34 Renal Access for PCNL: The Smaller the Better?

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Abstract

Although percutaneous nephrolithotomy (PCNL) has been considered as the gold standard for management of large renal stones, several issues such as severe complications and morbidity associated with renal access remain a matter of debate. To overcome these issues, many urologists investigated the risk factors of high morbidity and hypothesized that large tract size for renal access can be one of the major factors related to significant complications. Hence, there have been many endeavors and investigations to reduce the size of renal access tracts and to confirm the effectiveness and safety of smaller tract size for PCNL. Currently, miniaturized PCNL using a smaller nephrostomy tract for renal access has gained wide acceptance for the surgical treatment of small- or medium-sized renal stones; however, the efficacy of mini-PCNL is still controversial. In this chapter, we will review the recent literature related to miniaturized PCNL, such as mini-, ultramini-, and micro-PCNL, and discuss the practical advantages and drawbacks of these procedures compared to those of conventional PCNL.

Keywords

Percutaneous nephrolithotomy · Kidney stone · Mini-PCNL · Renal access · Bleeding

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34.1 Introduction

Nephrolithiasis is considered an important issue of general health and quality of life, and its overall incidence has increased over the years (Hesse et al. 2003). Percutaneous nephrolithotomy (PCNL) has become a standard procedure for management of large renal stones. Meanwhile, there are several options for smaller stones, such as extracorporeal shock wave lithotripsy (ESWL) and retrograde intrarenal surgery (RIRS) using a flexible ureteroscope, as well as PCNL. With the development of the flexible ureteroscope and lithotripters, most small- or medium-sized renal stones can be effectively managed with RIRS. However, there are still cases for which successful treatment with RIRS is difficult, such as nephrolithiasis of infants, some diverticular stones, and deep calyceal stones with a steep infundibular angle. For these cases, PCNL can be an option, but many urologists still hesitate to perform PCNL due to its associated high morbidity.

During the past two decades, nephroscopes and instruments have been miniaturized in an effort to decrease morbidity associated with PCNL. PCNL using smaller instruments, so-called mini-PCNL or mini-perc, was initially performed in 1997 for the management of pediatric nephrolithiasis (Jackman et al. 1998; Helal et al. 1997). Although there are still no absolute definitions, miniaturized PCNL can be categorized into mini-PCNL (14–22 Fr), ultramini-PCNL (11–13 Fr), and micro-PCNL (4.8–10 Fr), according to the nephrostomy tract size (Desai and Solanki 2013; Desai et al. 2011). It has been reported that nephrostomy tract size is one of the main factors affecting the occurrence of complications (Kukreja et al. 2004). Meanwhile, smaller nephrostomy tract size may negatively affect other procedure-related factors, such as surgical duration and stone-free rate (Giusti et al. 2007). We reviewed recent studies related to miniaturized PCNL to evaluate the advantages and drawbacks of smaller nephrostomy tract size for the treatment of renal stones and have discussed the benefits and harms of miniaturized renal access tracts.

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34.2 How to Achieve Renal Access for PCNL

For safe and successful PCNL, proper renal access is one of the most important steps. Fluoroscopic-guided renal access is the traditional approach and has been most commonly performed. However, this approach has several disadvantages, such as increased radiation exposure time for the surgeons and higher risk of possible iatrogenic visceral injury. In addition, if the larger bore for a nephrostomy tract is used, the complications can be more fatal. Moreover, it is difficult to apply this technique to patients with urinary diversions or a transplanted kidney due to the difficulty of retrograde ureteral catheter placement. To overcome these drawbacks of fluoroscopic-guided renal access, alternative techniques, such as ultrasound-guided, computed tomography (CT)-guided, and magnetic resonance imaging (MRI)-guided access, have been tried (Basiri et al. 2008; Ghani et al. 2009; Hagspiel et al. 1998; Hosseini et al. 2009; Karami et al. 2009; Matlaga et al. 2003; Kariniemi et al. 2009) Although several studies have reported satisfactory outcomes and fewer complications with ultrasound-, CT-, and MRI-guided access compared with that of fluoroscopic-guided access, each modality has its limitations. Ultrasound-guided access is operator-dependent and has limited ability to delineate fine details of renal anatomy, especially in obese patients or in patients without definite hydronephrosis (Park and Pearle 2006). CT-guided access is associated with concerns related to ionizing radiation exposure, and MRI-guided access involves the difficulty of visualizing the motion of fine instruments, such as a guidewire. Moreover, both techniques require specially designed equipment for their performance, which can be an obstacle to widespread use of these modalities. To treat nephrolithiasis, many urologists perform renal access with a combined approach using ultrasound and fluoroscopic guidance simultaneously. With fluoroscopic guidance, a targeted calyx can be easily pointed out, and then renal access can be achieved by using ultrasound guidance, resulting in less radiation exposure and reducing the risk of perirenal organ injury.

