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Minimally invasive percutaneous nephrolithotomy with multiple mini tracts in a single session in treating staghorn calculi

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Abstract There has been continuing controversy regarding multiple tracts in a percutaneous nephrolithotomy (PCNL) session that may bring more complications, especially severe bleeding need for transfusion, even nephrectomy. Little tracts may bring less trauma to renal parenchyma than standard PCNL tracts. We carried minimally invasive PCNL (MPCNL) in treating staghorn calculi with multiple 16Fr percutaneous tracts in a single session, in an attempt to get high stone free with little trauma, and compared the morbidity of standard PCNL procedures in a prospective trial. A total of 54 consecutive patients with staghorn calculi were prospectively randomized for MPCNL (29) and PCNL (25). The size and location of stone, operative parameters, number of tracts, stone-free rate, operating time, hospital stay and complications were analyzed. In MPCNL group, a total of 67 percutaneous tracts were established in 29 renal units, while 28 tracts in 25 renal units in PCNL group. Compared to PCNL, MPCNL was associated with higher clearance rate (89.7 vs. 68%, $p = 0.049$), less chance need for adjunctive procedure of SWL or second-look PCNL (24.1 vs. 60%, $p = 0.007$), while a similar complication rate (37.9 vs. 52%, $p = 0.300$). In conclusion, with the development of instruments and increased experience, judiciously made multiple percutaneous tracts in a single session of MPCNL for treating staghorn calculi were safe, feasible and efficient with an acceptable morbidity.

Keywords Renal calculi · Staghorn calculi · Percutaneous nephrolithotomy (PCNL)

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Introduction

Staghorn calculi are branched stones that fill the renal pelvis and branch into several or all of the calices. Over time, an untreated staghorn calculus was likely to destroy the function of kidney and/or cause life-threatening sepsis [1]. A retrospective analysis of almost 200 patients with staghorn calculi suggested that renal deterioration occurred in 28% of patients with staghorn calculi who were treated "conservatively" [2]. For staghorn calculi, there were several treatment considerations, such as open surgery, extracorporeal shock wave lithotripsy (SWL), percutaneous nephrolithotomy (PCNL), and a combination treatment [3–7]. The disadvantages such as high rates of re-treatment, increased risk of steinstrasse or obstructive pyelonephritis and long treatment time before the stones were removed entirely destined that SWL monotherapy has a very limited role in the management of staghorn calculi [3, 4, 6, 7]. In a prospective randomized comparison of open surgery versus PCNL in treating complete staghorn calculi, PCNL compared favorably to open surgery with regard to the intraoperative complication rate of 16.3 versus 37.8%, major postoperative complication rate of 18.6 versus 31.1%, operative time of 127 ± 30 versus 204 ± 31 min, hospital stay of 6.4 ± 4.2 versus 10 ± 4.2 days, time return to work of 2.5 ± 0.8 versus 4.1 ± 1 weeks, stone-free rates of 82 versus 74% [5]. Current evidence suggests that patients with staghorn calculi are best managed with PCNL-based therapy either as a single technique or in combination with SWL [3, 6, 7]. The American Urological Association Nephrolithiasis Clinical Guidelines panel recommended percutaneous stone removal as the first-line choice for the management of staghorn calculi. Neither SWL monotherapy nor open surgery should be used as a first-line treatment for staghorn stones in most patients [6, 7].

Complete removal of the stone was an important goal in order to prevent further stone growth and any associated infection, and to preserve the renal function [1, 2, 6, 7]. For these reasons, most urologists would agree that the clearance was the most meaningful determinative factor of the successful treatment of patients with staghorn calculi. The high success to a complete removal of renal staghorn calculi has encouraged the use of multiple tracts carried in the session of PCNL [8–11], especially in a single session. Controversy kept on that, multiple tracts in a session may bring more complications, especially severe bleeding need for transfusion, even nephrectomy. Even though they had concluded that multiple tracts' PCNL was safe with an acceptable complication rate [8–11], no randomized clinical trial had been performed to identify it.

