



# Long-term outcomes of ultrasound-guided percutaneous nephrolithotomy in patients with solitary kidneys: a single-center experience

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## Abstract

**Purpose** To report our experience with total ultrasound-guided percutaneous nephrolithotomy (PCNL) in the management of patients with solitary kidney, and evaluate the safety and feasibility of this technique.

**Materials and methods** Between October 2014 and December 2016, 48 patients with solitary kidneys underwent total ultrasound-guided PCNL at our institution. Stone-free rate (SFR), auxiliary procedures, and complications were recorded. Changes in renal function were evaluated by comparing preoperative and postoperative estimated glomerular filtration rates (eGFRs). Perioperative factors that may affect renal function were analyzed to define factors predicting renal function improvement on long-term follow-up. Of 48 patients, 44 were followed at least 6 months, whereas four patients were lost to follow-up.

**Results** Among all patients, staghorn calculi were found in 18 (37.5%) patients. 14 (29.2%) patients required a two-stage PCNL. Struvite was found in six (12.5%) patients. Complications were reported in eight (16.7%) patients. Severe bleeding was noticed in three patients; no angioembolization was required. After a median follow-up of 12 (6–26) months, the final SFR was 81.8% after auxiliary treatments. There was a significant improvement of eGFR from  $53.9 \pm 24.0$  to  $61.3 \pm 25.4$  mL/min/1.73 m<sup>2</sup> ( $P < 0.01$ ). Renal function was stable, improved and worse in 65.9% ( $n = 29$ ), 27.3% ( $n = 12$ ), and 6.8% ( $n = 3$ ) of patients, respectively, compared with preoperative levels.

**Conclusions** Ultrasound-guided PCNL is a safe and feasible procedure with an acceptably low complication rate in patients with solitary kidneys. At long-term follow-up, the renal function in more than 90% of the patients with solitary kidneys can be improved or stabilized after ultrasound-guided PCNL.

**Keywords** Ultrasound guidance · PCNL · Solitary kidney

## Abbreviations

PCNL Percutaneous nephrolithotomy  
SFR Stone-free rate  
eGFR Estimated glomerular filtration rate  
CKD Chronic kidney disease  
MS Metabolic syndrome  
CIRFs Clinically insignificant residual fragments

RIRS Retrograde intrarenal surgery  
DM Type 2 diabetes mellitus

## Introduction

Percutaneous nephrolithotomy (PCNL) is the standard treatment approach for large and complex renal calculi. High stone-free rates of greater than 90% have been reported [1]. However, there are risks of complications such as uncontrollable bleeding that may necessitate embolization or even a nephrectomy [2]. Therefore, PCNL for the treatment of stones in a solitary kidney still represents a special operative challenge.

Another main concern when performing PCNL in solitary kidneys was the long-term effect of percutaneous surgery on renal function [3]. However, it is difficult to evaluate this

Boxing Su and Wenyi Liang contributed equally to this work.

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effect accurately due to the influence of the contralateral kidney. Therefore, the solitary kidney represents an appropriate model in which to study the impact of PCNL on renal function and find out the underlying factors correlated with renal function improvement or deterioration.

There are many reports that addressed the issue of PCNL in management of stones in a solitary kidney [4]. However, most of them were under fluoroscopic guidance. Access for PCNL under total ultrasound guidance has been increasingly demonstrated as an acceptable alternative to fluoroscopy [5]. However, its safety and effectiveness have never been reported in the solitary kidneys.

In the present study, we reported our experience with total ultrasound-guided PCNL in the treatment of patients with solitary kidneys, evaluated its outcomes, complications, and investigated factors affecting renal function changes after long-term follow-up.