The development of endoscopy and optical puncture systems has introduced modified renal access techniques. Retrograde access was attempted using a steerable catheter and directing it into the desired calyx in a retrograde fashion, and then advancing a puncture wire out through the catheter to the skin (Lawson et al. 1983; Hunter et al. 1983). The performance of simultaneous fluoroscopic- and retrograde ureteroscopic-guided renal access was also endeavored (Grasso et al. 1995; Kidd and Conlin 2003). In addition, direct renal access using an optical puncture needle called an "all-seeing needle," which motivated the invention of micro-PCNL, was successfully performed (Bader et al. 2011).

34.3 Why Do We Need Miniaturized PCNL?

Since Helal et al. performed the first mini-PCNL using an 11 Fr peel-away sheath in 1997 (Helal et al. 1997), we have seen a paradigm shift from conventional PCNL to miniaturized PCNL with a nephrostomy tract size as small as 4.8 Fr. Although PCNL is a minimally invasive procedure with regards to the skin, it is invasive with regards to the kidney and has a risk of various complications. The overall complication rate of PCNL is reported to be 26% (Lang 1987), and it is known to be closely correlated with the surgeon's experience; it decreases from 61% to 3.7% with an increase in the level of surgical experience (Duvdevani et al. 2007). Bleeding is one of the most common and fatal complications of PCNL. Although general transfusion rates after PCNL have been reported as less than 1% (Lang 1987; Duvdevani et al. 2007), the initial series of PCNL outcomes reported an incidence of approximately 11% for postoperative transfusions (Lee et al. 1987). Thoracic complications such as pneumothorax, hydrothorax, hemothorax, and nephropleural fistula, also can occur after PCNL, and the incidence of these complications ranges from 0% to 18%. In particular, the supracostal approach for upper pole renal access is associated with a higher risk of thoracic complications than subcostal puncture (Radecka et al. 2003). Although it is rare, colonic perforation is a possible complication of PCNL, which has been reported in about 1% of cases (Lee et al. 1987).

Several studies demonstrated that the use of a small nephrostomy tract can cause less damage to the kidney, resulting in less hemorrhage and less renal impairment. A small nephrostomy tract also can be correlated with less postoperative patient discomfort. Karakose et al. reported that the use of a small-sized Amplatz sheath significantly decreased the nephrostomy tube size, blood loss, nephrostomy indwelling time, and hospital stay by comparing five groups based on Amplatz sheath size (22, 24, 26, 28, and 30 Fr) (Karakose et al. 2013).

Radiation exposure is a great concern for the procedure of renal access. Desai et al. found an inverse relation between nephrostomy sheath size and radiation exposure time (Desai and Ganpule 2017). In this study, the mean radiation exposure to the surgeon was 0.29 ± 0.12 millisievert (mSv), 0.18 ± 0.1 mSv, 0.16 ± 0.08 mSv, and 0.11 ± 0.04 mSv for the standard PCNL, mini-PCNL, ultramini-PCNL, and micro-PCNL, respectively. These results suggest that smaller nephrostomy tract sizes have a potential to reduce radiation exposure time, although it was not statistically validated.

