

# Recent advancement or less invasive treatment of percutaneous nephrolithotomy

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Since its initial introduction in 1976, percutaneous nephrolithotomy (PCNL) has been widely performed for the management of large renal stones and currently is recommended for staghorn calculi, kidney stones larger than 2 cm, and shock wave lithotripsy-resistant lower pole stones greater than 1 cm. However, except for open and laparoscopic surgery, PCNL is the most invasive of the minimally invasive stone surgery techniques. Over the years, technical and instrumental advances have been made in PCNL to reduce morbidity and improve effectiveness. A thorough review of the recent literature identified five major areas of progress for the advancement of PCNL: patient positioning, method of percutaneous access, development of lithotriptors, miniaturized access tracts, and postoperative nephrostomy tube management. This review provides an overview of recent advancements in PCNL and the outcomes of each area of progress and notes how much we achieve with less invasive PCNL. This information may allow us to consider the future role and future developments of PCNL.

**Keywords:** Kidney calculi; Minimally invasive surgical procedures; Percutaneous nephrostomy; Supine position; Surgical instruments

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## INTRODUCTION

The incidence of kidney stones has been increasing in Korea with the rise in dietary and lifestyle changes influenced by Western countries. Nephrolithiasis is one of the common causes of morbidity and deterioration of quality of life in the United States, with a lifetime prevalence of 5% to 10% [1]. In addition, urolithiasis is a recurrent disease, with lifetime recurrence risks reported to be as high as 50% [2]. Given this high incidence and recurrence, technological advances have been made to dramatically improve minimally invasive techniques for the management of kidney stones, such as percutaneous nephrolithotomy (PCNL), extracorporeal shock wave lithotripsy (ESWL), and

retrograde intrarenal surgery (RIRS). Although ESWL and RIRS are currently widely used as less-invasive treatment modalities for renal stones, PCNL still has a role depending on the size, position, shape, and composition of the stones [3]. PCNL is recommended as the treatment of choice for large renal stones (>20 mm) and for lower calyceal stones sized 10 to 20 mm with unfavorable factors for ESWL according to updated European Association of Urology guidelines [4]. Since its initial introduction in 1976 by Fernstrom and Johansson, PCNL has been widely performed for the management of large and complex renal stones and it remains the gold standard approach for difficult-to-treat renal stones (staghorn calculi, hard stones, stones associated with abnormal renal anatomy, and stones that have failed

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**Table 1.** History of the first advancement of percutaneous nephrolithotomy

Source	Year	Procedure
Goodwin et al. [100]	1955	First percutaneous nephrostomy
Fernstrom and Johansson [5]	1976	First percutaneous nephrolithotomy
Wickham et al. [81]	1984	First tubeless percutaneous nephrolithotomy
Valdivia et al. [14]	1987	First supine percutaneous nephrolithotomy
Helal et al. [59]	1997	First mini-perc

treatment with other less-invasive methods) [5-9]. However, although PCNL is considered as a minimally invasive procedure for stone removal, it is still a challenging surgical technique and can be associated with critical complications such as bleeding and septicemia. In addition, as the indications for RIRS have expanded, it has supplanted ESWL and PCNL for the treatment of some renal stones. Nevertheless, many efforts have been made to reduce morbidity and increase the efficiency and effectiveness of PCNL (Table 1), because PCNL remains indicated as a first-line treatment for many cases. Herein, recent advancements in PCNL in surgical technique, instrumentation, and perioperative care are reviewed from the current literature.

