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Review

Innovations in percutaneous nephrolithotomy

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HIGHLIGHTS

- Non contrast CT remains gold standard for PCNL. 3D reconstructions may be useful.
- Prone, supine or variation thereof depends on patient and surgeon preference.
- Accurate needle placement is key in PCNL, new techniques may improve outcomes.
- Ultrasound, pneumatic, combo or laser each have their place in stone disintegration.
- Tubeless PCNL is feasible, but remains underused. QoL of DJ vs tube is questioned.

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ABSTRACT

Technical innovations in all aspects of percutaneous nephrolithotomy have changed the field considerably. The current review is aimed at reporting on the most recent advancements in the field of percutaneous nephrolithotomy. Improvements in CT imaging and the possibility of 3D rendering have dethroned the intravenous pyelogram as gold standard for pre-operative imaging. Where gaining access in the lower pole in prone position with telescopic metal dilators, placing a 30F tract used to be standard, the plethora of alternatives provides the trained surgeon with a large armamentarium to tackle any obstacle. Novel lithotripters appear more efficient than their predecessors and with tubeless PCNL gaining some momentum, ambulatory PCNL is slowly but surely becoming feasible rather than fictional.

1. Introduction

Endourology is an ever evolving field of urology in which technology has played a pivotal role, transferring open stone surgery from contemporary surgical handbooks to surgical history books.

The past decade has provided us with significant technical innovations to experiment with and resulted in improved diagnostics, miniaturization of PCNL, a whole new armamentarium of potential needle guidance technologies and improved stone fragmentation and evacuation. In the current review, we discuss the most relevant new technologies and advancements that have been introduced into diagnosis and treatment of renal calculi with percutaneous nephrolithotomy (PCNL).

2. Preoperative imaging and treatment planning

Despite recent reports advocating ultrasound as primary imaging modality to assess patients with renal colic [1], non contrast computed tomography (NCCT) remains the gold standard of imaging for stone burden assessment, especially prior to percutaneous nephrolithotomy (PCNL) [2]. A NCCT will provide the clinician with essential pre-operative information such as stone size, density, complexity and location, as well as anatomical information about the patient, the kidney and its relations to surrounding organs.

Due to frequent imaging necessary during diagnosis, preoperative planning, intra-operative guidance and follow-up of patients with urinary stone disease that necessitates a PCNL, the radiation dose can accumulate considerably [3]. This has fueled the

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continuous search for low-dose and ultra-low-dose CT protocols using knowledge based iterative model reconstructions, filtered back projection and statistical iterative reconstruction. Using these protocols, the radiation dose can be reduced to 3 mSv or less while still providing an adequate image and comparable diagnostic performance when compared to regular dose CT protocol [4–7]. As radiation dosages of low-dose CT approach that of an X-ray of the Kidneys Ureters and Bladder (KUB) while providing significantly more information, a KUB may become redundant in the near future [8].

Although not widely available, dual-energy CT scans hold the promise of improved differentiation between different stone types. Whereas uric acid stones can be identified more accurately than with regular NCCT, recent reports are not unanimous in the potential of dual energy CT differentiating non-uric acid stone types with positive predictive values varying from 54.6% to 100% [9–12]. Miller and colleagues revisited the initial work by Brödel [13] and Sampaio [14] and aimed to identify the calyceal anatomy using three-dimensional (3D) CT rendering from a retrospective cohort of 100 kidneys. They demonstrated the lower pole to be mostly constructed of 3 calyces, the second of which is usually located posteriorly [15]. As several groups have reported promising clinical results with 3D reconstructions, further prospective evaluation is warranted to evaluate whether or not 3D reconstructions allow for a more accurate access during PCNL [16,17].

Adequate pre-operative imaging is also a prerequisite to the currently available prognostic models, aimed at predicting outcomes after PCNL. Multiple scoring systems have emerged in the past decade: including the Guy's score, the S.T.O.N.E. (stone size [S], tract length [T], obstruction [O], number of involved calices [N], and essence or stone density [E]) score, the Seoul Renal Stone Complexity Score, the CROES nomogram and the staghorn morphometry platform [18]. Although all these scoring systems have been compared and externally validated retrospectively, none of these has been consistently proven to be superior in its accuracy of predicting outcomes after PCNL [19–21]. Prospective validation of the current models may eventually demonstrate superiority or identify the need for a new, more comprehensive, more accurate prediction model.

