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Minimally Invasive Percutaneous Nephrolithotomy for Simple and Complex Renal Caliceal Stones: A Comparative Analysis of More Than 10,000 Cases

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Abstracts

Purpose: To determine whether minimally invasive PCNL (MPCNL) is as safe and effective in the management of complex renal caliceal stones as it is for simple renal stones.
Patients and Methods: We retrospectively reviewed 5761(41.2%) simple caliceal stones (isolated renal pelvis including isolated calix) and 8223 (58.8%) complex caliceal stones (renal pelvis accompanying two calices at least) that were managed by MPCNL between 1992 nd 2011. The safety, efficacy, and outcome were compared and analyzed.
Results: Stone burden was larger in complex caliceal stones (1763.0 *vs* 1018.6 mm^2, $P < 0.05$). Patients with simple stones had significantly shorter operative time, less frequency of multiple percutaneous accesses, and less hemoglobin drop. They also had a higher initial stone-free rate (SFR) (77.6% *vs* 66.4%) after a single session of MPCNL ($P < 0.05$). The differences diminished in the final SFR (86.7% *vs* 86.1%) after relook and/or auxiliary procedures ($P > 0.05$). The complication rate (17.9% *vs* 19.0%) and blood transfusion rate (grade II) (2.2% *vs* 3.2%) were similar in both groups ($P > 0.05$). Both groups had a low rate of high Clavien grade complications. Renal vascular embolizations (grade III), however, were significantly higher in patients with complex caliceal stones ($P < 0.05$).
Conclusions: MPCNL is a safe and effective treatment option for patients with complex caliceal stones except there is a slightly higher frequency rate of embolization. There was a higher initial SFR in simple stones, but this difference diminished with secondary procedures.

Introduction

Percutaneous nephrolithotomy (PCNL) is a well-established treatment option for patients with large and complex upper urinary tract stones. In the past, a 24F to 34F nephrostomy tract was used for this procedure, the so-called standard PCNL. More recently, there has been a trend to use smaller and smaller nephrostomy tracts—the so-called minimally invasive PCNL (mini-PCNL or MPCNL) to reduce the morbidities associated with PCNL. There have been, however, some concerns that by using the miniaturized access, there could be reduced visibility, increased operative time, and a decreased primary stone-free rate (SFR).[1,2] Furthermore, there was no clear definition as to what constitutes mini-PCNL. Reported series had used nephrostomy tracts ranging from 14F to 20F.

We developed a modified MPCNL procedure in 1992 to manage all upper urinary tract stones that necessitated PCNL. Initially, we performed this as a staged procedure. A 14F to 18F nephrostomy access was established during the first stage. At a minimum of 2 to 4 days later. the nephrostomy tract was dilated up to 18F, and lithotripsy was performed in the second stage.[3] In 1998, we consolidated the procedure into a single stage and have since used this technique for all stones.[4–7]

Large and complex stones constitute advanced calculus disease. The management strategy depends on the stone burden and their locations in the collecting system. One of the current treatment options for such stones is percutaneous debulking using single-tract PCNL followed by shockwave lithotripsy (SWL) or flexible ureteroscopy (URS) for the residual stone fragments. Obviously, the final result depends on

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the residual stone burden and renal anatomy. To improve the results, before the year of 2010, we more frequently used multiple 14F to 18F tracts for clearance, when indicated.[3,5]

We retrospectively reviewed the largest known series of patients who underwent MPCNL for treatment of both simple and complex stones and determined the safety and efficacy of this procedure for complex stones.

Patients and Methods

We retrospectively reviewed the records of 13,984 renal units in 12,482 patients with upper urinary tract calculi who underwent MPCNL between 1992 and 2011. Patients were divided into two groups according to the number of involved renal calices. Group 1 had simple stones (renal pelvis including isolated caliceal stones). Group 2 had complex stones (staghorn or renal pelvis accompanying two calices at least), regardless of their size and burden. The efficacy and safety of the treatment in these two groups were compared and analyzed. There was a change in our technique for MPCNL in 1998. The results were thus further divided into subgroups to reflect this change and for more applicable comparison.

