Curr Urol Rep (2015) 16: 29
DOI 10.1007/s11934-015-0501-2

NEW IMAGING TECHNIQUES (A RASTINEHAD AND S RAIS-BAHRAMI, SECTION EDITORS)

Percutaneous Stone Removal: New Approaches to Access and Imaging

Rick C. Slater · Michael Ost

Abstract Percutaneous renal access and removal of large renal calculi was first described nearly 40 years ago and has since become the gold standard in management of large and complex renal calculi. In this same time period, technological and medical advances have allowed this procedure to develop in improved efficacy and morbidity. The following review offers an update to new approaches to percutaneous renal access and imaging in the management of large and complex renal calculi.

Keywords Imaging techniques · Percutaneous renal access · Complex renal calculi

Introduction

Nephrolithiasis is a very common medical condition: within the USA, the prevalence is 8.8 % or 1 in every 11 people, or nearly 1.2 million people affected in 2014 [1, 2]. At time of presentation, stone size, location, and clinical parameters influence treatment options. Percutaneous nephrolithotomy (PCN) was first described in the 1970s [3]. Yet, shortly after PCN was described, shock wave lithotripsy (SWL) was introduced to the urological community as the first noninvasive treatment of renal and ureteral calculi, and this served to initially curb interest in PCN [4]. However, it was not long until the limitations SWL were recognized, particularly with respect to large and complex stones, and therefore, PCN became accepted as the treatment of choice for large renal calculi. In fact, stone size has such a profound influence on stone-free rates and need for subsequent procedures; this factor alone has led both the American Urologic Association (AUA) Guidelines for the Management of Staghorn Calculi [5] and the European Association of Urology Guideline on Urolithiasis to recommend PCN [6] for all stones equal to or greater than 2 cm and those equal to or greater than 1.5 cm in the lower pole.

Nearly four decades have passed since the description of the first PCN, and while the basic premise has remained, tremendous advances in medical imaging, renal access techniques, and surgical approaches have dramatically influenced this fundamental surgical technique of percutaneous stone removal.

Imaging

Medical imaging has dramatically influenced the medical community; modern clinical medicine capitalizes on a variety of the advances seen in this field—from the discovery of the X-ray by Röntgen in the nineteenth century, later advancements with sonar in medical applications (ultrasound), and the mid twentieth century expansion and discovery of cross-sectional computed tomography (CT) and magnetic resonance imaging (MRI) [7, 8]. These developments have also changed the field of urology, adding to the armamentarium available to the urologist in diagnosing, treating, and following patients with stone disease summarized in Table 1.

Dual-Energy CT

In addition to stone size and location, composition too has become essential information to account for when preparing treatment plans for patients. For example, uric acid (UA) stones can be treated with urinary alkalization, struvite stones typically require antibiotic management prior to surgical

---

This article is part of the Topical Collection on *New Imaging Techniques*

R. C. Slater (✉) · M. Ost
Department of Urology, University of Pittsburgh Medical Center,
5200 Centre Avenue, Suite 209, Pittsburgh, PA 15232, USA
e-mail: slaterrc@upmc.edu

Table 1 Summary of available imaging techniques

Imaging technique	Main use	Advantages	Disadvantages
X-ray (i.e. utilizes ionizing radiation for image acquisition)			
CT	Diagnosis Preoperative planning	3D reconstruction Axial imaging	High cost Radiation exposure
Dual-energy CT	Differentiate stone composition alongside conventional CT preoperative planning	All advantages of conventional CT plus ability to differentiate stone composition	Radiation exposure (same as low-dose CT) High cost
Fluoroscopy	Intraoperative real-time images	Real-time images Low cost	Operator-dependent radiation exposure 2D imaging
KUB	Preoperative planning and postoperative follow-up	Minimal radiation exposure	2D images Unable to see radiolucent stones
Ultrasound			
US 2D	Preoperative planning and intraoperative	Real-time images Able to perform percutaneous access under direct vision	Poor quality images 2D images User dependent Small stones missed
US 3D	Preoperative planning	3D images	No real time User dependent Small stones missed
Magnetic resonance imaging (MRI)			
MRI	Preoperative planning	High contrast and resolution in multiple different planes	High cost Long image acquisition time
Endoscopic imaging			
Nephroscope/ureteroscope	Intraoperative	Real-time visualization of structures and stones	Only visible information available

intervention, and calcium-containing stones of different densities may influence one surgical intervention over another. Preoperative determination of stone composition, therefore, may play a decisive role in determining the best management of these different patient populations' pathology.

