Effects of severe hydronephrosis on surgical outcomes of minimally invasive percutaneous nephrolithotomy (MPCNL)

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Abstract

Introduction: *The impact of severe hydronephrosis on the outcomes of minimally invasive percutaneous nephrolithotomy (MPCNL) remains controversial; it is still a subject well worth exploration.*
Aim: *To investigate the effects of severe hydronephrosis on surgical outcomes of MPCNL, especially on operative time (OT) and stone-free rate (SFR).*
Material and methods: *In total, 301 patients who underwent MPCNL were included in this study and divided into 4 groups according to the degree of hydronephrosis (nil, mild, moderate, and severe hydronephrosis, respectively). Univariate analyses and multivariate logistic analyses were used to determine the risk factors affecting OT and SFR.*
Results: *Patients with severe hydronephrosis had a longer OT ($p < 0.001$), a decreased SFR ($p < 0.001$), and a higher postoperative haemoglobin drop and blood transfusion rate compared to the other 3 cohorts ($p = 0.011$ and $p = 0.043$, respectively). Univariate analyses determined that severe hydronephrosis, calyx for access, stone location, stone type, stone size, and number of tracts significantly correlated with OT, while severe hydronephrosis, stone location, stone type, and stone size showed a strong association with SFR (all $p < 0.05$). Multivariate analyses further identified that severe hydronephrosis (OR = 3.496, $p = 0.013$), stone location (≥ 4 calyces: OR = 3.024, $p = 0.017$), stone type (staghorn: OR = 5.204, $p = 0.002$), and stone size (≥ 1600 mm^2: OR = 12.669, $p < 0.001$; 800–1599 mm^2: OR = 5.194, $p < 0.001$) were significant risk factors affecting OT, while SFR was independently influenced by stone type (staghorn: OR = 4.377, $p = 0.039$; multiple: OR = 3.778, $p = 0.044$), stone location (≥ 4 calyces: OR = 4.413, $p = 0.020$; 2–3 calyces: OR = 3.617, $p = 0.034$), and severe hydronephrosis (OR = 7.093, $p = 0.001$).*
Conclusions: *Severe hydronephrosis is a significant risk factor that can lead to longer OT and lower SFR, and correlates with increased risk of bleeding and blood transfusion rate in some cases during MPCNL. Accordingly, severe hydronephrosis is an influential factor that should not be ignored when performing MPCNL.*

Key words: *minimally invasive, percutaneous nephrolithotomy, hydronephrosis, operative time, stone-free rate, risk factors.*

Introduction

Renal calculus is one of the most prevalent diseases of the urinary tract system. With great improvements made in surgical techniques in recent years, minimally invasive percutaneous nephrolithotomy (MPCNL) has become a feasible and efficacious treatment for large renal and proximal ureteral stones [1, 2]. Because MPCNL exhibits evident

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advantages with respect to high stone-free rate and low incidence of complications such as haemorrhage, sepsis, injuries to adjacent organs, this modality is recommended by more and more urologists with its well-established efficacy and safety. Operative time (OT) and stone-free rate (SFR) are usually considered as important surrogate indicators of surgical outcomes of MPCNL [3], and operative time (OT) has been identified as a significant independent risk factor for severe complications after percutaneous nephrolithotomy [4, 5]. Thus, shortening the operative time, improving the stone clearance rate, and reducing the incidence of complications are common goals for urologists. The presence of stones in the kidney can lead to partial or complete urinary obstruction and hydronephrosis. However, no definite conclusion has been drawn on the effects of hydronephrosis on OT and SFR during MPCNL, and relevant studies are relatively limited. In a previous retrospective study, Akman *et al.* reported that the presence of severe hydronephrosis increased stone mobility during stone fragmentation procedures in hydronephrotic kidneys, thereby prolonging the operative duration, and it is associated with decreased stone-free rate after MPCNL [6, 7]. In contrast to Akman T's study, Karatag *et al.* noted that the presence of hydronephrosis did not have any effect on success rates and operative time in MPCNL [8]. Because the impact of severe hydronephrosis on the outcomes of MPCNL remains controversial, it is still a subject well worth exploration.

Aim

In the present paper, we reported our single-centre experience of MPCNL from a large retrospective cohort and aimed to investigate the factors that might affect surgical outcomes of MPCNL, especially exploring the effects of severe hydronephrosis on operative time (OT) and stone-free rate (SFR).

