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INVITED REVIEW

Percutaneous nephrolithotomy: complications and how to deal with them

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Abstract
Percutaneous nephrolithotomy is a common surgical treatment for large and complex stones within the intrarenal collecting system. A wide variety of complications can result from this procedure, including bleeding, injury to surrounding structures, infection, positioning-related injuries, thromboembolic disease, and even death. Knowledge of the different types of complications can be useful in order to prevent, diagnose, and treat these problems if they occur. This review describes the diversity of complications with the goal of improving their avoidance and treatment.

Keywords Percutaneous nephrolithotomy · PNL · Nephrolithiasis · Complications · Bleeding · Injury · Perforation · Supracostal access · Infections · Urosepsis

Introduction

Percutaneous nephrolithotomy (PNL) is a common procedure for treatment of large or complex intrarenal stones, with the indications expanding along with improving technology. Currently, the American Urological Association and Endourology Society Surgical Management of Stones Guidelines recommend PNL as first-line therapy for all patients with intrarenal stones > 20 mm or lower pole stones > 10 mm [1]. Despite these recommendations, PNL is still the least commonly utilized technique for nephrolithiasis given the concern for morbidity associated with the procedure. As with any surgical practice, complications can occur, although understanding of the possible outcomes, prompt recognition of such complications, and proper treatment can significantly decrease the risk of long-term morbidity. In this review, complications of PNL will be discussed with a specific focus on their identification and appropriate response.

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Bleeding complications

Some of the most common and concerning complications seen in patients undergoing PNL are related to blood loss, either intraoperative or postoperative. Transfusion rates vary widely based on series, but have been documented from 1 to 34% [2–9]. Across differing studies, many factors have been associated with such complications, including surgeon technique and experience, longer operative time, preoperative anemia and diabetes, patient age, increased stone burden, and need for multiple or larger access tracts [6, 8, 10]. Additionally, history of open stone surgery and intraoperative injury (e.g. infundibular or pelvic wall tear) have been associated with increased blood loss as well [9].

Intraoperative bleeding

Preoperative workup is necessary to decrease the bleeding risks associated with this procedure. The AUA recommends performing non-contrast CT scan and complete blood count with platelets prior to percutaneous surgery, both of which can be used to assist in preoperative planning [1]. Perioperative anticoagulation is a complicated situation, although it is generally agreed upon that, when possible, withholding of such medications—including warfarin, anti-platelets, and the anti-Xa medications—is preferred to decrease bleeding risk. Aspirin, which was typically held perioperatively, is now more frequently continued through the perioperative period as recent data demonstrate the safety of performing PNL on this medication [11]. Other anticoagulant medications should be stopped prior to PNL, if possible, although timing of cessation and restarting of these medications should be discussed with the prescribing physician [12]. Alternatively, perioperative removable inferior vena cava filter placement is another option in certain patients who are at high risk of thromboembolic disease [13–15].

Surgical technique is a significant modifiable risk factor for bleeding complications. In general, percutaneous access to the renal collecting system should be performed through a posterior calyx along its axis to avoid blood vessels that course alongside the infundibulum [16]. The nephrostomy tract should be dilated only to the edge of the collecting system, as medial dilation increases the risk of renal pelvic injury. Additionally, some studies show that retrograde endoscopically-guided percutaneous access may decrease intraoperative blood loss, possibly by increasing the chances of access through the center of the papilla and direct visualization of tract dilation [17]. Excessive torqueing of rigid instruments should be avoided, with placement of additional access points or the utilization of flexible instruments if the stones cannot easily be reached [18–21]. Similarly, over manipulation of the sheath can increase bleeding, especially if the sheath is accidently moved out of the collecting system [22, 23].

Tract dilation deserves additional discussion, as there is concern that tract size and dilation method may affect intraoperative and postoperative bleeding risk. Studies have shown contradicting results, including that balloon dilation is safest with regards to bleeding [10, 24], that serial dilation has a lower risk [25], or that dilation method has no effect on bleeding complications [6, 26, 27]. Studies also suggest that a smaller tract size may decrease bleeding risk, although this finding has not been definitively demonstrated [22].

Intraoperative bleeding may be encountered despite proper management of the above concerns. A small amount of bleeding, when it does not obscure the operating field, can often be improved by repositioning of the access sheath into the collecting system. One study noted irrigation with antifibrinolytic agents may decrease bleeding risk, although more data are needed to support this technique [28]. If a larger amount of intraoperative bleeding is noted, the procedure should be stopped, and a 30 French balloon dilator can be inflated within the tract with eventual placement of a large-bore (> 18 French) nephrostomy tube for tamponade [29]. Postoperative clamping of the nephrostomy tube usually resolves the issue if the bleeding is due to a venous injury; administration of mannitol may cause renal swelling to assist in tamponade of bleeding vessels along the nephrostomy tract [6, 30]. Additionally, specialized nephrostomy catheters or other hemostatic catheter-based methods have been developed to manage intraoperative bleeding with good results [31–33]. When these methods fail or arterial injury is suspected, renal angiography with angioembolization is prudent.

Given that nephrostomy tube-free PNL (tubeless PNL) is becoming more common, it is important to discuss perioperative hemorrhage risk in these cases, which appears to be on par with standard PNL [34]. It is recommended that in patients with significant intraoperative bleeding, a nephrostomy tube be left for tamponade, but other methods including point cautery within the nephrostomy tract and the use of hemostatic agents have been evaluated [35–37]. At this point, the data do not support use of hemostatic agents within the nephrostomy tract; nephrostomy tube placement should be standard in procedures complicated by excessive blood loss.

Postoperative bleeding

Postoperative bleeding risk continues for several weeks after the procedure, with approximately 1% of patients eventually requiring angiographic treatment for this complication [5, 7, 38]. If significant bleeding is noted upon removal of a nephrostomy tube, digital tamponade with eventual fluoroscopy-guided tube replacement is indicated, with subsequent bedrest and transfusion as needed. Perinephric hemorrhage is another cause of postoperative bleeding which should be suspected in cases of clear urine with dropping blood counts and flank pain, although this situation can similarly be managed conservatively with bedrest and transfusion. Delayed bleeding is often secondary to arteriovenous fistula or pseudoaneurysm and occurs approximately 1–3 weeks postoperatively. In cases of unresponsive hemorrhage, angiography with embolization is typically effective, although open surgical exploration with vascular repair and nephrectomy are options in cases where conservative management fails.

Collecting system injury

Perforation

Perforation of the collecting system is a complication that can occur during any portion of the procedure and has been reported in up to 7% of PNL procedures [39]. This complication should be suspected if retroperitoneal structures, perirenal fat or sinus fat is seen, with or without abdominal/flank distention. Fluid extravasation associated with a collecting system perforation can produce ventilation difficulties, electrolyte/hemodynamic abnormalities, and postoperative ileus [40].

This complication can be avoided by paying close attention to access and dilation methods discussed previously and by keeping the working sheath within the collecting system.