## Materials and methods

We retrospectively reviewed the records of 48 patients who underwent PCNL for stones in a solitary kidney at our institution between October 2014 and December 2016. No patient in our study underwent routine dialysis. Seven patients had a congenital solitary kidney (14.6%), 12 patients had a previous contralateral nephrectomy (25%), and 29 patients had a solitary functioning kidney with contralateral atrophy (60.4%). Non-functional contralateral kidneys were confirmed by Tc-99 m-DTPA renography. Patient demographic characteristics, including gender, age, the presence of type 2 diabetes mellitus (DM) and hypertension, body mass index (BMI), as well as previous ipsilateral kidney open surgery were recorded. Preoperative laboratory tests included serum creatinine, fasting glucose, triglyceride, total cholesterol, high-density lipoprotein (HDL) cholesterol, low-density lipoprotein (LDL) cholesterol levels, serum uric acid, liver function tests, complete blood count, coagulation screen tests, and urine cultures. Eighteen patients with positive preoperative urine cultures were treated according to antibiotic sensitivity tests. Preoperative nephrostomy was performed in five patients (10.4%) to relieve anuria and infection due to obstruction. Only the nadir serum creatinine after relief of obstruction was used for calculation of preoperative eGFR. Two patients with concurrent ureteral stones were initially treated with ureteroscopy. Stones were classified as complex (renal caliceal stones with pelvis stones, partial or complete staghorn stones,) or simple (isolated renal caliceal or pelvis stones), regardless of their size. Metabolic syndrome (MS) was diagnosed according to NCEP ATP-III criteria (2005 revision) [6].

## Technique

A retrograde 5F ureteric catheter was inserted into the renal pelvis with the patient in lithotomy position and renal access achieved with the patient prone. Access to the selected calyx was achieved under ultrasound guidance (3.5 MHz probe, LOGIQ e, GE Healthcare, USA) using a 17.5-gauge coaxial needle targeting its fornix, as we described in detail previously [7]. The tract was dilated with serial or balloon dilators (X Force<sup>®</sup> N30 balloon dilator, Bard Urological, Covington, Georgia) up to 24F under X-ray-free condition. The “two-step” method was used for serial dilation [7], and the process of balloon dilation was monitored under real-time ultrasound guidance (Supplementary material). Fragmentation of the stones was accomplished using an ultrasonic lithotripter or pneumatic lithotripter (Swiss Lithoclast, EMS Electro Medical Systems, Nyon, Switzerland) under a rigid nephroscope. Ultrasonography for residual stones was conducted to define whether additional tracts were needed. At the conclusion of the procedure, a 6F stent was inserted antegrade into the ureter and 14Fr nephrostomy tube was placed within the renal pelvis or the involved calyx. A plain X-ray of the kidneys, ureters, and bladder (KUB) was obtained 48 h after the operation. The nephrostomy tube was removed when the urine ran clear or during the next stage of surgery. SWL, retrograde intrarenal surgery (RIRS) or repeat PCNL was considered as auxiliary treatment alternative when indicated. The Double-J stent was left in situ for four weeks to facilitate the passage of stone fragments. Blood transfusion was administered when hemoglobin (Hb) < 7.0 g/L during or post operation. Severe bleeding was defined as intraoperative or postoperative renal hemorrhage requiring blood transfusion or angiographic embolization. Stone free was defined as the absence of any residual stones in kidney or had clinically insignificant residual fragments (CIRFs), meaning  $\leq 4$  mm, non-infectious, non-obstructive and asymptomatic residual fragments. All patients were assessed by KUB or computerized tomography (CT) 1 month after the final procedure to confirm the final stone-free rate (SFR).

## Follow-up

Follow-up protocol included history, blood routine test, urine analysis, serum creatinine, KUB and renal ultrasonography. CT scan was performed for assessment of patients with deteriorated renal functions or stone recurrence. Serum creatinine was measured before and 2 h after the operation, on the first postoperative day, and at each follow-up visit. The eGFR was calculated using the four-variable modification of diet in renal disease (MDRD) equation.

## Statistical analysis

Of 48 patients, 44 were followed for at least 6 months, whereas four patients were lost to follow-up; therefore, eGFR and CKD were calculated for the remaining 44 patients. Paired *t* test was used to compare the changes in the preoperative and postoperative serum creatinine and eGFR values. Increase in the eGFR over 20% was considered as improvement, decrease over 20% as deterioration, and changes within 20% as stationary in renal function [8]. Perioperative clinical factors that may affect renal function were tested using univariate (Student's *t* test or Fisher's exact test) analyses to define factors predicting renal function improvement on long-term follow-up.