Material and methods

Patients

This study was reviewed and approved by the Ethics Committee of the First Affiliated Hospital of Fujian Medical University (MTCA, ECFAH of FMU [2015]084-1). Data were collected and retrospectively analysed from 301 patients who underwent MPCNL for renal stones between October 2017 and April 2022 at our institution. All patients over 18 years old who did not have any urinary tract abnormality and required single-stage MPCNL with single or multiple tracts were included in this study. Patients who required stage MPCNL, underwent bilateral MPCNL, synchronously underwent another operation, had a nephrostomy tube or ureteric stent, concurrent ureteral stones or congenital kidney abnormalities (such as horseshoe kidney, medullary sponge kidney, or ureteropelvic junction obstruction), and individuals with specific conditions (including active tuberculosis, coagulation disorders, uncontrolled diabetes, pregnancy, severe skeletal deformity, severe cardiac and pulmonary dysfunction, abdominal aortic aneurysm, or renal artery stenosis/aneurysm) were excluded from this study. The patients were divided into 4 groups according to the degree of hydronephrosis. Hydronephrosis was graded as nil (no caliceal or pelvic dilatation), mild (pelvic dilatation only), moderate (enlargement of pelvis and calyx, and blunting of the calyceal fornices), and severe (ballooning of the pelvicalyceal system accompanied with renal parenchymal atrophy) diagnosed by computed tomography, as described previously [9, 10]. Demographic characteristics collected on patients in the study included sex, age, body mass index (BMI), history of diabetes mellitus (DM), history of hypertension, history of extracorporeal shock wave lithotripsy (ESWL), and previous kidney surgery. Preoperative evaluation consisted of laboratory tests (including routine blood test, coagulation tests, serum creatinine measurements, urinalysis, and urine culture), abdominal plain radiography (KUB), ultrasonography, and computed tomography (CT). The patients with positive urine cultures were treated with appropriate culture-guided antibiotics preoperatively. Prophylactic antibiotics were also administered similarly for all patients with an appropriate dose regimen before undergoing the surgery in a standard manner.

The following information was recorded as stone characteristics: stone laterality, stone location, stone composition, stone type, stone density (Hounsfield units [HU]), stone size, and STONE score. Stone location was classified into 3 groups as pelvic or single calyx, 2–3 calyces, and ≥ 4 calyces according to the number of involved calyces. Stone types were categorized as solitary, multiple calyceal stones and staghorn calculus (partial or complete). Stone size was defined as the size of the stone measured by multiplying the 2 longest axes of the stone. In the presence of multiple stones in the renal pelvis, the stone size was calculated as the sum of the dimensions of each calculus.

Intraoperative and postoperative detailed information was also recorded and analysed, including operation time (minutes), puncture site of MPCNL, target calyx for access, number of access tracts, stone-free rate (%), postoperative hospitalization (days), changes in haemoglobin level (g/l), and blood transfusion rate (%). The postoperative complications were evaluated using a modified Clavien grade system. The operative time was documented as the time from puncture for an access tract to the final placement of the nephrostomy tube. KUB radiography or computed tomography (in selected cases) was performed in each patient on the first postoperative day, and patients were rendered stone free when the follow-up image showed no residual stones or clinically insignificant residual fragments (CIRFs). CIRFs were considered to be residual stones when ≤ 4 mm without obstruction or infection according to the Chinese Guideline for Diagnosis of Urology and Male Diseases 2019. Changes in haemoglobin levels were defined as the difference between preoperative and 24-h postoperative Hb concentrations, and patients receiving blood transfusion were identified. It was considered that a one-unit blood transfusion increased the Hb level by 1 g/dl. Therefore, drops in Hb were calculated as follows: (preoperative Hb – postoperative Hb) + (number of units transfused × 1 g/dl Hb per unit transfused) [11].

Surgical procedure

The entire surgical procedure was carried out in the Urology Department under general anaesthesia in 301 patients, and all MPCNLs were performed in a prone position by a senior urologist. 18F access sheath was established in all cases. All patients underwent a one-stage procedure. Ureteral catheter insertion was applied for all patients. With the patient in the lithotomy position, a 5F open-end ureteral catheter was placed up to the renal pelvis as the initial step. The patient was then turned to a prone position with 2 bolsters, one bolster under the chest and one under the hip. Access to the target calix was achieved under ultrasound guidance or combined with C-arm guidance by using an 18-G needle (Cook Medical Inc., Bloomington, IN, USA). After removal of the stylet of the needle, a 0.035-inch J-tip guidewire was passed into the collecting system. The nephrostomy working tract was then established with a serial fascial dilators 14–18 F. After a peel-away sheath had been placed through the tract, a semi-rigid 8/9.8 F ureteroscope (Richard Wolf, Germany) was inserted into the kidney, and the stones were split into fragments smaller than a peel-away sheath in diameter using a pneumatic lithotripter (Swiss LithoClast, EMS Electro Medical Systems, Switzerland) controlled by surgeon using a foot pedal. An artificial vortex was generated by whirling the peel-away sheath in coordination with irrigating saline synchronously. Irrigation can be performed with an irrigation pump system keeping the pump pressure at 80 kPa and perfusion flow at 990 ml/min on constant mode (MMC Yiyong, Guangzhou, China). By utilization of an artificial vortex, the ureteroscope body was moved back and forth repeatedly in an uninterrupted fashion in the sheath to facilitate flushing out the stone fragments inside the sheath. Forceps were also employed as a means to remove stone debris if residual fragments deep in the calices were detected. Multiple tracts and a nephrostomy tube were used in necessary cases based on the surgeon's decision. At the end of the operation, X-ray fluoroscopy was routinely performed to verify the clearance of the stones, the ureteric catheter was replaced by a double-J stent, and a 18F nephrostomy tube was placed inside the renal pelvis or the involved calix. The nephrostomy tube was removed after 2 days in the absence of fever, extravasation, and significant haematuria. For patients who had double-J stents, these were removed 3–4 weeks later. While the primary outcome of our study was to evaluate the operational duration during the MPCNL procedure, secondary endpoints were the evaluation of stone-free rates and complication rates among groups in a comparative manner.

