AN OVERVIEW OF PERCUTANEOUS NEPHROLITHOTOMY

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ABSTRACT

Urolithiasis is a worldwide problem in the general population, due to its high prevalence and frequency of recurrence. Since the first successful stone extraction through a nephrostomy in 1976, percutaneous nephrolithotomy (PCNL) has become the preferred procedure especially for treatment of large, complex staghorn calculi. Of the minimally invasive treatment strategies, the PCNL procedure is simply based on the creation of a proper percutaneous renal access, through the most appropriate part of the kidney, dilation of this tract, and fragmentation. Most of these complications are related to tract formation and size. During the development of the PCNL technique, the different terminology emerged, mainly according to the tract size such as standard, micro-PCNL, mini-PCNL, and ultra-mini-PCNL. The aim of this study is an overview of the PCNL, including the history, training, procedure and type of PCNL, and possible complications.

Keywords: Urolithiasis, percutaneous nephrolithtomy (PCNL), mini-PCNL, micro-PCNL.

INTRODUCTION

Minimally invasive treatments, such as percutaneous nephrolithotomy (PCNL), retrograde intrarenal surgery (RIRS), non-invasive extracorporeal shock wave lithotripsy (ESWL), and laparoscopy procedures have almost completely replaced open surgery in the management of the urinary stone disease. PCNL which is based on the creation of a suitable percutaneous renal access, dilation of this tract, and fragmentation and elimination of the stone fragments using the nephroscope through an access sheath, is a well-established technique for the treatment of urinary stone in all age groups. Firstly, Goodwin et al.[1] described the use of a needle to decompress a hydronephrotic kidney. PCNL has become the preferred treatment, especially in cases of large, complex, staghorn calculi, since the first successful stone extraction was performed by a nephrostomy in 1976.[2]

Nowadays, except for the situations including contraindications for general anesthesia, anticoagulant therapy, untreated urinary tract infection, atypical bowel interposition, potential malignant kidney tumour, and pregnancy, PCNL has become a standard modality in the treatment of kidney stones that are larger than 2 cm in diameter and that do not respond to ESWL.[3] An abdominopelvic ultrasound (USG), plain abdominal films, and intravenous urography are the diagnostic imaging tools to determine stone size, location, and anatomical clues, as well as for planning treatment. Moreover, computerised tomography (CT) can be used when there is suspicion of hepatomegaly, splenomegaly, aortic aneurysm and retrorenal colon, allergies of the contrast medium, and in patients with non-opaque stone.[4]

Training

PCNL operation requires a certain skill level. There is a steep learning curve for surgeons to gain percutaneous renal access and thereby sufficient training is necessary. A resident has to perform approximately 24 PCNL procedures to provide proficiency during the residence period.[5] When surgical experience increases, the duration of operation and fluoroscopy usage gets shorter and the stone-free rate gets higher. Most complications are seen in the first 20 cases; however, the complication rate significantly decreases after 45 cases.[6] Due to the high risk of complications seen during the operation, at the learning stage, simulation operations can be done prior to contact with the chosen patients who have a suitable and non-risky kidney anatomy and body posture in the initial steps for refining the techniques and the tactics.[6]

Positioning

Fernstom and Johansson[2] have performed the PCNL in the prone position (Figure 1A). Anesthetic problems, especially in the patients with compromised cardiopulmonary status, high-risk conditions such as morbid obesity or other, have induced to explore alternative positioning. Firstly, Valdivia Uría et al.[7,8] have described supine PCNL performed without needing to turn the patient into prone position in 1987, and they reported the first clinical experience in supine position in 1998 (Figure 1B). According to their experience the advantages seen in the patient's comfort and the feasibility of the technic for the surgeon justify its use. In the subsequent time, the variations in the procedure, such as Galdakao modification of Valdivia positioning, which is more challenging but has much lower risk of the anesthesia, is allowed simultaneous anterograde and retrograde access to the whole urinary tract.[9]