Before 1998, we performed a staged procedure. A nephrostomy tract was first established. In the second stage, dilation and lithotripsy were performed after a minimum interval of 2 to 4 days. Since 1998, we simplified our technique into a single stage and have done so ever since. Patients with infection, obstruction, or renal insufficiency, however, were still Treated in two stages to improve function and drainage.[2] In our preoperative planning, we estimated the number of renal punctures that would be needed based on the number of calices to be accessed. We would choose one of the punctures as the main operative channel where the greatest stone burden could be cleared; the selection was based on stone configuration. The other punctures were considered as secondary accesses to be used for removal of residual or peripheral stones. The main tract was dilated to 18F to 20F, while secondary tracts, if necessary, were dilated to 14F to 18F.

We used an 8/9.8 F semi-rigid ureteroscope, 14F to 20F access sheath, and a pulsatile low-pressure perfusion pump for the MPCNL. The addition of a pulsatile perfusion pump reduced the frequency of using grasping forceps and stone baskets. The detailed description of our procedure had been published previously.[2] In cases in which the procedure was performed in stages, the puncturing nephrostomy tube was left in place. The subsequent procedure was performed through the same but now matured tract. Early in this series, when a complete SFR was not achieved in the initial procedure, a second-look PCNL was performed 2 to 4 days later. Since we adopted the multitract techniques in selected cases, our SFR improved. During the past 3 years, we had been using a flexible scope and basket through the nephrostomy tract to remove stones that could not be reached by a rigid scope. A secondary flexible URS or SWL was performed after a minimum interval of 3 to 10 days to remove any residual stone fragments.

We defined the initial SFR as absence of any visible stone fragments on nephroscopy at the end of the procedure and on the postoperative radiography of the kidneys, ureters, and bladder (KUB) or CT, if indicated, at the time of hospital discharge. The same criteria were applied for final stone-free status at 3 months after the auxiliary procedures. Complications were retrospectively collected from patients' medical charts. They were recorded according to the modified Clavien classification system. Mortality was defined as death that occurred during the hospital stay for the procedure.

Preoperative data collected include age, sex, previous stone intervention history, stone burden, and number of calices involved. The mean stone area was calculated by measuring the stone axis in two planes, left-right and cephalad-caudad, on the radiologic images and then multiplying these two values. If multiple stones were present, the area of each stone was added together to determine the total stone area. Intraoperative data included operative time (defined as the interval between renal puncture and skin closure of the nephrostomy tract), renal puncture site, location of access, size and number of the nephrostomy tract, and any intraoperative complications. Postoperative parameters obtained included SFR, hemoglobin drop, blood transfusion, any postoperative complications, hospital stay, and any auxiliary treatment (second-look MPCNL, repeated MPCNL, URS, SWL, or combined methods). Hospital stay was calculated from the date of hospitalization to the date of discharge and was rounded to the nearest whole day. Differences between the two groups were tested for statistical significance using the chi-square test, t test, and Mann-Whitney U test. $P < 0.05$ was considered statistically significant.

Results

There were 12,482 patients entered into this study, which included 7277 males and 5205 females with a mean age of 47.6 ± 13.7 years (range 0.6–93 years). A total of 13,984 MPCNLs were performed. Right-side, left-side, and bilateral PCNL were performed in 7063, 6921, and 1502 cases, respectively. According to the numbers of renal calices involved, 5761 (41.2%) stones in 5248 patients were classified as simple stones (group 1) and 8223 (58.8%) in 7234 patients as complex stones (group 2). The mean stone burden was $1018.6 \pm 787.3\,mm^2$ in group 1 and $1763.0 \pm 997.7\,mm^2$ in group 2, $P < 0.001$. There were 1924 (33.4%) in group 1 and 2722 (33.1%) in group 2 who had a history of surgical intervention, $P = 0.716$: 271 *vs* 344 had previous open surgery; 786 *vs* 1073 had SWL; 473 *vs* 897 had PCNL; 203 *vs* 342 had ureteroscopic lithotripsy, 103 vs. 154 had a combined modality. Demographic and preoperative characteristics of the patients are summarized in Table 1.