Additionally, fluoroscopic or endoscopically visualized dilation, sheath placement, and tube manipulation will decrease risk of perforation. Conversely, smaller access tracts, such as those seen with "mini-PNL" or "micro-PNL", may also introduce an elevated intrarenal pressure and increase the risk of perforation [41].

Once perforation of the collecting system is noted, the procedure should be terminated expeditiously, although the procedure can be completed with low-flow irrigation if the surgery is nearly complete and the patient is stable. A nephrostomy tube should be left in place at the conclusion of the procedure; most perforations heal within 72 h, but it is recommended to perform a nephrostogram approximately 7 days postoperatively to ensure complete healing. Open surgical repair or nephrectomy is rarely necessary [39].

Ureteral avulsion is an extreme form of collecting system perforation that is rare during PNL. It more commonly occurs during incision and dilation of a ureteropelvic junction or during antegrade treatment of ureteral calculi. If a drainage catheter (stent or nephroureteral catheter) can be passed across the defect, healing is common, although occasionally a percutaneous drain or open repair are required.

Stricture/stenosis

Stricture development is a rare complication of PNL, with an incidence of less than 1%, most commonly affecting the proximal ureter and ureteropelvic junction [3, 4]. Strictures are most typically due to inflammation from stone impaction or intraoperative trauma, including lithotripsy-associated injury or urine/stone extravasation. Importantly, postoperative ureteral strictures may be asymptomatic, thus it is recommended that all patients undergoing PNL have routine postoperative imaging to evaluate for silent obstruction [42, 43]. Most ureteral strictures seen after PNL can be managed endoscopically, although length of stricture (> 1 cm), degree of hydronephrosis, and poor renal function are all risk factors for failure of conservative management in these cases.

Infundibular stenosis is a similarly rare complication, with approximately 1–2% risk after PNL [3, 44, 45]. Studies suggest prolonged operative times, large stone burden, and extended nephrostomy drainage as risk factors for this occurrence, possibly due to increased inflammation or prolonged instrumentation [46]. This complication can often be treated endoscopically, although asymptomatic patients with normal renal function can be observed.

Extrarenal stone migration

Extrarenal or extraureteral stone migration is a relatively benign complication as these fragments are generally of little consequence. As long as the stone is not infected and fragment-associated inflammation does not obstruct the urinary tract, treatment is usually not necessary [47, 48]. Intraperitoneal migration of fragments has been reported with open extraction performed to prevent peritoneal complications [49]. In case of migration of fragments out of the urinary tract, endoscopic retrieval should not be attempted, as this may only enlarge the perforation. Yet, it is important to document that the stone is entirely outside the collecting system. This complication can be avoided by applying proper lithotripsy techniques and noticing any form of collecting system perforation early, with prompt cessation of the procedure if necessary.

Retained foreign bodies

Rarely, a piece of equipment used during PNL can break off and remain within the collecting system. This problem can occur at any point of a procedure and as such vigilance is required to prevent such a complication. A wide variety of retained foreign bodies has been reported, from plastic drape fragments and ureteral catheter pieces to wire baskets, laser fibers and portions of Malecot catheters [50–52]. Careful manipulation of equipment and close evaluation for device fatigue can decrease the risk of this complication. If a piece of equipment is noted to have broken off into the collecting system, such a foreign body can usually extracted endoscopically with fluoroscopic assistance, although retrograde ureteroscopic access can also be used if it is noted postoperatively.

Injury to surrounding structures

Lung and pleura

The most common peri-renal organs injured during PNL are the lungs and pleura, with this complication reported in 0.3–15.3% of cases [3, 4, 53–57]. It is no surprise that the risk of pleural injury increases with supra-costal access; CT imaging studies have shown that during maximal expiration, a supra-11 approach will theoretically traverse the pleura approximately 80% of the time [58]. This risk decreases to 15–30% with supra-12 approaches, although these rates are higher than those seen clinically [58].

Clinical studies note rates of intrathoracic complications closer to 10–15% with supracostal access (35% with supra-12, 10% with supra-11), compared to 1.5–4.5% with subcostal access [55, 56]. Of note, some studies suggest that operative position may vary the risk of pleural injury, with prone-flexed or supine positions potentially displacing the kidney caudally to allow for upper pole access without supra-costal puncture [59, 60].

Preoperative CT scan is essential for operative planning to determine positioning of access tracts and decrease intrathoracic complications [61]. PNL should be performed through a working access sheath, as the sheath may provide a barrier to the influx of air or fluid into the pleural cavity in cases of thoracic violation. Additionally, routine chest imaging at the conclusion of the procedure (or in the recovery room) can be useful to evaluate for obvious pneumothorax or hydrothorax in cases of supra-costal access [62].

In the case of recognized small-volume, asymptomatic pneumothorax or hydrothorax, the patient may be observed; if the patient becomes unstable or shows signs of pulmonary compromise, tube thoracostomy may be required [63]. While small-bore tubes are useful in this situation, if there is concern for spillage of infected fluid or stone material into the pleural cavity, a full-size chest tube may be more prudent. If these conservative treatments fail or complex effusion/empyema develop, thoracoscopic surgery or thoracotomy may be required, although this need is relatively rare [64].

A more formalized nephropleural fistula can manifest anytime from the conclusion of the procedure to 2 weeks postoperatively; symptoms can range from continued thoracostomy tube drainage to a delayed presentation with shortness of breath. Diagnosis is typically made by retrograde pyelography and treatment is often successful with dual drainage of the pleural space and urinary system (i.e. thoracostomy tube and ureteral stent/nephrostomy tube) [65]. Hemothorax can also occur due to injury of the diaphragm or intra-costal vessels, which course along the underside of each rib. Conservative management with thoracostomy tube and hemodynamic monitoring is reasonable, although thoracoscopic intervention may be required.

Colon

Colonic perforation is a rare complication of PNL as it is uncommon to find this organ in a retro-renal location; fewer than 1% of cases involve colon injury [39, 66–68]. Previous estimates show approximately 0.6% of patients harbor a retro-renal colon on preoperative CT scan, although some studies suggest a higher incidence of this finding on prone CT imaging (16.2%), arguing for operative planning with a prone CT [69–71]. Risk factors for such an injury have been investigated, with the following patients at higher risk for colonic perforation—congenital renal anomalies such as horseshoe kidney, colonic distention, lower pole puncture, left-sided procedure, previous colonic surgery, older age, and female sex [66, 67, 72]. Of note, supine positioning for PNL does not appear to increase the risk of colonic injury [73].

Early recognition of such an injury is of utmost importance, with a delay in diagnosis leading to severe complications. Signs of colon perforation include passage of gas or feces through or around the nephrostomy tube, intraoperative diarrhea/hematochezia, and peritonitis (often associated with fevers) [66, 67, 72, 74]. Some surgeons recommend nephrostogram at the conclusion of each procedure to rule out colonic injury [66].

Colonic injury can be managed conservatively in the majority of cases, especially if the injury is retroperitoneal and the patient is clinically stable [66, 75]. Double drainage should be established with a ureteral stent and foley along with withdrawal of the nephrostomy tube into the colon, which is often performed under fluoroscopic guidance [67]. The patient should be monitored closely on broad-spectrum antibiotics and low residue diet. Approximately 7–10 days after injury a contrast study should be performed through the colostomy tube to ensure resolution of the nephro-colic fistula, with subsequent tube removal [76]. Open surgical management may be required in patients with transperitoneal injury, peritonitis, clinical instability, sepsis, or in those patients for whom conservative management has failed.

