



The Current Status of Percutaneous Nephrolithotomy

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Abstract

Purpose of Review There have been remarkable advances in the field of endourology in the past century. This paper aims to provide practice updates in percutaneous nephrolithotomy (PCNL), ranging from preoperative to postoperative considerations.

Recent Findings PCNL remains the gold standard surgery for the treatment of stones larger than 20 mm and patients with complex anatomy. Patient positioning, device selection for stone treatment, and modality of access remain largely dependent on the surgeon's training and preference. There has been a general widespread movement towards miniaturization of renal access tract, tubeless PCNL, and ambulatory PCNL (aPCNL) over the past two decades.

Summary Advances in technology and surgical technique have allowed for safer PCNL surgery while maintaining excellent efficacy. The culmination of this progress has created a shift towards aPCNL, which may evolve into the standard of care for most complex stone surgery.

Keywords Percutaneous nephrolithotomy (PCNL) · Mini-PCNL · Ambulatory PCNL · Tubeless PCNL · Kidney stone · Ambulatory surgery center

Introduction

Percutaneous nephrolithotomy (PCNL) revolutionized the treatment of kidney stones. The inception of percutaneous access dates back to 1865, when a physician named Thomas Hillier attempted a percutaneous nephrostomy for therapeutic relief in a pediatric patient with congenital hydronephrosis [1, 2]. In the 1940s, the percutaneous extraction of renal stones was conceptualized as a less morbid alternative to anatomic nephrolithotomy [3]. However, it was not until the 1970s that Fenstrom and Johansson performed the first official PCNL under radiologic guidance [4]. Advances in surgical technique and technology have improved the safety and efficacy of PCNL, making it the gold standard approach for the treatment of large kidney stones.

Other surgical methods of stone treatment have evolved over the past century. Shock Wave Lithotripsy (SWL) is a

non-invasive option that has been used to treat renal calculi located in the kidney and proximal/mid-ureter [5]. However, SWL is not suitable for stones located in the lower pole of the kidney and for stones larger than 1.6 cm because the rate of clearance under these conditions decreases significantly [5, 6]. Ureteroscopy (URS) is a minimally invasive endoscopic treatment option for lithiasis in any part of the urinary tract, although the treatment of lower pole stones can be limited by the flexion of the ureteroscope and stone burden greater than 2 cm leads to reduced stone clearance rates. When compared to SWL, URS offers a higher stone free rate (90% vs. 72%) and requires fewer retreatments and secondary procedures [7].

The American Urological Association guidelines currently recommend SWL and URS as appropriate first line treatment options for stones less than 1 cm, while PCNL is the preferred treatment method for stones greater than 2 cm and staghorn calculi [8]. PCNL offers a higher stone free rate for stones of this size compared to these other options [8]. National trends indicate that the use of URS and PCNL have increased, while the use of SWL has decreased [9].

The surgical management of urolithiasis is an important area of investment in urology. Data from 2005 to 2015 suggests that the incidence of kidney stones continues to

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increase [10]. Hill et al. recently reported the results of a national survey in 2022 estimating the prevalence of kidney stones in the United States to be 11% with a 12-month incidence of 2.1% [11]. In this review, we discuss the status of PCNL practice, including the modality of access, intraoperative considerations, and postoperative management.

Modality of Intrarenal Access

Anatomic Considerations

Preoperative Planning

Review of the patient's most recent computerized tomography of the abdomen and pelvis in the axial, coronal, and sagittal planes is of paramount importance for surgical planning and key for a safe, efficient, and successful PCNL [12, 13]. The information collected by careful review of imaging is needed in order to decide optimal positioning (prone versus supine), target of renal access (upper pole, inter-pole, lower pole or diverticulum), lithotripter selection, size and number of tracts needed to achieve stone clearance, and of utmost importance in order to avoid potential and sometimes catastrophic pitfalls (e.g., unusable access tract, pleural violation, solid viscera and bowel perforation, large blood vessel puncture).