There is no debate that PCNL is the gold standard modality for management of staghorn renal calculi or large kidney stones (>2 cm). For small- (<1 cm) or medium-sized (1–2 cm) stones, ESWL is the most minimally invasive treatment modality and can be a first-line option if only there are no unfavorable factors, such as shockwave-resistant stones, steep infundibular-pelvic angle, long lower pole calyx, or narrow infundibulum. Meanwhile, for the ESWL-unfavorable medium- or small-sized renal stones (<2 cm), RIRS can be the first choice in most cases. Although new-generation flexible ureteroscopy can provide access to most calyces and effectively remove most calyceal stones, some renal calculi cannot be completely removed by RIRS, which include nephrolithiasis of infants, some diverticular stones, and deep calyceal stones with a steep infundibular-pelvic angle. In addition, the stones in a patient who cannot undergo a retrograde approach due to uncorrectable ureteral stricture, reimplanted ureter, or urinary diversion, cannot be successfully managed with RIRS. In these situations, PCNL can be an alternative, but many urologists still think PCNL is an excessive treatment for small-sized stones, and thus they hesitate to perform PCNL due to its high risk of morbidity. However, mini-PCNL can be a good option, with lower morbidity and high efficacy.

Several studies demonstrated that miniaturized PCNL is as effective and safe as conventional PCNL with tolerable complications (Ruhayel et al. 2017). Generally, stones less than 2 cm in size within a complex collecting system or lower pole, or diverticular stones are considered the best indications for mini-PCNL, but there is no consensus for absolute indications and no credible data to support an upper limit for stone size.

34.4 Pros and Cons of Miniaturized PCNL

Proponents of the miniaturized PCNL mention reduced blood loss, decreased postoperative pain and limited hospital stay. The major disadvantage of procedures using small instruments include the limited irrigation flow and more extensive stone fragmentation to fit through a reduced-size sheath leading to prolonged operative times. Although based on the assumption of lower morbidity from reduction in diameter of the tract and less renal trauma, controversy still exists on whether miniaturization leads to such a benefit. There have been several studies to compare the efficacy and safety between miniaturized PCNL and conventional PCNL. Of these studies, randomized controlled trials were performed in two studies (Cheng et al. 2010; Tepeler et al. 2014). Cheng et al. compared the perioperative outcomes of mini-PCNL using tract size 16 Fr with conventional PCNL (24 Fr) (Cheng et al. 2010). In their study, blood loss and transfusion rates were significantly lower in the mini-PCNL group, although the types of stone were not comparable. Hospital stay, postoperative pain, dose of postoperative analgesics, and ratio of positive fever were comparable between the two groups. The stone-free rates of the staghorn stone and the simple renal pelvis stone were also similar, whereas the mini-PCNL group achieved a significantly higher stone-free rate for multiple calyceal stones (85.2%) than the conventional PCNL group (70.0%). The surgical duration was significantly longer in the mini-PCNL group for all stone types. Additionally, Tepeler et al. compared intrarenal pelvic pressure as well as perioperative outcomes between micro-PCNL (4.8 Fr) using an all-seeing needle and conventional PCNL (30 Fr) (Tepeler et al. 2014). This study showed that the surgical duration and hospital stay were significantly longer in the conventional PCNL group. Stone-free and complication rates were comparable between both groups. Although blood loss was significantly lower, intrarenal pelvic pressure was significantly higher in the micro-PCNL group.

