An Overview on Technical Aspects in Percutaneous Nephrolithotomy

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Abstract

Percutaneous Nephrolithotomy (PCNL) is the standard of care for the removal of large (>2 cm), complex, or staghorn kidney stones. It is a minimally invasive procedure that involves accessing the renal collecting system through a small incision in the skin, followed by dilation of the tract and fragmentation or extraction of calculi under direct vision.

Keywords: Percutaneous Nephrolithotomy, Kidney, Stones

1.Introduction

Percutaneous nephrolithotomy (PCNL) is a cornerstone procedure in the surgical management of large and complex renal calculi, particularly stones larger than 2 cm, staghorn calculi, and those refractory to other minimally invasive techniques such as extracorporeal shock wave lithotripsy (ESWL) or ureteroscopy **(1,2).** First introduced in the 1970s, PCNL has undergone significant refinements in technique, instrumentation, and perioperative management, enhancing both safety and stone clearance rates **(3).**

The success of PCNL is heavily reliant on meticulous technical execution, encompassing patient positioning, optimal percutaneous access, tract dilation, stone fragmentation, and safe postoperative drainage. Accurate calyceal puncture under fluoroscopic, ultrasound, or combined guidance is a critical determinant of outcomes, affecting both efficacy and complication rates **(4).** Tract dilation methods have evolved from serial Amplatz dilators to balloon and single-step dilation, with miniaturized access gaining popularity due to its association with reduced morbidity **(5,6).**

Furthermore, innovations in nephroscopes, lithotripsy devices, and imaging modalities have refined stone retrieval techniques and reduced operative time. Decisions regarding exit strategies—such as nephrostomy tube placement or tubeless PCNL—depend on intraoperative findings and are integral to optimizing recovery **(7).**

Understanding the technical nuances of PCNL is vital for urologists to minimize complications such as bleeding, infection, and injury to adjacent structures while maximizing stone-free rates. This review discusses the key technical aspects of PCNL, emphasizing their clinical implications and the evolving landscape of endourological innovation.

The site of the kidney puncture:

The most important considerations when selecting the best access for stone removal are the location and weight of the stones. In most cases, a lower or middle pole renal puncture is preferred due to its lower risk of complications (8).

Prone position:

[1] Lower pole puncture:

For a lower pole puncture, a good starting point is 1 cm inferior and 1 cm medial to the tip of the 11th and 12th ribs **(9). (Fig.1)**

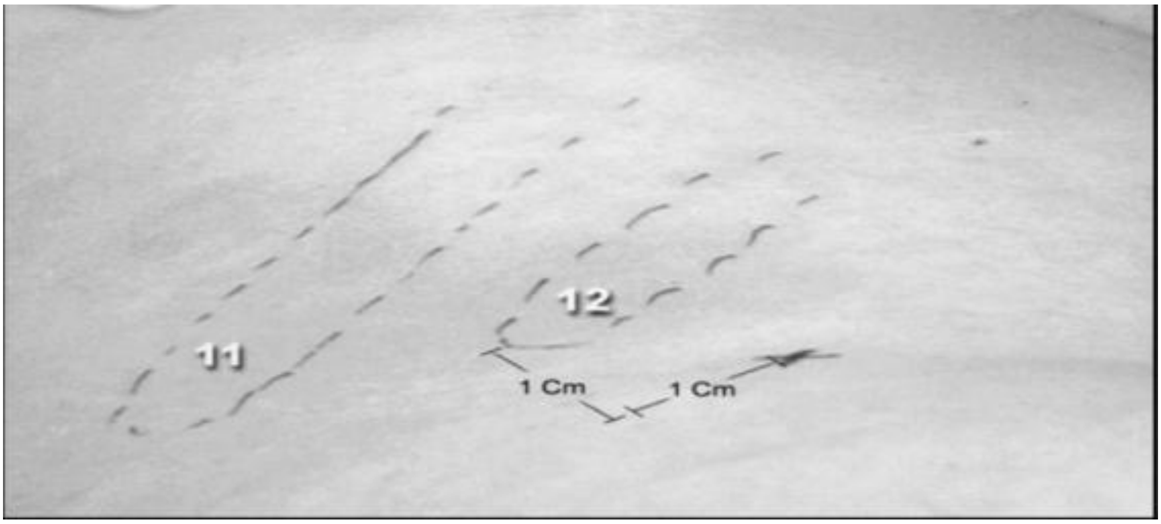

Figure (1): Site of lower pole puncture **(9)**

[2] Supra-costal puncture

A supracostal approach is indicated in patients with ureteropelvic junction obstruction requiring endopyelotomy, staghorn calculi with large upper pole stone burden, and upper ureteral stones **(10). (Fig.2)**