Small intestine

The second and third portions of the duodenum may be injured during PNL, as they are adjacent to the lower pole and renal pelvis of the right kidney. This complication is very uncommon and is most often seen during percutaneous access or with renal pelvis perforation [77]. This issue should be suspected if intestinal mucosa or contents are seen endoscopically, or nephrostogram delineates the small bowel lumen. Surgical exploration is the most common treatment, although small injuries can be managed conservatively. Such management consists of adequate double drainage of the intestine and urinary tract, antibiotics, nasogastric suction, and parenteral nutrition. Nephrostogram and upper gastrointestinal radiologic study should be performed 10–14 days following the perforation to ensure complete closure of the injury.

Liver, gallbladder, and spleen

The liver is rarely injured during PNL, although supra-costal access and hepatomegaly may increase this risk up to 14% [58]. This complication can be avoided by utilizing proper preoperative imaging and access techniques and considering CT-guided access for certain patients. If liver injury is noted, a nephrostomy tube should be left in place for 7–10 days to allow for tamponade and maturation of the tract. Open surgical repair remains an option with failure of conservative management.

The gallbladder is similarly a rare organ for PNL injury, with most patients presenting with peritonitis and signs of septic shock. Typical treatment consists of exploratory laparotomy/laparoscopy with cholecystectomy [73, 78].

Splenic injury is also typically only seen with supra-costal access, with a supra-11 approach increasing the risk as high as 33% [58]. Injury to the spleen can produce significant hemorrhage and hypovolemic shock and, while patients can occasionally be managed non-operatively (with bedrest, tube tamponade, and close monitoring), most patients eventually require splenectomy [73, 79].

Lymphatics

Disruption of lymphatics adjacent to the collecting system during PNL can lead to chyluria, which can often be controlled with optimal urinary drainage and total parenteral nutrition [80]. Additionally, a low fat, medium-chain triglyceride diet with the aid of somatostatin can be useful in some cases. If chyluria continues, retrograde instillation of silver nitrate or povidone-iodine can be performed as sclerotherapy, with open lymphatic ligation as a final option [81–83].

Medical complications

Infection and sepsis

Infectious complications are some of the most common and concerning problems that can occur perioperatively when performing PNL. Care must be taken preoperatively to reduce the risk of such perioperative infectious complications. All patients with urinary tract infection must be treated with appropriate antibiotics prior to PNL due to the overwhelming risk of bacteremia and sepsis associated with bacterial extravasation. While a single recommended perioperative antibiotic course has not been completely established, patients with infections should be treated with antibiotics at least 1 week prior to the procedure [84]. The use of prolonged preoperative prophylactic antibiotics in patients with sterile urine is controversial, although many urologists continue to give 1 week of preoperative antibiotics before PNL despite negative culture [85]. To this end, numerous studies have attempted to assess risk factors for infectious complications based on perioperative antibiotic dosing, without consistent results. Studies have noted an improvement in infections with preoperative antibiotic prophylaxis, specifically in patients with large and complex stones or hydronephrosis, although other studies have suggested that only perioperative antibiotics are required if preoperative urine cultures are negative [86–91].

Despite proper antibiotic use based on preoperative cultures, patients may still develop bacteremia or sepsis, likely because stone and renal pelvis urine cultures often are not predicted by bladder urine culture [92, 93]. Studies have documented that despite negative preoperative urine cultures, 25–43% of pelvic urine or stone cultures may be positive, with these patients at a significantly greater risk of postoperative urosepsis [93, 94]. In fact, the stone culture organism is more commonly the causative organism of a postoperative uroseptic episode when compared to bladder urine culture and, as such, renal pelvic urine and stone cultures should be sent during PNL to help guide postoperative therapy if needed [95].

Regarding risk profiles, many studies have attempted to isolate the perioperative risk factors for postoperative urosepsis. In addition to positive urine and stone cultures, increased stone burden, history of recurrent urinary infections, renal failure, longer surgical times, and multidrug-resistant bacteriuria are concerning factors that should raise suspicion and possibly alter preoperative antibiotic prophylaxis [96–99].

Occasionally, purulent urine is encountered at the time of collecting system access. It is reasonable to delay treatment in this setting, leaving a nephrostomy tube in place to drain the collecting system. The expressed fluid should be cultured and the patient should be observed on broad-spectrum antibiotic therapy until the results are known. Some surgeons have had success (and avoided a second procedure) by moving forward with PNL despite purulent access, although these patients were typically carefully selected and this method cannot be recommended in all situations [84, 100]. Of note, despite proper drainage and antibiotic administration, these patients can still develop urosepsis when the stone is eventually treated at a later time [101].

Postoperatively, sepsis has been reported in 0.6–1.5% of patients after PNL, which is typically due to bacteremia and endotoxemia [3, 4, 102]. Patients should be monitored closely for clinical signs or symptoms of infection, including vital sign or laboratory panel changes as well as alterations in mental status. Postoperative leukocytosis and fever are relatively common after PNL, but significant elevations in either of these parameters should be a cause for concern and lead to an escalation of care and antibiotic therapy [103, 104]. Additionally, lactate and procalcitonin levels may be useful for isolating a significant postoperative infection [105]. When a patient is suspected to be experiencing a septic episode, aggressive fluid and antibiotic management is paramount, as well as supportive measures including steroids and/or pressors. Patients who do not respond to these methods may be experiencing alternative pathology, including unrecognized injuries (which can be diagnosed by additional imaging) or fungal infections (especially in immunocompromised or diabetic patients or those with prolonged urinary drainage tubes) [106]. In some cases, patients will present postoperatively with a sepsis-like event with negative cultures due to endotoxemia; these patients require supportive measures alone, but antibiotic therapy should be utilized until cultures are deemed negative.

Loss of renal function

PNL is believed to have minimal long term effect on renal function. Studies that utilized functional imaging have noted small parenchymal scars and focal functional decrease at the access site, although overall renal function remained stable or improved in 84% of patients [107–109]. Additionally, studies have shown transient increases of serum creatinine (0.14 mg/dL) and bilateral decreases in individual renal unit creatinine clearance, although all of these injuries resolved after 72 h [110–112]. Longer term evaluation noted negligible changes in creatinine 1–2 years after PNL, with functional imaging documenting stable or increased renal function in 94.4% of patients [113–115].

Patients with staghorn calculi appear to represent a different group of patients with regard to renal deterioration after PNL; studies estimate a 25% risk of renal functional decline after surgery for a staghorn stone [116]. Risk factors associated with this decline include solitary kidney, recurrent stones, hypertension, complete staghorn calculi, urinary diversion, and neurogenic bladder [117, 118]. Taken together, it seems that the risk of renal functional deterioration in these patients is less apt to be surgically-related and more likely associated with the stone disease and comorbidities.