Conventional (single energy) noncontrast helical CT is usually the diagnostic test of choice for determining stone size and location. Furthermore, a Hounsfield unit (HU) measurement of the stone has long been believed to be an estimate of stone hardness and/or composition. While this has been demonstrated in vitro, results of in vivo studies have been disappointing, notating a significant overlap in radiodensities of different stone compositions [9]. However, this limitation can be overcome with dual-energy CT (DECT).

The DECT concept has been known since the development of the conventional CT. However, until recently, its clinical application has been limited by technical difficulties concerning radiation exposure and the generation of two different X-ray beams of low and high energy [10]. Simply, with DECT, two image datasets are obtained in the same anatomic location with two different X-ray tube potentials that allows for the production of color-coded reconstructed images based on the ratio of attenuations obtained. Ultimately, the analysis of different attenuations of the same materials provides a calculation of the effective atomic number (Zeff), a descriptor of density and atomic number of a material, used to differentiate materials. Thus, two different materials, which are similar in attenuation on one spectrum, are more easily differentiated on images acquired with another spectrum [2, 10–12]. Clinically, this concept provides a very useful diagnostic tool to the endourologist in determining stone composition, particularly when stones are of a mixed composition.

Recently published studies have given credence to the superiority of DECT over conventional CT, demonstrating not only the ability of DECT to accurately predict UA and non-UA stones of pure composition with near perfect sensitivity and accuracy but also being able to accurately stratify struvite, cysteine, and mixed calcium-salt stones [2, 13•]. In the setting of an indwelling ureteral stent, the DECT algorithm can clearly demarcate calculi adjacent a stent. Further, recent work has shown that commonly used ureteral stents are also color coded on their DECT attenuation characteristics, which allows for optimal stent selection at time of intervention to prevent follow-up imaging being obscured by the stent [14]. At least one case report has demonstrated the advantage of this color-contrasting ability by DECT which subsequently resulted in the successful medical treatment of the remaining stone burden following PCN [15].

Ultrasound

Ultrasound is a common technology in the armamentarium of the urologist as well and is now routinely utilized for percutaneous guidance to the kidney with documented success rates of 88–99 % [16]. Furthermore, ultrasound is noninvasive and has no ionizing radiation while offering a real-time visualization of surrounding structures and identification of non-opaque stones. However, ultrasound is still highly operator dependent; inaccurate assessment during ultrasound-guided needle puncture at time of PCN access can result in catastrophic injury to the kidney and surrounding organs.

Since the description of the first percutaneous nephrostomy placement in 1974 [17], efforts at modifying the surgical technique have continuously tried to improve the risk profile and patient outcomes of the PCN. However, until recently, these efforts have been fraught with the limitation of needing real-time 3D information but limited to 2D images during access. 2D images lack quality, are limited by shadowing and speckle artifacts, and are user dependent at obtaining optimal images. Furthermore, while ultrasound-guided percutaneous access to the kidney for PCN is attainable as has been recently shown to be successful in a large patient series [18], the experience and skill required to be proficient at maintaining an unobstructed view of the target while manipulating the ultrasound transducer is not acquired in most urologic training programs.

Still, on the horizon are novel approaches utilizing ultrasound guidance, but eliminating the spatial 2D limitations by utilizing electromagnetic tracking (EMT) sensors which provide constant real-time feedback to ascertain perfect needle position to the targeted area. This new approach has been demonstrated in an in vivo pig model [19]. Currently, systems such as the SonixGPS system (Ultrasonix, Medical Corp Richmond, BC, Canada) have been developed to predict and observe the trajectory of the needle before and during percutaneous needle access and therefore assists in needle-beam alignment and overall guidance to the target for successful PCN access [20].