## Results

The study included 48 patients [33 men (68.8%) and 15 women (31.2%)]. Patients' mean age was  $51.4 \pm 12.0$  years (range 24–74 years). The mean operative time was  $75.1 \pm 23.8$  min (range 30–130 min). The mean length of postoperative hospitalization was  $4.63 \pm 0.97$  days (range 3–7 days). In the 44 patients who completed the study, 24 patients (56.8%) were stone free after single session PCNL. For auxiliary treatments, 14 patients (31.8%) had residual stones for second stage PCNLs, RIRS retrieval was performed for five patients, and SWL was performed for three patients. After all the procedures, nine more patients became stone free, and three had insignificant fragments < 4 mm. So, the final stone-free rate was 81.8%. After a median follow-up of 12 months (range 6–26), spontaneous stone passage was noticed in one patient with CIRFs, two showed growth of the residuals, six showed the same post-PNL residuals, whereas one patient had recurrence of the stones. Those patients with recurrence or regrowth of the residuals were managed with RIRS or PCNL.

Average eGFR values were  $53.9 \pm 24.0$  mL/min/1.73 m<sup>2</sup> during the preoperative period,  $49.6 \pm 21.0$  mL/min/1.73 m<sup>2</sup> 2 h after operation,  $50.9 \pm 24.5$  mL/min/1.73 m<sup>2</sup> post operative day 1, and  $61.3 \pm 25.4$  mL/min/1.73 m<sup>2</sup> at the last follow-up visit ( $\geq 6$  months), respectively. The late postoperative eGFR was significantly improved when compared with the preoperative eGFR ( $P < 0.01$ ). Twelve patients (27.3%) showed improvement in eGFR, 29 (65.9%) showed stationary eGFR, whereas three (6.8%) showed deterioration. No patient developed end stage renal disease or maintained on hemodialysis.

In the 33 patients (68.7%) with complex stones, staghorn calculi were found in 18 (37.5%) patients. Stone analysis showed 40 (83.3%) calcium based stones, 2 (4.2%) uric acid stones, 6 (12.5%) struvite (magnesium ammonium phosphate).

Complications were reported in 8 patients (16.7%). Five patients (10.4%) had fever (temperature of 38.5 °C or greater). Blood transfusions were required in three (6.3%) patients. All of them were successfully treated conservatively; no angioembolization was required. No urosepsis was detected. Neither hydrothorax nor hemothorax developed in any patient. Factors that may associated with renal function changes were listed and analysed in Table 1.

## Discussion

PCNL is recommended as the gold standard intervention for patients with large and complex renal calculi [9]. This procedure has the advantages of a higher stone-free rate and acceptable complications when compared with other treatment alternatives such as RIRS and open surgery [2]. For challenging cases such as patients with solitary kidneys, PCNL is also an appropriate treatment choice [4].

Previous reported PCNLs in solitary kidneys were mostly performed under fluoroscopic guidance [4]. Ultrasound-guided renal access for PCNL has becoming more widely used, and was found to have shorter puncture time, higher success rate of fist puncture, and less blood loss, as compared with fluoroscopic guidance in patients with normal bilateral kidneys [10]. However, it is seldom reported in patients with solitary kidneys. In present study, all percutaneous renal accesses were achieved under total ultrasound guidance. Our final stone-free rate of 81.8% and total complication rate of 16.7% were comparable to those of fluoroscopy-guided PCNL in solitary kidneys (Tables 2). Moreover, staghorn calculi were found in 37.5% of patients in our study. These results fully demonstrated that ultrasound-guided PCNL is a safe and effective treatment approach for stones in solitary kidneys.

The primary concern of PCNL in solitary kidneys is the risk of uncontrollable hemorrhage that may necessitate embolization or even a nephrectomy [2]. Transfusion rate for severe bleeding generally varies between 3.3 and 18.8% according to previously reported PCNL series in solitary kidneys (Table 2). Most bleeding can be managed with conservative treatment, with less than 1.5% of the patients requiring angioembolization [11]. Reported risk factors for severe bleeding included multiple accesses, solitary kidney and an inexperienced surgeon [12]. In the present study, hemorrhage that required a blood transfusion was observed in three (6.3%) patients. The transfusion rate was comparable to prior fluoroscopy-guided series. All the three patients who needed blood transfusion had the staghorn calculi and required multiple accesses during the PCNL procedure. However, all of them were successfully treated conservatively, and no angioembolization was required.

