Risk factors for acute kidney injury after percutaneous nephrolithotomy

Implications of intraoperative hypotension

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Abstract

Percutaneous nephrolithotomy (PNL) is a minimally invasive technique for renal stone removal but can cause renal parenchymal injury. Renal stones can also affect renal function. We evaluated the risk factors for acute kidney injury (AKI) after PNL.

The study cohort included 662 patients who underwent PNL. Patient characteristics, preoperative laboratory values, intraoperative data, and stone characteristics were collected. Univariate and multivariate logistic regression analyses were performed to identify risk factors for AKI after PNL. Postoperative outcomes such as hospitalization, intensive care unit admission rate and stay duration, and chronic kidney disease were also evaluated.

Of the total study series, there were 107 (16.2%) cases of AKI after PNL (AKI group), and 555 (83.8%) patients who showed no injury (no-AKI group). The risk factors for AKI after PNL were found to be a higher preoperative serum uric acid level (odds ratio (OR) = 1.228; 95% confidence interval (CI) = 1.065–1.415; P = .005), longer operation time (OR = 1.009; 95% CI = 1.004–1.014; P < .001), and intraoperative hypotension (OR = 12.713; 95% CI = 7.762–20.823; P < .001). Hospitalization and intensive care unit stay duration were significantly longer in the AKI group (8.7±5.2 vs 6.6±2.8 days, P < .001; 0.34±1.74 vs 0.07±0.48 days, P = .002, respectively).

As intraoperative hypotension is an important risk factor for AKI after PNL, which leads to poor postoperative outcomes, it should be prevented or managed vigorously during PNL.

Abbreviations: AKI = acute kidney injury, CI = confidence interval, CKD = chronic kidney disease, CKD-EPI = CKD Epidemiology Collaboration, eGFR = estimated glomerular filtration rate, OR = odds ratio, PNL = percutaneous nephrolithotomy, RBC = red blood cell.

Keywords: acute kidney injury, intraoperative hypotension, percutaneous nephrolithotomy

1. Introduction

Percutaneous nephrolithotomy (PNL) is a minimally invasive technique for renal stone removal and is an efficient procedure for large, multiple, and complex stones, particularly staghorn calculi or smaller symptomatic stones that are refractory to extracorporeal shock wave lithotripsy therapy.[1–3] Nevertheless, PNL-related postoperative complications have been reported, including renal hemorrhage, colonic or pleural injury, postoperative pulmonary complications, and septicemia.[4,5] Hence, meticulous anesthetic and surgical management is required during PNL.

Postoperative acute kidney injury (AKI) can lead to poor postoperative outcomes and a longer hospital or intensive care unit stay.[6,7] AKI is a common postoperative complication in urology patients, with an incidence rate of 6.7% to 38.2%.[8–10] The PNL procedure can directly cause renal injury because it involves puncturing and dilating the renal parenchyma to remove the stones. In addition, renal stones can induce obstructive uropathy.[11] Hence, changes in renal function can occur after PNL. However, the incidence, risk factors, and outcomes of AKI after PNL have remained unclear. Furthermore, a definite treatment course for postoperative AKI has not been well established. It is therefore necessary to evaluate the risk factors for AKI after PNL to prevent and minimize its occurrence.

We sought in our current study therefore to identify independent risk factors for AKI after PNL. In addition, we evaluated the postoperative outcomes in patients who have undergone this procedure, including hospitalization, intensive care unit admission rate and stay duration, and chronic kidney disease (CKD).

2. Methods

2.1. Patients

We performed a retrospective cohort study of patients who underwent PNL from January 2005 to December 2015 at Asan...
Medical Center, a tertiary care hospital in Seoul, Republic of Korea. Our study protocol was approved by the Institutional Review Board of Asan Medical Center (approval number: 2016-0432). For patients who underwent more than 1 PNL procedure, we analyzed the AKI incidence and postoperative outcomes after their first surgery. We excluded patients under the age of 18 years and those with a known CKD.