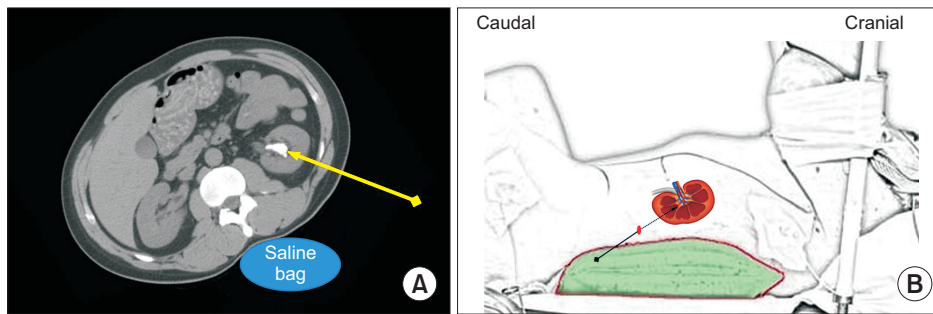
## POSITIONING

Traditionally, PCNL has been performed with the patient in a prone position, and retrograde ureteral catheter placement is usually performed in the dorsal lithotomy position before the main lithotripsy procedure. The prone position provides a larger surface area for the choice of puncture site, including upper pole puncture, a wider space for manipulating the nephroscope and lithotriptors, and a lower risk of other perirenal visceral injury [10]. However, there are also disadvantages to performing PCNL in a traditional prone position, such as patient discomfort, a relatively longer overall operation time owing to repositioning, and anesthesiological risks including circulatory problems, ventilatory difficulties, suboptimal airway control, increased sympathetic activity, ocular and pharmacokinetic effects, and possible lesions of the cervical spine or peripheral nerves. Moreover, repositioning of the anesthetized patient is inevitable for retrograde access if it is needed, and this can lead to wasted time and increased risk of iatrogenic articular and peripheral nerve inadvertent pressure injury [11-14]. To overcome these limitations, various modifications of patient positioning have been proposed over the years.

The prone split-leg position was introduced as a modification of standard prone PCNL to increase efficiency and reduce the operation time [15]. This position obviously

decreases the operation time and the need for operative staff for multiple patient transfers, but it still has disadvantages related to anesthesiological risks. Another modification of the prone position is the prone-flexed position [16]. This position provides a larger surface area and wider working space. The distance from the posterior iliac crest to the 12th rib is reported to be increased by 2.9 cm with the prone-flexed position compared with the standard prone position [16]. This means that this position has an advantage for easier access to upper pole puncture. Although standard and modified prone positions have been successfully performed, they still have drawbacks related to increased cardiopulmonary risks. In particular, obese patients and those with cardiopulmonary comorbidities may have increased risks of cardiopulmonary-related complications for long operations in the prone position. To overcome these drawbacks, supine PCNL was introduced.

Since Valdivia et al. [14] first performed supine PCNL in 1987, several studies have reported favorable outcomes and the technical benefits of this technique [17-25]. A recent systemic review and meta-analysis comparing supine and prone PCNL reported a shorter operation time in supine PCNL and similar complication and transfusion rates between supine and prone PCNL [23,25]. Theoretically and practically, the advantages of supine PCNL compared with standard prone PCNL are as follows: (1) optimal cardiovascular and airway control, (2) better in high-risk patients with heart failure or in obese patients, (3) shorter operation time due to no need for repositioning, (4) opportunity for a combined retrograde approach, (5) better stone fragment washout due to horizontal dorsal sheath angle, and (6) less radiation exposure to the surgeons' hands. However, supine PCNL also has several limitations, as follows: (1) limited space for renal puncture and nephroscope mobility (Fig. 1); (2) upper pole calyx puncture is more challenging; (3) more complex tract dilation due to high kidney mobility; (4) increased risk of spleen and liver injury during upper pole puncture; (5) decreased filling of the collecting system, which is constantly collapsed; and (6) spinal interposition in the fluoroscopic field during antero-posterior projections [11,13,26-28].



**Fig. 1.** Schematic images of percutaneous access for percutaneous nephrolithotomy (PCNL) in the supine position. The position is usually modified by using a saline bag or a specially made cushion below the ipsilateral upper flank, except in the complete supine position PCNL. (A) Transverse view, (B) lateral view. Arrow indicates direction of percutaneous access.

In addition to supine PCNL, various modified positions have recently been proposed, such as supine oblique [29], semisupine [30], lateral decubitus [31], split-leg modified lateral [32], flank [33], and flank prone position [34]. The advantage of these positions is the possibility for simultaneous antegrade and retrograde access to the kidney without repositioning. However, there are still limited studies available to validate the efficacy and safety of PCNL in these various positions, including supine PCNL. Therefore, a large, prospective, multicenter, randomized controlled trial is necessary to verify the feasibility and safety of PCNL in modified positions.