Ethical approval and consent to participate

The study was reviewed and approved by the Ethics Committee of the First Affiliated Hospital of Fujian Medical University (MTCA, ECFAH of FMU [2015]084-1). Written informed consent was obtained from each patient. All methods were performed in accordance with relevant guidelines and regulations of the Helsinki Declaration.

Statistical analysis

IBM SPSS version 21.0 (IBM Co., Armonk, NY, USA) was used for statistical analysis. Categorical data were depicted as numbers and percentages. The conformance of continuous variables to normal distribution was assessed by the Shapiro-Wilk test. Normally distributed variables were presented as mean and standard deviation, and those without normal distribution were presented as median and interquartile range (IQR). Student's *t*-test (2-tailed independent) and one-way ANOVA or Mann-Whitney U test and Kruskal-Wallis test were used for continuous variables based on the normality of the distribution, as appropriate. The chi-square and Fisher exact test were used in the comparison of categorical data. Multivariate binary logistic regression was conducted for further investigation if any parameter was found to be significant with a univariate test. Odds ratio (OR) and statistical estimate were calculated and expressed with 95% confidence interval (CI). A *p*-value < 0.05 was deemed as statistically significant.

Results

The detailed demographic and preoperative characteristics of patients are summarized in Table I. No significant difference was detected in terms of age, gender, BMI, history of DM, history of hypertension, history of previous urological treatment, preoperative creatinine, preoperative haemoglobin, and urine culture rate in the comparison of groups (all $p > 0.05$). Also, stone characteristics such as stone laterality, stone location, stone composition, stone

Table I. Demographic and preoperative characteristics of the study population

Variables	Hydronephrosis				*P*-value
	No	Mild	Moderate	Severe	
	(*n* = 50)	(*n* = 75)	(*n* = 104)	(*n* = 72)	
Gender, *n* (%):					
Male	28 (56.0)	52 (69.3)	73 (70.2)	42 (58.3)	
Female	22 (44.0)	23 (30.7)	31 (29.8)	30 (41.7)	0.170
Age [years]	50 (42.5–60)	55 (44–62)	55 (46–65)	54 (45–61)	0.231
BMI [kg/m^2]	24.13 (21.90–26.32)	24.28 (21.88–25.86)	24.40 (22.50–26.01)	23.67 (21.90–25.35)	0.526
Hypertension, *n* (%):					
Absent	37 (74.0)	52 (69.3)	68 (65.4)	50 (69.4)	
Present	13 (26.0)	23 (30.7)	36 (34.6)	22 (30.6)	0.749
Diabetes mellitus, *n* (%):					
Absent	43 (86.0)	63 (84.0)	85 (81.7)	63 (87.5)	
Present	7 (14.0)	12 (16.0)	19 (18.3)	9 (12.5)	0.755
Previous urological treatment, *n* (%):					
None	45 (90.0)	66 (88.0)	90 (86.5)	50 (69.4)	
ESWL	3 (6.0)	3 (4.0)	4 (3.8)	6 (8.3)	
RIRS	0 (0.0)	3 (4.0)	3 (2.9)	6 (8.3)	
PCNL	1 (2.0)	3 (4.0)	4 (3.8)	5 (6.9)	
Open nephrolithotomy	1 (2.0)	0 (0.0)	3 (2.9)	5 (6.9)	0.130*
Preoperative creatinine [µmol/l]	66.35 (57.65–78.38)	72.7 (58.70–86.90)	74.55 (62.43–85.93)	75.12 (67.05–84.55)	0.072
Preoperative haemoglobin [g/l]	137.98 ±17.01	142.72 ±17.50	141.62 ±17.09	137.96 ±17.96	0.240
Positive urine culture, *n* (%):					
No	44 (88.0)	69 (92.0)	93 (89.4)	58 (80.6)	
Yes	6 (12.0)	6 (8.0)	11 (10.6)	14 (19.4)	0.173

*BMI – body mass index, DM – diabetes mellitus, ESWL – extracorporeal shock-wave lithotripsy, RIRS – retrograde intrarenal surgery, PCNL – percutaneous nephrolithotomy. Continuous data with normal distribution are presented a mean ± SD. Continuous data without normal distribution are presented as median (interquartile). Categorical data are presented as n (%) and compared by the chi-squared test or *Fisher's exact test, as appropriate. P-value < 0.05 was considered as statistically significant.*

Table II. Comparison of stone characteristics of the study population before operation

