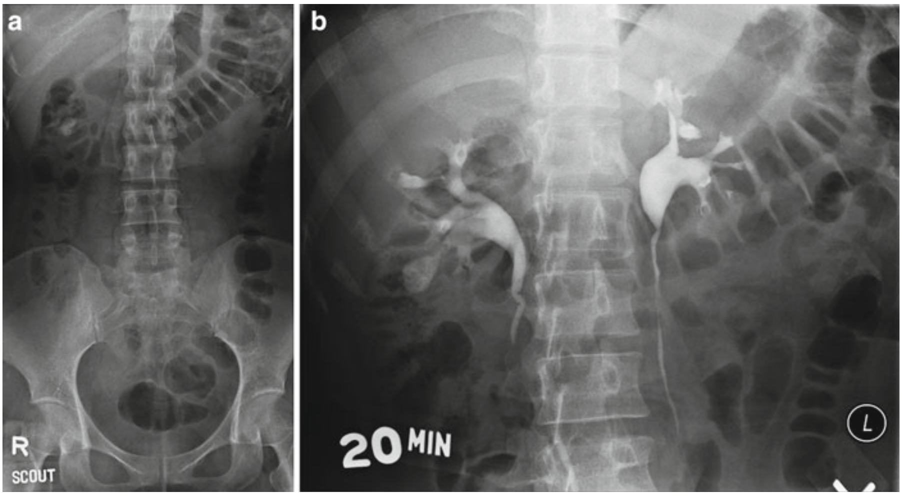

Fig. 1.8 (**a**, **b**) Intravenous pyelogram demonstrating stone within a right caliceal diverticulum arising from the mid-pole calix

Fig. 1.9 Intraoperative retrograde pyelogram demonstrates stone within a caliceal diverticulum arising from the mid pole calix

ureteric orifice and advanced to the level of the right renal pelvis. A 5 Fr ureteral catheter was advanced over the wire under fluoroscopic guidance. Retrograde injection of contrast revealed stone within a caliceal diverticulum (Fig. 1.9).

Utilizing the "bulls-eye" technique, the diverticulum was punctured with an 18 G needle. An angled-tip 0.035 in. hydrophilic guidewire was then advanced through the puncture needle. The diverticular neck was identified with retrograde contrast injection and was able to be cannulated with the wire. The wire was coiled in the renal pelvis and a 5 Fr Kumpe catheter was inserted to direct the wire down the right ureter and to facilitate exchange for an extra stiff guidewire over which dilation could be performed. The tract was dilated with a balloon device to 30 Fr, allowing placement of a working sheath. Rigid nephroscopy confirmed the adequacy of access. Multiple stones were evacuated from the diverticulum. Once complete stone removal was confirmed, the infundibular neck was readily seen and dilated with a 6–10 ureteral balloon dilation device. This facilitated advancement of the rigid nephroscope into the main portion of the renal collecting system. No further stones were identified.

An 18 Fr Councill tip catheter was advanced over the wire and placed across the diverticular neck (Fig. 1.10). The patient tolerated the procedure well and made an uneventful recovery. After radiological confirmation complete stone removal, the nephrostomy tube was clamped and removed on the second postoperative day. Subsequent stone analysis demonstrated the stone to be calcium oxalate in composition.

Discussion

Caliceal diverticula are peripherally located cavities lined with nonsecretory transitional stratified epithelium [31]. Communication with the main

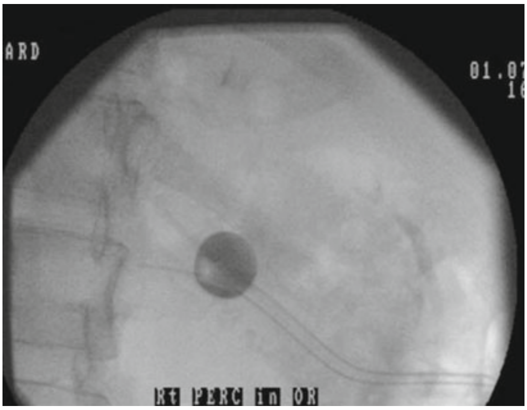

Fig. 1.10 At the completion of stone removal, a Councill catheter was placed across the diverticular neck with its tip in the main portion of the collecting system

portion of the renal collecting system is via a neck of variable width. Urine usually enters the cavity by retrograde passive filling. Although a proportion of patients with CD are asymptomatic, calculi may form with resultant pain, hematuria, or urosepsis.