Systematic review of imaging is routinely conducted. The number of renal stones, their volume and shape, radiographic density, location within the continuous upper collecting system or possible diverticular location is meticulously assessed. The kidneys are inspected for size, parenchymal thickness, presence of cysts or masses, possible duplication, shape and complexity of the collecting system, presence of hydronephrosis, their positioning within the retroperitoneum and their relationship with

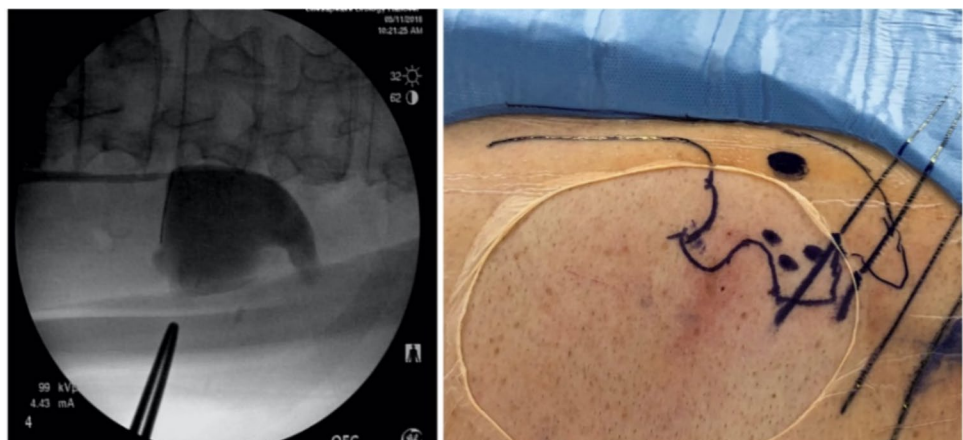
surrounding structures like the perirenal fat, eleventh and twelfth ribs, diaphragm, liver, spleen, bowel, hilum, aorta, and vena cava. The ureters are inspected for distention, presence of stones, acute narrowing concerning for stricture, course within the retroperitoneum and to estimate their length. The bladder is examined looking for distention, shape, presence of stones, presence of diverticula, possible presence of ureterocele, protrusion of prostate in males, and anterior vaginal wall prolapse in females.

Intraoperative Anatomic Landmarks

The anatomic landmarks that frame the percutaneous access window should be readily identifiable prior to puncture and throughout the procedure. These include the posterior and middle axillary line laterally, the paraspinous muscle medially, the eleventh and twelfth ribs cephalad, and the iliac crest caudally [14].

The middle and posterior axillary lines should be identified and their correlation with the retroperitoneal reflection and intra-abdominal contents in the patient's imaging should be clear to the surgeon prior to surgery. The location of the eleventh and twelfth ribs can be palpated or, alternatively, identified using sonographic or fluoroscopic guidance. The relationship of the ribs with the target for access in the collecting system should be assessed and is of particular importance when considering an upper pole access target (Fig. 1). Identification of the diaphragm and solid viscera and their relationship to the ribs should always be established when anticipating the need for a possible supracostal tract. The paraspinous muscle should be used as a marker indicating potentially dangerous proximity to the large blood vessels [15].

Fig. 1 Intraoperative marking of anatomic landmarks assists in identifying optimal percutaneous access location



Fluoroscopic Access

Overview

A C-arm and a radiolucent frame or table are used depending on patient positioning choice of prone or supine, respectively. Scout anteroposterior fluoroscopic imaging is routinely obtained to identify radiopaque stones and osseous structures. A scout image is saved and used as a reference of the stone burden starting point. The collecting system is delineated by a retrograde ureteropyelogram performed by injecting contrast in a retrograde manner through a previously placed ureteral catheter and the images are saved for reference. The access target is selected after careful examination of retrograde ureteropyelogram [16]. Two techniques are commonly described for obtaining fluoroscopic renal access: triangulation and bullseye. Selection of technique to be employed is based on the surgeon's preference.