Stone characteristics	Hydronephrosis				*P*-value
	No (*n* = 50)	Mild (*n* = 75)	Moderate (*n* = 104)	Severe (*n* = 72)	
Laterality of stone, *n* (%):					
Left	30 (60.0)	45 (60.0)	52 (50.0)	43 (59.7)	
Right	20 (40.0)	30 (40.0)	52 (50.0)	29 (40.3)	0.438
Stone location, *n* (%):					
Pelvic or single calyx	18 (36.0)	24 (32.0)	22 (21.2)	22 (30.6)	
2–3 calyces	21 (42.0)	32 (42.7)	60 (57.6)	27 (37.5)	
≥ 4 calyces	11 (22.0)	19 (25.3)	22 (21.2)	23 (31.9)	0.121
Stone composition, *n* (%):					
Calcium oxalate	6 (12.0)	9 (12.0)	22 (21.2)	7 (9.7)	
Calcium phosphate	2 (4.0)	8 (10.7)	8 (7.7)	7 (9.7)	
Uric acid and magnesium ammonium phosphate	3 (6)	6 (8.0)	12 (11.5)	4 (5.6)	
Complex	39 (78.0)	52 (69.3)	62 (59.6)	54 (75.0)	0.307*
Stone type, *n* (%):					
Solitary	9 (18.0)	25 (33.3)	25 (24.0)	16 (22.2)	
Multiple	25 (50.0)	38 (50.7)	58 (55.8)	35 (48.6)	
Staghorn	16 (32.0)	12 (16.0)	21 (20.2)	21 (29.2)	0.192
Stone density on CT (HU), *n* (%):					
< 1000	9 (18.0)	17 (22.7)	22 (21.2)	11 (15.3)	
≥ 1000	41 (82.0)	58 (77.3)	82 (78.8)	61 (84.7)	0.673
Stone size [mm^2], *n* (%):					
0–399	12 (24.0)	18 (24.0)	17 (16.3)	13 (18.1)	
400–799	14 (28.0)	18 (24.0)	24 (23.1)	11 (15.3)	
800–1599	11 (22.0)	19 (25.3)	30 (28.8)	20 (27.8)	
≥ 1600	13 (26.0)	20 (26.7)	33 (31.7)	28 (38.9)	0.610
STONE score	8.24 ±1.73	8.37 ±1.50	9.58 ±1.59	9.82 ±1.72	< 0.001

*Continuous data with normal distribution are shown as a mean ± SD. Continuous data without normal distribution are presented as median (interquartile). Categorical data are described as n (%) and performed by the c2 test or *Fisher's exact test, as appropriate. P-value < 0.05 was considered as statistically significant.*

type, stone density, and stone size did not statistically differ among these groups (all $p > 0.05$). However, a significant difference was noted in STONE score ($p < 0.001$), which is a well-known scoring system developed on the basis of stone size, tract length (skin-to-stone distance), degree of obstruction (hydronephrosis), number of calyces involved, and stone essence, and it is frequently used to assess stone complexity in clinical practice (Table II). The intra- and post-operative characteristics including puncture site, calyx for access, number of working tracts, loss of haemoglobin, postoperative hospitalization, and complications were also compared in these groups, and they were depicted in Table III. The results indicated that the difference among groups on puncture site, calyx for access, number of working tracts, and postoperative hospitalization did not reach statistical significance, except for loss of haemoglobin and blood transfusion rate. Patients with severe hydronephrosis showed greater haemoglobin loss (19.11 ±12.04 g/l vs. 14.96 ±9.76 g/l, 13.39 ±11.62 g/l, 14.38 ±10.96; $p = 0.011$) and a higher proportion of blood transfusion (9.7% vs. 4.0%, 1.3%, 1.9%, $p = 0.043$) as compared to other

Table III. Comparison of intraoperative and postoperative outcomes of the study population

Variables	Hydronephrosis				*P*-value
	No (*n* = 50)	Mild (*n* = 75)	Moderate (*n* = 104)	Severe (*n* = 72)	
Puncture site, *n* (%):					
Supracostal	16 (32.0)	9 (12.0)	23 (22.1)	16 (22.2)	
Subcostal	31 (62.0)	60 (80.0)	71 (68.3)	48 (66.7)	
Multiple	3 (6.0)	6 (8.0)	10 (9.6)	8 (11.1)	0.205
Calyx for access, *n* (%):					
Upper calyx	13 (26.0)	15 (20.0)	21 (20.2)	14 (19.4)	
Middle calyx	25 (50.0)	34 (45.3)	49 (47.1)	25 (34.7)	
Lower calyx	8 (16.0)	19 (25.3)	17 (16.3)	17 (23.6)	
Multiple	4 (8.0)	7 (9.3)	17 (16.3)	16 (22.2)	0.250
Number of working tracts, *n* (%):					
1	38 (76.0)	67 (89.3)	85 (81.7)	56 (77.8)	
≥ 2	12 (24.0)	8 (10.7)	19 (18.3)	16 (22.2)	0.191
Loss of haemoglobin [g/l]	14.96 ±9.76	13.39 ±11.62	14.38 ±10.96	19.11 ±12.04	0.011
Postoperative hospitalization [days]	3 (3–5)	3 (3–4)	3 (3–4)	3 (2–5)	0.891
Postoperative complications, *n* (%):					
Postoperative transient fever[a] (< 38)	3 (6.0)	3 (4.0)	5 (4.8)	2 (2.8)	0.841*
Perirenal haematoma[a]	1 (2.0)	1 (1.3)	2 (1.9)	2 (2.8)	0.946*
Blood transfusion[b]	2 (4.0)	1 (1.3)	2 (1.9)	7 (9.7)	0.043*
Sepsis[b]	2 (4.0)	1 (1.3)	3 (2.9)	2 (2.8)	0.750*
Angioembolization[c]	1 (2.0)	1 (1.3)	1 (1.0)	2 (2.8)	0.770*
Pleural injury requiring drainage[c]	1 (2.0)	0 (0.0)	1 (1.0)	0 (0.0)	0.423*
Colon or Splanchnic injury[c]	0	0	0	0	–
Sepsis shock ICU management[d]	0	0	0	0	–
Death[e]	0	0	0	0	–