Acute renal injury resulting in renal loss is a rare complication of PNL, usually secondary to uncontrollable hemorrhage, with an incidence between 0.1 and 0.3% [102, 119]. Prevention of such a complication utilizes previously discussed methods above.

Fluid overload

It is known that irrigation fluid can be absorbed during PNL, with collecting system perforation, bleeding, and other similar complications increasing the risk and amount of fluid absorbed [120]. Careful monitoring of intraoperative fluid input and output can detect this problem, although other signs of fluid absorption may include unexplained hypertension, hypoxemia, and ventilation difficulties. Use of a working sheath and low irrigation pressures can minimize absorption, while normal saline must be used during all PNL procedures to decrease the risk of hyponatremia in cases of fluid absorption. This complication can also be prevented by limiting the procedure duration and terminating the surgery in the setting of significant collecting system perforation; additionally, diuretic administration can be used to facilitate clearance of excess fluid.

Hypothermia

Core body temperature is known to decrease during PNL, with a drop below 36 °C defined as hypothermia. Intraoperative hypothermia can be multifactorial, with causes ranging from anesthetic vasodilation, procedure length, exposed body surface, room temperature, and the use of un-warmed irrigant. Hypothermia may lead to impaired platelet function, altered drug clearances, and increased oxygen consumption due to shivering which can prompt cardiac ischemia or arrhythmias. The risk of hypothermia can be decreased by use of warmed irrigant, patient coverage with heat-preserving drapes, and keeping patients as dry as possible during surgery [121, 122].

Positioning-related injury

Given that PNL is traditionally performed in a prone position, proper positioning is essential, as injuries can occur to the brachial plexus and other peripheral nerves, shoulders can be dislocated, and cutaneous skin trauma is possible. Compared to a supine position, intraoperative anesthesia parameters, including heart rate and peak airway pressures, were seen to worsen in prone position, although other studies demonstrated no change in airway pressures between positions [123, 124].

With a recent increase in supine positioning for PNL around the world, this previously alternative position is becoming more common. While this position appears to be simpler for the anesthesiologist, multiple studies and meta-analyses have relatively inconsistent results. Complication rates have been similar despite positioning method, along with similar hospital stay, operative times, and stone-free rates [125, 126].

The inconsistent data show that no position is safer or more advantageous for the average patient; care must be taken to avoid positioning-related injuries no matter the method utilized. Great care must be taken to pad all pressure points and avoid joint strain, and with attention to detail and proper padding, most problems can be avoided whatever the surgical position. Despite proper positioning, injuries can still occur; if neurapraxia is a possible postoperative concern, neurologic evaluation is recommended, although most of these injuries resolve with time and physical therapy.

Thromboembolic complications

Deep venous thrombosis (DVT) has been reported in 1–3% of patients undergoing PNL [102, 127]. The risk of DVT can be lessened by use of sequential compression devices and thromboembolic disease-prevention stockings in the operating room, as well as stressing early postoperative ambulation. There is little in the way of official guidelines regarding thromboprophylaxis in the perioperative period, although the EAU guidelines recommend against pharmacologic prophylaxis in all patients undergoing PNL and only utilizing mechanical prophylaxis in high-risk patients; they accept that the level of evidence in this case is weak [128]. If DVT is documented on duplex sonography, anticoagulation is typically required with the goal of preventing propagation and embolism; in the immediate postoperative period bleeding may be a concern and as such an inferior vena cava filter may be needed [129]. In patients with mature nephrostomy tracts or patients who are closely watched with minimal bleeding postoperatively, anticoagulation may be safely tolerated.

Air embolism is a reported complication of PNL, although it is extremely rare [130, 131]. This complication may be associated with airflow reversal through the ultrasonic lithotripter. Theoretically, air pyelography may cause an air embolism, yet recent studies have documented large numbers of air pyelograms performed without a single episode [132]. This complication can be recognized by hypoxemia, bradycardia, a fall in end tidal carbon dioxide, or cardiopulmonary arrest; intraoperative diagnosis is made with echocardiography.

If this complication is suspected, the procedure must be terminated and the patient should be placed in the left lateral decubitus position. Theoretically, a central venous line or puncture can be performed in order to attempt aspiration of the air bubble. Patients may need close postoperative cardiopulmonary monitoring, inotropic support, intensive supportive care, and—in cases with cerebral involvement—hyperbaric oxygen therapy [133].

Mortality

Postoperative mortality is extremely rare after PNL, with a rate of approximately 0.2% [134]. In the Clinical Research Office of the Endourological Society (CROES) study of nearly 6000 patients, urosepsis was the cause of the two mortalities reported [135]. Most deaths associated with this procedure are due to sepsis, myocardial infarction, and pulmonary embolism in high-risk patients, suggesting the need for proper preoperative workup and counseling. Additionally, close cardiopulmonary monitoring should be utilized intraoperatively and postoperatively to ensure early diagnosis of associated complications.

Conclusions

PNL can be associated with a large variety of complications, including bleeding, injury to the urinary system, injury to adjacent organs, infection, and even death. Appropriate patient selection and preoperative workup can minimize these complications, as well as understanding of the potential pitfalls as discussed in this review [136]. Patient counseling should focus on the complexity of the procedure and create proper expectations in the perioperative period.

Proper surgical technique is of paramount importance, with great care and focus required to decrease the risk of most intraoperative complications. Increased case loads have been shown to decrease complication rates associated with PNL and thus an experienced surgeon should be able to safely perform this procedure. Most importantly, prompt recognition of complications is essential, as most complications can be managed conservatively. Typically, safety and success are the most common outcomes of PNL procedures.

Compliance with ethical standards

Conflict of interest The authors declare no competing financial interest.

Research involving human participants and/or animals None.

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References

1. Assimos D, Krambeck A, Miller NL, Monga M, Murad MH, Nelson CP et al (2016) Surgical management of stones: American Urological Association/Endourological Society Guideline, PART I. J Urol 196(4):1153–1160
2. Clayman RV, Surya V, Hunter D, Castaneda-Zuniga WR, Miller RP, Coleman C et al (1984) Renal vascular complications associated with the percutaneous removal of renal calculi. J Urol 132(2):228–230
3. Lang EK (1987) Percutaneous nephrostolithotomy and lithotripsy: a multi-institutional survey of complications. Radiology 162(1 Pt 1):25–30
4. Roth RA, Beckmann CF (1988) Complications of extracorporeal shock-wave lithotripsy and percutaneous nephrolithotomy. Urol Clin N Am 15(2):155–166
5. Srivastava A, Singh KJ, Suri A, Dubey D, Kumar A, Kapoor R et al (2005) Vascular complications after percutaneous nephrolithotomy: are there any predictive factors? Urology 66(1):38–40
6. Stoller ML, Wolf JS Jr, St Lezin MA (1994) Estimated blood loss and transfusion rates associated with percutaneous nephrolithotomy. J Urol 152(6 Pt 1):1977–1981
7. El-Nahas AR, Shokeir AA, El-Assmy AM, Mohsen T, Shoma AM, Eraky I et al (2007) Post-percutaneous nephrolithotomy extensive hemorrhage: a study of risk factors. J Urol 177(2):576–579
8. Kukreja R, Desai M, Patel S, Bapat S, Desai M (2004) Factors affecting blood loss during percutaneous nephrolithotomy: prospective study. J Endourol 18(8):715–722
9. Said SH, Al Kadum Hassan MA, Ali RH, Aghaways I, Kakamad FH, Mohammad KQ (2017) Percutaneous nephrolithotomy; alarming variables for postoperative bleeding. Arab J Urol 15(1):24–29
10. Turna B, Nazli O, Demiryoguran S, Mammadov R, Cal C (2007) Percutaneous nephrolithotomy: variables that influence hemorrhage. Urology 69(4):603–607
11. Leavitt DA, Theckumparampil N, Moreira DM, Elsamra SE, Waingankar N, Hoenig DM et al (2014) Continuing aspirin