Triangulation Technique

Starting with the C-arm in the anteroposterior position (horizontal plane), the access needle is placed on the skin, perpendicular to the image intensifier, and its tip is oriented towards the chosen target using fluoroscopy. This establishes the trajectory (though not the angle of depth) that the needle will need to take to reach the target. The skin is punctured at an angle (deeper trajectory for obese patients) and advanced towards the target. Once the needle's tip is close to the target, the C-arm is rotated +20 degrees to assess the vertical plane orientation of the needle tip with relation to the target. When the vertical orientation correction is made, the C-arm is placed back at the anteroposterior position and the needle is advanced until perfectly overlying the target (Fig. 2). Tactile sensation of resistance should be felt passing through (sequentially) the fascia, renal capsule, and finally a "pop" with puncture into the collecting system. Return of urine

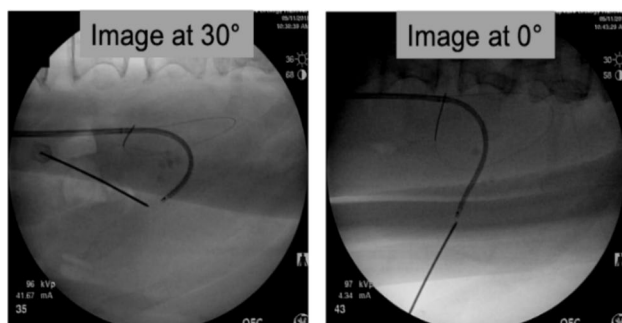


Fig. 2 Fluoroscopic guided intrarenal access using a biplanar triangulation technique. The tip of the retrograde flexible ureteroscope is the target

upon removal of the needle's inner stylet confirms access into the collecting system.

Bull's Eye Technique

Starting with the C-arm rotated between +10 and +20 degrees, the access needle is placed on the skin; its tip is oriented towards the chosen target and in a parallel to the image intensifier. Using fluoroscopy, the goal is to consolidate the needle into a radiographic dot over the target (Fig. 3). Once this is achieved, the needle is advanced through the skin into the target while maintaining a radiographic dot over the target. The C-arm can be intermittently rotated to the anteroposterior position to assess for aligned advancement and depth. Return of urine upon removal of the needle's inner stylet confirms access into the collecting system.

Endovision Guided Access

PCNL can be augmented by the simultaneous use of retrograde endoscopic visualization of the upper collecting system [17]. Flexible ureteroscopy is a technique familiar and common to urologists; therefore, potentially decreasing the barrier to entry and adoption when performing a PCNL. It can be effectively used during prone or supine positions [18, 19].

In our practice, a retrograde ureteral safety wire and an 11 × 13 ureteral access sheath are placed at the beginning of the procedure to allow for safe and readily available

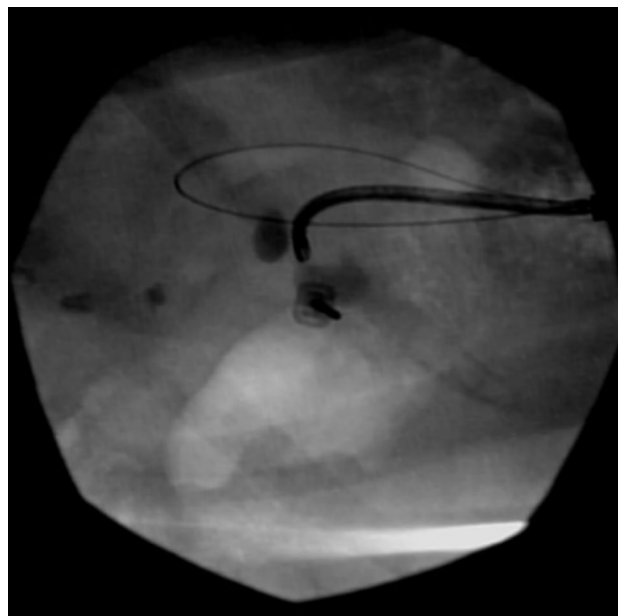


Fig. 3 Fluoroscopic guided intrarenal access using the Bull's Eye technique. The C-arm is rotated at +20 degrees with the goal of consolidating the needle into a radiographic dot over the target

retrograde endoscopic access to the upper collecting system throughout the procedure. In this approach to PCNL, a flexible ureteroscope is passed through the access sheath and used to survey the upper collecting system prior to needle puncture to select the calyx best suited for access. Once the target calyx is selected, fluoroscopic guidance is used to advance the needle towards the tip of the ureteroscope using the previously described triangulation or bull's eye fluoroscopic techniques. Access in the collecting system is immediately confirmed by direct visualization of needle entry (Fig. 4).