**Table 1** Univariate analysis of risk factors for deterioration of the renal function after PCNL in solitary kidney (Fisher or *t* test). Univariate analysis of factors for improvement of renal function after PCNL in solitary kidney (Fisher or *t* test)

Factors	Deteriorated or stationary eGFR	Improved eGFR	<i>P</i> value
Age in year, mean (SD)	50.4 (13.4)	50.6 (9.3)	0.967
Baseline eGFR (ml/min/1.73 m <sup>2</sup> ), mean (SD)	55.5 (23.8)	49.7 (24.9)	0.476
	<i>N</i> (%)	<i>N</i> (%)	
Gender			1.000
Male	23 (71.9)	9 (28.1)	
Female	9 (75.0)	3 (25.0)	
Metabolic syndrome			0.663
Yes	5 (62.5)	3 (27.5)	
No	27 (75.0)	9 (25.0)	
Hyperuricemia			0.315
Yes	18 (66.7)	9 (33.3)	
No	14 (82.4)	3 (17.6)	
Open surgery history			1.000
Yes	8 (72.7)	3 (27.3)	
No	24 (72.7)	9 (27.3)	
eGFR category			0.322
> 30 mL/min	29 (76.3)	9 (23.7)	
15–30 mL/min	3 (50)	3 (50)	
Urine culture			0.733
Positive	14 (77.8)	4 (22.2)	
Negative	18 (69.2)	8 (30.8)	
Nature of solitary kidney			0.507
Non-functional	15 (78.9)	4 (21.1)	
Functional	17 (68.0)	8 (32.0)	
Stone burden			0.259
Simple	7 (58.3)	5 (41.7)	
Complex	25 (78.1)	7 (21.9)	
Number of tracts			0.068
Single	19 (63.3)	11 (36.7)	
Multiple	13 (92.9)	1 (7.1)	
Hydronephrosis			0.658
None or mild	28 (73.7)	10 (26.3)	
Moderate or severe	4 (66.6)	2 (33.4)	
PCNL			0.068
One stage	19 (63.3)	11 (36.7)	
Staged	13 (92.9)	1 (7.1)	
Tract dilation			0.722
Balloon	10 (66.7)	5 (33.3)	
Serial	22 (75.9)	7 (24.1)	
Severe Bleeding			0.551
Yes	3 (100)	0 (0)	
No	29 (70.7)	12 (29.3)	
Post-PCNL residuals			0.733
Stone free	18 (69.2)	8 (30.8)	
Residual stones	14 (77.8)	4 (22.2)	

**Table 1** (continued)

Factors	Deteriorated or stationary eGFR	Improved eGFR	<i>P</i> value
Stone composition			1.000
Struvite	3 (50)	3 (50)	
Non-struvite	29 (76.3)	9 (23.7)	
Auxiliary procedure			0.173
Yes	17 (85.0)	3 (15.0)	
No	15 (62.5)	9 (37.5)	
Preoperative anemia			1.000
Yes	3 (42.9)	4 (57.1)	
No	29 (78.4)	8 (21.6)	

The second concern when performing PCNL in solitary kidneys was the possible effect of PCNL on renal function at both short- and long-term follow-ups. In the present study, the mean preoperative eGFR was  $53.9 \pm 24.0$  mL/min/1.73 m<sup>2</sup> and calculated at  $50.9 \pm 24.5$  and  $61.3 \pm 25.4$  mL/min/1.73 m<sup>2</sup> during the early and late postoperative periods, respectively. A significant improvement in mean eGFR was detected at the last follow-up when compared with the preoperative level ( $P < 0.01$ ). Thus, the postoperative function of solitary kidneys after long-term follow-up was significantly improved in our study. This result was in accordance with other fluoroscopic-guided series (Table 2). The possible reasons for such improvement could be clearance of infection and relief of obstruction by stone removal [13]. However, a temporary decrease in mean eGFR during the early postoperative period was also detected, which may be due to acute injury or hydrodistention of the kidney during the surgery [14].