therapy during percutaneous nephrolithotomy: unsafe or underutilized? J Endourol 28(12):1399–1403
12. Culkin DJ, Exaire EJ, Green D, Soloway MS, Gross AJ, Desai MR et al (2014) Anticoagulation and antiplatelet therapy in urological practice: ICUD/AUA review paper. J Urol 192(4):1026–1034
13. Kefer JC, Turna B, Stein RJ, Desai MM (2009) Safety and efficacy of percutaneous nephrostolithotomy in patients on anticoagulant therapy. J Urol 181(1):144–148
14. Lange JN, Mufarrij PW, Passman CM, Assimos DG (2013) Safety and efficacy of removable inferior vena cava filters in anticoagulated patients undergoing percutaneous nephrostolithotomy. J Endourol 27(2):168–171
15. Nerli RB, Reddy MN, Devaraju S, Hiremath MB (2012) Percutaneous nephrolithotomy in patients on chronic anticoagulant/antiplatelet therapy. Chonnam Med J 48(2):103–107
16. Mahaffey KG, Bolton DM, Stoller ML (1994) Urologist directed percutaneous nephrostomy tube placement. J Urol 152(6 Pt 1):1973–1976
17. Sountoulides PG, Kaufmann OG, Louie MK, Beck S, Jain N, Kaplan A et al (2009) Endoscopy-guided percutaneous nephrostolithotomy: benefits of ureteroscopic access and therapy. J Endourol 23(10):1649–1654
18. Aghamir SM, Elmimehr R, Modaresi SS, Salavati A (2016) Comparing bleeding complications of double and single access totally tubeless PCNL: is it safe to obtain more accesses? Urol Int 96(1):73–76
19. Lam HS, Lingeman JE, Mosbaugh PG, Steele RE, Knapp PM, Scott JW et al (1992) Evolution of the technique of combination therapy for staghorn calculi: a decreasing role for extracorporeal shock wave lithotripsy. J Urol 148(3 Pt 2):1058–1062
20. Olvera-Posada D, Tailly T, Alenezi H, Violette PD, Nott L, Denstedt JD et al (2015) Risk factors for postoperative complications of percutaneous nephrolithotomy at a tertiary referral center. J Urol 194(6):1646–1651
21. Watterson JD, Soon S, Jana K (2006) Access related complications during percutaneous nephrolithotomy: urology versus radiology at a single academic institution. J Urol 176(1):142–145
22. Karakose A, Aydogdu O, Atesci YZ (2014) Does the use of smaller Amplatz sheath size reduce complication rates in percutaneous nephrolithotomy? Urol J 11(4):1752–1756
23. Ugras M, Gunes A, Baydinc C (2002) Severe renal bleeding caused by a ruptured renal sheath: case report of a rare complication of percutaneous nephrolithotomy. BMC Urol 2:10
24. Davidoff R, Bellman GC (1997) Influence of technique of percutaneous tract creation on incidence of renal hemorrhage. J Urol 157(4):1229–1231
25. Yamaguchi A, Skolarikos A, Buchholz NP, Chomon GB, Grasso M, Saba P et al (2011) Operating times and bleeding complications in percutaneous nephrolithotomy: a comparison of tract dilation methods in 5537 patients in the Clinical Research Office of the Endourological Society Percutaneous Nephrolithotomy Global Study. J Endourol 25(6):933–939
26. Li Y, Yang L, Xu P, Shen P, Qian S, Wei W et al (2013) One-shot versus gradual dilation technique for tract creation in percutaneous nephrolithotomy: a systematic review and meta-analysis. Urolithiasis 41(5):443–448
27. Srivastava A, Singh S, Dhayal IR, Rai P (2017) A prospective randomized study comparing the four tract dilation methods of percutaneous nephrolithotomy. World J Urol 35(5):803–807
28. Bansal A, Arora A (2016) A double-blind, placebo-controlled randomized clinical trial to evaluate the efficacy of tranexamic acid in irrigant solution on blood loss during percutaneous nephrolithotomy: a pilot study from tertiary care center of North India. World J Urol 35(8):1233–1240
29. Cormio L, Preminger G, Saussine C, Buchholz NP, Zhang X, Walfridsson H et al (2013) Nephrostomy in percutaneous nephrolithotomy (PCNL): does nephrostomy tube size matter? Results from the Global PCNL Study from the Clinical Research Office Endourology Society. World J Urol 31(6):1563–1568
30. Lee KL, Stoller ML (2007) Minimizing and managing bleeding after percutaneous nephrolithotomy. Curr Opin Urol 17(2):120–124
31. Gupta M, Bellman GC, Smith AD (1997) Massive hemorrhage from renal vein injury during percutaneous renal surgery: endourological management. J Urol 157(3):795–797
32. Kaye KW, Clayman RV (1986) Tamponade nephrostomy catheter for percutaneous nephrostolithotomy. Urology 27(5):441–445
33. Millard WW 2nd, Jellison FC, Tenggardjaja C, Ebrahimi KY, Baldwin DD (2010) Hemostatic sandwich to control percutaneous nephrolithotomy tract bleeding. J Endourol 24(9):1415–1419
34. Jou YC, Cheng MC, Lin CT, Chen PC, Shen JH (2006) Nephrostomy tube-free percutaneous nephrolithotomy for patients with large stones and staghorn stones. Urology 67(1):30–34
35. Jou YC, Cheng MC, Sheen JH, Lin CT, Chen PC (2004) Electrocauterization of bleeding points for percutaneous nephrolithotomy. Urology 64(3):443–446 **(discussion 6–7)**
36. Shah HN, Hegde S, Shah JN, Mohile PD, Yuvaraja TB, Bansal MB (2006) A prospective, randomized trial evaluating the safety and efficacy of fibrin sealant in tubeless percutaneous nephrolithotomy. J Urol 176(6 Pt 1):2488–2492 **(discussion 92–93)**
37. Wang J, Zhang C, Tan G, Yang B, Chen W, Tan D (2014) The use of adjunctive hemostatic agents in tubeless percutaneous nephrolithotomy: a meta-analysis. Urolithiasis 42(6):509–517
38. Kessaris DN, Bellman GC, Pardalidis NP, Smith AG (1995) Management of hemorrhage after percutaneous renal surgery. J Urol 153(3 Pt 1):604–608
39. Lee WJ, Smith AD, Cubelli V, Badlani GH, Lewin B, Vernace F et al (1987) Complications of percutaneous nephrolithotomy. Am J Roentgenol 148(1):177–180
40. Ghai B, Dureja GP, Arvind P (2003) Massive intraabdominal extravasation of fluid: a life threatening complication following percutaneous nephrolithotomy. Int Urol Nephrol 35(3):315–318
41. Akbulut F, Ucpinar B, Savun M, Kucuktopcu O, Ozgor F, Simsek A et al (2015) A major complication in micropercutaneous nephrolithotomy: upper calyceal perforation with extrarenal migration of stone fragments due to increased intrarenal pelvic pressure. Case Rep Urol 2015:792780
42. Meretyk S, Albala DM, Clayman RV, Denstedt JD, Kavoussi LR (1992) Endoureterotomy for treatment of ureteral strictures. J Urol 147(6):1502–1506
43. Weizer AZ, Auge BK, Silverstein AD, Delvecchio FC, Brizuela RM, Dahm P et al (2002) Routine postoperative imaging is important after ureteroscopic stone manipulation. J Urol 168(1):46–50
44. Buchholz NP (2001) Double infundibular obliteration with abscess formation after percutaneous nephrolithotomy. Urol Int 66(1):46–48
45. Weir MJ, Honey JD (1999) Complete infundibular obliteration following percutaneous nephrolithotomy. J Urol 161(4):1274–1275
46. Parsons JK, Jarrett TW, Lancini V, Kavoussi LR (2002) Infundibular stenosis after percutaneous nephrolithotomy. J Urol 167(1):35–38
47. Evans CP, Stoller ML (1993) The fate of the iatrogenic retroperitoneal stone. J Urol 150(3):827–829
48. Verstandig AG, Banner MP, Van Arsdalen KN, Pollack HM (1986) Upper urinary tract calculi: extrusion into perinephric and periureteric tissues during percutaneous management. Radiology 158(1):215–218