Sonographic Guided Access

Overview

Ultrasound allows for potential renal access without the use of ionizing radiation. It has the potential to significantly decrease (and in some few reported cases completely avoid) patient and surgical personnel radiation exposure at the time of PCNL; however, this technique presents some challenges and limitations [20–22•]. The technique requires familiarity and understanding of sonographic principles, techniques, and anatomy, which are not standard skills and competencies uniformly taught in urology residency programs; therefore, there is usually a steeper learning curve associated with the technique [22, 23].

Preoperative careful review of CT abdominal imaging is necessary at the time of patient selection for the use of ultrasound guided renal access since certain anatomical characteristics can make its use difficult or even preclude it from being used [24]. Anatomical features that can potentially hinder the use of sonogram for renal access are the following: obesity, unusual renal moiety location and position

(e.g. ectopic crossed fused kidneys, horseshoe kidneys), renal atrophy, absence of hydronephrosis, and nearby abnormal organs (e.g. hepatomegaly, splenomegaly, presence of bowel).

Sonographic Guided Access Technique

The renal parenchyma, collecting system, stones, and surrounding structures (to avoid hindrance from ribs, a pleural space violation or puncturing the surrounding viscera) are visualized using a curved transducer probe in the 3.5 MHz range. The depth of the ultrasound is set between 8 and 12 cm and is adjusted to maximize the size of the kidney in the machine's screen. Gain is set to the midrange and adjusted as needed to increase the contrast of the needle against the collecting system and renal parenchyma to facilitate visualization of the potential access target calyx and needle advancement. The posterior calyx is chosen in most instances except when the stones are in a favorable anterior calyx or a diverticulum. Renal stones are identified by their characteristic hyperechoic signal accompanied by acoustic shadowing.

The puncture can be accomplished in the longitudinal or the transverse imaging plane. In the longitudinal approach the skin is punctured either side of the long axis of the probe. The needle travels in-plane and is kept fully visualized from skin to kidney as its tip is advanced into the target calyx. In contrast, in the transverse approach the skin is punctured parallel to the short axis of the probe. The probe is swept back and forth to visualize the needle path to guide the needle tip to the target calyx. An in-depth understanding of both approaches is needed to be successful at obtaining sonographic guided renal access. A summary of all the intrarenal access techniques discussed above can be found in Table 1.

Antegrade and Retrograde Treatment

Antegrade Treatment

Upon obtaining needle percutaneous renal access, a guide-wire is introduced through the needle into the upper collecting system. Once the wire is confirmed to be in the upper collecting system (ideally down the ureter), another wire is introduced to be used as a safety measure, and the tract is dilated.

Tract size, dilation type (e.g., balloon or Amplatz dilators) and lithotripter type (e.g., pneumatic, ultrasonic, laser) selection should be made based primarily after analysis of the patient's anatomical and stone burden characteristics, with consideration of the available equipment and the surgeon's preferences. A standard PCNL tract is a percutaneous access sheath 24 French or larger; usually a balloon dilator is used for dilation under fluoroscopic guidance. Traditionally,

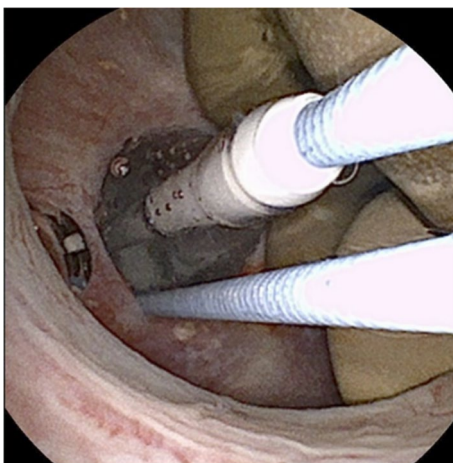


Fig. 4 Retrograde endoscopic visualization of the intrarenal access location and balloon dilation of the tract during PCNL