In general, little tracts may bring less trauma to renal parenchyma than standard PCNL tracts, especially in these cases needed multiple tracts in a single session. Therefor, we carried minimally invasive PCNL (MPCNL) in treating staghorn calculi with multiple 16Fr percutaneous tracts in a single session, in an attempt to get high clearance with little trauma. In this prospective randomized trial, MPCNL using multiple 16Fr percutaneous tracts in a single session was compared to standard PCNL procedures with flexible nephroscopy for the management of staghorn calculi, and we investigate that if multiple mini tracts would bring much more complications.

Table 1 Preoperative characteristics of both treatment groups

	MPCNL ($n = 29$)	PCNL ($n = 25$)	p
Age (years)[a]	41.00 (26–76)	38.00 (26–64)	0.053[†]
Sex ratio (M:F)	14:15	11:14	1.000[‡]
Preoperative UTI	8 (27.6)	7 (28)	1.000[‡]
Serum creatinine (μmol/L)[a]	90.2 (74–196)	97.1 (46–220)	0.716[†]
Hydronephrosis			0.799[‡]
Mild	21 (72.4)	16 (64)	
Moderate	7 (24.1)	8 (32)	
Marked	1 (3.4)	1 (4)	
Stone burden (cm^2)[a]	11.7 (8.8–22.8)	10.8 (8.4–20.2)	0.061[†]
Type of stone			0.625[‡]
Complete staghorn	18 (62.0)	13 (52)	
Borderline	5 (17.2)	7 (28)	
Partial staghorn	6 (20.7)	5 (20)	

Values in parentheses are percentages unless indicated otherwise

MPCNL minimally invasive percutaneous nephrolithotomy, *PCNL* percutaneous nephrolithotomy, *UTI* urinary tract infection

[†] Student's *t* test

[‡] χ^2 test or Fisher's exact test (proportions)

[a] Values are median (range)

Methods

Between February 2008 and January 2009, consecutive patients with staghorn calculi were enrolled in this prospective study. All of these patients were eligible and were informed about the study, and this study had been approved by the ethics committee. Exclusion criteria included children, patients with end-stage renal disease, those with uncorrectable coagulopathy and any other complicated cases such as solitary kidney, horseshoe kidney and transplanted kidney. Randomization was done on the day of intervention using the closed envelope method. At last, a total of 54 patients with staghorn calculi were prospectively randomized for MPCNL ($n = 29$) or PCNL ($n = 25$) group. The characteristics of the patients, stones of both treatment groups are summarized in, both groups were comparable regarding age, sex, urinary tract infection (UTI), preoperative serum creatinine, hydronephrosis, stone burden and other characteristics (Table 1).

In addition to history, clinical examination and routine laboratory investigations, radiological evaluation included plain abdominal radiography (KUB) and ultrasonography (US) was received. Excretory urography (IVP) was performed if serum creatinine was 150 μmol/L or less. In patients with higher serum creatinine, computerized tomography (CT) was performed. UTI was treated in all patients according to middle stream urine culture sensitivity.

Operative procedures

A novel single session MPCNL with multiple mini tracts was carried out in 29 cases. In a split lower limbs position, a 5Fr open-ended external ureteral catheter (Boston Scientific Corporation, Miami Technology Center, USA) was inserted into the target ureter under direct ureteroscopic vision, and also under X-ray fluoroscopic guidance to make sure that the end of catheter indwelled at ureteropelvic junction (UPJ), which would prevent the migration of stone fragments from renal collecting system down the ureter. In addition, the catheter allowed retrograde injection of contrast medium to facilitate renal puncture at the appropriate site. Then, the patients were turned to a prone position with a pack under the ipsilateral hemi-pelvis. Fluoroscopy-guided percutaneous punctures were made by the urologists followed by puncture of an 18-gauge coaxial needle (Cook Incorporated, Bloomington, IN) into the designed calyx. A flexible 0.035 in. Zebra™ guide wire (Boston Scientific Corporation, Miami Technology Center, USA) was then inserted into renal collecting system or down the ureter through the needle sheath under fluoroscopic guidance. An 8Fr fascial dilator (Cook Incorporated, Bloomington, IN) was employed initially, the percutaneous tract was dilated to 16Fr along the guide wire gradually. A matched peel-away sheath (Cook Incorporated, Bloomington, IN) was advanced into the renal collecting system. The stones were fragmented with pneumatic lithotripsy through 8/9.8Fr rigid ureteroscope (Richard Wolf GmbH, Germany). During the first session, significant residual stone gained another more percutaneous tract in the same way as the first tract to the target calyx, no flexible scopy was used. At the end of the procedure, double-J stent was indwelled and 16Fr silastic nephrostomy tubes were left to each puncture.

