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Armamentariums Related to Percutaneous Nephrolithotripsy (PCNL)

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3.1 Nephroscopes

The choice of the nephroscope is of utmost importance. Although most of the scopes used are rigid ones, the nephroscope's choice depends absolutely on personal preference and availability [1].

3.1.1 Rigid Nephroscopes

Rigid nephroscopes have the advantage of superior optical quality due to the rod lens system, excellent irrigation and working channels. The optimal nephroscope should have a sufficient working length, a large working channel, a reduced outer diameter and a watertight entry site for instruments and accessories [1].

Practically, all nephroscope models have their optical and light cables and the irrigation lines located on the same side of the shaft. Most nephroscope models are designed with a continuous flow system, managed with an inflow and an outflow valve. However, when using a plastic Amplatz sheath, the outer shaft with the outflow valve loses its role; in fact, the irrigation fluid can flow out between the nephroscope and the Amplatz sheath. Although rigid nephroscopes have proven their efficacy and safety through years, they are characterized by limited maneuverability through long tracks (e.g. in cases of horseshoe kidneys) or around complex intrarenal anatomy due to the distance and the spatial location of calculi in the calyces [1, 2].

3.1.2 Flexible Nephroscope

A flexible cystoscope/nephroscope is essential during a contemporary single tract PCNL since it allows access in peripheral calyces that are not reachable with a rigid instrument (e.g. in staghorn stones). With the flexible scope the number of tracts can be minimized. However, through the working channel only flexible instruments can be utilized. For instance, stone fragmentation can be performed only with laser lithotripsy [2].

3.2 Renal Access

Safe and accurate percutaneous renal access is of utmost importance [3]. The best approach to the kidney is ideally achieved by a transpapillary

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puncture with direct access to the renal pelvis [2, 3]. Identifying the ideal target calyx preoperatively as well as obtaining a three-dimensional knowledge of the kidney anatomy and stone burden is the hallmark of a state-of-the-art PCNL. The principal steps of PCNL are primarily puncture of the calyx, followed by tract dilation, stone fragmentation and proper pelvicalyceal system drainage. Standard methods for obtaining access include fluoroscopic and/or ultrasound guidance performed either by radiologists or solely urologists, regardless of the operator's experience [4].

Initially, under fluoroscopic guidance, a 5–7 F ureteric catheter should be inserted cystoscopically (either with a rigid or with a flexible cystoscope) into the renal pelvis or at about 1 cm above the obstructing stone [2].

Non-ionic contrast medium (diluted at 1:2–1:3 ratio in normal saline) sometimes with a few drops of methylene blue is injected for opacification of the collecting system and distend it so that the puncture would be more accurate [2, 5].

The ureteric catheter is fixed to a urethral catheter in order to prevent displacement and provide free access for contrast injection or guide wires insertion.

Equipment

- 5–7 F open-ended ureteric catheter with a Luer-lock fixed proximally
- Urethral (Foley) catheter 14–18 F
- Contrast medium diluted with 0.9% saline and if needed 0.2–0.5 mL of methylene blue in order to give a faint blue color to the mixture so as to be distinguished from urine or blood
- A two-part puncture needle: usually 18-G straight stiff puncture needle, with an oblique beveled tip, 2 cm longer than the Amplatz sheath
- Guide wires (Table 3.1): Preferably, hydrophilic guide wires 0.035–0.038 inch in diameter/150 cm in length, with a straight floppy tip. They are called "slippery" because they can easily slip out of the kidney or through the surgeon's or assistant's hands [5]. They are more expensive than standard polytetrafluoroethylene (PTFE) wires [5, 6]. They can easily find their way and coil in the pelvicalyceal system, by-pass ureteric or renal stones or advance through ureter in the urinary bladder. In rare conditions they can pass through the pelvicalyceal system or ureteric wall, causing a "false route" passage. In order to avoid the latter, we may use a "J-tip" wire, whose tip is a half-circle [5–7]. However, when there is resistance while advancing the hydrophilic wire through the needle there is a risk of stripping its surface. Therefore, the hydrophilic wire should not be pushed in and out the wire when there is resistance

Table 3.1 Guide wire types

Type	Tip	Characteristics
Hydrophilic	Straight or "J"	Diameter: 0.035–0.038 inch Length: 150 cm
Super stiff	Straight	
PTFE	Straight or "J"	

3.2.1 Standard MiniPerc (Table 3.2)

– 12 F rigid nephroscope and 15 F sheath [8, 9]. MiniPerc is the term used for PCNL cases with tract size less than or equal to 18–20 F [10, 11].