2.2. Anesthetic and surgical techniques

Anesthetic techniques for PNL were performed in accordance with our institutional standards. Briefly, anesthesia was induced by propofol, rocuronium, and sevoflurane, and maintained using a 1.5 to 2.5 vol% sevoflurane and a 50% O2/air mixture with supplemental rocuronium. The radial artery was cannulated for continuous arterial blood pressure monitoring. Mechanical ventilation was performed with a tidal volume of 8 to 10 mL/kg at a respiratory rate of 10 to 14 breaths/min to maintain an end-tidal carbon dioxide concentration at 35 to 40 mm Hg. Fluid was administered according to our institutional protocol with a guidance of mean arterial blood pressure, heart rate, and blood loss. Crystalloid [lactated Ringer solution or Plasma solution A (CJ Pharmaceutical, Seoul, Korea)] was administered at a rate of 2 to 4 mL/kg/h, and colloid (Voloven, 6% hydroxyethyl starch 130/0.4) was administered when estimated blood loss >500 mL occurred during PNL. Mean arterial blood pressure was maintained at >70 mm Hg. If the mean arterial blood pressure was not maintained at >70 mm Hg, additional fluids or drugs such as ephedrine, phenylephrine, and norpinephrine were administered. Transfusion of red blood cells (RBCs) was performed when the hemoglobin concentration decreased to <8 g/dL during surgery.

PNL procedures were performed using standard techniques at our institution. Briefly, the patient was placed in the lithotomy position and a ureteral catheter was placed using cystoscopy. After placement of the patient in a prone position, the ureteral catheter position was confirmed by fluoroscopy, and a renal puncture was performed using an intercostal or subcostal approach. After inserting the guide wire, the track was dilated using a balloon and a 34-French working sheath was inserted. The stone was broken using an ultrasonic lithotripter, a ballistic lithotripter, or a holmium: YAG laser, and then removed using a grasping forceps. Finally, a 14-French malecot nephrostomy tube was placed in the renal pelvis to allow the urine to drain.

2.3. Data collection

The following data were collected: patient characteristics, preoperative laboratory values, intraoperative data, stone characteristics, and postoperative outcomes. Patient characteristics included age, gender, body mass index, American Society of Anesthesiologists physical status, comorbidities (hypertension and diabetes mellitus), preoperative beta-blocker use (atenolol, carvedilol, propranolol, or disoprolol), preoperative calcium channel blocker use (amlodipine, felodipine, nifedipine, dilta-zem, or nicardipine), preoperative angiotensin converting-enzyme inhibitor or angiotensin II receptor blocker use (captopril, losartan, valsartan, or candesartan), and preoperative nonsteroidal anti-inflammatory drug use (aspirin, ibuprofen, or aceclofenac). Preoperative laboratory values included serum hemoglobin, platelet, prothrombin time, uric acid, albumin, blood urea nitrogen, creatinine, sodium, and potassium.

Intraoperative data included operation time, RBC transfusion, amounts of total fluid administered, amounts of crystalloid administered, amounts of colloid administered, estimated blood loss, intraoperative lowest hematocrit, intraoperative hypotension, hydrenephrosis, and surgical approach (intercostal or subcostal). Estimated blood loss was calculated by the following formula: Estimated blood loss (mL) = patient’s estimated blood volume (mL) x (preoperative hematocrit (%) - postoperative hematocrit (%)) + (transfused RBC in units x 213 mL x 70%); in this formula, the patient’s estimated blood volume was 75 mL/kg for males and 65 mL/kg for females, the average volume of RBC was 213 mL, and the average hematocrit of RBC was 70%.[13,14] Stone characteristics included number, location, size, analysis, and staghorn stone. Postoperative outcomes included hospitalization, intensive care unit admission rate and stay duration, and CKD at 12 months after PNL.