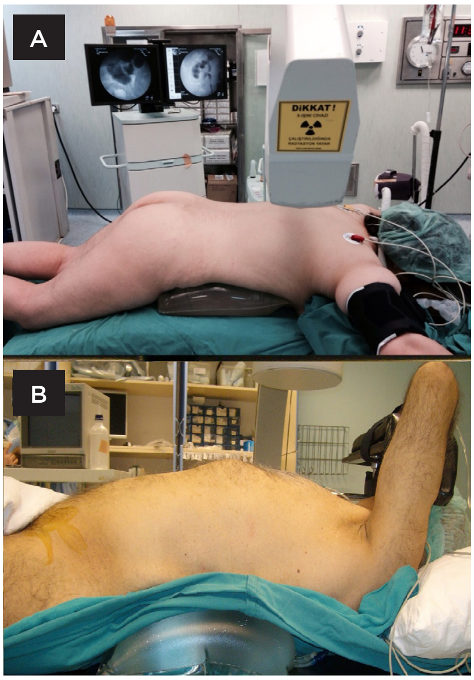

Figure 1: The position in prone (A) and supine (B) percutaneous nephrolithotomy.

De Sio et al.[10] compared prone technique done in 39 patients with supine technique done in 36 patients via forming the homogeneous groups in which the upper calyx puncture and the complete staghorn calculi were excluded. There were no significant differences in colonic injury or other complications between the two groups; however operation time was significantly lower in the supine group. Another randomised study reported by Falahatkar et al.[11] compared supine with prone PCNL. In this study, the stone-free rates were similar in both groups. Although the operation duration was lower but transfusion rate was higher in the supine group.

In a prospective study, the Clinical Research Office of the Endourological Society (CROES)[12] has evaluated the patients treated with PCNL in 96 centres between 2007 and 2009. The results of this study suggested that prone position was still the most popular (80.3%) approach for PCNL; however, there were differences between the centres: for example, although PCNL was done in prone position in 98.5% of the patients in North America, this rate was 76.5% in Europe. While the mean operation duration was lower in the prone group, the rate of blood transfusion and stone-free was higher.

PCNL PROCEDURE

Percutaneous renal access can be considered the most important point in PCNL, and directly affects the success and the complication rates of this surgery. Also ensuring the correct depth of initial percutaneous needle insertion is considered one of the major impediments. It is crucial to puncture through the centre of the calyceal papilla to avoid damage to interlobar and arcuate branches of the renal artery that may occur with puncture directly into the infundibulum or renal pelvis. However, İt is reported that injury to an interlobar vessel was seen in 67% and 13% during the upper-pole infundibulum and lower-pole infundibulum punctures, respectively.[13] There are many imaging techniques, including fluoroscopy, USG, and CT, to assess the intrarenal collecting system. C-arm fluoroscopy is the most commonly used method.[14,15] Biplanar fluoroscopy provides the optimal calyceal access via determining depth of the targeted calyx.[16] On the other hand, multiple calyceal structures can be seen as a single unit due to overlap on vertical plane and the actual depth of appropriate calyx for entry cannot be well evaluated as an inmonoplanar access technique.[14] Two primary methods under biplanar fluoroscopic guidance have been described: 'triangulation' and the 'eye of the needle' (or bull's eye) techniques.[16,17] Also, various alternative access techniques, including the all-seeing needle method by Bader et al.[18] or blind puncture technique by Basiri et al.,[19] have been described in the literature over time. All of these methods have been used safely and efficiently in urologic practice.