*Continuous data with normal distribution are depicted as mean ± SD. Continuous data without normal distribution are presented as median (interquartile). Categorical data are shown as n (%) and performed by the χ^2 test or *Fisher's exact test, as appropriate. The postoperative complications were graded from grade I to V according to the modified Clavien classification system, [a]grade I, [b]grade II, [c]grade III, [d]Clavien grade IV, [e]Clavien grade V. P-value < 0.05 was considered statistically significant.*

cohorts. Of note, among 301 patients, haemorrhage necessitating transfusion occurred in 12 (4.0%) patients in total, while haemorrhage requiring arterial embolization occurred in 5 (1.7%) patients (1, 1, 1, 2 patients in nil, mild, moderate, and severe hydronephrosis groups, respectively). Aside from blood transfusion and angioembolization, the other complications such as postoperative fever, perirenal haematoma, and sepsis were also seen in this study, and the incidence of these complications did not vary significantly between groups ($p > 0.05$). No devastating complications occurred in our study population, including colon or splanchnic injury, sepsis shock ICU management, and mortality.

We further sought to investigate the factors likely to affect the operative time (OT) and stone free rate (SFR) of MPCNL by univariate and multivariate analysis. On univariate analysis, as shown in Table IV, the following factors were significantly associated with OT: severe hydronephrosis ($p < 0.001$), calyx for access ($p = 0.007$), stone location ($p < 0.001$), stone type ($p < 0.001$), stone size ($p < 0.001$), and tract number ($p = 0.002$). The following all notably affected SFR: severe hydronephrosis ($p < 0.001$), stone location ($p < 0.001$), stone type ($p = 0.001$), and stone size ($p = 0.008$) (Table V). In a comparison of OT among groups, it is worth mentioning that the operation time was obviously prolonged in the severe hydronephrosis

Table IV. Factors affecting OT of MPCNL assessed by univariate analysis

Variables	Cases	Operation time [min] Median (25th–75th percentile)	*P*-value
Gender:			
Male	195	38 (27–56)	
Female	106	38.5 (28–53)	0.985
BMI [kg/m^2]:			
< 24	144	38 (23.25–62.75)	
≥ 24	157	39 (31.5–50)	0.294
Previous urological treatment:			
Nil	251	39 (28–54)	
ESWL	16	28 (21–38.5)	
RIRS	12	34.5 (26–53.75)	
PCNL	13	45 (34.5–64.5)	
Open nephrolithotomy	9	50 (23–84)	0.179
Hydronephrosis:			
Nil	50	35 (25–51.5)	
Mild	75	36 (28–43)	
Moderate	104	38.5 (26.25–53)	
Severe	72	50 (35.25–73)	< 0.001
Laterality of stone:			
Left	170	38 (27–52.25)	
Right	131	39 (28–60)	0.604
Stone composition:			
Calcium oxalate	44	47.5 (29.75–55.75)	
Calcium phosphate	25	39 (29–53)	
Uric acid and magnesium ammonium phosphate	25	49 (31–69.5)	
Complex	207	37 (26–51)	0.164
Puncture site:			
Supracostal	64	42.5 (30.25–60)	
Subcostal	210	37 (26–55)	
Multiple	27	43 (32–50)	0.435
Calyx for access:			
Upper calyx	63	36 (25–50)	
Middle calyx	133	37 (27–55)	
Lower calyx	61	38 (25–49.5)	
Multiple	44	48 (37.25–65.75)	0.007
Stone location:			
Pelvic or single calyx	86	29.5 (20.75–38)	
2–3 calyces	140	40 (29.25–50.75)	
≥ 4 calyces	75	55 (37–75)	< 0.001

Table IV. Cont.

Variables	Cases	Operation time [min] Median (25th–75th percentile)	*P*-value
Stone type:			
Solitary	75	29 (20–43)	
Multiple	156	37 (27–48)	
Staghorn	70	61 (44–79.25)	< 0.001
Stone density [HU]:			
< 1000	59	39 (28–54)	
≥ 1000	242	38 (27–55)	0.782
Stone size [mm^2]:			
0–399	60	24.5 (18.25–31.5)	
400–799	67	31 (23–44)	
800–1599	80	43 (35–56.5)	
≥ 1600	94	50.5 (40–73)	< 0.001
Number of working tracts:			
Single	246	37 (25.75–52.25)	
Multiple	55	45 (36–60)	0.002