2.4. Definitions

Intraoperative hypotension was defined as a mean arterial blood pressure of <70 mm Hg for >5 minutes recorded in the intraoperative anesthesia records.[15] Postoperative AKI was defined by applying the Kidney Disease: Improving Global Outcomes criteria, that is, an increase in the serum creatinine level by ≥0.3 mg/dL within 2 days after surgery or an increase in the serum creatinine level to ≥1.5 times the baseline value within 7 days after surgery.[16] CKD was evaluated at 12 months after the PNL procedure and was defined by an estimated glomerular filtration rate (eGFR) of <60 mL/min/1.73 m2.[17] eGFRs were calculated using the CKD Epidemiology Collaboration (CKD-EPI) equation: eGFR_{CKD,EPI} = 141 × [minimum of standardized serum creatinine (mg/dL)/κ or 1]^{-1.209 × 0.993^{age} × (1.018 if male) × (1.159 if black)}, where κ is 0.7 for women and 0.9 for men and α is –0.329 for women and -0.411 for men.[18]

2.5. Statistical analysis

All data were expressed as the mean ± standard deviation and number (percentage). The Student t test or Mann–Whitney U test was used for continuous variables. The Chi-square test or Fisher exact test was used for categorical variables. Univariate logistic regression analysis was performed to identify risk factors for AKI after PNL. All variables that had P value <.05 on univariate logistic regression analysis were entered into stepwise multivariate logistic regression analysis. All variables for logistic regression analysis were checked for multicollinearity, and only the variables with variance inflation factors <10 were used. In addition, univariate and multivariate logistic regression analyses were performed to evaluate the variables associated with intraoperative hypotension during PNL. P values <.05 were considered to be statistically significant. All statistical analyses were performed using SPSS version 22.0 (IBM, Armonk, NY).

3. Results

A total of 662 patients who underwent PNL at our hospital during the study period were included (Fig. 1). Table 1 presents the demographic characteristics of the study patients. Of the 662 study patients, 107 (16.2%) experienced AKI after PNL. Preoperative beta-blocker and nonsteroidal anti-inflammatory drug uses were significantly higher in the AKI cases. The preoperative serum uric acid and creatinine levels were also significantly higher in the AKI group. Table 2 lists the
intraoperative data and stone characteristics. Operation time was significantly longer in the AKI group; RBC transfusion, amount of total fluid administered, amount of colloid administered, estimated blood loss, and intraoperative lowest hematocrit were significantly higher in the AKI group as well. Intraoperative hypotension was also significantly higher in the AKI group cases. The stone characteristics did not differ significantly between the 2 groups.

The results of univariate logistic regression analysis indicated that the preoperative beta-blocker use, preoperative nonsteroidal anti-inflammatory drug use, preoperative serum uric acid level, preoperative serum creatinine level, operation time, RBC transfusion, amounts of colloid administered, estimated blood loss, intraoperative lowest hematocrit, and intraoperative hypotension were significantly associated with AKI after PNL (Table 3). Multivariate logistic regression analysis further
Table 2
Intraoperative data and stone characteristics.