Operative characteristics are listed in Table 2. In summary: 5652 (98.1%) patients in group 1 had a single nephrostomy tract for the MPCNL; 93 (1.6%) had two tracts; and 16 (0.3%) had three tracts. For group 2, a single tract was performed in 6520 (79.3%) cases, two tracts in 11 (18.0%), three tracts in 157 (1.9%), four tracts in 36 (0.4%), and five tracts in 32 (0.4%). Mean operative time in those with complex stones was significantly longer than in those with simple stones, at 90.4 ± 41.9 *vs* 72.4 ± 28.4 min ($P < 0.001$). The mean hemoglobin decrease was 1.23 ± 1.07 (0.2–5.9) g/dL for group 1 and 1.44 ± 1.16 (0.2–7.1) g/dL for group 2, $P < 0.001$. The mean hospital stay was similar in both groups: 9.4 ± 3.2 days and 10.9 ± 7.8 days, $P < 0.001$. As our experience increased and less staged procedures were performed, the operative time, decrease in hemoglobin level, mean hospital stay, and number of nephrostomy tracts correspondingly diminished. This was especially evident in those with simple stones.

Table 1. Perioperative Data of Surgical Groups

Characteristic	*Overall*	*Simple stones*	*Complex stones*	P
No. patients	12482	5248	7234	-
No. renal units	13984	5761(41.2%)	8223(58.8%)	-
Before 1998	2350(16.8%)	976(7.0%)	1374(9.8%)	-
After 1998	11634(83.2%)	4785(34.2%)	6849(50.0%)	-
Mean age (yr)	47.6 ± 13.7	47.7 ± 13.8	47.5 ± 13.6	0.308
Gender, male, n (%)	7277(58.3%)	3038(57.9%)	4239(58.6%)	0.427
BMI (kg/m^2)	23.5 ± 4.6	23.4 ± 4.2(14.7–36.2)	23.5 ± 4.9(14.9–39.3)	0.233
Surgery history, n (%)	4646(33.2%)	1924 (33.4%)	2722(33.1%)	0.716
Mean stone burden (mm^2)	1456.3 ± 987.4	1018.6 ± 787.3	1763.0 ± 997.7	< 0.001
Stone classification, n (%)				0.382
Staghorn	4405(31.5%)	0	4405(31.5%)	
Multiple	5468(39.1%)	1650(11.8%)	3818(27.3%)	
Single	4111(29.4%)	4111(29.4%)	0	
Mean operative time (min)	83 ± 38(25–215)	72.4 ± 28.4(25–109)	90.4 ± 41.9(55–215)	< 0.001
Before 1998	100.1 ± 40.3	83.8 ± 31.7	111.6 ± 43.4	< 0.001
After 1998	79.5 ± 34.7	70.1 ± 21.1	86.1 ± 40.3	< 0.001
Number of tracts:				< 0.001
Single tract	12172(87.0%)	5652 (98.1%)	6520(79.3%)	
Multiple tracts	1812(13.0%)	109(1.9%)	1703(20.7%)	
Mean number tracts(n)	1.15 ± 0.45	1.02 ± 0.14	1.25 ± 0.55	< 0.001
Initial stone free (%)	9930(71.0%)	4468(77.6%)	5462(66.4%)	< 0.001
Before 1998	1674(71.2%)	742(76.0%)	932(67.8%)	< 0.001
After 1998	8256(71.0%)	3726(77.9%)	4530(66.1%)	< 0.001
Final stone free (%)	86.8%	86.7%	86.1%	0.322
Auxiliary procedures (%)	3593(25.7%)	1205(20.9%)	2388(29.0%)	< 0.001
Mean hemoglobin drop (g/dL)	1.35 ± 1.13(0–7.1)	1.23 ± 1.07	1.44 ± 1.16	< 0.001
Before 1998	1.64 ± 1.23	1.46 ± 1.23	1.76 ± 1.21	< 0.001
After 1998	1.29 ± 1.10	1.18 ± 1.03	1.38 ± 1.14	< 0.001
Mean hospital stay (d)	10.3 ± 6.4(2–22)	9.4 ± 3.2	10.9 ± 7.8	< 0.001
Before 1998	13.8 ± 6.9	12.5 ± 3.1	14.8 ± 8.6	< 0.001
After 1998	9.4 ± 6.0	8.4 ± 2.5	10.1 ± 7.4	< 0.001
Overall complications rate (%)	2591 (18.53%)	1031(17.9%)	1560(19.0%)	0.107
Before 1998	398(16.9%)	160(16.4%)	238(17.3%)	0.554
After 1998	2193(18.8%)	871(18.2%)	1322(19.3%)	0.136

BMI = body mass index.