Without the compensation of contralateral normal kidney, patients with solitary kidneys provided a unique opportunity to investigate the factors affecting renal function in the late post-PCNL period. Struvite pertains to the infectious stones, which were associated with infection of urease-producing bacteria, such as *proteus mirabilis* [15]. Patients with struvite are deemed at high risk of recurrence, and often suffer from repeated urinary infection, which deteriorated the renal function [16]. Mayo et al. [17] found significant improvement in the function of renal units containing infectious stones underwent PCNL through radionuclide studies. However, in our study, we detected no statistically significant correlation between stone composition and postoperative kidney function.

Tract dilatation is a major procedure in PCNL, which can be done using serial or balloon dilators. Balloon dilation has been observed with higher bleeding and transfusion rates as well as a total longer operative time compared with serial dilation [18]. However, their influence on renal function has never been reported due to the influence of normal contralateral kidney. In our series of patients with solitary kidneys,

**Table 2** Literature review of guidance method, outcomes, complications, and postoperative renal function changes of patients with solitary kidneys underwent PCNL

References	Patient number	Guidance	Initial stone-free rate (%)	Final stone-free rate (%)	Complication (%)	Transfusion (%)	Renal function change
Liou et al. [22]	30	X-ray	NR	NR	NR	NR	Stable
Canes et al. [13]	81	X-ray	NR	NR	8.6	4.3	Improved
Resorlu et al. [23]	16	X-ray	81.3	93.7	62.5	18.8	Improved
Akman et al. [14]	47	X-ray	84.5	90.9	10.6	6.4	Improved
Basiri et al. [24]	30	X-ray	NR	95.3	23.3	3.3	Stable
Bucuras et al. [25]	189	X-ray and/or US	65.4	NR	29.6	10.1	Improved
Wong et al. [26]	17	X-ray	58.8	76.5	35.3	5.9	Improved
EI-Tabey et al. [8]	200	X-ray	81.5	89.5	17	5.0	Improved
Torricelli et al. [27]	27	X-ray	NR	67	29.6	18.5	Improved
Hosseini et al. [28]	412	X-ray	81	91.3	19.2	4.6	NR
Bai et al. [29]	60	X-ray	35.7	88.3	31.7	11.7	NR

US ultrasound, NR not reported

balloon dilation was used in 34.1% of the patients; the rest of them were dilated with serial dilation. We detected no significant correlation between dilation method and postoperative kidney function. This result indicated that the dilation method has little effect on renal function improvement after PCNL.

The metabolic syndrome (MS) is a cluster of cardiovascular disease risk factors that includes dyslipidemia, hypertension, central obesity, hyperglycemia, and diabetes mellitus [6]. This disease is also associated with an increased risk for chronic kidney disease and urolithiasis [19]. Akman et al. [19] reported that MS was associated with worsening renal function in patients underwent PCNL after a minimum follow-up of 12 months, and the mean eGFR was decreased significantly at last follow-up in the MS group. However, the normal contralateral kidney may be a confounding factor in this study. In two studies about PCNL in solitary kidney, underwent PCNL, patient-related factors including BMI, hypertension and diabetes mellitus, which were components of MS, have been reported to have no significant correlation with postoperative kidney function [8, 14]. In the present study, eight patients were diagnosed with MS. The eGFR at last follow-up were deteriorated in one patient, improved in three patients, and stationary in others. We detected no statistically significant correlation between MS and postoperative kidney function. In addition, we also found no significant correlation between postoperative kidney function and hyperuricemia, which is closely associated with MS and has been considered as an independent risk factor for renal impairment in patients who had renal cell carcinoma and underwent unilateral nephrectomy [20, 21]. Therefore, the correlation between MS, hyperuricemia and post-PCNL renal function needs further investigation depending on a large-scale prospective study.

We recognize three limitations in our study. First, it is limited by its retrospective nature as well as relatively short follow-up duration and small patient numbers. Future large-scale and long-term prospective studies are needed. Secondly, the influence of some variables such as mean stone volume, operative time, history of PCNL, and estimated blood loss were not included in our study. Thirdly, we can not analyze risk factors for renal function deterioration after PCNL, which is important in differentiating high-risk patients before operation. Further studies can be done from this perspective.

## Conclusions

Ultrasound-guided PCNL is a safe and feasible procedure, compared to fluoroscopy-guided PCNL, with acceptably low complication rate in patients with solitary kidneys. The renal function in more than 90% of the patients with solitary kidneys can be improved or stabilized after PCNL at long-term follow-up.

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