| Variables                      | All patients (n = 662) | AKI group (n = 107) | No-AKI group (n = 555) | P  |
|--------------------------------|------------------------|---------------------|------------------------|----|
| Operation time, min            | 89.4 ± 45.2            | 106.4 ± 56.4        | 86.1 ± 42.0            | < .001 |
| RBC transfusion                | 26 (4.2)               | 14 (13.1)           | 14 (2.5)               | < .001 |
| Total fluid administered, mL   | 1358.3 ± 792.8         | 1578.0 ± 1068.1     | 1315.9 ± 721.5         | .002 |
| Crystalloid administered, mL   | 1286.1 ± 689.7         | 1381.2 ± 749.1      | 1267.6 ± 676.8         | .113 |
| Colloid administered, mL       | 68.2 ± 232.5           | 179.1 ± 426.4       | 67.6 ± 163.3           | < .001 |
| Estimated blood loss, mL       | 173.8 ± 234.6          | 258.9 ± 382.6       | 157.4 ± 189.7          | < .001 |
| Intraoperative lowest hematocrit (%) | 38.0 ± 5.4         | 36.9 ± 6.6          | 38.2 ± 5.2             | .018 |
| Hydronephrosis                 | 458 (69.2)             | 37 (73.8)           | 379 (68.3)             | .255 |
| Surgical approach (intercostal) | 341 (51.5)            | 98 (17.7)           | 98 (17.7)              | < .001 |
| Stone number (multiple)        | 496 (74.9)             | 415 (74.8)          | 415 (74.8)             | .840 |
| Stone location                 |                        |                     |                        | .924 |
| Diverticulum                   | 13 (2.0)               | 2 (1.9)             | 11 (2.0)               | 1.000 |
| Calyx                          | 218 (32.9)             | 181 (32.6)          | 181 (32.6)             | 1.000 |
| Pelvis                         | 431 (65.1)             | 363 (65.4)          | 363 (65.4)             | 1.000 |
| Largest stone size, mm         | 26.1 ± 12.4            | 27.3 ± 13.3         | 25.9 ± 12.2            | .294 |
| Stone analysis                 |                        |                     |                        | .234 |
| Mixed stone                    | 282 (42.6)             | 236 (42.5)          | 236 (42.5)             | 1.000 |
| Uric acid                      | 129 (19.5)             | 107 (19.3)          | 107 (19.3)             | 1.000 |
| Calcium oxalate monohydrate    | 113 (17.1)             | 93 (16.8)           | 93 (16.8)              | 1.000 |
| Carbonate apatite              | 63 (9.5)               | 59 (10.6)           | 59 (10.6)              | 1.000 |
| Others†                        | 75 (11.3)              | 60 (10.8)           | 60 (10.8)              | 1.000 |
| Staghorn stone                 | 250 (37.8)             | 204 (36.8)          | 204 (36.8)             | 1.000 |

Data are presented as the mean ± standard deviation or number (%). AKI = acute kidney injury, RBC = red blood cell.

Comparison between the AKI group and no-AKI group.

† Others include struvite, brushite, cystine, ammonium urate, and cholesterol stones.

Table 3
Univariate and multivariate logistic regression analyses for predictors of acute kidney injury after percutaneous nephrolithotomy.

| Variables                      | OR (95% CI) | P     | OR (95% CI) | P     |
|--------------------------------|-------------|-------|-------------|-------|
| Age                            | 1.009 (0.992–1.026) | .297  | 1.009 (1.004–1.014) | < .001 |
| Gender (male/female)           | 0.645 (0.412–1.009) | .055  | 0.807 (0.593–1.115) | .272  |
| Body mass index                | 1.921 (0.600–6.149)  | .272  | 1.921 (0.600–6.149) | .272  |
| Hypertension                   | 1.140 (0.950–1.380)  | .055  | 1.140 (0.950–1.380) | .055  |
| Diabetes mellitus              | 0.961 (0.593–1.555)  | .870  | 0.961 (0.593–1.555) | .870  |
| ASA physical status            | 1.203 (0.337–4.294)  | .776  | 1.203 (0.337–4.294) | .776  |
| Preoperative beta blocker      | 2.237 (1.158–4.318)  | .016  | 2.237 (1.158–4.318) | .016  |
| Preoperative CCB               | 1.032 (0.647–1.645)  | .895  | 1.032 (0.647–1.645) | .895  |
| Preoperative ACEi/ARB          | 1.093 (0.516–2.316)  | .815  | 1.093 (0.516–2.316) | .815  |
| Preoperative NSAID             | 2.048 (1.068–3.928)  | .031  | 2.048 (1.068–3.928) | .031  |
| Uric acid                      | 1.217 (1.075–1.377)  | .002  | 1.217 (1.075–1.377) | .002  |
| Creatinine                     | 1.666 (1.047–2.650)  | .031  | 1.666 (1.047–2.650) | .031  |
| Operation time                 | 1.009 (1.005–1.013)  | < .001 | 1.009 (1.005–1.013) | < .001 |
| RBC transfusion                | 5.817 (2.686–12.599) | < .001 | 5.817 (2.686–12.599) | < .001 |
| Crystalloid administered       | 1.001 (1.000–1.003)  | .108  | 1.001 (1.000–1.003) | .108  |
| Colloid administered           | 1.002 (1.001–1.003)  | < .001 | 1.002 (1.001–1.003) | < .001 |
| Estimated blood loss           | 1.001 (1.001–1.002)  | < .001 | 1.001 (1.001–1.002) | < .001 |
| Intraoperative lowest hematocrit (%) | 0.956 (0.922–0.993) | .019  | 0.956 (0.922–0.993) | .019  |
| Intraoperative hypotension     | 12.543 (7.770–20.247) | < .001 | 12.543 (7.770–20.247) | < .001 |
| Stone number (multiple/single) | 1.051 (1.649–1.701)  | .840  | 1.051 (1.649–1.701) | .840  |
| Staghorn stone                 | 1.009 (0.993–1.025)  | .294  | 1.009 (0.993–1.025) | .294  |
| Hydronephrosis                 | 1.310 (0.822–2.089)  | .256  | 1.310 (0.822–2.089) | .256  |
| Surgical approach (intercostal/subcostal) | 1.297 (0.853–1.974) | .224  | 1.297 (0.853–1.974) | .224  |