The SFR after a single session of MPCNL (initial SFR) was 77.6% (4468 cases) in group 1 and 66.4% (5462 cases) in group 2, $P = 0.001$. There were 436 (5.8%) in group 1 and 1619 (20.9%) in group 2 who underwent second-look PCNL. The SFR increased to 81.3% (4684) and 80.1% (6586). If we included patients with no stones and with small residual stones < 4 mm, the SFR increased to 92.3% (5316) in group 1 and 88.3% (7258) patients in group 2. Many reports in the literature considered stones < 4 mm to be clinically insignificant stones. Other auxiliary procedures were used in 8.4% of cases. Among the auxiliary procedures, 321 (2.3%) patients underwent a repeated MPCNL that necessitated a new nephrostomy tract, in contrast to the second-look PCNL; 405 (2.9%) underwent ureterorenoscopy; and 448 (3.2%) had SWL. Follow-up at 3 months was available in 12,914 (92.3%) of treated renal units—5092 in group 1 and 7882 in group 2. It showed a final SFR of 86.7% (4414/5092) and 86.1% (6786/7882), respectively, $P = 0.322$.

We identified 3624 perioperative complications in 2591 (18.53%) procedures. We assessed the complications following the Clavien classification, Table 2. Grade I was documented in 16.84%, grade II in 5.05%, grade III in 3.95%, and grade IV in 0.05%. There were three postoperative deaths in group 2, grade V complication, for a mortality rate of 0.02%. The causes of death were disseminated intravascular coagulopathy resulting from uncontrolled sepsis in one and myocardial infarction in the other two. There was no difference in perioperative complications between groups 1 and 2 (17.9% *vs* 19.0%, $P = 0.107$). Arterial embolization for bleeding, grade III complication, was significantly more common in patients with complex stones ($P < 0.05$). The blood transfusion rate, grade II complication, was similar between the two groups (2.2% *vs* 3.2%, $P > 0.05$).

Discussion

PCNL is a well-accepted treatment option for patients with large and complex upper urinary tract stones. In the past, a 24F to 34F nephrostomy tract was used for this procedure, the so-called standard PCNL. Some researchers developed the MPCNL procedure to decrease the size of the nephrostomy tract.[1] Although they found that there was no statistically significant difference between conventional PCNL and mini-PCNL in the loss of functional tissue and postoperative renal scarring,[8] the use of a smaller access sheath results in reduced intraoperative blood loss.[9–11] There have been concerns that