3.2.2 Super MiniPerc

– Use of active irrigation and active suction.
– 7 F nephroscope and 8 F sheath. The telescope consists of a 3 F fibre-optic bundle [12].

3.2.3 Ultra MiniPerc

– 3.5 F miniature nephroscope and 11/13 F sheath [13].

3.2.4 Micro PCNL

– Micro-fiber optics of 2–3 F, all-seeing needle 4.8 F or 8 F micro-sheath. Drainage of collecting system is provided through a ureteral catheter inserted preoperatively [14].

Table 3.2 Conventional and miniaturized PCNL

	Conventional	Mini	Super mini	Ultra mini	Micro
Dilatation	Yes	Yes	Yes	Yes	No
Fragmentation	Ultrasound Pneumatic Combined Laser	Laser	Laser	Laser	Laser
Amplatz sheath	30 F	15 F (<18–20 F)	8 F	11 F/13 F	No
Nephrostomy	Mostly	Rare	No	No	No

3.3 Renal Tract Dilation

Tract dilation is the second crucial step for a successful PCNL procedure where costly disposables could be utilized. There are five standard tract dilation techniques for PCNL: Amplatz fascial dilation (AFD) [15], metal telescopic dilation of the Alken type (AT) [16, 17], balloon dilation (BD) [18], one-shot dilation (OSD) [19] and radially expanding single-step nephrostomy dilator (RESN) [20]. Each of the five types has its own advantages and disadvantages. In general, the choice depends on the availability and the surgeon experience and, therefore, there is no consensus regarding the best dilation technique [21]. For instance, there are no significant differences in stone-free and transfusion rates between OSD and AT while there are significant differences in tract dilatation fluoroscopy time and hemoglobin decrease between the OSD and AT groups. Significant differences in transfusion rates were found between the BD and AT groups while among patients without previous open renal surgery those who underwent BD exhibited a lower blood transfusion rate and a shorter surgical duration compared with those who underwent AFD. The OSD technique is safer and more efficient than the AT technique for tract dilation during PCNL, particularly, in patients with previous open renal surgery, resulting in a shorter tract dilatation fluoroscopy time and a lesser decrease in hemoglobin. The efficacy and safety of BD are better than AFD in patients without previous open renal surgery. As a result, the OSD technique should be considered for most patients who undergo PCNL therapy [21–23].

Equipment

1. Amplatz fascial dilators [15, 24]
   - Polyurethane, single use
   - 8F flexible polyurethane dilator sliding over the working guidewire and whenever it is possible descending into the ureter
   - The polyurethane dilator protects the guidewire and prevents kinking during progressive dilation
   - Stepwise tract dilation until the desired caliber is reached (usually up to 30–32 F)
   - Each dilator has to be removed before next insertion of the larger dilator and, therefore, in the time interval the tract may bleed
   - In cases of large hydronephrosis, the kidney can collapse between dilator exchanges
2. Alken-type telescopic dilators [16]
   - Metal, reusable and autoclavable
   - Prevent bleeding between each dilator insertion due to parenchymal tamponade
   - No hydronephrotic system deflation, no serial exchange
   - Particularly fit for patients with previous open renal surgery/scar tissue
3. Balloon dilator [18]
   - Olbert balloon catheter 8–10 mm in diameter and 4 cm long attached to an Amplatz gauge system, a racket and screw mechanism as well as a syringe
   - Single use
   - Balloon over the guide wire (through the fasciae and into the kidney) and inflated under fluoroscopy, usually up to 20 atm
   - Radial inflation, not shearing process
   - Kidney tamponade with inflation
   - Difficult to inflate in dense scar tissue