Implications of novel ultrasound technology and techniques are far reached; developing countries which have communities that lack medical infrastructure and large percentages of the populations which belong to a low socio-economical status benefit greatly from these advances. Upper urinary tract drainage is required in variety of clinical situations, particularly when prompt percutaneous decompression is required. In a recent stepwise description of an ultrasound-guided PCN tube placement, the authors sought to emphasize a technique which was easy to acquire, economical, and mathematically precise for such a situation [21].

Access

Each surgery has its critical steps which overwhelmingly influence the outcome, and PCN is no different; establishing renal access is a critical step, and the location of such access has dramatic impacts on the overall outcome of the PCN. Recent literature appears to confirm the notion that access obtained by a radiologist is inferior to access obtained by the urologist in respect to complications and stone-free rates [22–24]. Although, it should be noted that this conclusion is drawn with the caveat that most of these retrospective reviews include patients whose renal access was obtained primarily by radiologists in an emergent setting for purposes of acute renal decompression, not necessarily accounting for needed future operative access.

A recent survey of fellowship trained endourologists demonstrated that the majority of endourology fellowship trained urologists, 77 %, planned and obtained their own access immediately prior to the PCN [25]. Although, this was in contrast to a previous survey which assessed the clinical activities of a broader range of urologists in the treatment of larger renal stones and found that roughly three quarters of those surveyed preformed PCNL, but only 11 % obtained their own access [26]. Without question, the most notable difference here is the populations surveyed, primarily fellowship trained urologists versus those from a broader training spectrum. Current literature has demonstrated a plethora of new techniques and tricks to teach the developing urologist the necessary critical skills to competently perform a successful PCN from access to stone clearance. In just the past several of years alone, for example, among others, there has been the creation and validation of a surgical virtual reality simulator for PCN [27–29], a three-finger technique aimed at helping junior urology trainee comprehend access [30], and development of a silicone collecting system model for training [31]—all aimed to address the steep learning curve, which has been estimated to be about 60 cases [32].

The importance of the location of renal access location cannot be overstated. Upper pole renal access remains the most versatile of all access locations, but typically requires traversing hazardous anatomical landmarks (e.g., lung, spleen, liver). When upper pole access tracts were evaluated in a large series, nearly three quarters were found to be above the 12th rib and the remaining above the 11th rib with an overall complication rate of 16.3 % [33]. Thus, until recently, there was a paucity of robust data to augment the risk of primarily obtaining access anywhere but first in the relatively safe lower pole collecting system if given a choice. Attempting to answer this question, the large Clinical Research Office of the Endourological Society (CROES) study reviewed data on 4494 patients from 96 centers globally undergoing PCN that found that in select patients, isolated upper pole access had a higher stone-free rate, albeit with the caveat of a higher complication rate and longer hospital stay [34]. Nevertheless, this data has fueled further investigation which is now challenging the dogma of primary lower pole access; a recent comparison of PCN cases where patients either underwent a primary lower pole access versus primary upper pole access demonstrated not only no difference in analgesic requirements and overall complication rate but also upper pole access was superior to lower pole access in stone-free rate after second-look PCN [35].

Tubeless PCNL

Another active area of investigation is the latest developments in whether or not to retain access following a PCN via a nephrostomy tube. In many practices, it is still customary to leave a large bore (20–28 Fr) nephrostomy tube in place following a PCN to allow for maximal collecting system drainage, tamponade any bleeding along the access tract, and facilitate quick access for second-look nephroscopy. However, advances in endoscopic skill, technology, and knowledge of the impact of nephrostomy tube morbidity have paved the way for a new conversation. It has been known for some time that smaller diameter nephrostomy tubes did indeed result in less postoperative pain, narcotic requirements, and hospital stays [36–39], and therefore, surgeons have consistently edged to leave the collecting systems drained with the smallest available tube.

The miniperc, or minimally invasive PCN, technique was demonstrated first in infants and preschool children with the use of a miniaturized nephroscope and a 11-Fr peel-away vascular sheath [40]. In the succession of attempting to gain a lesser morbid operation through smaller access tracts in the adult population, the “ultra miniperc” has evolved and been described with good success [41]. This too, essentially simultaneously, has continued to evolve to test the limits of leaving the collecting system undrained, a procedure known as a “tubeless” PCN procedure, where drainage is accomplished with only an internal ureteral stent. The pinnacle of this achievement, however, has been coined a “total tubeless” PCNL; the collecting system is left without drainage or immediate removal in the perioperative period of an externalized ureteral stent, a procedure which has evolved dramatically [42]. Though, it can be argued that a stringent patient selection criterion is one of the largest factors contributing to the success of this operation [39, 42, 43••, 44–46].