Table 1 A summary of the intrarenal techniques

Intrarenal Access Technique	Description	Pros	Cons
Fluoroscopic Access	C-arm and fluoroscopy utilized to guide needle placement; retrograde ureteropyelogram performed to delineate collecting system	Excellent delineation of the collecting system Technique uniformly taught in urology residency programs	Ionizing radiation Inability to assess surrounding soft tissue organs
Triangulation	C-arm starts in the anteroposterior plane to establish trajectory; C-arm rotated to +20 degrees to determine vertical orientation	Alignment of the needle is helpful for end-calyx access Commonly used for prone and supine PCNL	Difficulty with repositioning of the needle in morbidly obese patients Difficult method for upper pole, intercostal, and diverticular access
Bull's Eye	C-arm starts between +10 and +20 degrees; needle consolidated into radiographic dot over target calyx	Ability to access directly onto a target (i.e., preferred method for upper pole, intercostal, and diverticular access)	Less control over exact intrarenal access location (i.e., may not obtain end-calyx access) Difficult method for supine PCNL
Endovision Guided Access	Simultaneous retrograde endoscopic visualization	Immediate confirmation of access within collecting system Allows for treatment of ureteral stones and renal stones unreachable through percutaneous tract	Often requires skilled assistant Requires additional equipment and steps for retrograde ureteral access sheath placement
Sonographic Guided Access	Curved transducer probe used to visualize path of access needle in the longitudinal and transverse imaging plane	Limits ionizing radiation Allows for assessment of surrounding soft tissue organs Retrograde access of the urinary tract not required (i.e., excellent option in setting of altered genitourinary anatomy or urinary tract strictures)	Anatomic variations (obesity, horseshoe kidney, nearby abdominal organs, etc.) can limit usage Visualization and intrarenal access may be difficult when no hydronephrosis present Requires understanding of ultrasound techniques not uniformly taught in urology residency programs

standard tracts are selected for a total stone burden ≥ 20 mm or a lower pole stone ≥ 10 mm [25, 26]. Mini-PCNL (mPCNL) tract is any percutaneous access sheath < 24 French; usually a metal dilator is used for dilation under fluoroscopic guidance. Mini tracts are usually used for treatment of patients with a total stone burden ≥ 15 mm or a lower pole stone > 8 mm [27, 28]. Stone burden size is not a strict criterion, but it serves as a rule of thumb for selection of tract size. Clinical judgment based on the surgeon's prior training and experience should be utilized to select the most suitable tract size for every case. Once the percutaneous tract is dilated and established, a rigid nephroscope is introduced into the collecting system. The stones are identified and antegrade treatment is performed with lithotripsy and stone extraction. Upon completion of extraction, flexible nephroscopy should be performed to identify any potentially non-visualized stones, missed fragments, or collecting system injury.

Retrograde Treatment

As previously described, a retrograde ureteral safety wire and a ureteral access sheath are placed at the beginning of the procedure. A flexible ureteroscope is passed through the access sheath and advanced into the collecting system. Having a retrograde flexible ureteroscope in the collecting system acts as an adjuvant to PCNL since it allows for visualization of stone clearance during antegrade treatment, vacuum stone extraction due the Venturi effect, retrograde treatment of stones (e.g., laser lithotripsy, stone basket manipulation), and flexible nephroscopy upon completion of PCNL. It also allows for retrograde treatment of any ureteral stones or fragments and for full inspection of the ureter upon completion of PCNL.

Miniaturization of PCNL

The trajectory of PCNL surgery has been propelled toward the use of smaller and smaller tracts, eventually leading to development of what has been called the “mini”, “ultra mini” and “micro” tracts. mPCNLs encompass the same general procedure as standard PCNL, however, a miniature nephroscope is moved through a much smaller (< 24 Fr) percutaneous tract [29] (Fig. 5). Papers published during the early period of this shift highlight the main reasons for the updated protocol with one being that tract size has been shown to be a major cause for complications with < 22 Fr tract associated with less blood loss than a dilation to 28Fr or larger [30]. While mPCNL can be used for a variety of stone sizes, 20 mm–40 mm has shown to be a range where complication rates are minimal [31••]. In comparison to standard PCNL, mPCNL has been shown to have less blood