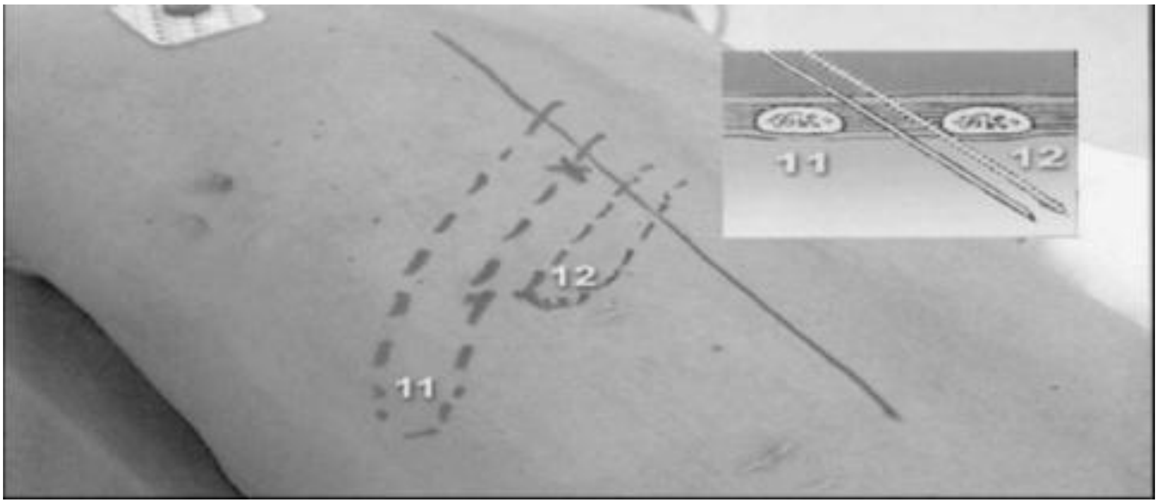

Figure (2): The point of entry for a supracostal upper pole puncture **(11).**

Supine position:

The skin is punctured in the posterior axillary line, 1 cm below the last rib for a lower calyceal puncture. For an upper calyceal puncture, the skin is punctured above the last rib **(12).**

Intrarenalaccess through an infundibulum:

A puncture through an infundibulum (in any part of the kidney) presents clear hazards. Superior pole puncture is most dangerous through the upper-pole infundibulum because large vessels surround this region almost completely. The most serious vascular accident in upper infundibulum puncture is a lesion of the posterior segmental artery (ureteropelvic artery) (13). (Fig.3)

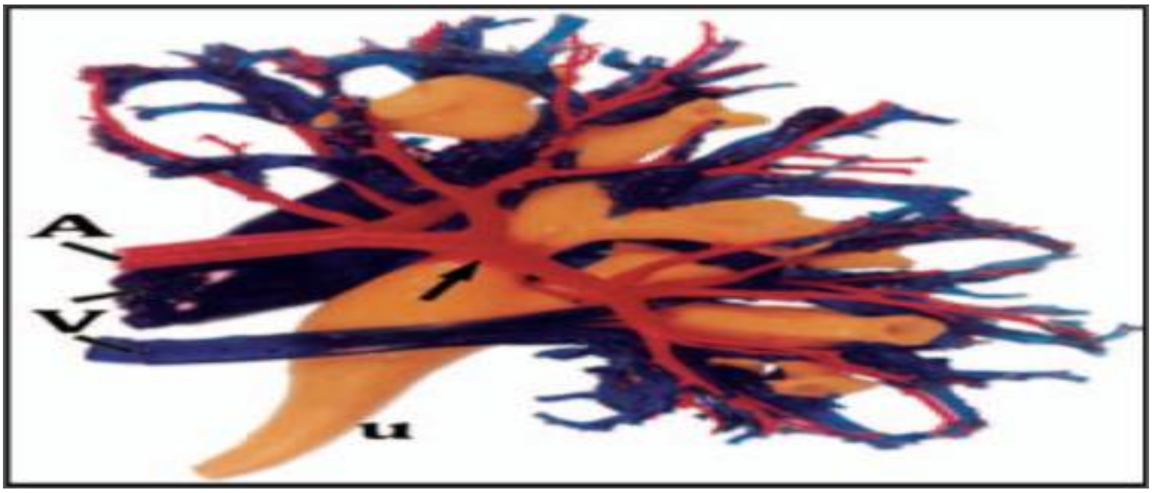

Figure (3): Posterior view of an endocast from a right kidney reveals the posterior segmental artery (ureteropelvic artery) crossing the posterior surface of the upper infundibulum (arrow). A = renal Artery; V = renal Vein; u = ureter **(13).**

Infundibular puncture presents a danger of through-and-through (two-wall) puncture of the collecting system and posesthe risk of bleeding from interlobar (infundibular) arteries. The major segmental branches of the renal artery and primary tributaries of the renal vein lie on the front side of the renal pelvis. Therefore, an anterior puncture can cause significant bleeding. Additionally, because anterior vessels are located far away in the nephrostomy tract, it is challenging to effectively tamponade damaged anterior vessels **(14).**

Intrarenal access through the renal pelvis:

Direct puncture of the renal pelvis for endourologic surgery should be excluded. Besides the fact that the nephrostomy tube inserted at this site is easily dislodged and difficult to reintroduce during the operative maneuvers, renal pelvis puncture has a prohibitive and unnecessary risk of injuring a ureteropelvic vessel (artery and/or vein) (**15**).