Until recently, there was little strong evidence for a total tubeless PCN. However, a recent meta-analysis in which pooled result analysis showed the tubeless and stentless group had significantly decreased hospital stay duration, analgesic requirements, and time to normal activity in the tubeless procedure [43••]. Furthermore, these findings have been confirmed in a safety and cost-effectiveness study comparing the clinical outcomes and cost analysis of standard PCN and totally tubeless PCN which also demonstrated a significantly decreased analgesia requirements, hospital stays, and comparable stone-free rates with more than $465 in cost savings [47].

Conclusions

Since the description of the first PCN in the 1970s and its subsequent adoption as the mainstay treatment for large renal calculi, the field of urology has evolved rather dramatically. This evolution has seen significant advances in the appreciation of the natural history and pathology of stone disease. Moreover, as PCN has remained the surgical mainstay of treatment for large renal calculi, this evolution has encompassed major advances in medical imaging and preoperative preparation, improvements in percutaneous renal access safety and efficacy, and lastly, dramatic changes in the PCN procedure itself. If the past is any predictor to the future, the future is bright and ripe with opportunities to continue these advances in percutaneous stone removal.

Compliance with Ethics Guidelines

Conflict of Interest Dr. Rick C. Slater and Dr. Michael Ost each declare no potential conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance

1. Scales CD Jr, Smith AC, Hanley JM, Saigal CS; Urologic Diseases in America Project. Prevalence of kidney stones in the United States. Eur Urol. 2012;62(1):160–5.
2. Kulkarni NM, Eisner BH, Pinho DF, Joshi MC, Kambadakone AR, Sahani DV. Determination of renal stone composition in phantom and patients using single source dual energy CT. J Comput Assist Tomogr. 2013;37(1):37–45.
3. Fernstrom I, Johansson B. Percutaneous pyelolithotomy. A new extraction technique. Scand J Urol Nephrol. 1976;10(3):257–9.
4. Antonelli JA, Pearle MS. Advances in percutaneous nephrolithotomy. Urol Clin N Am. 2013;40(1):99–113.
5. Preminger GM, Assimos DG, Lingeman JE, Nakada SY, Pearle MS, Wolf JS Jr; AUA Nephrolithiasis Guideline Panel. Chapter 1: AUA guideline on management of staghorn calculi: diagnosis and treatment recommendations. J Urol. 2005;173(6):1991–2000.
6. Türk C, Knoll T, Petrik A, Sarica K, Skolarikos A, Straub M, et al. Guidelines on urolithiasis. Arnhem: European Association of Urology (EAU); 2013. p. 100 *[687 references].*