Standard PCNL was performed with nephroscope via 26Fr percutaneous tract established by Amplatz sheath in 25 cases, multiple tracts were also planed if significant residual stone was found, flexible nephroscopy was used for slight residual stone. At the end of the procedure, double-J stent was indwelled and silastic nephrostomy tubes were left to each puncture.

Postoperative evaluation

The need for blood transfusion was decided on the basis of postoperative hemoglobin. Stone clearance was documented on plain abdomen X-ray (KUB) the next morning. Complete stone clearance was defined as the absence of any fragments on KUB. Patients with clinically insignificant residual fragments (CIRF) were those residual non-symptomatic, non-obstructing and non-infected fragments less than 4 mm in diameter. Patients with significant residual stones in both groups were subjected to additional second-look procedure through the existed tract or a new percutaneous tract, or SWL (Dornier Medical Systems, Inc., Marietta, GA). In patients with complete stone clearance, the nephrostomy tubes were clamped and subsequently removed 3–4 days after the surgery. Follow up was made over 2 weeks to 4 months.

Statistical analysis

Continuous data were recorded as mean ± SD if normally distributed or median if not normally distributed. Normally distributed data were analyzed with Student's *t* test, Wilcoxon rank sum test was used for non-normally distributed data. Categorical data were compared with the χ^2 test or Fisher's exact test (proportions). $p<0.05$ was considered statistically significant. Statistical analysis was performed using SPSS® for Windows version 12.0.

Results

A total of 95 percutaneous tracts were established in 54 renal units during 68 operations including 14 second-look procedures for these 54 patients (Table 2). In PCNL group, most cases (22/25, 88%) was subjected to only one 26Fr tract, while in MPCNL group 22 cases (22/29, 75.9%) required 2 mini tracts, 5 cases (5/29, 17.2%) required 3 mini tracts and 2 cases (2/29, 6.9%) required 4 mini tracts. The points of entry of these tracts were 76.1 and 39.3% supracostal in MPCNL and PCNL groups, respectively.

Table 2 Percutaneous tracts in both treatment groups

	MPCNL ($n = 29$)	PCNL ($n = 25$)	p
No. of patients with percutaneous tracts (%)			0.000‡
1 tract	0	22 (88)	
2 tracts	22 (75.9)	3 (12)	
3 tracts	5 (17.2)	0	
4 tracts	2 (6.9)	0	
No. of point of tracts	67	28	0.071‡
Upper pole	15 (22.4)	3 (10.7)	
Middle pole	38 (56.7)	13 (46.4)	
Lower pole	14 (20.9)	12 (42.9)	
Costal adjacent			0.001‡
Supracostal punctures	51 (76.1)	11 (39.3)	
Inferocostal punctures	16 (23.9)	17 (60.7)	

Values in parentheses are percentages unless indicated otherwise

MPCNL minimally invasive percutaneous nephrolithotomy, *PCNL* percutaneous nephrolithotomy

‡ χ^2 test or Fisher's exact test (proportions)