Prior to the emergence of endoscopic stone surgery, treatment options for CD included partial nephrectomy, diverticulectomy, or deroofing [32]. Ureteroscopy (URS), extracorporeal shock wave lithotripsy (SWL), laparoscopy, and PCNL have now virtually replaced open surgical approaches. SWL presents as an attractive minimally invasive option however results are generally regarded as inferior with SFR [33]. Thirty-one percent of patients treated with SWL for CD stones required salvage with either URS or PCNL [34]. Laparoscopic techniques have been described with excellent SFR although the role of laparoscopy appears to be mainly in the management of stones within anteriorly located or thin walled CD. The gold standard for the management of CD is PCNL [35]. Most series report achieving SFR of approximately 80–90 % percent [36, 37]. As a result, PCNL is now widely considered the treatment of first choice for most patients.

Before contemplating percutaneous management, cross-sectional imaging with CT should be performed in all cases to ensure the diverticulum is posterior and amenable to direct percutaneous access. With the aid of a flexible cystoscope, a guidewire may be passed into the renal pelvis under fluoroscopic guidance and 5 Fr open-ended ureteral catheter positioned to allow for contrast injection to delineate the anatomy of the intrarenal collecting system. One should carefully examine the retrograde pyelogram images. In some cases, it may be possible to identify the diverticular neck and filling of the diverticulum.

Access to the diverticulum in the prone position may be achieved using the bulls-eye or triangulation techniques described previously. Ideally, once the tip of the access needle is placed into the diverticulum, one should attempt to negotiate a guidewire through the lumen of the diverticular neck. This maneuver may be facilitated by the use of a steerable, angled catheter (Fig. 1.5). If the neck cannot be identified preventing guidewire advancement into the renal pelvis, or the diverticulum is not large enough to allow curling of the guidewire, a transdiverticular puncture and neoinfundibulotomy (TDPN) is a useful means of salvage and is associated with excellent stone- and patient-related outcomes [37].

Using fluoroscopic guidance, a combination of anterior-posterior and oblique projections may be utilized to direct a Neff set (Cook Urological, Bloomington, IN) puncture needle through the wall of the diverticulum, out its back wall and into the renal collecting system (Fig. 1.11). At the completion of stone fragmentation and extraction, the neck of the diverticulum may be dilated with a ureteral balloon device. The nephroscope can then be advanced to the renal pelvis to ensure complete stone removal. At the completion of the case, a 16 or 18 Fr Councill catheter may be placed over the guidewire and through the neoinfundibulum to act as a nephrostomy tube. The nephrostomy tube should remain in place for 2–3 days postoperatively, followed by a trial of clamping and removal in the absence of pain or fever.

Other investigators have described alternative techniques such as a single-stage approach, where a puncture is made directly in to the CD, using the calculi as target without the use of retrograde contrast. The guidewire is coiled in the cavity without any attempt to communicate the CD with the urinary system [38]. The main drawback of this technique is that slippage or loss of the guidewire can occur with a resultant loss of access.

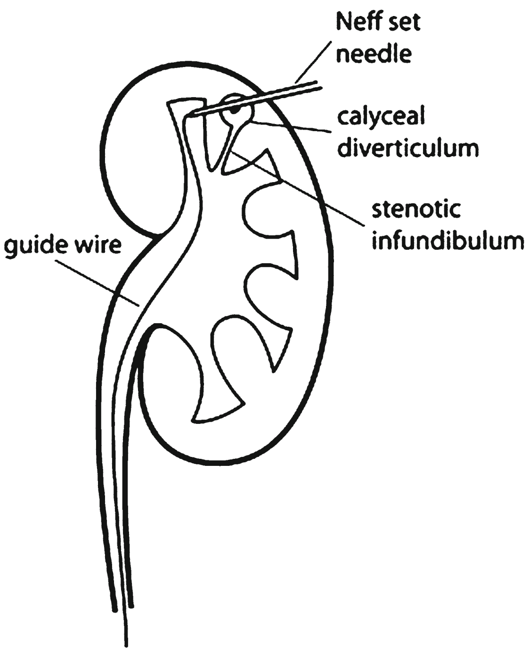

Fig. 1.11 Transdiverticular puncture and creation of a neoinfundibulotomy. *Reproduced from Méndez-Probst CE, et al. J Endourol 2011;25(11):1741–1745 with permission (Figure 1)*

Table 1.3 Key take-home messages: prone percutaneous access

• Appropriate preoperative evaluation incorporating history, physical examination, and review of radiological investigations is essential to the successful performance of PCNL
• Percutaneous renal access must be achieved through the tip of the desired calix to minimize the risk of significant renal vascular injury
• One should aim to puncture a posteriorly oriented calix where possible to facilitate access to the collecting system
• Upper pole access should be approached via a tract at the upper border of the 12th rib. Supra 11th rib punctures are associated with a significantly higher rate of pulmonary complications
• When supracostal access is necessary, one should ensure the sheath remains within the collecting system at all times to prevent extravasation of irrigation fluid into the thoracic cavity

The single-stage approach has the added disadvantage of precluding second look nephroscopy as access to the collecting system is not achieved. We propose that the safety and success of PCNL in this context can be maximized by adhering to the principles outlined in Table 1.3.

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