Radiation exposure is an important point if the calyceal access is performed under fluoroscopic guidance. Renal puncture under fluoroscopy carries a radiation exposure risk for the surgical team and the patient. Total radiation dose of 50 mSv is the proposed annual dose limit for occupational exposure by The International Commission on Radiological Protection.[20] Bush et al.[21] showed that the skin on the flank area, the testes, and the ovaries received 0.25 mSv, 1.6 mSv, and 5.8 mSv of radiation, respectively, during the operation. Kumari et al.[22] reported that the mean radiation exposure dose to the urologist was 0.28 mSv, while the mean radiation exposure to the finger of the patient was 0.56 mSv. The biological effects of radiation include infertility, cataract, skin damage, and haematopoietic, gastrointestinal tract, and genetic changes, such as cancer.[23]

In recent studies, the success of USG-guided PCNL has been reported more frequently.[24-26] Gamal et al.[24] reported a PCNL series in which only USG, instead of fluoroscopy, was used during the whole procedure. It was applied to 34 patients and 94% of these patients were stone free. The advantages of USG guidance included the absence of radiation exposure, the ability to evaluate the residual non-opaque and semi-opaque stones that could not be visualised by fluoroscopy, imaging of the intervening structures between the skin and kidney (retrorenal colon), the ability to distinguish between anterior and posterior calyces.[25,26] In another study, Osman et al.[27] reported that puncture under USG guidance and dilatation under X-ray lowered the blood loss or major complications.

The dilation of renal tract is one of the major cost facts and steps in PCNL. This process can be performed with three different basic techniques, including Amplatz dilation (AD), metal telescopic dilation (MTD), and balloon dilation (BD) methods, which can add different operation costs.[28] BD has been generally regarded as the most modern and safe technique. Handa et al.[29] showed the superiority of a BD over AD via reducing the incidence of haemorrhage, blood transfusion, and morbidity, as well as providing a shorter surgery time and recovery period. AD still remains as the best and first method by many urologists for tract dilatation. In a study, Gönen et al.[30] compared BD with AD and reported that there were no significant differences in the operation time or blood transfusion rate between both groups. Metal telescopic dilation is usually selected for usage when the other methods of dilation have been failed or in the patients with severe perinephric scar tissue detected during diagnostic evaluation.[31] In previous years some innovative dilation techniques, such as one-shot dilatation that was firstly introduced be Frattini et al.,[32] have been developed.

In comparing these methods, BD is found to decrease the tract dilatation fluoroscopy time for both patient and urologist, so it has been regarded as the most safe and effective method for renal tract dilation.[33] Unsal et al.[31] evaluated the impact of tract dilatation methods on global and regional renal function using quantitative single-photon emission computed tomography of technetium-99m–dimercaptosuccinic acid (QSPECT of ^{99m}Tc-DMSA). They found that there were no significant differences for total uptake and area of the treated kidneys, serum creatinine, and blood pressure before and after PCNL. There are some instruments used during intracorporeal lithotripsy (ICL). Ultrasonic and pneumatic lithotripsy are usually used with rigid nephroscope; however, holmium YAG (Ho:YAG) laser is more feasible to use with flexible instruments.[3]

The last step before completion of PCNL, placement of a nephrostomy tube is considered as standard procedure. Besides providing haemostasis, nephrostomy tube also prevents urinary extravasation and maintains adequate drainage of the kidney, even if it causes discomfort, pain, and prolonged hospitalisation for the patients. That is why several authors have described new modifications, such as retrograde applied ureteral catheter or double J stent, used to alternatively drain the renal unit, known as tubeless PCNL.[34,35]

Wickham et al.,[36] who firstly described tubeless PCNL in 1984, reported 94% stone free rate, the average hospitalisation of 2.8 days, and 6% transfusion rate. Although Bellman et al.[37] placed a nephrostomy tube in first 50 patints, but they used just double-J (DJ) stent instead of nephrostomy tube in the subsequent patients in their study. The hospitalisation time, analgesia requirements, time to return to daily activities, and the cost were significantly lower in the DJ stent group. Tubeless PCNL became popular in many centres, after this study. Istanbulluoglu et al.[38] compared tubeless with standard PCNL in 176 patients, the hospitalisation time and the amount of narcotic analgesics required were significantly higher in the standard nephrostomy catheter group. In their series, the majority of patients, who underwent the tubeless procedure, were discharged from the hospital in less than 24 hours. In another study, Kara et al.[39] compared tubeless with standard PCNL in elderly patients (range, 60-77 years of age). The hospitalisation and analgesic requirements were less than the standard PCNL. Some of the patients in the tubeless group may complain of the symptoms such as dysuria and increased urinary frequency. A short-time ureteral catheter can be used instead of a DJ-stent. Al-Ba'adani et al.[40] performed tubeless PCNL leaving only a 6 Fr retrograde ureteral catheter in 121 patients. The ureteral catheter was kept for 7-72 hours. There was low postoperative pain, and little need for postoperative analgesia with this procedure Lojanapiwat et al.[41] used ureteral catheter after PCNL in the selected patients. Their criteria were to be single access site, a non-obstructed renal unit, non-significant perforation of the collecting system, and bleeding. In their study, the mean hospitalisation time was 3.63 days, which was so long when compared with other studies. In a recent prospective randomised study, totally tubeless (no nephrostomy and no DJ stent) PCNL was reported as a safety method by Sabnis et al.[42]