Additionally, several nonrandomized comparative studies have been conducted, which compared perioperative outcomes between mini-PCNL and conventional PCNL (Knoll et al. 2010; Mishra et al. 2011; Xu et al. 2014; Yamaguchi et al. 2011). Yamaguchi et al. analyzed the PCNL global study database of the Clinical Research Office of the Endourological Society (CROES), and divided the patients into four groups (≤18, 24–26, 27–30, and ≥32 Fr) according to the nephrostomy tract size. They reported that blood loss and transfusion rates significantly increased with tract size (Yamaguchi et al. 2011). Mishra et al. compared the outcomes of mini-PCNL (15–20 Fr) with those of conventional PCNL (24–30 Fr) for the treatment of 1–2 cm-sized renal stones (Mishra et al. 2011). Although it is a limitation that they used different energy sources for lithotripsy (holmium laser in the mini-PCNL group and pneumatic lithotripter in the conventional PCNL group), they reported less blood loss, shorter hospital stay, and longer surgical duration in the mini-PCNL group, while stone-free rates and analgesic use were similar in both groups. Xu et al. also reported less blood loss and comparable surgical duration, hospital stay, stone-free and complication rates in the mini-PCNL group compared to those of the conventional PCNL group, although the mean stone size was smaller in the mini-PCNL group (Xu et al. 2014). Giusti et al. observed a smaller hematocrit drop, lower transfusion rate, shorter duration of hospitalization, and similar use of analgesics in the mini-PCNL group, but significantly longer surgical duration and lower stone-free rate were found in the mini-PCNL group than in the conventional PCNL group (Giusti et al. 2007).

Likewise, several studies demonstrated that mini-PCNL has some advantages in terms of less blood loss and comparable stone-free and complication rates compared with that of conventional PCNL. However, there are a few studies that showed no advantages of mini-PCNL in terms of blood loss. Knoll et al. observed similar blood loss, surgical duration, analgesic requirements, stone-free and complication rates between the mini-PCNL and standard PCNL groups; even the mean stone size was significantly larger in the standard PCNL group (Knoll et al. 2010). Nevertheless, there are no reports that mini-PCNL is associated with more blood loss compared to that of conventional PCNL. There have been concerns about poor visibility of mini-PCNL due to the small-sized endoscope and weak irrigation flow, but most urologists who have performed mini-PCNL found almost no differences in visibility between conventional and mini-PCNL.

Miniaturized PCNL may have additional advantages over not only conventional PCNL, but also RIRS, using flexible ureteroscopy. For example, one chief advantage is patient positioning. Currently, PCNL is being performed in a supine or modified supine position at many centers, but less flank exposure and subsequent limited movement of instrumentation are well-known drawbacks of supine PCNL (Liu et al. 2010; Yuan et al. 2016). Miniaturized PCNL also can be performed in the supine and prone positions, and limitation of instrument movement can be theoretically and practically less affected, even in the supine position. Likewise, mini-PCNL can be performed in various positions, even when compared to positioning of RIRS; RIRS typically can only be performed in limited positions, such as the lithotomy or supine positions.

Another advantage of miniaturized PCNL is the straightforward creation of renal access. For conventional PCNL, several steps are required for renal access; even a balloon dilator is used. In contrast, only a single puncture is required for micro-PCNL using an all-seeing needle. In the case of mini- or ultramini-PCNL, fewer steps are required for the creation of a nephrostomy tract, which may induce reduced renal parenchymal damage, radiation exposure, and overall surgical duration. For these reasons, miniaturized PCNL may also be more advantageous than conventional PCNL for single-session cases requiring multiple punctures due to multicalyceal stones.

Many cases require a supracostal puncture technique for effective and successful stone removal, but supracostal renal access and dilatation is more challenging and problematic than that of the subcostal approach. One of the reasons for the difficulty of the supracostal approach is that the diameters of the dilator and nephrostomy sheath are wider than the intercostal space. In this scenario, an Amplatz sheath can be difficult to manage, and even can be bent during surgery. However, miniaturized PCNL requires a much narrower nephrostomy tract and smaller instruments; thus, the nephrostomy sheath can pass through the intercostal space smoothly and can angle downward easily without bending. Therefore, miniaturized PCNL can be considered advantageous for supracostal renal access.