Fig. 5 Depiction of the small skin incision made during a supine mPCNL case (17.5Fr intrarenal access tract)

loss, lower rates of blood infusions, and shorter length of stay, with no change between the two in stone free rates [32–34], though these papers were limited by selection bias. While there is no set definition for the tract size used in each procedure, the majority of mPCNLs performed are between 14 and 22Fr, and recently “ultra-mini”, “super-mini” and “micro” PCNL techniques have been introduced to further reduce morbidity and mortality [32].

The first miniaturization of tract size, the mPCNL technique, was described in 1997 by Jackman et al. where 11Fr catheters were used in the pediatric population with success, and later employed in the adult population with 13Fr catheters. They performed this novel technique on all patients with stone burdens < 20 mm. Stone fragments were removed with forceps, suction, or basket. Stone free rates in this procedure was 89% [35].

The first use of the “ultra-mini” PCNL was by Desai et al., in 2013 where they used a novel 6Fr scope through a 11–13Fr tract. The stone was disintegrated into 2 mm fragments via 365 μ m laser fiber and implementation of a high-pressure zone allowed for the small stone fragments to escape with addition of saline to promote a vortex or vacuum effect. The ultra-mini PCNL procedure was first performed on patients with renal stones < 20 mm with high stone free rates and low rates of complication. Stone free rates in this procedure was 87% [36].

Zeng et al., in 2015 also presented their use of miniature tracts, “super-mini” PCNL, utilizing 10–14Fr tracts. Suction sheath was added in this procedure prior to nephroscope with irrigation system utilization. Stones were disintegrated via a 365 μ m laser, and irrigation was delivered through endoscope sheath via a pump. Continuous and active suction was implemented leading to stone fragment removal. Super-mini PCNL procedures were first done on patients with stone size < 25 mm, with lower pole stones showing the most success as well as those 20 mm and below as compared

to other methods of stone removal [37]. Stone free rates in this procedure was 90% [38].

Micro-PCNL was first introduced in 2011 by Brader et al., utilizing an “all seeing needle” through a 4.85Fr tract. In this procedure, 0.6 mm and 0.9 mm micro-optic cameras were inserted through the tract site, with the 0.9 mm camera having higher visibility. Stones were disintegrated via holmium laser, and irrigation was performed via pumping mechanism. Micro-PCNL tract size does not allow for fragment retrieval, so stone clearance had to be obtained retrograde through the ureter. Stone free rates in this procedure was 89% [39].

Site of Service

Advances in technology and surgical technique have allowed for less invasive, safer surgeries while maintaining excellent efficacy. When compared to open surgery, PCNL significantly improved the safety profile of complex stone treatment with exceptional stone-free rates. Historically, PCNL was considered a surgery that required postoperative hospital admission due to concerns for infection and blood loss. The first outpatient PCNLs were successfully performed in 1986 by Preminger et al. [40]. In this case series of 5 patients, nephrostomy tubes were used for drainage postoperatively and there were no significant complications [40]. However, outpatient PCNL was still not considered the standard of care.

In 2010, the idea of outpatient PCNL was re-visited with the emergence of tubeless PCNL, which increased patient comfort and satisfaction post-operatively [41]. Since that time, more studies emerged with outpatient PCNLs performed in the hospital setting and usually included 23-h observation [42].

In 2018, Abbott et al. described the first successful pilot study for tubeless, ambulatory PCNL (aPCNL) performed at a freestanding ambulatory surgery center (ASC) [43]. Given that only 1/3 of surgeries performed annually in the United States require post-operative hospital admission, freestanding ASCs have gained widespread popularity [44]. There are more than 5000 facilities operating today in the United States [44, 45]. Compared to hospital-based outpatient surgery, freestanding ASCs offer reduced costs per case [44, 45]. Currently, most low to medium complexity urologic surgeries are being performed in freestanding ASCs, particularly endoscopic and penoscrotal cases [46].