MINIMALLY INVASIVE PCNL

Although different sized nephroscopes have been used according to the tract size, a 26–30 Fr access tract can be big enough for standard PCNL. In parallel with the development of technology, reducing the nephroscope diameter became the main goal of minimising the surgical morbidity of PCNL. Thus, mini-PCNL and micro-PCNL have been developed (Figure 2).[43,44] The percutaneous tract is serially dilated to 16-20 Fr in mini-PCNL. Nowadays, mini-PCNL is generally defined for PCNL procedure performed through the access tract of 18 Fr. Previously, this has been used in paediatric cases, but it has also been shown to be highly efficient and safe in adults. In a study reported by Abdelhafez et al.,[45] 73 patients with 83 renal units were treated for large renal stones (>20 mm in diameter) with mini-PCNL. They assessed the stone-free rate, the complications, the decrease in haemoglobin and creatinine level, and the duration of operation and hospital stay. The only significant difference was the stone-free rate which was 96.9% and 66.7% in simple and complex stones, respectively. Zeng et al.[46] reviewed >10,000 cases involving simple and complex calyceal stoneswere treated with mini-PCNL. A 24-34 Fr nephrostomy tract was used for this procedure. The stone-free rate was 77.6% and 66.4%, respectively.

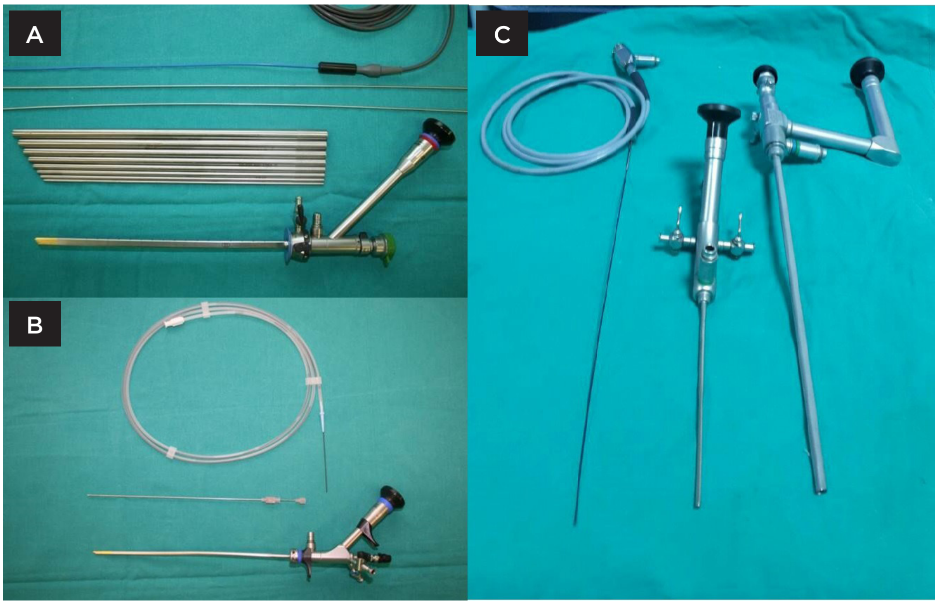

Figure 2: Nephroscopes with different diameters and their equipment. A) 22 Fr nephroscope; B) 16 Fr nephroscope; C) micro-percutaneous nephrolithotomy (PCNL), ultra-mini PCNL, and mini-PCNL nephroscopes.