Table 2. Complications by Modified Clavien Grading Classification

Characteristic	*Overall*	*Simple stones*	*Complex stones*	P
No. kidneys with complications (%)*	2591(18.53%)	1031(17.9%)	1560(19.0%)	0.107
No. complications	3624(25.92%)	1450(25.17%)	2164(26.32%)	0.127
% Grade I:	2355(16.84%)	983(17.1%)	1362(16.6%)	0.436
Postoperative pain	801(5.73%)	346(6.01%)	455(5.53%)	0.236
Transient bleeding	495(3.54%)	172(2.99%)	323(3.93%)	0.003
Fever with antipyretic therapy	607(4.34%)	262(4.55%)	335(4.07%)	0.172
Others	452(3.23%)	203(3.52%)	249(3.03%)	0.103
% Grade II:	706(5.05%)	247(4.29%)	459(5.58%)	0.001
Urinary tract infection	140(1%)	58(1.01%)	82(1.0%)	0.955
Blood transfusion	393(2.8%)	126(2.2%)	267(3.2%)	0.000
Urosepsis only needing additional antibiotics	15(0.11%)	5(0.09%)	10(0.12%)	0.536
Else	158(1.13%)	58(1%)	100(1.22%)	0.249
% Grade III:	553(3.95%)	219(3.82%)	334(4.06%)	0.468
Urine leakage	182(1.30%)	63(1.09%)	119(1.45%)	0.069
Bleeding (needing multiple bladder washout/irrigation)	116(0.83%)	51(0.89%)	65(0.79%)	0.543
Embolization	71(0.51%)	16(0.28%)	55(0.67%)	0.001
Urosepsis needing surgical intervention	13(0.09%)	6(0.1%)	7(0.09%)	0.716
Pleural injury needing chest tube	126(0.90%)	60(1.04%)	66(0.80%)	0.141
Colonic perforation	3(0.02%)	0	3(0.04%)	0.147
Renal pelvic perforation	11(0.08%)	6(0.1%)	5(0.06%)	0.368
Perirenal abscess by percutaneous drainage	17(0.12%)	10(0.17%)	7(0.09%)	0.14
Else	14(0.10%)	7(0.17%)	7(0.09%)	0.503
% Grade IV	7(0.05%)	1(0.02%)	6(0.07%)	0.252
Nephrectomy	2(0.01%)	0	2(0.02%)	0.515
Urosepsis causing organ injury	5(0.04%)	1(0.02%)	4(0.05%)	0.655
% Grade V	3(0.02%)	0	3(0.04%)	0.273
Death	3(0.02%)	0	3(0.04%)	0.273

*Some patients experienced one or more complications.

MPCNL might not be a suitable procedure for complex calculi because of the limited working channel. It was thought that MPCNL might result in increased operative time, decreased visibility, difficulty in handling endoscopic graspers, and ultimately reduced stone clearance.[1,2] Our present study aimed to investigate the feasibility of MPCNL for treating patients with complex renal stones and to resolve these issues.

The initial SFR for complex stones in the present study was 66.4%, similar to the results of 67.9% for complex stones reported by Cho and colleagues.[12] As expected, the SFR after the initial treatment was lower than that for simple renal stones. No significant difference was noted between the two groups in the final outcome after auxiliary treatment, however. The initial SFR of 66.4% is also on par with a recent large, prospective multicenter trial of conventional PCNL.[13] In the report, the SFR, including staghorn stones, was 56.9%. Once staghorn stones were excluded from the analysis, the success rate increased to 82.5%.[13] Stone burden, presence of staghorn stone, stone location, and stone numbers were the predictors of SFR.[14] The efficacy of MPCNL has been validated by other studies. Authors found no significant difference in SFR between the mini-PCNL and conventional PCNL.[10,11] Furthermore, for multiple caliceal stones, the SFR was even higher in the mini-PCNL group (85.2% *vs* 70.0%).[10]

We have routinely used multitract PCNL for complex stones, which accounts for 20.7% of our patients. We agree that by adding flexible nephroscopy and/or URS either concomitantly or subsequent to the initial PCNL, we could increase the SFR and decrease the morbidities of PCNL. The wide use of newer technologies, however, requires considerable training and experience, not to mention the availability of the equipment. The perceived concerns of increased bleeding and other complications associated with multitract-PCNL had been addressed by other studies.[15] Hegarty and associates[16] reported that the mean hemoglobin drop and other complications in patients having multitract PCNL were similar to patients with single-tract PCNL. In our previous report, a "prospective randomized trial between miniperc and standard PCNL in single sessions for staghorn stones,"[7] we established that mini-PCNL would necessitate more nephrostomy tracts. Nevertheless, it had similar complications yet a better stone clearance rate.[7] Aron and coworkers[17] also reported that PCNL monotherapy using multiple tracts is safe and effective and had an initial SFR of 84%. It could be the first-line option for staghorn renal calculi.