In recent years, there has been growing evidence that supports the feasibility of performing aPCNL in freestanding ASCs. Most published studies have been small series with strict selection criteria [47, 48]. In 2021, Chong et al. published an analysis of 500 consecutive aPCNL cases, the largest study to date, with minimal morbidity and excellent

outcomes [49]. Subsequently the same group demonstrated safety data from 1250 + patients with a <3% minor complication rate and no major complications [50••].

Across all studies, proper case selection remains pivotal, with medical comorbidities and social factors considered. Particularly, factors that increase the risk of sepsis and bleeding must be carefully evaluated. Overall, these studies have found readmission rates ranging from 2 to 4% with complication rates up to 13.5%, the majority being Clavien I–II complications, and all had excellent stone-free rates averaging around 80% [47–49].

We conclude that a shift in standard of care will occur where most complex renal stones will be treated as aPCNL at freestanding ASCs, with only the most high-risk patients treated in the hospital setting. This is based on evidence that surgical efficacy and patient safety can be maintained, while reducing the financial healthcare burden.

Other Considerations

Patient Positioning: Supine vs. Prone

American urologists have traditionally performed PCNL in the prone position; however, supine positioning (a catch-all phrase for several modifications of a patient slightly tilted to facilitate flank renal access) has emerged as a rival technique with many advantages for the patient, urologist, and anesthesiologist. With one exception [51], there was no difference in stone free rate between positions [52], regardless of stone size [53–55], complexity [56••], location (renal, ureteral) [57–59], or patient population (obese, non-obese, pediatric) [53, 61]. Operative time has generally been found to be shorter in supine [51–57, 59]. Mean hospital stay and blood loss was generally similar regardless of position [51, 53–55, 57, 59, 60]. A study found a higher rate of Clavien ≥ 3 complications in prone compared to supine [56]; however, other studies found no difference in other complications such as injury to adjacent organs [53, 58], or creatinine changes [60]. Fluoroscopy time has been found to be shorter in supine [55], with similar mean nephrostomy time [54] and similar stent duration [60]. Overall, supine positioning yields a non-inferior stone free rate, length of hospital stays, blood loss, and complication rate with a shorter operative time.

Finally, the effects of positioning for anesthesia care should also be considered. Primarily, airway access is greatly facilitated in the supine position. Two studies showed similar arterial CO₂ and HCO₃ blood gases between supine and prone [60, 62], while one showed better oxygenation in prone [62]. Another study found greater changes in mean blood pressure, mean heart rate, and peak airway pressure in prone [57]. Thus, patients with respiratory and

cardiovascular comorbidities may receive different benefits from supine or prone positions.

Device Selection: Laser vs. Lithotripter

Once the patient is positioned and percutaneous access is successful, stones can be cleared via laser (usually holmium or thulium), or lithotripter (most commonly through a dual ultrasonic/ballistic mechanism). Four studies have compared surgical outcomes following laser vs lithotripsy stone removal.

Malik et al. compared PCNL with holmium laser vs pneumatic lithoclast in patients with a 2.5 cm stone in the renal pelvis. Residual stone rate, hospital stay, and complication rate (postoperative fever, hematuria requiring transfusion) were similar between both groups, but Pneumoclast lithotripsy required shorter operating time [63]. El-Nahas et al. compared PCNL with holmium laser vs ultrasonic lithotripsy in patients with staghorn calculi reaching each major calyx [64]. Stone free rates after 3 months were similar. Ultrasound lithotripsy required a shorter operative time but had higher blood loss. Rates of blood transfusion and complications were similar.

Lai et al. compared mini-PCNL with holmium laser vs ultrasound lithotripsy [65]. Patients treated with laser had higher initial stone free rate and shorter operative time with similar rates of postoperative fever and blood transfusion. Song et al. studied mini-PCNL with holmium laser vs third generation EMS ultrasound/ballistic lithotripsy in patients with stones > 2 cm [66]. Lasers had a higher stone free rate and lower intraoperative bleeding, but mean stone clearance time was similar. Overall, both lasers and lithotripters are safe and effective methods to clear stones in a diversity of patient presentations.