The blood transfusion rates were 2.2% for simple stones and 3.2% for complicated stones in this study.

The aim of mini-PCNL procedure is to decrease the size of nephrostomy tract. Although there was no significant difference in the loss of functional tissue and postoperative renal scarring between standard PCNL and mini-PCNL.[47] But mini-PCNL is known to be less invasive with a lower transfusion rate. On the other hand, the rate of complex calculi treated in this study was not enough to define a clear conclusion. The absence of large-scale randomised controlled trials limits to demonstrate the superiority of mini-PCNL to standard PCNL.[48]

Desai and Solanki[49] designed a new technique ultra-mini PCNL (UMP) in which the renal tract was dilated to 11-13 Fr and any expensive stone retrieval instruments such as baskets and graspers were not required. UMP had a minimal complication rate, a high rate of stone-free and a very low rate of auxiliary procedures; however, it can be useful for the stones <20 mm in diameter and in lower calyx. On the other hand, when compared with ESWL, it has an advantage only in lower calyx stones with long and narrow calyces and a pointed angle where fragments do not pass easily.

In order to decrease the complications, Desai et al.[44] described the concept of 'All-seeing needle' to provide a one-step PCNL through a 4.85 Fr tract in 2011. This was the first clinical article on the safety and efficacy of microperc in the treatment of renal stones. In this single-step procedure technique, an access tract even smaller than those of mini-PCNL or UMP was used. As in micro-PCNL, the stone fragments were extracted via vacuum cleaner effect without requirement for any extraction instrument; however, Ho:YAG laser was required for ICL in this type of PCNL.

The most important advantage of micro-PCNL is to reduce blood loss. In micro-PCNL, single-step access under direct visualisation helps to prevent complications, such as bleeding, occurring during access, and dilatation of the tract. In the first micro-PCNL study, the mean decrease in haemoglobin level was 1.4 mg/dL. The blood loss requiring transfusion, which was 0.71%, was reported in one of the subsequent studies.[50] In this type of PCNL, drainage of the collecting system was mainly provided through the ureteral catheter inserted preoperatively, and that stone extraction was not required was another difference of micro-PCNL compared with standard PCNL. One of the most important points of micro-PCNL is to localise the stone exactly under direct visualisation, which facilitates complete and definitive fragmentation of the stone using laser lithotripsy. In addition, the urologist who can perform standard PCNL can easily learn micro-PCNL procedure. Hatipoglu et al.[50] evaluated the results of 136 patients treated with micro-PCNL in four referral hospitals. The overall success rate was 82.14% in this study. Moreover, the mean hospital stay was 1.76 (1-4) days, and the mean drop in haemoglobin level was 0.87 (0–4.1) mg/dL. Three patients (2.19%) had abdominal distension due to extravasation of the irrigation fluid. Sabnis et al.[51] compared micro-PCNL and RIRS for the management of renal calculi <1.5 cm. Although DJ stent usage was highly related with RIRS but higher analgesic requirement and haemoglobin reduction were more prominent in micro-PCNL induced patients.

The Complications

Nowadays, the modified Clavien–Dindo classification of surgical complications is the most commonly used assessment method. De la Rosette et al.[52] reported that no complications were seen in 79.5% of cases in an analysis of CROES. On the other hand, low-grade (Grade 1-2), medium-grade (Grade 3a and 3b) and severe (Grade 4-5) complications were seen in 16.4%, 3.6%, and 0.5%, respectively.