7. Bradley WG. History of medical imaging. Proc Am Philos Soc. 2008;152(3):349–61.
8. Seibert J. One hundred years of medical diagnostic imaging technology. Health Phys. 1995;69(5):695–720.
9. Motley G, Dalrymple N, Keesling C, Fischer J, Harmon W. Hounsfield unit density in the determination of urinary stone composition. Urology. 2001;58(2):170–3.
10. Kraśnicki T, Podgórski P, Guziński M, Czarnecka A, Tupikowski K, Garcarek J, et al. Novel clinical applications of dual energy computed tomography. Adv Clin Exp Med. 2012;21(6):831–41.
11. Matlaga BR, Kawamoto S, Fishman E. Dual source computed tomography: a novel technique to determine stone composition. Urology. 2008;72(5):1164–8.
12. Kaza RK, Platt JF, Cohan RH, Caoili EM, Al-Hawary MM, Wasnik A. Dual-energy CT with single- and dual-source scanners current applications in evaluating the genitourinary tract. RadioGraphics. 2012;32:353–69.
13.• Wisenbaugh ES, Paden RG, Silva AC, Humphreys MR. Dual-energy vs conventional computed tomography in determining stone composition. Urology. 2014;83(6):1243–7. *The authors do an impressive job at demonstrating how this new and exciting technology of dual-energy CT is superior to conventional CT and propose and provide a foundation for future validation studies*.
14. Jepperson MA, Thiel DD, Cernigliaro JG, Broderick GA, Parker AS, Haley WE. Determination of ureter stent appearance on dual-energy computed tomography scan. Urology. 2012;80(5):986–9.
15. el Ibrahim SH, Haley WE, Jepperson MA, Thiel DD, Wehle MJ, Cernigliaro JG. Three-dimensional dual-energy computed tomography for enhancing stone/stent contrasting and stone visualization in urolithiasis. Case Rep Urol. 2013;2013:646087.
16. Lojanapiwat B. The ideal puncture approach for PCNL: fluoroscopy, ultrasound or endoscopy? Indian J Urol. 2013;29(3):208–13.
17. Pedersen JF. Percutaneous nephrostomy guided by ultrasound. J Urol. 1974;112(2):157–9.
18. Yan S, Xiang F, Yongsheng S. Percutaneous nephrolithotomy guided solely by ultrasonography: a 5-year study of >700 cases. BJU Int. 2013;112(7):965–71.
19. Rodrigues PL, Vilaça JL, Oliveira C, Cicione A, Rassweiler J, Fonseca J, Rodrigues NF, Correia-Pinto J, Lima E. Collecting system percutaneous access using real-time tracking sensors: first pig model in vivo experience. J Urol. 2013;190(5):1932–7.
20. Li R, Li T, Qian X, Qi J, Wu D, Liu J. Real-time ultrasound-guided percutaneous nephrolithotomy using SonixGPS navigation: clinical experience and practice in a single center in China. J Endourol. 2015;29(2):158–61.
21. Lodh B, Gupta S, Singh AK, Sinam RS. Ultrasound guided direct percutaneous nephrostomy (PCN) tube placement: stepwise report of a new technique with its safety and efficacy evaluation. J Clin Diagn Res. 2014;8(2):84–7.
22. Watterson JD, Soon S, Jana K. Access related complications during percutaneous nephrolithotomy: urology versus radiology at a single academic institution. J Urol. 2006;176(1):142–5.
23. El-Assmy AM, Shokeir AA, Mohsen T, El-Tabey N, El-Nahas AR, Shoma AM, Eraky I, El-Kenawy MR, El-Kappany HA. Renal access by urologist or radiologist for percutaneous nephrolithotomy—is it still an issue? J Urol. 2007;178(3 Pt 1):916–20. *discussion 920*.
24. Tomaszewski JJ, Ortiz TD, Gayed BA, Smaldone MC, Jackman SV, Averch TD. Renal access by urologist or radiologist during percutaneous nephrolithotomy. J Endourol. 2010;24(11):1733–7.
25. Sivalingam S, Cannon ST, Nakada SY. Current practices in percutaneous nephrolithotomy among endourologists. J Endourol. 2014;28(5):524–7.
26. Bird VG, Fallon B, Winfield HN. Practice patterns in the treatment of large renal stones. J Endourol. 2003;17:355–63.
27. Mishra S, Kurien A, Ganpule A, Muthu V, Sabnis R, Desai M. Percutaneous renal access training: content validation comparison between a live porcine and a virtual reality (VR) simulation model. BJU Int. 2010;106(11):1753–6.
28. Papatsoris AG, Shaikh T, Patel D, Bourdoumis A, Bach C, Buchholz N, Masood J, Junaid I. Use of a virtual reality simulator to improve percutaneous renal access skills: a prospective study in urology trainees. Urol Int. 2012;89(2):185–90.