Intrarenal access through a calyceal fornix:

Less than 8% of kidneys sustain venous damage when a puncture is made through the calyx's fornix. These injuries happen randomly in the calyces of the upper, mid, and lower poles. There are no artery lesions found as a result of a fornical puncture. Furthermore, in the event of a lesion caused by puncturing through a calyx's fornix, the harm is invariably to a peripheral vessel, like a little venous arcade **(16).** (Fig.4)

Figure (4): Posterior view of an endocast from a right kidney and an inferior puncture performed through a fornix of a calyx. The arrows show a lesion to a small peripheral venous arcade. The arrowheads demonstrate the needle tract. P = renal Pelvis; u = ureter **(16).**

Nephroscopes:

Standard rigid nephroscopes range from 19.5 to 27 French (F) in diameter and feature rod lenses with offset eyepieces or fiberoptic bundles. Flexible nephroscopes, with an outer diameter of around 15F, are also available, though a flexible cystoscope can often serve the same purpose. Rigid and flexible nephroscopes complement each other. Rigid nephroscopes typically provide better visualization due to superior optics and larger irrigation channels. They also allow for the use of larger, more powerful auxiliary instruments. Flexible nephroscopes, on the other hand, provide access to difficult-to-reach calyces without the need for secondary punctures **(17).**

Classical percutaneous nephrolithotomy (PCNL) traditionally involved the use of a 30 French (FG) Amplatz sheath and a 24FG nephroscope. This approach offered the significant advantage of achieving very high stone clearance rates, exceeding 90% in a single session. However, its application in small children was challenging due to the increased risk of renal damage and excessive bleeding, often necessitating blood transfusion **(18).**

The miniaturization of PCNL equipment for pediatric patients has expanded its applicability across all age groups, enabling the treatment of smaller stones that might otherwise be managed with ESWL or RIRS. PCNL continues to be the gold standard for managing large renal stones (>2 cm) and complex stones **(19, 20)**.

Retrospective comparative studies suggest that mini PCNL achieves a stone-free rate comparable to RIRS for moderate-sized stones. Additionally, mini PCNL (14FG) has shown superior outcomes for renal calculi measuring 10–25 mm in preschool children compared to ESWL, with similar complication rates but a longer hospital stay **(21, 22)**.

A large retrospective multi-institutional cohort study involving 1,205 pediatric renal units undergoing PCNL identified sheath sizes larger than 20FG as an independent predictor of complications and bleeding requiring transfusion (**23**). Several other studies have corroborated this association between larger tract sizes and increased blood loss (**24**). Consistent with these findings, PCNL performed with a smaller tract (<24FG) has been shown to reduce blood loss without compromising the success rate **(25).**

A study involving 1,135 renal units found that the requirement for blood transfusions was significantly lower across all age groups when a sheath size of <20FG was used. However, the transfusion rate was notably higher in children with larger stone burdens and younger children due to their lower tolerable blood loss **(26)**.

Using the right procedures with a thorough grasp of pelvicalyceal and intrarenal vascular anatomy is essential to prevent bleeding during PCNL. The puncture site should be carefully chosen based on the stone's location, with the puncture directed through the fornix toward the infundibulum to minimize trauma to blood vessels near the infundibulum. Additionally, during stone fragmentation and retrieval, careful manipulation of the nephroscope is crucial to avoid excessive torque and the formation of false passages that could damage the renal parenchyma **(27).**

Currently, there is no standardized nomenclature for PCNL, leading to variability in classifications across the literature. Proposed classifications include standard or conventional PCNL (22–30FG), mini PCNL (11–22FG), minimally invasive PCNL (9.5–26FG), Chinese mini PCNL (14–20FG), ultra-mini PCNL (11–13FG), micro PCNL (4.8FG), mini-micro PCNL (8FG), and super-mini PCNL (10–14FG). The first recorded mini PCNL, performed by Jackman, utilized an 11FG peel-away vascular access kit. Over time, as miniaturized PCNL techniques have expanded, the term "mini PCNL" has been loosely applied to tract sizes ranging from 11 to 22FG, resulting in a lack of clear definition (**28**).

Microperc:

Micropercis a system that combines the telescope, working channel, and irrigation into a single needle as small as 4.8FG. This approach requires only a single puncture, eliminating the need for tract dilatation (**29**). One of its primary advantages in pediatric cases is the significant reduction in bleeding.