In our institution, the postprocedural stone-free status is generally assessed by KUB and ultrasonography. Although CT has the greatest sensitivity in detecting residual fragments, this advantage must be weighed against the greater radiation exposure and cost compared with the other imaging modalities. Furthermore, CT probably should not be routinely used in patients with radiopaque stones. It had been shown CT did not perform statistically better than plain radiography and linear tomography in the diagnosis of significant residual stone.[18]

Our current study used the modified Clavien grading system to report perioperative complications. In 2007, Tefekli and colleagues[19] were the first to adopt this system to stratify complications of conventional PCNL. They reported an overall

complication rate of 29.2%. In our current study, it was 25.5%. In their series, the grade I, II, IIIa, IIIb, IVa, IVb, and V complications were 4%, 16.3%, 6.6%, 2.8%, 1.1%, 0.3%, and 0.1%.[19] Using modified Clavien grading system Seitz and associates[20] reviewed and redistributed the complications to 88.1% class I, 7% class II, 4.1% class IIIa, 1.3% class IIIB, 0.6% class IVa, and 0.04% class V. In another multicenter trial using conventional PCNL,[21] the reported complications using the modified Clavien system were 11.1% in class I, 5.3% Class II, 2.3% class IIIa, 1.3% class IIIb, 0.3%, class IVa, 0.2% class IVb, and 0.03% class V. In our series, the grade III to V complications were extremely rare and compared very favorably with the previous mentioned studies.[19–21] de la Rosette and coworkers[22] demonstrated that the validity of the Clavien grading system is the highest for grade V and the lowest for grade I. Many had argued that many of the low-grade complications might be inherent to any surgical procedures and anesthesia and not specifically related to PCNL. Therefore, some the disparity of the reported low-grade complications among different centers might be attributed to this phenomenon.

It has been shown that the complications of PCNL can be reduced by minimizing the size of the nephrostomy. Some studies had reported that MPCNL reduced blood loss (0.8 g/dL *vs* 1.3 g/dL) and transfusion rate (1.4% *vs* 10.4%) when compared with conventional PCNL.[10] We found the total complication rate and the rate of higher grade complications did not differ significantly between the patients with simple and complex stones. Blood transfusion (grade II) and arterial embolization (grade III), however, were more common in patients with complex stones. This difference can be attributed to the facts that the complex stone had greater stone burden and multitract approaches were more frequently used. In contemporary studies, the reported transfusion rates were 4.5% for nonstaghorn and 9% for staghorn stones, respectively.[13] We believe the more severe complications, graded III or higher, should be quite rare and were more likely related to surgical techniques and experiences as well as coexisting medical disorders such as solitary kidney and diabetes, etc.

de la Rosette and coworkers[22] had shown that the postoperative stay increased with higher Clavien complications. Our hospital stay was much longer than those cited in the literature. This difference, however, was a reflection of our culture and customs rather than complications. In China, the cost of the hospital stay was extremely low, few U.S. dollars per day and is set by the government. Patients generally prefer if not demand to stay until they are well recovered from surgery. It is not socially acceptable to discharge a patient home with a nephrostomy tube in place. Furthermore, per our government policy, all preoperative evaluations, including blood work, have to be done as an inpatient before they can be reimbursed. All secondary procedures, such as second-look PCNL, have to be performed in the same hospitalization to be reimbursed. Therefore, we could not discharge a patient if he or she needed an auxiliary procedure after the initial MPCNL.

Conclusion

MPCNL is a safe and effective modality for the treatment of complex stones. There are, however, some caveats: Complex stones needed more percutanous tracts. The number of calices involved inversely affects the initial SFR. Most of the patients could be rendered stone free with the addition of a single auxiliary procedure. There were limitations of this study. There might be a patient selection bias because of the variables collected for this review. This was not a prospective randomized comparison of MPCNL with conventional PCNL. Rather, this was an intrainstitutional comparison of MPCNL between simple and complex stone disease. Therefore, we could not ascertain whether MPCNL was equally safe and effective as conventional PCNL.

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Disclosure Statement

No competing financial interests exist.

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Abbreviations Used

CT = computed tomography
KUB = kidneys, ureters, and bladder
MPCNL = minimally invasive percutaneous nephrolithotomy
PCL = percutaneous nephrolithotomy
SFR = stone-free rate
SWL = shockwave lithotripsy
URS = ureteroscopy