ACEi/ARB = angiotensin-converting enzyme inhibitor or angiotensin II receptor blocker, ASA = American Society of Anesthesiologists, CCB = calcium channel blocker, CI = confidence interval, NSAID = nonsteroidal anti-inflammatory drug, OR = odds ratio, RBC = red blood cell.
Table 4

Univariate and multivariate logistic regression analyses for variables associated with intraoperative hypotension during percutaneous nephrolithotomy.

| Variables            | OR (95% CI) | Univariate analysis | P     | OR (95% CI) | Multivariate analysis | P     |
|----------------------|-------------|---------------------|-------|-------------|-----------------------|-------|
| Age                  | 1.031 (1.013–1.047) | <.001               |       | 1.024 (1.008–1.040) | <.004                |       |
| Gender (male/female) | 0.869 (0.607–1.242) | <.440               |       |             |                       |       |
| Body mass index      | 1.006 (0.961–1.053) | .805                |       |             |                       |       |
| ASA physical status  | 0.919 (0.292–2.887) | .884                |       |             |                       |       |
| Hypertension         | 1.418 (1.002–2.006) | .049                |       |             |                       |       |
| Diabetes mellitus    | 3.149 (2.162–4.587) | <.001               |       |             |                       |       |
| Preoperative beta blocker | 2.216 (1.223–4.015) | <.009               |       |             |                       |       |
| Preoperative CCB     | 0.931 (0.628–1.380) | .721                |       |             |                       |       |
| Preoperative ACE/ARB | 2.171 (1.216–3.877) | <.009               |       |             |                       |       |
| Hematocrit           | 0.976 (0.942–1.012) | .184                |       |             |                       |       |
| Operation time       | 1.003 (0.999–1.007) | .115                |       |             |                       |       |
| RBC transfusion      | 5.423 (2.452–11.909) | <.001               |       | 5.073 (2.223–11.576) | <.001               |       |
| Crystalloid administered | 1.000 (1.000–1.000) | .072               |       |             |                       |       |
| Colloid administered | 1.002 (1.001–1.002) | <.001               |       |             |                       |       |
| Estimated blood loss | 1.001 (1.001–1.002) | .001                |       |             |                       |       |
| Intraoperative lowest hematocrit | 0.945 (0.916–0.976) | .001               |       |             |                       |       |
| Stone number (multiple/single) | 1.048 (0.702–1.564) | .818               |       |             |                       |       |
| Largest stone size   | 1.004 (0.990–1.018) | .589                |       |             |                       |       |
| Hydronephrosis       | 0.975 (0.670–1.412) | .884                |       |             |                       |       |
| Staghorn stone       | 1.198 (0.842–1.704) | .315                |       |             |                       |       |
| Surgical approach (intercostal/subcostal) | 0.940 (0.662–1.339) | .729               |       |             |                       |       |