Postoperative Drainage Options

Postoperative kidney drainage varies between standard PCNL (with a nephrostomy tube), and tubeless PCNL (a stent and/or ureteric catheter is placed). Tubeless PCNL may require cystoscopy for stent removal and loses the advantage of postoperative nephroscopic access, however, it has other advantages over standard PCNL. Most studies found similar operative time regardless of drainage, but shorter length of hospitalization in tubeless PCNL [67–75]. Most studies also found lower analgesic requirements and non-inferior pain levels in tubeless PCNL [67, 69–74].

Except for a lower chance of hydrothorax in tubeless PCNL [68], the complication rates between tubeless and standard PCNL were similar and included blood loss, hematuria, hematoma, hemothorax, fever, and infection [67–84]. Patients undergoing tubeless PCNL had less urinary leakage [69, 83, 84] and a faster return to normal activities [70, 82].

In one study, quality of life (QOL) was similar at one month post operation, but worse after tubeless PCNL at 7–10 days [73]. Another study found that patients with nephrostomy tubes had better postoperative QOL than those with stents, but worse QOL than patients with ureteral catheters [76]. Furthermore, the group with stents was less willing to undergo retreatment with the same drainage option if needed in the future. In mPCNL, patients with tubeless drainage had better postoperative QOL than those with a tube [81]. Other studied outcomes showed lower cost of tubeless PCNL than standard PCNL [85], but better ease of tube placement and radiopacity in standard PCNL [42].

In addition, totally tubeless PCNL, which lacks the insertion of a nephrostomy tube, stent, or ureteral catheter, has emerged as a drainage option. When compared to standard PCNL, both drainage options led to similar stone-free rates and retreatment, regardless of population or renal anomalies (horseshoe, ectopic kidney or rotational anomalies) [86–89]. While operative time was usually similar between groups [86, 88–92], most studies showed shorter length of hospital stay and lower analgesic requirements in totally tubeless [86–95]. Complication rates such as blood loss, creatinine changes, and infection rate were overall similar [86–92, 94, 95]. Patients undergoing totally tubeless PCNL showed faster return to normal activity in two studies [86, 88], and no difference in one [94]. In one study, both approaches had similar postoperative QOL scores, but the trend of pain progression varied: pain following standard PCNL was lower in one week while pain following tubeless PCNL was fully resolved in one month [91]. Another study found better pain visual analog scores in totally tubeless [94]. In well selected patients all drainage options can be safe and effective, but tubeless and totally tubeless appear to offer an easier recovery.

Conclusions

PCNL remains the gold standard surgery for the treatment of stones larger than 20 mm. A systematic review of CT imaging with intraoperative correlation to anatomic landmarks is a vital part of performing the case safely and successfully. Patient positioning, device selection for stone treatment, and modality of access remain largely dependent on the surgeon's training and preference. The use of a retrograde flexible ureteroscope during PCNL is an asset, allowing for direct visualization of renal access and stone clearance. It also provides the benefit of retrograde treatment of stones in the kidney that are difficult to reach via antegrade approach, as well as treatment of ureteral stones.

There has also been a major shift towards miniaturization of renal access tracts. This approach has been shown to reduce case morbidity while maintaining equivalent

stone free rates and is currently widely used for stone burden less than 25 mm. Tubeless PCNL has also become a more common practice. Patients generally prefer and tolerate ureteral stents rather than nephrostomy tubes.

One of the greatest developments in PCNL practice over the past decade is the movement towards aPCNL in freestanding ASCs. We conclude that there will be a shift in the standard of care where only the highest-risk patients will be treated in the hospital setting. There is strong evidence to suggest that surgical efficacy and patient safety can be maintained while lowering healthcare costs.

Author Contributions Abstract, site of service, conclusions: NLAVIntroduction: NLAV and SWMiniaturization of PCNL and Other Considerations: DCR, RK, and ABModality of Renal Access: AM, JD, MDPreparation of figures and table: NLAV and LXAll authors reviewed the manuscript

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Declarations

Conflict of interest The authors declare no conflict of interests with respect to authorship or publication of this paper.

Research Involving Human and Animal Rights This article does not contain any studies with human or animal subjects.

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- Of importance,
- Of major importance

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