Mean operative time was 116 (96–130) min in MPCNL group and 103 (88–105) min in PCNL group, respectively, no difference of significant value ($p = 0.052$, Table 3). Similarly, hospital stay, including preoperative preparation for operation of 3 days, was no significantly longer in the MPCNL group (9.8 vs. 7.1 days, $p = 0.072$). Complete stone clearance was achieved in 24 cases (24/29, 82.8%) in MPCNL group and 14 cases in PCNL group cases (14/25, 56%), respectively, in a single session, a difference of significant value ($p = 0.032$). Additional treatment was required significantly more frequent in PCNL group than MPCNL group ($p = 0.007$). 4 cases required second-look PCNL and 3 cases received SWL in MPCNL group, while 10 cases required second-look PCNL and 5 cases received SWL in PCNL group. A complete stone clearance rate of 89.7% was achieved after combination of repeat PCNL and SWL in MPCNL group, and 68% in PCNL group ($p = 0.049$). Residual stones remained in 11 cases with a median diameter of 8 mm (range 6–12 mm), they had no further treatment but with a regular follow-up observation.

Intraoperative and postoperative complications in terms of ureteral injury, renal collecting system injury, algor/fever with sepsis, severe bleeding, postoperative fever, urine extravasation, pneumothorax, transfusion were recorded in

Table 3 Results of treatment in both groups

	MPCNL ($n = 29$)	PCNL ($n = 25$)	p
Operative time (min)[a]	116 (96–130)	103 (88–105)	0.052†
Hospital stay[a]	9.8 (6–13)	7.1 (6–12)	0.072†
Clearance after first session	24 (82.8)	14 (56)	0.032‡
Ancillary treatment	7 (24.1)	15 (60)	0.007‡
No. of second look	4 (13.8)	10 (40)	0.028‡
No. of patients received SWL	3 (10.3)	5 (20)	0.449‡
Clearance before discharge	26 (89.7)	17 (68)	0.049‡
Hemoglobin drop (g/L)	3.2 (2.3–4.1)	3.5 (2.8–5.0)	0.094†

Values in parentheses are percentages unless indicated otherwise

MPCNL minimally invasive percutaneous nephrolithotomy, *PCNL* percutaneous nephrolithotomy, *SWL* extracorporeal shock wave lithotripsy

† Student's *t* test

‡ χ^2 test or Fisher's exact test (proportions)

[a] Values are median (range)

Table 4 Intraoperative and postoperative complications in both treatment groups

	MPCNL ($n = 29$)	PCNL ($n = 25$)	p
No. of intraoperative complications	5 (17.6)	5 (20)	1.000
Ureteral injury	1 (3.4)	1 (4)	1.000
Renal collecting system injury	2 (6.9)	2 (8)	1.000
Algor fever with sepsis	1 (3.4)	0	
Severe bleeding	1 (3.4)	2 (8)	0.591
No. of postoperative complications	6 (20.7)	8 (32)	0.344
Fever	3 (10.3)	3 (12)	1.000
Urine leakage	1 (3.4)	2 (8)	0.591
Pneumothorax	1 (3.4)	0	
Transfusion	1 (3.4)	3 (12)	0.326
Total complications	11 (37.9)	13 (52)	0.300

Values in parentheses are percentages unless indicated otherwise. χ^2 test or Fisher's exact test for proportions

MPCNL minimally invasive percutaneous nephrolithotomy, *PCNL* percutaneous nephrolithotomy

11 patients (11/29, 37.9%) in MPCNL and 13 (13/25, 52%) in PCNL group, no difference of significant value ($p = 0.300$, Table 4). Most intraoperative complications such as urinary tract injury, including ureteric orifice and renal collecting system mucous membrane were observed in three cases in each group, no difference of significant value ($p = 1.000$). 3 cases had severe bleeding during the operation, and second-look procedure was arranged. Urinary tract injury was managed with adequate drainage and double-J stent indwelled. Most postoperative complications including fever, urinary leakage, pneumothorax, massive hematuria requiring blood transfusion or superselective embolization were observed in six patients (6/29, 20.7%) in MPCNL group and in eight cases (8/25, 32%) in PCNL group, no difference of significant value. All complications were managed conservatively without any renal unit loss or morbidity. Six patients with a postoperative fever of 38.5°C or greater were administered with transvenous antibiotics injection according to middle stream urine culture sensitivity until body temperature was normal. 4 patients required blood transfusion, when their hemoglobin dropped below 80 g/L. 3 patient had postoperative nephrostomy tube urine leakage, and it is relieved after the adjustment of drainage tube. 1 patient had hydropneumothorax following a supracostal puncture between 10th and 11th ribs, required closed drainage of thoracic hydropneumothorax. The follow-up chest X-ray was normal with no residual sequelae.