It is typically reserved for highly selected cases. It enables direct puncture into the target calyx using an "all-seeing" needle and allows for in situ fragmentation or powdering of the stone. By eliminating the need for tract dilatation, this approach decreases radiation exposure and shortens operating time, which may help lower complication rate (**30**).

However, microperc has several limitations. Vision is easily compromised by minor bleeding or stone dust, as the irrigation fluid is delivered intermittently without a consistent outflow channel, resulting in suboptimal visibility compared to mini PCNL. Intrarenal pelvic pressure can become significantly elevated during microperc, requiring precautions to mitigate this risk. These include placing a large-caliber ureteric catheter in the renal pelvis and closely monitoring saline irrigation throughout the procedure (**31**).

Another limitation is the inability to access stone fragments that migrate to other calyces, making fragment retrieval difficult or impossible. Additionally, microperc instruments are designed to be disposable and are costly, limiting their accessibility in resource-constrained settings where pediatric stone burdens are high **(32**).

The choice to use ultra-miniaturetracts should be tailored to each case, considering the size and location of the stone. This decision must also account for limitations such as reduced irrigation flow, compromised visualization, and restricted use of disintegration tools and grasping forceps. Careful evaluation of these factors is crucial to achieving optimal outcomes while minimizing complications.

The common principle of the mini-PCNL technique is the use of small instruments and small-diameter sheaths. Access sizes ranging from 11 F to less than 20 F have been reported in the literature (**33**).

Different authors have described using a variety of endoscopes for stone disintegration and fragment removal. The most common instruments used are an 8/9.8 F rigid or semi-rigid ureteroscope and a specially assigned 12 F mini nephroscope with a 6 F working channel and automatic pressure control (34).

Hydrodynamic effects of a specially designed metallic Amplatz sheath (15 F/16.5 F/18 F/20 F) placed over a one-step metallic dilator were used to evacuate fragmented stones without additional pressure or suction (**34**).

- **Irrigation**:

Physiologic solutions should be used for irrigation during PNL to minimize the risk of dilutional hyponatremia in the event of large-volume extravasation (**35**).

The height of the irrigant should be maintained at 80 cm or less above the patient to minimize intrapelvic pressure and prevent fluid absorption through myelogenous backflow (**36**).

Stone fragmentation and extraction:

If the stone is less than 1 cm in size, a grasper can be used to remove it through the 30F sheath. However, most stones requiring PNL will be larger than 1cm, and a range of lithotripsy techniques will be required.

Most stone fragments can be washed out along with the back flow through the specially design edmetallic Amplatz sheath without increasing intrarenal pressure, while bigger fragments can be removed with stone forceps or tipless baskets (**37**).

For a large stone burden, simultaneous retrograde flexible ureterorenoscopy can be used to move the stone into the renal pelvis, as it can be fragmented and extracted through the percutaneous tract (**38**).

a) Ultrasonic lithotripsy:

One of the most popular techniques for intracorporeal lithotripsy is ultrasonic energy because of its proven effectiveness and safety (**39**).

b) Lithoclast:

Another major energy source is the pneumatic lithoclast (**40**). While rigid probes were required in the past, modern pneumatic lithotripters now offer flexible probes (**41**).

c) Laser lithotripsy:

The advantages of using laser are that very tough stones can be shattered, and flexible nephroscopy can be utilized with these energy sources **(42).**

Standard vs. tubeless vs. small bore tubes:

After stone fragmentation and extraction, the standard procedure is the placement of a nephrostomy tube. Many groups propose the elimination of the nephrostomy with the advantages of shorter hospitalizations, lack of external drainages tubes, and less postoperative pain. A lack of standardization with regard to kidney drainage and precise indication for the tubeless PNL are an obstacle to widespread utilization of this technique, and its real benefits are not clear **(43).**

Tefekli et al. (44) compared the outcomes of standard and tubeless PNL and found that tubeless PCNL was associated with shorter hospital stay and less postoperative analgesia and concluded that tubeless PNL is safe for selected patients with simple renal stones of mild-moderate burden and that mean hospitalization time and analgesia requirement is diminished with this modification.

Shah et al. (45) use criteria for indication of tubeless PNL excluding only patients that needed more than three accesses, presence of significant bleeding that persisted throughout surgery and presence of a significant residual stone burden.

Desai et al. (46) compared outcomes among tubeless, conventional large bore nephrostomy drainage and small bore nephrostomy drainage and found that the tubeless PCNL was associated with the least postoperative pain, urinary leakage, and hospital stay. Small bore nephrostomy drainage was associated with better outcomes than large bore nephrostomy and they concluded that it may be a reasonable option in patients in whom the incidence of stent dysuria is likely to be higher.

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