ACE/ARB = angiotensin-converting enzyme inhibitor or angiotensin II receptor blocker, ASA = American Society of Anesthesiologists, CCB = calcium channel blocker, CI = confidence interval, NSAI = nonsteroidal anti-inflammatory drug, OR = odds ratio, RBC = red blood cell.

4. Discussion

Our present analysis has indicated that 16.2% of the patients in our study cohort experienced AKI after a PNL procedure. A high preoperative serum uric acid level, long operation time, and a high incidence of intraoperative hypotension were identified as risk factors for postoperative AKI. Intraoperative hypotension was significantly associated with old age, diabetes mellitus, angiotensin-converting-enzyme inhibitor or angiotensin II receptor blocker use, and RBC transfusion. In addition, patients who experienced AKI after PNL showed significantly prolonged hospitalization and intensive care unit stay, and a higher incidence of CKD.

Our current study findings demonstrate that intraoperative hypotension is a significant risk factor for AKI after a PNL procedure. The definition of intraoperative hypotension varies widely in the published literature[13] but in our present study was defined as a reduction of the mean arterial blood pressure of <70 mm Hg for more than 5 minutes.[19] Intraoperative hypotension is known to cause cardiac complications such as myocardial injury and rhythm abnormality, and ischemic stroke, resulting in increased mortality, morbidity, and health care costs.[15–21] Renal blood flow is maintained between a mean arterial pressure of 75 and 170 mm Hg and is known to be dependent on an arterial pressure beyond this range. Intraoperative hypotension may therefore lead to a decrease in the glomerular filtration rate and renal perfusion, which subsequently increases the risk of postoperative AKI. Most instances of perioperative AKI are caused by preoperative azotemia or acute tubular necrosis due to renal hypoperfusion.[22,23] Hence, intraoperative hypotension-related renal hypoperfusion is a suggested cause of adverse outcomes such as renal ischemic injury.

In our current study, intraoperative hypotension was significantly associated with old age, diabetes mellitus, preoperative hyperuricemia, and long operation time. Intraoperative hypotension was also independently associated with a high incidence of postoperative AKI.

Table 5

Postoperative outcomes.

| Variables            | AKI group (n = 107) | No-AKI group (n = 555) | P     |
|----------------------|---------------------|-----------------------|-------|
| Hospitalization, d   | 8.7 ± 5.2           | 6.6 ± 2.8             | <.001 |
| Intensive care unit admission rate | 7 (6.5)             | 14 (2.5)              | .062  |
| Intensive care unit stay duration, d | 0.34 ± 1.74         | 0.07 ± 0.48           | .002  |
| Chronic kidney disease* | 14 (63.6)           | 29 (36.7)             | .024  |

Data are presented as the mean ± standard deviation or number (%). AKI = acute kidney injury.