The most important complication seen in PCNL surgery is bleeding, which can occur in forms of perioperative, immediate postoperative, and delayed. The rate of blood transfusion is reported between 0-20% in the related studies. The predicting factors for massive blood loss have been reported as body mass index, multiple punctures, dilation with larger dilators, stone size, long operative time, and the degree of preoperative hydronephrosis.[53] The other potential complications are fever and sepsis. Urinary infection seen with PCNL is a frequent problem; however, very few cases progress to septic shock. All patients should undergo urinalysis and culture before PCNL.[3] The incidence of fever following PCNL ranges between 2.8% and 32.1%.[54] Fever can be due to preoperative bacteriuria, neurogenic bladder dysfunction, renal anomalies, high intrarenal pressure during the surgical procedure that can be occurred via high flow of isotonic solutions to get a better view during bleeding, the stone size, the severity of urinary obstruction, and long surgical time.[55] Antibiotic prophylaxis is acceptable and recommended by many authors to prevent such complications. The accidental puncture of other intra-abdominal or thoracic organs such as bowel, spleen, liver, and pleura is very rare (<0.5%); however, it can cause fatal complications.[54] Pleural complications, which can be mostly seen in intercostal punctures, are uncommon (<2%).[52] On the other hand, colonic perforation is more common in left-sided procedures. The prominent risk factors are old age and the presence of kidney anomalies such as horseshoe kidney.[56] The mortality rate of PCNL has been reported between 0.04-0.8.[57]

CONCLUSION

PCNL has been successfully and safely used to treat patients with renal stones for more than a quarter of a century. Still, the use of PCNL in treating renal stones in different patient groups, such as children, obese patients, patients with renal congenital anomalies, patients who had previous open renal surgery. Various aspects of the procedure such as patient positioning, renal access, the ideal dilating method, the type of nephrostomy tube used, as well as the actual need for drainage, have been debated.

During the development of the PCNL technique, different terminology emerged, mainly according to the tract size such as standard, micro-PCNL, mini-PCNL and UMP. Miniaturisation of instruments in PCNL has spawned an interest in so-called 'microperc' in which the procedure is carried out through a 16-gauge needle. Miniperc has generated a lot of enthusiasm in the last few years. Miniperc utilises tract size of 20 Fr or less, hence the complication rates are much less. Haematocrit drop is significantly reduced and blood transfusion rates have gone down. Reduced pain and hospital stay without affecting success rate is the remarkable achievement of this procedure. Although initially it was supposed to be for small sized stones, many authors have utilised mini-PCNL even for large and complex stones with good clearance rate. The quintessential element of an innovative PCNL, which is termed as UMP is using a novel 6 Fr mini nephroscope through an 11–13 Fr metal sheath to perform Ho:YAG laser lithotripsy. Dilation is achieved in one step with much less fluoroscopy time, and the cross-section of the puncture channel is only approximately 30% of that required with the conventional mini-PCNL. This miniaturisation is the main reason why no blood transfusion and nephrostomy tube are routinely placed in this group of patients.

REFERENCES

1. Goodwin WE et al. Percutaneous trocar (needle) nephrostomy in hydronephrosis. J Am Med Assoc. 1955;157:891-4.

2. Fernström I, Johansson B. Percutaneous pyelolithotomy. A new extraction technique. Scand J Urol Nephrol. 1976;10(3):257-9.

3. Türk C et al. Guidelines on urolithiasis. European Urological Association. 2014.

4. Altintas R et al. The importance of instrument type in paediatric percutaneous nephrolithotomy. Urolithiasis. 2014;42(2):149-53.

5. de la Rosette JJ et al. Training in percutaneous nephrolithotomy--a critical review. Eur Urol. 2008;54:994–1001.

6. Mishra S et al. Training in percutaneous nephrolithotomy. Curr Opin Urol. 2013;23:147-51.

7. Valdivia Uría JG et al. [Percutaneous nephrolithectomy: simplified technic (preliminary report)]. Arch Esp Urol. 1987;40:177-80.

8. Valdivia Uría JG et al. Technique and complications of percutaneous nephroscopy: experience with 557 patients in the supine position. J Urol. 1998;160(6 Pt 1):1975-8.

9. Ibarluzea G et al. Supine Valdivia and modified lithotomy position for simultaneous anterograde and retrograde endourological access. BJU Int. 2007;100(1):233-6.