## ACCESS

One of the most important steps for successful PCNL is well-placed access into the kidney. Traditionally, intraoperative percutaneous access was most commonly performed by use of fluoroscopic guidance. However, this approach has some drawbacks, including increased radiation exposure for the surgeon, operating room staff, and patient, and possible iatrogenic visceral injury such as to the colon, liver, spleen, and pleura. Moreover, it is hard to perform fluoroscopic-guided access in patients in whom retrograde ureteral catheter placement is difficult or impossible, such as in patients with urinary diversions or renal transplants.

To overcome these limitations of fluoroscopy, an alternative is ultrasound-guided percutaneous access. The advantages of this approach are less radiation exposure and the ability to identify nearby organs. Several studies have reported satisfactory outcomes and fewer complications with ultrasound-guided access compared with fluoroscopic-guided access [35-38]. According to these studies, the success rate in the targeted calyces of ultrasound- and fluoroscopic-guided access ranges from 90% to 100% and from 96% to 100%, respectively. Visceral injury was not reported in these studies. Basiri et al. [35] reported intraoperative bleeding rates of 10% (5 of 50) in an ultrasound-guided access group and 6% (3 of 50) in a fluoroscopic-guided access group ( $p=0.5$ ).

However, ultrasound-guided access is surgeon-dependent and has some limitations for delineating fine details of the renal anatomy, especially in patients with nondilated collecting systems or in obese patients [39]. In this condition, my preference for percutaneous access is a combined approach using ultrasound and fluoroscopic guidance simultaneously. With fluoroscopic guidance, I can easily focus on the targeted calyx, and then percutaneous access can be performed by using ultrasound guidance, resulting in less radiation exposure and reducing the risk of nearby organ injury. Moreover, large branches of the renal artery can be identified by using the Doppler ultrasound setting, which may reduce the risk of bleeding by avoiding punctures to that area.

If the patients have a collecting system that is difficult to access or a spinal deformity such as spina bifida or scoliosis, fluoroscopic-guided access can cause adjacent organ injury and may not guarantee successful PCNL. In these situations, computed tomography (CT)-guided percutaneous access can be a good alternative [27]. Matlaga et al. [40] reported six cases of CT-guided access due to spinal deformity, retrorenal colon, or transplanted kidney and showed favorable outcomes. They reported that percutaneous access was achieved successfully without complications in all cases and the stone-free rate was 83% (5 of 6).

Because fluoroscopic-guided or CT-guided access can have concerns related to ionizing radiation exposure, and ultrasound-guided access may obscure fine details of the renal anatomy, magnetic resonance imaging (MRI)-guided access has been introduced as an alternative means of nonionizing radiation [41]. Kariniemi et al. [42] performed percutaneous access using open-configuration, C-arm shaped MRI and reported success in seven of eight patients. They demonstrated that a drawback of this approach is difficulty visualizing the guidewire with MRI. Besides, the need for specially designed equipment to perform this technique can also be an obstacle to widespread use of MRI-guided access.

In addition to these various imaging-guided access methods, the development of endoscopy such as flexible

ureteroscopy and optical puncture systems has introduced modified techniques for safe and desirable access. Lawson et al. [43] and Hunter et al. [44] used a retrograde approach that can be applied by directing a steerable catheter in a retrograde fashion into the desired calyx and then advancing a puncture wire out through the catheter to the skin. Grasso et al. [45] and Kidd and Conlin [46] reported simultaneous retrograde ureteroscopic and fluoroscopic-guided percutaneous access. Bader et al. [47] reported successful use of an optical puncture needle named an “all-seeing needle” to confirm the optimal percutaneous access.

## LITHOTRIPTORS

After successful percutaneous access and tract dilatation, efficient stone fragmentation and evacuation depend on the effectiveness of the lithotriptors. Traditionally, ultrasonic and pneumatic lithotriptors have been most commonly used for PCNL. Ultrasonic lithotriptors can effectively fragment most stones except very hard stones, such as cystine or calcium oxalate monohydrate stones, and can simultaneously aspirate stone fragments [48]. Pneumatic lithotriptors can fragment hard stones more efficiently than ultrasonic lithotriptors but have no or limited suctioning function [49].