29. Zhang Y, Yu CF, Liu JS, Wang G, Zhu H, Na YQ. Training for percutaneous renal access on a virtual reality simulator. Chin Med J. 2013;126(8):1528–30.
30. Shergill IS, Abdulmajed MI, Moussa SA, Rix GH. The 3-finger technique in establishing percutaneous renal access: a new and simple method for junior trainees. J Surg Educ. 2012;69(4):550–3.
31. Turney BW. A new model with an anatomically accurate human renal collecting system for training in fluoroscopy-guided percutaneous nephrolithotomy access. J Endourol. 2014;28(3):360–3.
32. Tanriverdi O, Boylu U, Kendirci M, Kadihasanoglu M, Horasanli K, Miroglu C. The learning curve in the training of percutaneous nephrolithotomy. Eur Urol. 2007;52(1):206–11.
33. Munver R, Delvecchio FC, Newman GE, Preminger GM. Critical analysis of supracostal access for percutaneous renal surgery. J Urol. 2001;166:1242–6.
34. Tefekli A, Esen T, Olbert PJ, Tolley D, Nadler RB, Sun YH, Duvdevani M, de la Rosette JJ; CROES PCNL Study Group. Isolated upper pole access in percutaneous nephrolithotomy: a large-scale analysis from the CROES percutaneous nephrolithotomy global study. J Urol. 2013;189(2):568–73.
35. Lightfoot M, Ng C, Engebretsen S, Wallner C, Huang G, Li R, Alsyouf M, Olgin G, Smith JC, Baldwin DD. Analgesic use and complications following upper pole access for percutaneous nephrolithotomy. J Endourol. 2014;28(8):909–14.
36. Maheshwari PN, Andankar MG, Bansal M. Nephrostomy tube after percutaneous nephrolithotomy: large-bore or pigtail catheter? J Endourol. 2000;14(9):735–7.
37. Pietrow PK, Auge BK, Lallas CD, Santa-Cruz RW, Newman GE, Albala DM, et al. Pain after percutaneous nephrolithotomy: impact of nephrostomy tube size. J Endourol. 2003;17(6):411–4.
38. Desai MR, Kukreja RA, Desai MM, Mhaskar SS, Wani KA, Patel SH, Bapat SD. A prospective randomized comparison of type of nephrostomy drainage following percutaneous nephrostolithotomy: large bore versus small bore versus tubeless. J Urol. 2004;172(2):565–7.
39. Crook TJ, Lockyer CR, Keoghane SR, Walmsley BH. A randomized controlled trial of nephrostomy placement versus tubeless percutaneous nephrolithotomy. J Urol. 2008;180(2):612–4.
40. Jackman SV, Hedican SP, Peters CA, Docimo SG. Percutaneous nephrolithotomy in infants and preschool age children: experience with a new technique. Urology. 1998;52(4):697–701.
41. Desai J, Solanki R. Ultra-mini percutaneous nephrolithotomy (UMP): one more armamentarium. BJU Int. 2013;112(7):1046–9.
42. de Cogain MR, Krambeck AE. Advances in tubeless percutaneous nephrolithotomy and patient selection: an update. Curr Urol Rep. 2013;14(2):130–7.
43.•• Zhong Q, Zheng C, Mo J, Piao Y, Zhou Y, Jiang Q. Total tubeless versus standard percutaneous nephrolithotomy: a meta-analysis. J Endourol. 2013;27(4):420–6. *The authors address the current literature on a popular new way of preforming PCN: tubeless. This meta-analysis includes 5 randomized and 4 case controlled trials, and concludes that total tubeless PCNL is a safe and effective procedure, reducing hospital stays, analgesic requirements, and time to normal activity without compromising complication rates in select patients*.
44. Rifaioglu MM, Onem K, Buldu I, Karatag T, Istanbulluoglu MO. Tubeless percutaneous nephrolithotomy: yes but when? A multicentre retrospective cohort study. Urolithiasis. 2014;42(3):255–62.
45. Isac W, Rizkala E, Liu X, Noble M, Monga M. Tubeless percutaneous nephrolithotomy: outcomes with expanded indications. Int Braz J Urol. 2014;40(2):204–11.

46. Pillai S, Mishra D, Sharma P, Venkatesh G, Chawla A, Hegde P, Thomas J. Tubeless simultaneous bilateral percutaneous nephrolithotomy: safety, feasibility and efficacy in an Indian setting. Int J Urol. 2014;21(5):497–502.
47. Choi SW, Kim KS, Kim JH, Park YH, Bae WJ, Hong SH, Lee JY, Kim SW, Hwang TK, Cho HJ. Totally tubeless versus standard percutaneous nephrolithotomy for renal stones: analysis of clinical outcomes and cost. J Endourol. 2014;28(12):1487–94.