group compared to that in the 3 other cohorts (50 min vs. 35 min, 36 min, 38.5 min, p < 0.001, p = 0.004, p = 0.025, respectively). With regard to SFR, the stone free rate in the severe hydronephrosis group was dramatically reduced compared to the other cohorts (65.3% vs. 92%, 89.3%, 89.4%, all p < 0.001). Furthermore, in multivariate logistic stepwise regression analysis, severe hydronephrosis (odds ratio (OR) = 3.496, 95% CI: 1.296–9.433, p = 0.013; compared to nil hydronephrosis), stone location (≥ 4 calyces: OR = 3.024, 95% CI: 1.222–7.485, p = 0.017; compared to single calyx), stone type (staghorn: OR = 5.204, 95% CI: 1.873–14.454, p = 0.002; compared to solitary calculus), and stone size (≥ 1600 mm^2: OR = 12.669, 95% CI: 4.810–33.373, p < 0.001; 800–1599 mm^2: OR = 5.194, 95% CI: 2.063–13.073, p < 0.001; compared to 0–399 mm^2, respectively) were identified as the most important parameters affecting OT (Table VI). Meanwhile, stone location (≥ 4 calyces: OR = 4.413, 95% CI: 1.259–15.466, p = 0.020; 2~3 calyces: OR = 3.617, 95% CI: 1.103–11.859, p = 0.034; compared to single calyx, respectively), stone type (staghorn: OR = 4.377, 95% CI: 1.077–17.785, p = 0.039; multiple: OR = 3.778, 95% CI: 1.034–13.810, p = 0.044; compared to solitary calculi, respectively), and severe hydronephrosis (OR = 7.093, 95% CI: 2.149–23.410, p = 0.001; compared to nil hydronephrosis) were determined as independent risk factors influencing SFR (Table VII).

Discussion

As compared with conventional standard PCNL, MPCNL causes less traumatic injury of kidney, and owing to its high stone clearance rate and low complication rate, this therapeutic modality has become one of the preferred endourologic techniques for the surgical treatment of renal calculi [3, 12]. Operation time is an important index to evaluate surgical outcomes of MPCNL, and it is closely related to the occurrence of perioperative complications [10, 13]. Many factors such as hydronephrosis can influence the operative time and success rate of PCNL. However, several published clinical trials focusing on this issue have revealed contradictory results. The impact of hydronephrosis on operative time remains elusive and requires further clarification. In a previous retrospective clinical study, Akman *et al.* reviewed and analysed the clinical data of 1897 patients with renal stones undergoing PCNL. The authors demonstrated that the presence of severe hydronephrosis, renal stone size, and stone type significantly affected the operative time during PCNL. The positive correlation between degree of hydronephrosis and operative time may be explained by relatively high rates of stone fragment mobility between calices in hydronephrotic kidneys [6]. Micoogullari *et al.* reported that the operation duration was shorter in the hydronephrosis group as compared

Table V. Factors affecting SFR of MPCNL assessed by univariate analysis

Variables	Stone free		*P*-value
	Yes (*n* = 253)	No (*n* = 48)	
Gender, *n* (%):			
Male	164 (84.1)	31 (15.9)	
Female	89 (84.0)	17 (16.0)	0.975
Age [years]	54 (18–82)	52 (33–72)	0.468
BMI [kg/m^2]	24.09 (22.21–25.99)	24.43 (22.41–25.33)	0.715
Previous urological treatment, *n* (%):			
Nil	212 (84.5)	39 (15.5)	
ESWL	13 (81.3)	3 (18.7)	
RIRS	9 (75.0)	3 (25.0)	
PCNL	10 (76.9)	3 (23.1)	
Open nephrolithotomy	9 (100.0)	0 (0.0)	0.504*
Hydronephrosis, *n* (%):			
Nil	46 (92.0)	4 (8.0)	
Mild	67 (89.3)	8 (10.7)	
Moderate	93 (89.4)	11 (10.6)	
Severe	47 (65.3)	25 (34.7)	< 0.001
Laterality of stone, *n* (%):			
Left	144 (84.7)	26 (15.3)	
Right	109 (83.2)	22 (16.8)	0.725
Stone composition, *n* (%):			
Calcium oxalate	36 (81.8)	8 (18.2)	
Calcium phosphate	23 (92.0)	2 (8.0)	
Uric acid and magnesium ammonium phosphate	20 (80.0)	5 (20.0)	
Complex	174 (84.1)	33 (15.9)	0.629*
Puncture site, *n* (%):			
Supracostal	57 (89.1)	7 (10.9)	
Subcostal	175 (83.3)	35 (16.7)	
Multiple	21 (77.8)	6 (22.2)	0.355
Calyx for access, *n* (%):			
Upper calyx	57 (90.5)	6 (9.5)	
Middle calyx	112 (84.2)	21 (15.8)	
Lower calyx	50 (82.0)	11 (18.0)	
Multiple	34 (77.3)	10 (22.7)	0.302
Stone location, *n* (%):			
Pelvic or single calyx	82 (95.3)	4 (4.7)	
2–3 calyces	117 (83.6)	23 (16.4)	
≥ 4 calyces	54 (72.0)	21 (28.0)	< 0.001

Table V. Cont.