The stone composition in this series was calcium oxalate (11/54, 20.3%), calcium phosphate (9/54, 16.7%), struvite (17/54, 31.5%), uric acid (4/54, 7.4%) and admixture with the main bulk of calcium oxalate and calcium phosphate (13/54, 24.1%). Separatively, calcium oxalate (7/29, 24.1%), calcium phosphate (5/29, 17.2%), struvite (10/29, 34.5%), uric acid (2/29, 6.9%), admixture with the main bulk of calcium oxalate and calcium phosphate (5/29, 17.2%) in MPCNL group and calcium oxalate (4/25, 16%), calcium phosphate (4/25, 16%), struvite (7/25, 28%), uric acid (2/25, 8%), admixture with the main bulk of calcium oxalate and calcium phosphate (8/25, 32%) in PCNL group.

Discussion

PCNL was a well-established option for upper urinary tract stones. Interest kept on the issue regarding the injury of percutaneous tract to renal parenchyma, especially multiple tracts in a renal unit. Clayman [12] and Traxer [13] had examined the amount of renal damage caused by different size nephrostomy tract dilatation in pigs, and founded that mean scar volume was 0.294–0.430 mm^3, the ratio to total kidney volume was 0.13–0.16%, this may reveal limit injury of percutaneous tract to renal parenchyma. The high success to a complete removal of renal staghorn calculi had triggered the plan to carry multiple tracts' PCNL with 30/34Fr Amplatz sheath for adult large complete staghorn calculi [8–10], and even in children [11].

MPCNL was mostly used in pediatric urinary stones or lower pole stones $\leq 2\ cm^2$ in adults [14, 15], and was regarded as not suitable for large burden calculi since the limited percutaneous working sheath may increase the operating time. In fact, with the development of instruments and increased experience, MPCNL with little percutaneous tract of 16Fr was technically feasible. In this series, we used a powerful pneumatic lithotripter, mean operative time of MPCNL group was 116 min, there was no statistical significance to 103 min in PCNL group ($p = 0.052$).

Residual stones were detected by C-arm fluoroscopy during MPCNL operation, if it is inaccessible from the existing tract, another percutaneous tract was needed, especially in the case that the location of residual calculi in a calyx parallel to the existing percutaneous access tract, or arranged in two rows (anterior and posterior). Aron [8] had pointed out that rud manipulation from a single tract to removal a complete staghorn calculi usually bring severe bleeding, it's judicious to made multiple tracts in a PCNL session in these cases. Combined PCNL and flexible nephroscopy/ureteroscopy management can effectively reduce the number of percutaneous access tracts which would otherwise be required for managing complex and branched renal calculi [16]. While if there was significant ongoing bleeding, irrigation through the small working channel may not be adequate for good visualization, and also the flexible ureteroscopy was much more costly and technical challenge. With aggressive MPCNL using multiple mini tracts, we achieved a clearance rate of 82.8% in a single session in such complicated cases, it is higher than PCNL group (82.8 vs. 56%, $p = 0.032$). The higher stone-free rate achieved with an aggressive percutaneous approach avoids the discomfort and expense of adjunctive second-look PCNL or SWL in the majority of patients. After combination of repeat PCNL and SWL, clearance of MPCNL group was still higher than PCNL group (89.7 vs. 68%, $p = 0.049$). Large burden (10.8 cm^2) of calculi in PCNL group in this series and insufficient experience of flexible nephroscopy may contribute to a lower clearance rate than other series [6, 7].