To combine the characteristics of both ultrasonic and pneumatic lithotriptors, dual-modality devices, such as the Swiss LithoClast Ultra (Boston Scientific Corp, Natick, MA, USA) and the CyberWand dual ultrasonic lithotripter (Gyrus ACMI, Southborough, MA, USA) have been developed that provide efficient stone fragmentation with concomitant aspiration [50,51]. Pietrow et al. [52] performed a randomized controlled study comparing the Swiss LithoClast Ultra with a standard ultrasonic lithotripter and demonstrated a better stone clearance rate (40 mm<sup>2</sup>/min vs. 17 mm<sup>2</sup>/min, p=0.028) and shorter mean time to stone clearance (21 minutes vs. 44 minutes, p=0.036) with the Swiss LithoClast Ultra. However, another multicenter randomized clinical trial showed no advantage of the CyberWand dual ultrasonic lithotripter compared with a single-probe ultrasonic lithotripter with regard to time to stone clearance, stone-free rate, and complication rate [53]. Another new device is the holmium: yttrium aluminium garnet (YAG) laser. This device can be used alone or in combination with an ultrasound lithotripter. The vaporizing and bursting effect of the holmium:YAG laser can fragment the stone quickly regardless of stone composition; therefore, it may reduce the lithotripsy and operation time [54,55]. Recently, a cordless lithotripsy device, the LMA stone Breaker Pneumatic Lithotripter (Cook Medical, Bloomington, IN, USA), was developed.

The advantage of this device is that it is portable and can generate high velocity at the probe tip, but no clinical trials have compared the efficiency and safety of this device with those of other lithotriptors [56].

## MINI-PCNL

Standard PCNL is usually performed through 24- to 30-Fr percutaneous tracts. Recently, several reports have suggested that the risk of bleeding is associated with sheath size [57,58]. Thus, to decrease morbidity related to larger tracts, such as bleeding, postoperative pain, and potential renal damage, modifications to technique and the size of the instruments have been made. This technique of using a small caliber working sheath, known as mini-PCNL or miniperc, was originally developed for the management of large renal stones in pediatric patients. Helal et al. [59] first reported miniaturized PCNL for 2-year-old pediatric patients with renal stones with the use of a 15-Fr peel-away vascular sheath. Then, Jackman et al. [60] accomplished mini-PCNL using an 11-Fr access sheath. In their series, the mean decreases in operation time, estimated blood loss, and hematocrit were 176 minutes, 83 mL, and 6.6%, respectively. The stone-free rate was 89% (8 of 9) without any procedure-related complications. However, there is still no exact definition as to what should be called mini-PCNL or miniperc. Since the first trial of miniaturized PCNL, several authors have utilized various sizes of working sheaths ranging from 11 to 20 Fr [60-63]. Thus, the term *mini-PCNL* is used for any PCNL that utilizes access tracts of 20 Fr or smaller [2]. In addition, Desai et al. [64] recently introduced the smallest sized access tract (4.8 Fr), which was named “microperc.”

Definite indications for mini-PCNL have not been clearly defined. However, mini-PCNL can be the first-line treatment for renal stones with a diameter larger than 2 cm in children [2], and general indications for mini-PCNL in adults may include renal stones less than 2 or 2.5 cm in size with previous failure of ESWL or RIRS, cystine stones, and anatomical abnormalities inhibiting retrograde access or distal passage of stones [61]. Mini-PCNL can also be used in patients with a narrow or long infundibulum or as a secondary access for inaccessible or residual stones after standard PCNL [2,61]. Nevertheless, mini-PCNL has not only been used for the management of smaller renal stones or pediatric renal stones but for large impacted upper ureteral stones and staghorn calculi as well [65-68].