Variables	Stone free		*P*-value
	Yes (*n* = 253)	No (*n* = 48)	
Stone type, *n* (%):			
Solitary	72 (96.0)	3 (4.0)	
Multiple	130 (83.3)	26 (16.7)	
Staghorn	51 (72.9)	19 (27.1)	0.001
Stone density on CT [HU], *n* (%):			
< 1000	47 (79.7)	12 (20.3)	
≥ 1000	206 (85.1)	36 (14.9)	0.304
Stone size [mm^2], *n* (%):			
0–399	57 (95.0)	3 (5.0)	
400–799	60 (89.6)	7 (10.4)	
800–1599	64 (80.0)	16 (20.0)	
≥ 1600	72 (76.6)	22 (23.4)	0.008
Number of working tracts, *n* (%):			
Single	210 (85.4)	36 (14.6)	
Multiple	43 (78.2)	12 (21.8)	0.188

to the cohort without hydronephrosis (although this difference was not statistically significant). Due to the wider caliceal mouth to be accessed and more evident distribution of opaque material in the pelvis, they mentioned that the presence of hydronephrosis may facilitate calyx access by reducing the attempts of renal puncture trials and thusly decreased the operative time [14]. Karatag *et al.* compared the results of MPCNL with and without hydronephrosis. They reported that the presence of hydronephrosis had no effect on the surgical outcomes including operative time and success rates [8]. In the present study, we found that patients with severe hydronephrosis showed significantly longer operation time compared to patients with nil, mild, and moderate hydronephrosis (50 min vs. 35 min, 36 min, 38.5 min, $p < 0.001$, $p = 0.004$, $p = 0.025$, respectively). Depending on multivariate stepwise logistic analysis, we further corroborated that severe hydronephrosis was an independent significant factor influencing operative time. Our results are in good agreement with those of Akman. As is well known, hydronephrosis generates a sharp outline of the collecting system, so it is relatively easy to perform percutaneous renal puncture and then establish a nephrostomy tract in patients with moderate or severe dilation of the renal pelvis and calices. Nevertheless, renal stones are not easy to fix for fragmentation in the enlarged pelvis and calices, and stone debris are more likely to migrate from the original sites and scatter into other remote areas of the collecting system, hence increasing the time to remove residual stones. Additionally, in our MPCNL procedure, stones were firstly broken into fragments smaller than the peel-away sheath in diameter using a pneumatic lithotripter. Next, an artificial vortex, which was generated by whirling the peel-away sheath in coordination with continuous saline irrigation, was used to retrieve stone fragments that were flushed inside the sheath. The seriously dilated collecting system would greatly slow down the speed of the artificial vortex and consequently reduce the stone clearance efficiency. We also observed that the group with severe hydronephrosis had notably higher STONE scores, which implied that this study population consisted of patients with more complex stones; this may also partially explain why the operative time in the severe hydronephrosis group was longer than that in the other 3 cohorts. Our observation in this study was in line with earlier research [15].

The stone free rate (SFR) was another important indicator to assess the outcomes of MPCNL. To date, there is limited literature concerning on the effect of hydronephrosis on SFR. Zhu *et al.* re-

Table VI. The risk factors affecting OT based on multivariate stepwise logistic analysis

Variables	Coefficient	Odds ratio (OR)	95% CI	*P*-value
Hydronephrosis:				
Nil (Reference)	–	–	–	–
Mild	0.164	1.178	0.448–3.093	0.740
Moderate	0.557	1.746	0.705–4.327	0.229
Severe	1.252	3.496	1.296–9.433	**0.013**
Stone location:				
Pelvic or single calyx (Reference)	–	–	–	–
2–3 calyces	0.689	1.992	0.960–4.130	0.064
≥ 4 calyces	1.107	3.024	1.222–7.485	**0.017**
Calyx for access:				
Upper calyx (Reference)	–	–	–	–
Middle calyx	0.504	1.656	0.732–3.745	0.226
Lower calyx	0.642	1.901	0.754–4.792	0.173
Multiple calyces	0.577	1.780	0.604–5.246	0.296
Stone type:				
Solitary (Reference)	–	–	–	–
Multiple	0.071	1.074	0.523–2.206	0.847
Staghorn	1.649	5.204	1.873–14.454	**0.002**
Stone size [mm^2]:				
0–399 (Reference)	–	–	–	–
400–799	0.459	1.583	0.605–4.145	0.350
800–1599	1.647	5.194	2.063–13.073	**< 0.001**
≥ 1600	2.539	12.669	4.810–33.373	**< 0.001**
Number of working tracts:				
Single (Reference)	–	–	–	–
Multiple	0.435	1.545	0.719–3.319	0.265

OR – odds ratio, CI – confidence interval. The significance of bold values was set as p < 0.05.

viewed the clinical profile of 865 MPCNLs performed on patients and demonstrated that stone number and size, location in a calyx, staghorn calculus, and moderate to severe hydronephrosis were associated with decreased SFR after MPCNL [7]. Kadihasanoglu *et al.* evaluated the relationship between the degree of renal hydronephrosis and stone free status. Their studies concluded that the stone clearance rate decreased with the degree of hydronephrosis [16]. We reached the same conclusion, i.e. that severe hydronephrosis adversely affected the MPCNL SFR in this study. We found that patients with severe hydronephrosis displayed a lower SFR than those with nil, mild, and moderate hydronephrosis (65.3% vs. 92%, 89.3%, 89.4%, all $p < 0.001$). What is more, multivariate analyses further identified that the SFR was independently influenced by severe hydronephrosis. However, in an another study by Li *et al.* [17], they claimed that hydronephrosis was not a significant risk factor affecting the stone clearance rate of MPCNL. The different results of the effect of hydronephrosis on SFR could be derived from mobilization of stone due to a seriously enlarged pelvicalyceal system. The severe hydronephrosis might cause mobilization of stones and complicate continued fragmentation during lithotripsy. Moreover, we used a pneumatic lithotripter for stone fragmentation in the current study. When stones were split, stone fragments were