*Chronic kidney disease was evaluated in 101 patients at 12 months after percutaneous nephrolithotomy.
angiotensin-converting enzyme inhibitor or angiotensin II receptor blocker use, and RBC transfusion. Association between old age and intraoperative hypotension has been reported in previous studies,[28,29] and elderly patients have reduced plasma volume, which increases the risk of intraoperative hypotension.[30,31] It has also been reported that age-related cardiac dysfunction and neuronal impairment are associated with intraoperative hypotension.[27] Thus, elderly patients require meticulous anesthetic managements. It is known that autonomic neuropathy-related diabetes mellitus damages the parasympathetic and sympathetic nerve fibers of the cardiovascular system. Therefore, diabetes mellitus is a significant risk factor for hypotension, tachycardia, and silent ischemia. Autonomic neuropathy, a complication of diabetes mellitus, can also lead to hypotension by blunting the hemodynamic response during general anesthesia.[28,29] Patients with diabetes mellitus should therefore be made aware that hypotension is a common occurrence during surgery. In addition, angiotensin-converting enzyme inhibitors and angiotensin II receptor blockers have also been reported to cause intraoperative hypotension by impairing the responsiveness and actions of catecholamine in the renin-angiotensin system in patients undergoing general anesthesia. Indeed, it has been recommended to withhold these drugs on the day of surgery.[30,31] In our present study patients, we performed a RBC transfusion if the hemoglobin was less than 8 g/dL. We consider that patients who underwent a transfusion during surgery were more likely to develop intraoperative hypotension.

In line with the results of previous studies,[8,32] our present findings indicated that a high preoperative uric acid level is also a risk factor for AKI after PNL. Hyperuricemia causes endothelial dysfunction and oxidative stress. This in turn activates the renin-angiotensin system and the development of renal vasoconstriction.[33,34] In addition, uric acid induces proinflammatory responses that interfere with endothelial cell proliferation and alter renal autoregulation.[34,35] Through these mechanisms, hyperuricemia exerts negative effects on renal hemodynamics and can thereby cause subsequent AKI.

Prolonged operation times can lead to complications such as hemorrhaging that require blood transfusions or hemo-pneumothorax during a PNL procedure.[36] We observed in our present study that a prolonged surgery duration increased the risk of postoperative AKI following PNL. This is because longer PNL operations typically require more complex surgical procedures and increase the chance of directly or indirectly damaging the kidney during the perioperative period.

Previous studies have reported that surgical factors such as approach method and stone characteristics affect the occurrence of perioperative bleeding and blood transfusion, postoperative pulmonary complications, colon perforation, and renal artery fistula.[36,37] In contrast, our current findings suggest that surgical factors and stone characteristics do not significantly affect the occurrence of postoperative AKI. This is, at least in part, likely due to the considerable experience of our surgical team.

It is notable that we observed an adverse impact of AKI on postoperative outcomes. Postoperative AKI extended the duration of hospitalization and intensive care unit stay, and a higher incidence of AKI could not follow-up the serum creatinine level at 12 months after PNL. Indeed, we observed an adverse impact of AKI on postoperative outcomes. Postoperative AKI extended the duration of hospitalization and intensive care unit stay, and a higher incidence of AKI could not follow-up the serum creatinine level at 12 months after PNL. This is, at least in part, likely due to the considerable experience of our surgical team.

It is notable that we observed an adverse impact of AKI on postoperative outcomes. Postoperative AKI extended the duration of hospitalization and intensive care unit stay, which is in line with previous studies.[38,39] Moreover, we found in our current cohort that postoperative AKI was associated with a higher incidence of CKD, which was not unexpected because AKI has been reported to directly induce end-stage renal disease, increase the risk of developing incident CKD, and aggravate underlying CKD.[40,41]

This study had several limitations of note. First, our retrospective observational design may have introduced a selection bias, which would have influenced our results. However, we evaluated almost all of the possible factors that were likely to influence the postoperative renal function following PNL. Hence, we believe that we effectively minimized the possibility of selection bias in our current analysis. Second, we could not follow-up the serum creatinine level at 12 months after PNL in all patients. Thus, we were only able to evaluate CKD development in 101 cases in our study.

In conclusion, a high preoperative serum uric acid level, long operation duration, and intraoperative hypotension are independent risk factors for postoperative AKI following PNL. In addition, postoperative AKI is associated with prolonged hospitalization and intensive care unit stay, and a higher incidence of CKD. Therefore, it is essential to minimize the risk of intraoperative hypotension with meticulous anesthetic and surgical management in patients undergoing PNL.

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