10. De Sio M et al. Modified supine versus prone position in percutaneous nephrolithotomy for renal stones treatable with a single percutaneous access: a prospective randomized trial. Eur Urol. 2008;54(1):196-202.

11. Falahatkar S et al. Complete supine percutaneous nephrolithotripsy comparison with the prone standard technique. J Endourol. 2008;22(11):2513-7.

12. Valdivia JG et al; Croes PCNL Study Group. Supine versus prone position during percutaneous nephrolithotomy: a report from the clinical research office of the endourological society percutaneous nephrolithotomy global study. J Endourol. 2011;25(10):1619-25.

13. Sampaio FJ. Renal anatomy. Endourologic considerations. Urol Clin North Am. 2000;27(4):585-607, vii.

14. Tepeler A et al. Impact of percutaneous renal access technique on outcomes of percutaneous nephrolithotomy. J Endourol. 2012;26(7):828–33.

15. Hatipoglu NK et al. Monoplanar access technique for percutaneous nephrolithotomy. Urolithiasis. 2013;41(3):257-63.

16. Miller NL et al. Techniques for fluoroscopic percutaneous renal access. J Urol. 2007;178(1):15–23.

17. Irby PB et al. Percutaneous access techniques in renal surgery. Tech Urol. 1999;5(1):29-39.

18. Bader MJ et al. The "all-seeing needle": initial results of an optical puncture system confirming access in percutaneous nephrolithotomy. Eur Urol. 2011;59(6):1054–9.

19. Basiri A et al. Blind puncture in comparison with fluoroscopic guidance in percutaneous nephrolithotomy: a randomized controlled trial. Urol J. 2007;4(2):79–83; discussion 83-5.

20. Ferrandino MN et al. Radiation exposure in the acute and short-term management of urolithiasis at 2 academic centers. J Urol. 2009;181(2):668-72;

discussion 673.

21. Bush WH et al. Radiation exposure to patient and urologist during percutaneous nephrostolithotomy. J Urol. 1984;132: 1148-52.

22. Kumari G et al. Radiation exposure to the patient and operating room personnel during percutaneous nephrolithotomy. Int Urol Nephrol. 2006;38:207-10.

23. Anderson PD, Bokor G. Nuclear and radiological terrorism: continuing education article. J Pharm Pract. 2013;26(3):171-82.

24. Gamal WM et al. Solo ultrasonography-guided percutaneous nephrolithotomy for single stone pelvis. J Endourol. 2011;25(4):593-6.

25. Desai M. Ultrasonography-guided punctures-with and without puncture guide. J Endourol. 2009;23(10):1641-3.

26. Penbegul N et al. Role of ultrasonography in percutaneous renal access in patients with renal anatomic abnormalities. Urology. 2013;81(5): 938-42.

27. Osman M et al. Percutaneous nephrolithotomy with ultrasonography-guided renal access: experience from over 300 cases. BJU Int. 2005;96(6):875-8.

28. Al-Kandari AM et al. Comparative study of degree of renal trauma between Amplatz sequential fascial dilation and balloon dilation during percutaneous renal surgery in an animal model. Urology. 2007;69(3):586-9.

29. Handa RK et al. Acute effects of percutaneous tract dilation on renal function and structure. J Endourol. 2006;20(12):1030–40.

30. Gönen M et al. Balloon dilatation versus Amplatz dilatation for nephrostomy tract dilatation. J Endourol. 2008;22(5):901-4.

31. Unsal A et al. Effect of percutaneous nephrolithotomy and tract dilatation methods on renal function: assessment by quantitative single-photon emission computed tomography of technetium-99m-dimercaptosuccinic acid uptake by the kidneys. J Endourol. 2010;24(9): 1497-502.

32. Frattini A et al. One shot: a novel method to dilate the nephrostomy access for percutaneous lithotripsy. J Endourol. 2001;15(9):919–23.