In the past, long-term courses of antibiotics have been suggested for patient with large stones and dilated systems [22,23]. In response, several groups have demonstrated that a longer course of pre-operative or post-operative antibiotics did not procure a lower infection rate when compared to a prophylaxis of 24 hours or less [24–26]. The CROES database has taught us that omitting a prophylactic dose of antibiotics comes with a significantly increased risk of infectious complications [27]. The most recent guidelines of the American Urological Association and the European Association of Urology recommend the use of a single dose of oral or intravenous antibiotic prophylaxis in the absence of any risk factors such as a non-sterile pre-operative urine sample or the presence of known infectious stone disease [28,29].

3. Patient positioning

Since the first description of PCNL in 1976 in prone position [30], many different patient positioning alternatives and modifications have been evaluated, to facilitate a combined antegrade and retrograde approach such as the reverse lithotomy and prone split leg position, or to accommodate morbidly obese or respiratory challenged patients such as supine positions (Table 1). Although the first description of supine PCNL was published over 25 years ago [31], its popularity increased only in the past 10–15 years with cardiovascular, respiratory and ergonomic benefits becoming more and more apparent [32]. An initial meta-analysis published in 2010, including a mere 389 patients from 2 randomized controlled trials (RCTs) and 2 case-control studies, concluded that prone and supine positions for PCNL resulted in equivalent stone free rates (SFR) and complications [33]. A more recent meta-analysis, published in 2016, comprised of 6881 patients from six RCTs and seven retrospective studies [34]. Due to the large number of patients from the CROES database, accounting for 5775 of all the patients in the analysis, and the high degree of heterogeneity, the results should be interpreted with caution. Taking the sensitivity analyses into account, supine PCNL confers no benefit over prone PCNL with regards to SFR, transfusion rate and hospital stay but does come with a significantly reduced operating time (OT) and risk of postoperative fever [34]. The large variety of possible positioning alternatives may indicate that there is no ideal positioning that is universally accepted. Patient positioning depends on multiple factors, including patient-related factors, stone burden and surgeon's preference. An online survey recently administered to endourologists demonstrated prone PCNL still to be predominantly preferred [35].

Table 1
Modifications to the prone and supine positions for PCNL.

Prone modifications	Supine modifications
Classic prone 1976 [30]	Valdivia 1990 [31]
Reverse lithotomy 1988 [122]	Galdakao-modified Valdivia 2007 [123]
Prone split-leg 1991 [124]	Complete supine 2008 [125]
Flank roll 1993 [126]	Barts Technique 2008 [127]
Lateral/Flank 1994 [128]	Oblique supine lithotomy 2012 [129]
Prone-flexed 2009 [130]	Flank suspended 2012 [131]
	Barts flank-free modified 2012 [132]
	Modified complete supine 2013 [133]

4. Percutaneous access

4.1. Gaining access

Whether positioned prone, supine or in any of the modified positions, gaining adequate access into the collecting system is key to performing successful PCNL. Interestingly, 24% of respondents to an online survey report to rely on interventional radiology or other means to gain access into the kidney for PCNL [35]. According to the CROES PCNL global study, fluoroscopy guided access (by triangulation or bull's eye technique) represents 63.6% of the global approach, whereas 15% uses both fluoroscopy and ultrasound to gain access [36]. CT-guided and endoscopy guided access was performed in 11.1% of cases and ultrasound guided access was least performed with only 10.4%. In recent years however, it seems that in an effort to reduce radiation exposure to both the surgical staff and the patient, ultrasound guided techniques are gaining popularity [37–40]. The learning curve for an experienced endourologists was established to be 20 cases and using a phantom model, ultrasound-guided needle placement appears to be a skill teachable to trainees as well [38,41]. In a matched case analysis, based on the CROES PCNL Global Study database, Andonian et al. demonstrated that the imaging modality used to gain access does not influence the SFR or complication rate after PCNL [42]. Several small RCTs have corroborated these results, demonstrating that in trained hands, the outcomes of ultrasound guided PCNL with regards to SFR, complications and hospital stay are comparable to fluoroscopy guided PCNL [43–46].

Direct endoscopic visualization of the targeted calyx with retrograde ureteroscopy or antegrade flexible nephroscopy can be a useful adjunct to either of the imaging guidance modalities in either prone or supine position. A web-based survey identified 68%