4. One-shot (single-stage) dilator [19]
    - A single 25 F or 30 F Amplatz dilator pulled in on the Alken guide or on the 8 F first polyurethane dilator of the Amplatz set
    - Single use
    - Dilator inserted over guidewire in a single rotating maneuver
    - Kidney tamponade during insertion
5. Radially expanding single-step dilator [20]
    - 8 F woven sleeve with an inner stylet
    - 30 F tapered fascial dilator
    - Amplatz-like working sheath
    - Significantly low axial forces transmitted in kidney
6. Amplatz sheath [5]
    - Firm Teflon or polyurethane tube
    - Not to be advanced blindly
    - Usually with diameter of 30 F
    - The hydrostatic pressure perioperatively is always less than 10 cm H_2O
    - Smaller Amplatz sheaths, those compatible with 22 F nephroscopes
    - Conventional Amplatz sheaths are inadequate for obese patients. Place a suture at the outer edge to avoid inward migration
    - “Peel away” sheath to facilitate nephrostomy tube placement in the end of procedure

3.4 Lithotripsy

Several fragmentation devices are available for clinical use. The three mostly used devices for intra-corporeal lithotripsy, include ultrasound, ballistic and laser lithotripters, or a combination of these energies.

3.4.1 Ultrasound Lithotripters

Contemporary ultrasonic lithotripters consist of a handpiece containing a piezoelectric crystal which is stimulated by electric energy and is activated by a pedal switch [25, 26]. The stone fragmentation is achieved by high-frequency vibration (23.000–27.000 Hz) [1, 5, 8]. The longitudinal vibration is transmitted to the stone with the help of a hollow probe, resulting in rapid fragmentation especially in cases of soft stones [27]. The handpiece has also a central channel on the same axis of the probe, allowing suction of the irrigation fluid and stone particles during all the fragmentation process as well by keeping the visual field clear in the unlikely event of bleeding [28]. Unfortunately, it may be obstructed by fine stone remnants or collapse the collecting system of the kidney, thus limiting vision intraoperatively. It is usually atraumatic to tissues and also helps to cool both probe and handpiece. It can remove large volumes of stone without needing to remove and re-insert the nephroscope; however, since it should be directly applied to the stone, the stone should be immobilized. For conventional PCNL, usually 10 F probes are used [1, 5, 8].

3.4.2 Pneumatic (Ballistic) Lithotripters

Pneumatic lithotripsy works similarly to a pneumatic jackhammer [29]. It functions with the use of compressed air that practically bursts against the head of the metal probe at a frequency up to 12 cycles per second [1, 5, 30]. Shots can be triggered by a foot pedal switch in a single- or a multiple-pulse mode setting. It is more effective in large and hard renal stones that should preferably be immobilized but the latter combined with the “jackhammer effect” may cause bleeding [31, 32].

A relatively novel handheld pneumatic lithotripter has been presented [1]. It is a cordless handheld device that is powered by a disposable, detachable compressed carbon dioxide (CO_2) cartridge [1, 5]. The shot is initiated by a hand-activated trigger rather than a foot pedal. When the CO_2 abruptly expands, its pressure projects the hammer against the firing pin, transmitting the kinetic energy to a metallic probe that should be held in contact with the stone. One significant advantage of this device is the minimal displacement at the tip of the probe, despite the high energy of the mechanical shock [33]. The amount of pressure transmitted to the stone is 31 bars, compared with the 3 bars of standard pneumatic lithotripters.

Large fragments are easily generated and can be quickly extracted. Because of progressive drop of the gas pressure inside the cartridge, the energy of the impulses simultaneously decreases. One cartridge provides approximately 70 shocks [1, 5].

3.4.3 Combined Pneumatic and Ultrasound Lithotripter

This device consists of a combined generator delivering simultaneously pneumatic ad ultrasonic energy. The two sources of energy are transmitted to a handpiece and triggered with a dual foot switch. The 3 F pneumatic probe, set to a 5 Hz frequency, is advanced through the hollow 10 F ultrasonic probe without protruding [1, 5]. The pneumatic shockwave produces gross fragmentation. The ultrasound completes the fragmentation and allows for aspiration of fine stone fragments. Suction is synchronized with ultrasound fragmentation [34–36].

3.4.4 Laser

The principle of laser fragmentation of the stones consists of the localized explosive boiling of water near the stone, resulting in a shockwave [37–39]. Lasers used for stone treatment should have a wavelength belonging to the infrared spectrum, such as erbium:YAG, holmium:YAG or CO_2.