49. Diri A, Karakan T, Resorlu M, Kabar M, Germiyanoglu C (2014) Intraperitoneal stone migration during percutaneos nephrolithotomy. Arch Ital Urol Androl 86(4):293–294
50. Kaba M, Pirincci N, Kaba S, Cobanoglu U, Eryilmaz R, Eren H (2015) A rare complication observed during percutaneous nephrolithotomy: foreign body migration from the right kidney to the left lung. Eur J Pediatr Surg Rep 3(1):15–17
51. Koolpe HA, Lord B (1990) Eccentric nephroscopy for the incarcerated nephrostomy. Urol Radiol 12(2):96–98
52. Lynch M, Ghani KR, Patel U, Anson K (2006) Plastic within renal pelvis on nephroscopy: a potential hazard during percutaneous nephrolithotomy. Urology 68(5):1122 e1–e2
53. Gupta R, Kumar A, Kapoor R, Srivastava A, Mandhani A (2002) Prospective evaluation of safety and efficacy of the supracostal approach for percutaneous nephrolithotomy. BJU Int 90(9):809–813
54. Kekre NS, Gopalakrishnan GG, Gupta GG, Abraham BN, Sharma E (2001) Supracostal approach in percutaneous nephrolithotomy: experience with 102 cases. J Endourol 15(8):789–791
55. Lojanapiwat B, Prasopsuk S (2006) Upper-pole access for percutaneous nephrolithotomy: comparison of supracostal and infracostal approaches. J Endourol 20(7):491–494
56. Munver R, Delvecchio FC, Newman GE, Preminger GM (2001) Critical analysis of supracostal access for percutaneous renal surgery. J Urol 166(4):1242–1246
57. Yadav R, Aron M, Gupta NP, Hemal AK, Seth A, Kolla SB (2006) Safety of supracostal punctures for percutaneous renal surgery. Int J Urol 13(10):1267–1270
58. Hopper KD, Yakes WF (1990) The posterior intercostal approach for percutaneous renal procedures: risk of puncturing the lung, spleen, and liver as determined by CT. Am J Roentgenol 154(1):115–117
59. Falahatkar S, Enshaei A, Afsharimoghaddam A, Emadi SA, Allahkhah AA (2010) Complete supine percutaneous nephrolithotomy with lung inflation avoids the need for a supracostal puncture. J Endourol 24(2):213–218
60. Ray AA, Chung DG, Honey RJ (2009) Percutaneous nephrolithotomy in the prone and prone-flexed positions: anatomic considerations. J Endourol 23(10):1607–1614
61. Ng CS, Herts BR, Streem SB (2005) Percutaneous access to upper pole renal stones: role of prone 3-dimensional computerized tomography in inspiratory and expiratory phases. J Urol 173(1):124–126
62. Ogan K, Corwin TS, Smith T, Watumull LM, Mullican MA, Cadeddu JA et al (2003) Sensitivity of chest fluoroscopy compared with chest CT and chest radiography for diagnosing hydropneumothorax in association with percutaneous nephrostolithotomy. Urology 62(6):988–992
63. Benson JS, Hart ST, Kadlec AO, Turk T (2013) Small-bore catheter drainage of pleural injury after percutaneous nephrolithotomy: feasibility and outcome from a single large institution series. J Endourol 27(12):1440–1443
64. Kumar S, Gautam S, Kumar S, Rai A (2014) Chronic empyema thoracis after percutaneous nephrolithotomy. BMJ Case Rep. https://doi.org/10.1136/bcr-2014-203637
65. Lallas CD, Delvecchio FC, Evans BR, Silverstein AD, Preminger GM, Auge BK (2004) Management of nephropleural fistula after supracostal percutaneous nephrolithotomy. Urology 64(2):241–245
66. El-Nahas AR, Shokeir AA, El-Assmy AM, Shoma AM, Eraky I, El-Kenawy MR et al (2006) Colonic perforation during percutaneous nephrolithotomy: study of risk factors. Urology 67(5):937–941
67. Nouira Y, Nouira K, Kallel Y, Feki W, Horchani A (2006) Colonic perforation complicating percutaneous nephrolithotomy. Surg Laparosc Endosc Percutaneous Tech 16(1):47–48
68. Vallancien G, Capdeville R, Veillon B, Charton M, Brisset JM (1985) Colonic perforation during percutaneous nephrolithotomy. J Urol 134(6):1185–1187
69. Chalasani V, Bissoon D, Bhuvanagir AK, Mizzi A, Dunn IB (2010) Should PCNL patients have a CT in the prone position preoperatively? Can J Urol 17(2):5082–5086
70. Hadar H, Gadoth N (1984) Positional relations of colon and kidney determined by perirenal fat. Am J Roentgenol 143(4):773–776
71. Sherman JL, Hopper KD, Greene AJ, Johns TT (1985) The retrorenal colon on computed tomography: a normal variant. J Comput Assist Tomogr 9(2):339–341
72. Hussain M, Hamid R, Arya M, Peters JL, Kellett MJ, Philip T (2003) Management of colonic injury following percutaneous nephrolithotomy. Int J Clin Pract 57(6):549–550
73. Ozturk H (2014) Gastrointestinal system complications in percutaneous nephrolithotomy: a systematic review. J Endourol 28(11):1256–1267
74. Noor Buchholz NP (2004) Colon perforation after percutaneous nephrolithotomy revisited. Urol Int 72(1):88–90
75. Gerspach JM, Bellman GC, Stoller ML, Fugelso P (1997) Conservative management of colon injury following percutaneous renal surgery. Urology 49(6):831–836
76. Neustein P, Barbaric ZL, Kaufman JJ (1986) Nephrocolic fistula: a complication of percutaneous nephrostolithotomy. J Urol 135(3):571–573
77. Culkin DJ, Wheeler JS Jr, Canning JR (1985) Nephro-duodenal fistula: a complication of percutaneous nephrolithotomy. J Urol 134(3):528–530
78. Fisher MB, Bianco FJ Jr, Carlin AM, Triest JA (2004) Biliary peritonitis complicating percutaneous nephrolithomy requiring laparoscopic cholecystectomy. J Urol 171(2 Pt 1):791–792
79. Kondas J, Szentgyorgyi E, Vaczi L, Kiss A (1994) Splenic injury: a rare complication of percutaneous nephrolithotomy. Int Urol Nephrol 26(4):399–404
80. Thrasher JB, Snyder JA (1990) Post-nephrolithotomy chyluria. J Urol 143(3):578–579
81. Dhabalia JV, Pujari NR, Kumar V, Punia MS, Gokhale AD, Nelivigi G (2010) Silver nitrate sclerotherapy for chyluria: evaluation for the optimal instillation regime. Urol Int 85(1):56–59
82. Hemal AK, Gupta NP (2002) Retroperitoneoscopic lymphatic management of intractable chyluria. J Urol 167(6):2473–2476
83. Shrestha A, Shrestha PM, Verma R (2014) Is single dose povidone iodine sclerotherapy effective in chyluria? Int Urol Nephrol 46(6):1059–1062
84. Wollin DA, Joyce AD, Gupta M, Wong MY, Laguna P, Gravas S et al (2017) Antibiotic use and the prevention and management of infectious complications in stone disease. World J Urol 35(9):1369–1379
85. Mariappan P, Smith G, Moussa SA, Tolley DA (2006) One week of ciprofloxacin before percutaneous nephrolithotomy significantly reduces upper tract infection and urosepsis: a prospective controlled study. BJU Int 98(5):1075–1079
86. Bag S, Kumar S, Taneja N, Sharma V, Mandal AK, Singh SK (2011) One week of nitrofurantoin before percutaneous nephrolithotomy significantly reduces upper tract infection and urosepsis: a prospective controlled study. Urology 77(1):45–49
87. Deshmukh S, Sternberg K, Hernandez N, Eisner BH (2015) Compliance with American Urological Association Guidelines for Post-Percutaneous Nephrolithotomy Antibiotics does not appear to increase rates of infection. J Urol 194(4):992–996
88. Dogan HS, Sahin A, Cetinkaya Y, Akdogan B, Ozden E, Kendi S (2002) Antibiotic prophylaxis in percutaneous nephrolithotomy: prospective study in 81 patients. J Endourol 16(9):649–653
89. Rivera M, Viers B, Cockerill P, Agarwal D, Mehta R, Krambeck A (2016) Pre- and postoperative predictors of infection-related