The advantages of mini-PCNL, based on several prospective trials, are less bleeding, increased maneuverability, lower



postoperative pain, and reduced hospital stay. However, the longer operation time due to the need to disintegrate stones into small fragments to evacuate through a small-sized sheath is a limitation of mini-PCNL [69-71]. Most studies reported similar stone-free rates and comparable overall complication rates between mini-PCNL and standard PCNL for the management of renal stones less than 2.5 cm in size [2,69]. Compared with ESWL, mini-PCNL has been reported to have significantly higher stone-free rates, especially for renal stones greater than 1 cm, although it is more invasive [72,73]. Compared to RIRS, mini-PCNL has shown better stone-free rates for the management of larger renal stones (2–3 cm) [74] and large impacted upper ureteral stones [75], but similar effectiveness was reported when treating smaller renal stones between both procedures [76,77]. In these studies, mini-PCNL was superior in terms of operation time for the management of comparably sized stones, but was inferior with respect to invasiveness. However, the combination of RIRS and mini-PCNL showed better outcomes than did mini-PCNL alone for large renal stones (>3 cm) with shorter operation times [78].

Microperc, which uses the smallest sized access tract, can be applicable for small or intermediate-sized lower calyceal stones, especially stones that are ESWL-resistant or retrograde inaccessible. Specifically, microperc can also be used for the management of renal stones in calyceal diverticula and in horseshoe and ectopic kidneys [64]. However, further prospective randomized controlled trials will be needed to validate the safety, efficacy, and applicability of this technique.

## TUBELESS PCNL

After completing the lithotripsy, the final step in PCNL is sealing the nephrostomy tract. Traditionally, a large-caliber nephrostomy tube, such as a 24-Fr Council catheter, a reentry Malecot catheter, or a nephroureteral stent, was placed to provide hemostasis of the tract and maintain adequate urine drainage. The nephrostomy tube was historically left indwelling for several days, which required a prolonged hospital stay, increased analgesic use owing to patient discomfort, and resulted in urinary extravasation around the tube. Many trials have been conducted to overcome these drawbacks.

The first such trial involved the placement of a smaller sized nephrostomy tube instead of a large-bore one. Several studies have compared the outcomes of PCNL using different sized nephrostomy tubes. Maheshwari et al compared a patient group who underwent PCNL and

had either a 28-Fr nephrostomy tube or a 9-Fr pigtail catheter postoperatively [79]. In that study, the incidence of hematuria was comparable between the two groups, but the 9-Fr pigtail catheter group showed a lower analgesic requirement, less urine leakage, and a shorter hospital stay. Pietrow et al. [80] also reported similar results from their randomized prospective trial comparing a 22-Fr Council catheter with a 10-Fr pigtail catheter.

Although Wickham et al. [81] first described no placement of a nephrostomy tube after PCNL in 1984, tubeless PCNL was not actively attempted for over 10 years because postoperative hemorrhage was reported [82]. The first series of tubeless PCNL was reported in 1997 by Bellman et al. [83]. In that study, the tubeless PCNL group showed comparable stone-free and complication rates, a lower analgesic requirement (11.58 mg vs. 36.06 mg of morphine sulfate,  $p=0.0001$ ), a reduced hospital stay (0.6 days vs. 4.6 days,  $p=0.0001$ ), and an earlier return to normal activity (17.85 days vs. 26.6 days,  $p=0.0004$ ) compared with the standard PCNL group with a 22-Fr nephrostomy tube. Since then, many studies have evaluated the safety and applicability of tubeless PCNL. Desai et al. [84] compared three different randomly divided groups (22-Fr nephrostomy tube, 9-Fr pigtail catheter, and 6-Fr double-J stent without nephrostomy tube) and reported no significant differences in blood loss among the three groups. They also found that analgesics were most frequently required in the 22-Fr nephrostomy tube group, and the duration of urine leakage and hospital stay was the shortest in the tubeless group. Marcovich et al. [85] also reported no significant difference in blood loss or the transfusion rate when comparing three different groups according to the size of the nephrostomy tube (24-Fr reentry catheter, 8-Fr pigtail catheter, and tubeless). However, analgesic use and hospital stay were also not significantly different in their series. Meta-analysis also showed that tubeless PCNL was associated with lower analgesic requirements, shorter hospital stay, and comparable blood loss compared with standard PCNL [86,87].