The holmium:YAG laser is characterized by high water absorption and a penetration that does not exceed 0.4 mm with pulse duration varying between 150 and 1000 μs. Lasers are mostly used for miniaturized PCNL as presented above with fibers up to 500 um [1, 5].

3.5 Retrieval Equipment

3.5.1 Graspers

Alligator forceps have an active grasping mechanism, similar to surgical forceps, practically having a scissor handle that allows to open and close its jaws [40]. The jaws open in a “V” shape and, therefore, cannot grasp large fragments (bigger than 4 mm) since they are pushed away as the jaws close [41].

Triradiate forceps have a passive grasping mechanism with a U-shaped handle without joints or complex hinges [1, 5]. Stones are grasped by three-serrated jaws with a sharp claw at the tip [42, 43]. They can grasp larger stone fragments. However, since the jaws are sharp and thin and when widely spreading out they can easily perforate the collecting system and further tear it during closure. In practice, they are better used in dilated or larger than confined spaces. In order to avoid trauma to the collecting system the forceps could be slightly rotated before retrieval in order to check all three jaws.

3.5.2 Baskets

Tipless dismembered baskets are very useful, especially for large fragment extraction. Basket wires are of smaller caliber compared to metallic grasper jaws and, therefore, allow removal of larger stone fragments through the Amplatz sheath [43, 44].

3.5.3 Flashing out Fragments

In cases of fragments that can pass through the Amplatz sheath, a cut nasogastric tube (14–16 F) can be inserted through the sheath—if possible next to or behind the fragments. By repeatedly moving forward and backward in a “jerking” motion while saline is instilled under some pressure to create turbulence, the mechanical flushing out of stone fragments is achieved based on the “Bernoulli effect” [45].

3.6 Nephrostomy/Exit Strategies

Most urologists leave a 10–18 F nephrostomy/catheter in the kidney following PCNL in order to achieve *nephrostomy trifecta*: kidney drainage (primarily of urine, blood clots and small stone debris), hemostasis and healing and access of collecting system postoperatively (reentry, imaging or chemolysis). It is usually left open draining the kidney for first 24–48 h postoperatively [46, 47]. It is initially closed, left in place and re-opened if the patient experiences pain or fever or removed if the case is uneventful [48].

3.6.1 Loop Nephrostomy

The fine self-retaining (pig-tail-like) nephrostomy with an internal string attached in order to form a loop into collecting system can be easily removed by cutting the string. Care must be taken when a loop nephrostomy is inside the upper loop of a JJ stent [49]. In this case they can be tangled, and the JJ stent accidentally removed with nephrostomy removal [1, 5, 8].

3.6.2 Balloon Catheter

Simple or two-piece balloon catheters 12–18 F which are easily placed and removed [50]

3.6.3 Tubeless Nephrostomy

No nephrostomy/drainage is left while a JJ stent may be or may not be in situ. This is an advantage of miniaturized PCNL which is gaining popularity with novel laser technology [51].

3.6.3.1 Tubeless but Stented PCNL

In particular cases, where an alternative ureteral drainage is needed in order to prevent urine leakage through the percutaneous tract, a JJ stent is placed. Ureteral spasm or stenosis or UPJ edema revealed with difficult passage of the contrast medium down the ureter to the bladder small stone fragments in the ureter or cases with risk of clot formation, which are the most frequent criteria for JJ stent placement [1]. JJ stents used are either with a string attached that can be removed by the patient within a few days or without string that are usually left for longer periods (e.g. 3–6 weeks). Advantages of JJ stent placement are urine drainage facilitation leading to better percutaneous tract healing, dilation of the ureter in cases of spasm, edema or stenosis and ease of small stone fragment passage. Disadvantages of JJ stent placement are stent-related symptoms that need to be relieved with medication, cost increase and need for further endoscopic procedure to remove it [52–56].

3.6.3.2 Totally Tubeless (Unstented) PCNL

The totally tubeless PNL (tubeless and stentless with no postoperative drainage of the operated collecting system at all) is reserved for very selected cases with no bleeding, no residual stone fragments or other complicating elements [1].

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