33. Dehong C et al. A comparison among four tract dilation methods of percutaneous nephrolithotomy: a systematic review and meta-analysis. Urolithiasis. 2013;41(6):523-30.

34. Limb J, Bellman GC. Tubeless percutaneous renal surgery: review of first 112 patients. Urology. 2002;59(4):527-31; discussion 531.

35. Shah HN et al. Tubeless percutaneous nephrolithotomy: a prospective feasibility study and review of previous reports. BJU Int. 2005;96(6):879-83.

36. Wickham JE et al. Percutaneous nephrolithotomy: one stage or two? Br J Urol. 1984;56:582-5.

37. Bellman GC et al. Tubeless percutaneous renal surgery. J Urol. 1997;157:1578-82.

38. Istanbulluoglu MO et al. Percutaneous nephrolithotomy: nephrostomy or tubeless or totally tubeless? Urology. 2010;75(5):1043-6.

39. Kara C et al. A randomized comparison of totally tubeless and standard percutaneous nephrolithotomy in elderly patients. Urology. 2010;76(2):289-93.

40. Al-Ba'adani TH et al. Tubeless percutaneous neprolithotomy: the new gold standard. Int Urol Nephrol. 2008;40:603-8.

41. Lojanapiwat B et al. Tubeless percutaneous nephrolithotomy in selected patients. J Endourol. 2001;15: 711-3.

42. Sabnis R et al. PD7-10 Exit strategy following MPNL – prospective randomized study. J Urol. 191(4S):e187.

43. Monga M, Oglevie S. Minipercutaneous nephorlithotomy. J Endourol. 2000;14:419–21.

44. Desai MR et al. Single-step percutaneous nephrolithotomy (microperc): the initial clinical report. J Urol. 2011;186:140–5.

45. Abdelhafez MF et al. Minimally invasive percutaneous nephrolitholapaxy (PCNL) as an effective and safe procedure for large renal stones. BJU Int. 2012;110(11 Pt C):E1022-6.

46. Zeng G et al. Minimally invasive percutaneous nephrolithotomy for simple and complex renal caliceal stones: a comparative analysis of more than 10,000 cases. J Endourol. 2013;27(10):1203-8.

47. Traxer O et al. Renal parenchymal injury after standard and mini percutaneous nephrostolithotomy. J Urol. 2001;165:1693–5.

48. Hu G et al. A novel minimally invasive percutaneous nephrolithotomy technique: safety and efficacy report. Scand J Urol. 2014:1-7. [Epub ahead of print].

49. Desai J, Solanki R. Ultra-mini percutaneous nephrolithotomy (UMP): one more armamentarium. BJU Int. 2013;112(7):1046–9.

50. Hatipoglu NK et al. Initial experience of micro-percutaneous nephrolithotomy in the treatment of renal calculi in 140 renal units. Urolithiasis. 2014;42(2): 159-64.

51. Sabnis RB et al. Micropercutaneous nephrolithotomy (microperc) vs retrograde intrarenal surgery for the management of small renal calculi: a randomized controlled trial. BJU Int. 2013;112(3):355-61.

52. de la Rosette J et al; CROES PCNL Study Group. The Clinical Research Office of the Endourological Society Percutaneous Nephrolithotomy Global Study: indications, complications, and outcomes in 5803 patients. J Endourol. 2011;25(1):11–7.

53. Lee JK et al. Predictive factors for bleeding during percutaneous nephrolithotomy. Korean J Urol. 2013;54(7):448–53.

54. Michel MS et al. Complications in percutaneous nephrolithotomy. Eur Urol. 2007;51(4):899–906; discussion 906.

55. Kreydin EI, Eisner BH. Risk factors for sepsis after percutaneous renal stone surgery. Nat Rev Urol. 2013;10(10):598-605.

56. El-Nahas AR et al. Colonic perforation during percutaneous nephrolithotomy: study of risk factors. Urology. 2006;67(5):937-41.

57. Kyriazis I et al. Complications in percutaneous nephrolithotomy. World J Urol. 2014. [Epub ahead of print].