Although the indications for tubeless PCNL have not been clearly defined, initially, tubeless PCNL was performed only in highly selected cases such as uncomplicated stones, smaller stones (less than 3 cm), normal renal function, single-tract procedure, short operation time, complete stone removal, no collecting system perforation, and no active bleeding from the tract at completion [10]. Since then, there have been several efforts to apply tubeless PCNL in more complicated cases, including multiple, complex, and bilateral stones; patients with elevated serum creatinine; children; obese patients; and elderly patients [88-90]. On the basis of

these current experiences and analyses, many investigators have concluded that tubeless PCNL should be avoided in case of multiple access, serious intraoperative bleeding, collecting system perforation, and need for early second-look surgery [10,56].

Although many studies have reported that tubeless PCNL can be safely performed in well-selected cases, there are still concerns associated with tract bleeding. Limb and Bellman [91] reported a postoperative transfusion rate of 5.4% (6 of 112) and 2 cases (1.8%) of renal pseudoaneurysm, which were managed by selective angioembolization, in their first 112 tubeless renal surgery cases. To overcome these concerns, several techniques for tract sealing, such as electrocauterization of bleeding points, applying fibrin glue, and placement of hemostatic matrix into the tract, have been tried [92-95]. Most of these studies reported favorable outcomes in terms of safety and efficacy for the tract control, but routine use of these tract-sealing techniques in tubeless PCNL to prevent tract bleeding or urine leakage is still controversial. Moreover, the possibility of stone formation in the collecting system due to misplacement of these biological sealants or worsening of bleeding with further renal parenchymal injury due to inappropriate electrocauterization are possible side effects of these techniques. Thus, meticulous care must be taken when the tract-sealing technique is considered for tubeless PCNL.

Initially, tubeless PCNL was performed with placement of an internal double-J stent for the purpose of preventing urinary extravasation. The internal stent can also cause patient discomfort owing to bladder irritation symptoms and urine reflux. In addition, the most bothersome fact is the need for postoperative stent removal by use of cystoscopy. To avoid this procedure, several attempts such as leaving the string attached to the stent and using externalized ureteral stents have been tried, but there is the risk that patients may pull out their stents prematurely by accident, and the risk of urinary tract infection may be increased. To overcome these drawbacks, "totally tubeless" PCNL, which is tubeless and stentless, has been introduced [96,97]. Many investigators have suggested that the best available urinary drainage method from the kidney is the normal peristaltic ureter and the only indication for ureteral stent placement is ureteral obstruction due to edema, inflammation, presence of residual stones, or stricture [10,88]. Several studies have demonstrated that totally tubeless PCNL is safe, effective, and well tolerated in selected patients and is associated with a shorter hospital stay, less postoperative pain, and decreased analgesic requirements compared with standard PCNL [98,99]. There are limited prospective randomized

study data comparing totally tubeless and tubeless PCNL, but Istanbuloglu et al. [99] found that totally tubeless PCNL had comparable blood loss, success rates, operation time, hospital stay, analgesic requirements, and complication rates with the advantage of no need for stent removal even compared with tubeless PCNL in their retrospective study. To validate these data, further prospective randomized trials will be needed to compare safety and efficacy between totally tubeless and tubeless PCNL.

## CONCLUSIONS

PCNL was developed to reduce the morbidity and mortality associated with open renal surgery, and it currently remains the first-line treatment for large renal stones. However, it represents the most morbid of the minimally invasive endoscopic surgeries for renal stones. Over the years, with the development of endoscopic instruments and techniques, the role of ESWL and RIRS has increased. Nevertheless, PCNL still has many advantages over ESWL and RIRS in some cases. Currently, many efforts and trials to reduce morbidity and increase the efficiency and effectiveness of PCNL have furthered this procedure technically and have broadened its indications. Recent advancements that make PCNL a less-invasive technique promise higher success rates and less perioperative complications. Further efforts will be needed to validate the many promising retrospective data by use of large-scale prospective studies and to develop this procedure more safely and effectively.

## CONFLICTS OF INTEREST

The authors have nothing to disclose.

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