complications in patients undergoing percutaneous nephrolithotomy. J Endourol 30(9):982–986
90. Seyrek M, Binbay M, Yuruk E, Akman T, Aslan R, Yazici O et al (2012) Perioperative prophylaxis for percutaneous nephrolithotomy: randomized study concerning the drug and dosage. J Endourol 26(11):1431–1436
91. Tuzel E, Aktepe OC, Akdogan B (2013) Prospective comparative study of two protocols of antibiotic prophylaxis in percutaneous nephrolithotomy. J Endourol 27(2):172–176
92. Benson AD, Juliano TM, Miller NL (2014) Infectious outcomes of nephrostomy drainage before percutaneous nephrolithotomy compared to concurrent access. J Urol 192(3):770–774
93. Margel D, Ehrlich Y, Brown N, Lask D, Livne PM, Lifshitz DA (2006) Clinical implication of routine stone culture in percutaneous nephrolithotomy—a prospective study. Urology 67(1):26–29
94. Mariappan P, Smith G, Bariol SV, Moussa SA, Tolley DA (2005) Stone and pelvic urine culture and sensitivity are better than bladder urine as predictors of urosepsis following percutaneous nephrolithotomy: a prospective clinical study. J Urol 173(5):1610–1614
95. Eswara JR, Shariftabrizi A, Sacco D (2013) Positive stone culture is associated with a higher rate of sepsis after endourological procedures. Urolithiasis 41(5):411–414
96. Koras O, Bozkurt IH, Yonguc T, Degirmenci T, Arslan B, Gunlusoy B et al (2015) Risk factors for postoperative infectious complications following percutaneous nephrolithotomy: a prospective clinical study. Urolithiasis 43(1):55–60
97. Patel N, Shi W, Liss M, Raheem O, Wenzler D, Schallhorn C et al (2015) Multidrug resistant bacteriuria before percutaneous nephrolithotomy predicts for postoperative infectious complications. J Endourol 29(5):531–536
98. Sharma K, Sankhwar SN, Goel A, Singh V, Sharma P, Garg Y (2016) Factors predicting infectious complications following percutaneous nephrolithotomy. Urol Ann 8(4):434–438
99. Shoshany O, Margel D, Finz C, Ben-Yehuda O, Livne PM, Holand R et al (2015) Percutaneous nephrolithotomy for infection stones: what is the risk for postoperative sepsis? A retrospective cohort study. Urolithiasis 43(3):237–242
100. Etemadian M, Haghighi R, Madineay A, Tizeno A, Fereshtehnejad SM (2008) Delayed versus same-day percutaneous nephrolithotomy in patients with aspirated cloudy urine. Urol J 5(1):28–33
101. Aron M, Goel R, Gupta NP, Seth A (2005) Incidental detection of purulent fluid in kidney at percutaneous nephrolithotomy for branched renal calculi. J Endourol 19(2):136–139
102. Segura JW, Patterson DE, LeRoy AJ, Williams HJ Jr, Barrett DM, Benson RC Jr et al (1985) Percutaneous removal of kidney stones: review of 1000 cases. J Urol 134(6):1077–1081
103. Bozkurt IH, Aydogdu O, Yonguc T, Koras O, Sen V, Yarimoglu S et al (2015) Predictive value of leukocytosis for infectious complications after percutaneous nephrolithotomy. Urology 86(1):25–29
104. Cadeddu JA, Chen R, Bishoff J, Micali S, Kumar A, Moore RG et al (1998) Clinical significance of fever after percutaneous nephrolithotomy. Urology 52(1):48–50
105. Zheng J, Li Q, Fu W, Ren J, Song S, Deng G et al (2015) Procalcitonin as an early diagnostic and monitoring tool in urosepsis following percutaneous nephrolithotomy. Urolithiasis 43(1):41–47
106. Gautam G, Singh AK, Kumar R, Hemal AK, Kothari A (2006) Beware! Fungal urosepsis may follow endoscopic intervention for prolonged indwelling ureteral stent. J Endourol 20(7):522–524
107. Chatham JR, Dykes TE, Kennon WG, Schwartz BF (2002) Effect of percutaneous nephrolithotomy on differential renal function as measured by mercaptoacetyl triglycine nuclear renography. Urology 59(4):522–525 **(discussion 5–6)**
108. Moskovitz B, Halachmi S, Sopov V, Burbara J, Horev N, Groshar D et al (2006) Effect of percutaneous nephrolithotripsy on renal function: assessment with quantitative SPECT of (99 m)Tc-DMSA renal scintigraphy. J Endourol 20(2):102–106
109. Urivetsky M, Motola J, King L, Smith AD (1989) Impact of percutaneous renal stone removal on renal function: assessment by urinary lysozyme activity. Urology 33(4):305–308
110. Handa RK, Matlaga BR, Connors BA, Ying J, Paterson RF, Kuo RL et al (2006) Acute effects of percutaneous tract dilation on renal function and structure. J Endourol 20(12):1030–1040
111. Nouralizadeh A, Sichani MM, Kashi AH (2011) Impacts of percutaneous nephrolithotomy on the estimated glomerular filtration rate during the first few days after surgery. Urol Res 39(2):129–133
112. Sichani MM, Behnamfar A, Khorami MH, Nourimahdavi K, Alizadeh F, Izadpanahi MH (2014) Percutaneous nephrolithotomy: effect of unilateral procedure on contralateral kidney function. Adv Biomed Res 3:227
113. Dawaba MS, Shokeir AA, Hafez A, Shoma AM, El-Sherbiny MT, Mokhtar A et al (2004) Percutaneous nephrolithotomy in children: early and late anatomical and functional results. J Urol 172(3):1078–1081
114. Kurien A, Baishya R, Mishra S, Ganpule A, Muthu V, Sabnis R et al (2009) The impact of percutaneous nephrolithotomy in patients with chronic kidney disease. J Endourol 23(9):1403–1407
115. Yaycioglu O, Egilmez T, Gul U, Turunc T, Ozkardes H (2007) Percutaneous nephrolithotomy in patients with normal versus impaired renal function. Urol Res 35(2):101–105
116. Teichman JM, Long RD, Hulbert JC (1995) Long-term renal fate and prognosis after staghorn calculus management. J Urol 153(5):1403–1407
117. Fayad AS, Elsheikh MG, Mosharafa A, El-Sergany R, Abdel-Rassoul MA, Elshenofy A et al (2014) Effect of multiple access tracts during percutaneous nephrolithotomy on renal function: evaluation of risk factors for renal function deterioration. J Endourol 28(7):775–779
118. Kuzgunbay B, Gul U, Turunc T, Egilmez T, Ozkardes H, Yaycioglu O (2010) Long-term renal function and stone recurrence after percutaneous nephrolithotomy in patients with renal insufficiency. J Endourol 24(2):305–308
119. Moskowitz GW, Lee WJ, Pochaczevsky R (1989) Diagnosis and management of complications of percutaneous nephrolithotomy. Crit Rev Diagn Imaging 29(1):1–12
120. Kukreja RA, Desai MR, Sabnis RB, Patel SH (2002) Fluid absorption during percutaneous nephrolithotomy: does it matter? J Endourol 16(4):221–224
121. Roberts S, Bolton DM, Stoller ML (1994) Hypothermia associated with percutaneous nephrolithotomy. Urology 44(6):832–835
122. Tekgul ZT, Pektas S, Yildirim U, Karaman Y, Cakmak M, Ozkarakas H et al (2015) A prospective randomized double-blind study on the effects of the temperature of irrigation solutions on thermoregulation and postoperative complications in percutaneous nephrolithotomy. J Anesthesia 29(2):165–169
123. Al-Dessoukey AA, Moussa AS, Abdelbary AM, Zayed A, Abdallah R, Elderwy AA et al (2014) Percutaneous nephrolithotomy in the oblique supine lithotomy position and prone position: a comparative study. J Endourol 28(9):1058–1063
124. Siev M, Motamedinia P, Leavitt D, Fakhoury M, Barcohana K, Hoenig D et al (2015) Does peak inspiratory pressure increase in the prone position? An analysis related to body mass index. J Urol 194(5):1302–1306
125. Wang Y, Wang Y, Yao Y, Xu N, Zhang H, Chen Q et al (2013) Prone versus modified supine position in percutaneous nephrolithotomy: a prospective randomized study. Int J Med Sci 10(11):1518–1523