Although many studies showed several advantages of miniaturized PCNL and demonstrated that the use of miniaturized PCNL systems is safe and effective, there are also several disadvantages of miniaturized PCNL. Compared to conventional PCNL, the major disadvantage of miniaturized PCNL is that it requires the fragmentation of stones into smaller pieces so that the stone fragments can be removed through the narrower sheath. It can also cause longer surgical duration, especially for larger stones. To overcome these time-consuming procedures, several surgeons recently used modified Amplatz sheaths, which can be connected to a vacuum suction system, and stone fragments can be simultaneously removed via vacuum suctioning during stone fragmentation (Mager et al. 2016; Nicklas et al. 2015; Nagele and Nicklas 2016).

In terms of renal damage, miniaturized PCNL is generally assumed to be associated with lower morbidity and less renal damage than conventional PCNL because less blood loss has been reported by several studies. However, Li et al. investigated the systemic response to conventional and mini-PCNL by assessing the levels of acute-phase proteins such as tumor necrosis factor-alpha, interleukin-6, interleukin-10, C-reactive protein, and serum amyloid A, and found no significant differences between the two groups (Li et al. 2010). In addition, Traxer et al. compared the extent of renal injury in pigs undergoing 11 or 30 Fr-percutaneous nephrostomy (Traxer et al. 2001). They observed that the mean scar volume and fractional loss of parenchyma was not significantly different between the groups.

Intrarenal pelvic pressure during surgery and hemodynamic, electrolyte, and metabolic changes have been compared between conventional and miniaturized PCNL. Tepeler et al. measured intrarenal pelvic pressure during procedures, comparing conventional and micro-PCNL (Tepeler et al. 2014). Intrarenal pelvic pressure was significantly higher in the micro-PCNL group during all steps of the procedure, although the complication and success rates were not significantly different. The increased intrarenal pelvic pressure may lead to pyelovenous, pyelolymphatic, and pyelotubular backflow, as well as forniceal rupture. Moreover, systemic absorption of bacteria and endotoxins from the irrigation fluid can be a risk factor for postoperative fever and urinary tract infection (Tepeler et al. 2014). Therefore, surgeons should be aware of higher intrarenal pelvic pressure during miniaturized PCNL, and placement of a ureteral catheter intraoperatively can be helpful for the drainage of irrigation fluid and reducing the pressure. Xu et al. compared hemodynamic, electrolyte, and metabolic changes between conventional and mini-PCNL (Xu et al. 2014). In their study, although no significant hemodynamic and electrolyte changes were found in both groups, a trend toward metabolic acidosis was observed as the irrigation time progressed in the mini-PCNL group.

34.5 Summary

While the clear indications of miniaturized PCNL are still under investigation, data in literature suggests miniaturized PCNL is as efficacious and safe as conventional PCNL with acceptable complications. Based on current literature and recent experiences, miniaturized PCNL can be used for the removal of renal stones in all calyces accessible to conventional PCNL. The best indications for miniaturized PCNL seem to be small- or medium-sized stones of up to 2 cm, although there is no definite evidence to support the establishment of an upper size limit. In general, patients with small collecting systems and narrow infundibulae may benefit from the use of miniaturized PCNL systems. Moreover, the presence of calyceal diverticular stones can be a good potential indication for miniaturized PCNL. Although it is suitable to perform conventional PCNL using a large- bore Amplatz sheath for larger (>2 cm) or staghorn renal stones, for smaller stones (<2 cm), miniaturized PCNL is associated with a similar stone-free rate when compared to conventional PCNL, with less bleeding, tolerable renal damage, shorter hospital stay, and less postoperative discomfort. Additional advantages of miniaturized PCNL include improved safety with the supracostal puncture approach, excellent access to almost all calyces and the upper ureter, and effective performance in both the supine and prone positions. However, surgeons must always keep in mind possible complications related to higher intrarenal pelvic pressure, as well as the trend towards the development of metabolic acidosis during PCNL using a smaller nephrostomy tract. Moreover, it should be noted that comparison of the miniaturized PCNL with the conventional techniques may be related to biases due to poor quality of evidence with small sample sizes and variable inclusion criteria. Thus, well-designed, randomized, multi-institutional studies are needed before considering them a standardized procedure with potential for replacing conventional PCNL or as an alternative to ESWL or RIRS.

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