Most intraoperative complications were urinary tract injury, including ureteric orifice and renal collecting system mucous membrane [6, 7, 19]. The limitation of rigid nephroscope lies in its lack of maneuverability around the sharp angles frequently encountered in the renal collecting system with narrow infundibulum neck. Aron [8] also noted that 'torquing' a rigid nephroscope against the pelvicalyceal system to get to an inaccessible calyx is the most important cause of bleeding during PCNL and is largely responsible for increasing transfusion rates, and extravasation. 3 cases had severe bleeding during PCNL operation, we had to terminate the operation and arrange second-look procedure. Renal hemorrhage continues to be the most worrisome and concerned complications for PCNL, especially the severe hemorrhage was always life-threatening. Although most patients with bleeding can be managed conservatively, several patients require superselective segmental renal artery embolization for vascular complication control [17]. In Turna' s [18] retrospective research on various variables that influence hemorrhage of 193 patients, staghorn stones, multiple tracts, the presence of diabetes was associated with increased renal hemorrhage during PCNL on multivariate analysis. In Singla' s report [10], of 149 patients with staghorn calculi who underwent PCNL using multiple (two or more) access tracts, 46 patients required transfusion. Little percutaneous tract was believed to bring less blood losing, in this series, aggressive MPCNL using multiple mini tracts did not bring a higher transfusion rate than PCNL group ($p = 0.326$).

Most postoperative complications including fever, urinary leakage, pneumothorax, massive hematuria requiring blood transfusion or superselective embolization were observed [6, 7, 17–19]. Previously, others [7, 19] have cautioned against the supracostal approach due to concern about the increased risk of intrathoracic complications. Pleural injury during PCNL is closely related to the level of percutaneous tract. Lallas [19] retrospectively review their experience with percutaneous renal surgery with a particular emphasis on identifying the incidence of nephropleural fistula and management of this unusual complication. Of 375 patients, 4 (1%) developed a nephropleural fistula. Of the 87 with supracostal-12th rib access, 2 (2.3%) developed a nephropleural fistula, and 2 (6.3%) of the 32 with supracostal-11th rib access developed the same complication. The overall incidence of nephropleural fistulas in their patient population per access tract placed was 0.87% (4/462), which increased to 3.3% (4/20) when considering only supracostal access. To our knowledge, supracostal PCNL had acceptable rates of intrathoracic complications which can be managed easily. In this series, among 95 percutaneous tracts, 62 were supracostal, only 1 patient had hydropneumothorax following a supracostal puncture between 10th and 11th ribs, required closed drainage of thoracic hydropneumothorax. The follow-up chest X-ray was normal with no residual sequelae. Even though, a supracostal puncture should be cautious.

SWL may be utilized in cases where remaining stones cannot be reached with safe approach via another access tract or flexible endoscopy. However, total removal of fragments from the collecting system after SWL without subsequent nephroscopy is unlikely [20]. The Nephrolithiasis Guideline Update Panel of the AUA Education and Research noted that combination therapy is being used less frequently as a result of improvements in endoscopic and intracorporeal lithotripsy technology. The panel believes that repeat PCNL, or second-look nephroscopy through an established tract, may prove more efficient for complete stone removal than the combination approach [2].

The limitation of this study includes, whether it seems unfair or unreasonable, that in MPCNL group we used multiple tracts in all cases while 12% of standard PCNL group were employed multiple tracts. MPCNL group had higher clearance on the ground with much more percutaneous tract, but it should not be ignored that PCNL group had the assistance of flexible nephroscopy. As a surgical treatment strategy, MPCNL with multiple tracts in a single session was another good choice to get high clearance in cases of no flexible nephroscopy, just as PCNL with flexible nephroscopy. Previous study had reported that both techniques had positive result with high clearance. Thus, the most important issue of this study was that multiple mini tracts would bring much more complications.

Based on our prospectively randomized study, patients treated with multiple mini tracts MPCNL had higher clearance, while complications with such an aggressive approach were comparable to those of PCNL. Thus, judiciously made multiple mini percutaneous tracts in a single session MPCNL for treating staghorn calculi was safe, feasible and efficient with an acceptable morbidity.

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