126. Zhang X, Xia L, Xu T, Wang X, Zhong S, Shen Z (2014) Is the supine position superior to the prone position for percutaneous nephrolithotomy (PCNL)? Urolithiasis 42(1):87–93
127. Lee WJ, Smith AD, Cubelli V, Vernace FM (1986) Percutaneous nephrolithotomy: analysis of 500 consecutive cases. Urol Radiol 8(2):61–66
128. Violette PD, Cartwright R, Briel M, Tikkinen KA, Guyatt GH (2016) Guideline of guidelines: thromboprophylaxis for urological surgery. BJU Int 118(3):351–358
129. Patel A, Fuchs GJ (1998) Air travel and thromboembolic complications after percutaneous nephrolithotomy for staghorn stone. J Endourol 12(1):51–33
130. Cadeddu JA, Arrindell D, Moore RG (1997) Near fatal air embolism during percutaneous nephrostomy placement. J Urol 158(4):1519
131. Droghetti L, Giganti M, Memmo A, Zatelli R (2002) Air embolism: diagnosis with single-photon emission tomography and successful hyperbaric oxygen therapy. Brit J Anaesth 89(5):775–778
132. Lipkin ME, Mancini JG, Zilberman DE, Raymundo ME, Yong D, Ferrandino MN et al (2011) Reduced radiation exposure with the use of an air retrograde pyelogram during fluoroscopic access for percutaneous nephrolithotomy. J Endourol 25(4):563–567
133. Chahal D, Ruzhynsky V, McAuley I, Sweeney D, Sobkin P, Kinahan M et al (2015) Paradoxical air embolism during percutaneous nephrolithotomy due to patent foramen ovale: case report. Can Urol Assoc J 9(9–10):E658–E660
134. Morris DS, Wei JT, Taub DA, Dunn RL, Wolf JS Jr, Hollenbeck BK (2006) Temporal trends in the use of percutaneous nephrolithotomy. J Urol 175(5):1731–1736
135. Kamphuis GM, Baard J, Westendarp M, de la Rosette JJ (2015) Lessons learned from the CROES percutaneous nephrolithotomy global study. World J Urol 33(2):223–233
136. Leavitt DA, Motamedinia P, Moran S, Siev M, Zhao PT, Theckumparampil N et al (2016) Can activities of daily living predict complications following percutaneous nephrolithotomy? J Urol 195(6):1805–1809