Table VII. The risk factors affecting SFR based on multivariate stepwise logistic analysis

Variables	Coefficient	Odds ratio (OR)	95% CI	*P*-value
Stone location:				
Pelvic or single calyx (Reference)	–	–	–	–
2–3 calyces	1.286	3.617	1.103–11.859	**0.034**
≥ 4 calyces	1.485	4.413	1.259–15.466	**0.020**
Stone size [mm^2]:				
0–399 (Reference)	–	–	–	–
400–799	0.640	1.896	0.425–8.452	0.402
800–1599	0.986	2.681	0.665–10.801	0.166
≥ 1600	1.008	2.740	0.689–10.902	0.153
Stone type:				
Solitary (Reference)	–	–	–	–
Multiple	1.329	3.778	1.034–13.810	**0.044**
Staghorn	1.476	4.377	1.077–17.785	**0.039**
Hydronephrosis:				
Nil (Reference)	–	–	–	–
Mild	0.514	1.672	0.450–6.205	0.442
Moderate	0.276	1.318	0.382–4.551	0.662
Severe	1.959	7.093	2.149–23.410	**0.001**

OR – odds ratio, CI – confidence interval. The significance of bold values was set as $p < 0.05$.

more prone to diffuse into the abnormal collecting system. This will also cause difficulty in finding the stone fragments and complicate the evacuation of stone residuals. Also, an artificial vortex created by high-speed saline irrigation was applied to clear stone fragments during our MPCNL procedure. As the speed of the artificial vortex was reduced due to dilatation of the pelvicalyceal system, it was troublesome to carry out the stone removal, which resulted in stone residuals. In light of the above information, it is likely that the presence of severe hydronephrosis may adversely affect SFR. To summarize from our single-centre experience of MPCNL, we also realized that the application of a pneumatic lithotripter for patients with severe hydronephrosis may be a disadvantage in stone lithotripsy as compared with an ultrasonic lithotripsy system with negative pressure suction. It has been reported that the stone free rate varied among groups by using different lithotripters for proximal ureteral calculi with severe hydronephrosis during percutaneous nephrolithotomy [18]. When an ultrasonic lithotripter is used, because of negative-pressure suctioning, stones can be attached to the end of the ultrasonic probe to avoid calculi escape, which will make the stone disintegration easier. In addition, small stone debris can also be suctioned out while relatively larger fragments are removed when withdrawing the ureteroscope, which aids in keeping a clear surgical view and improving the SFR. Based on the above reasoning, we speculated that the ultrasonic lithotripter may be superior to the pneumatic lithotripter for renal stones with severe hydronephrosis. Further comparative study on the efficacy of MPCNL between pneumatic lithotripter and ultrasonic lithotripter will be conducted to confirm this speculation in future.

It has been well documented that stone characteristics including stone location, stone size, and staghorn stone are prominent factors affecting OT and SFR [10, 19, 20]. In a recent study by Doykov, it was reported that staghorn stones and stones in more than one location clearly increased the risk of residual stones, and staghorn stones and larger volume showed a close correlation with a longer operative duration [19]. Likewise, Karalar *et al.* reported a significant correlation between stone location, stone type, stone burden, and stone free status [20]. Similar results were obtained in our study.

We observed that the operative duration as well as stone residual rate had a tendency to increase when the grade of stone size, stone location, and stone type increased in univariate analysis. Multivariate logistic regression analysis further indicated that stone type (staghorn stone), stone location (number of involved calyces ≥ 4), and stone size (≥ 1600 mm^2 and 800–1599 mm^2) were significant independent factors affecting OT, while the SFR was independently influenced by stone type (multiple stones and staghorn stones) and stone location (number of involved calyces = 2–3 and ≥ 4 calyces). Our results were consistent with previous studies, which provided more updated evidence for the association between stone characteristics and OT and SFR. Intriguingly, we also observed operation-related parameters such as calyx for access and number of tracts had an impact on operative time in the univariate analysis. Because multiple calyces for access and multiple tracts are often needed to remove complicated stones inside complex caliceal patterns, the operators will spend more time establishing a nephrostomy channel and clearing the renal calculi. It is understandable why calyx for access and number of tracts were important variables in influencing OT, although these 2 parameters did not independently prolong OT with adjustment of other variables in multivariate analysis.

Haemorrhage is one of the major complications of MPCNL. In most cases, postoperative bleeding is mild and can be managed conservatively, such as nephrostomy obstruction, fluid supply, or haemostatic. Blood transfusion is also taken as a conservative treatment in some cases, and the transfusion rate is reported to vary between 0.8% and 24% [21]. However, approximately 0.3% to 1.4% of cases eventually require an interventional angioembolization to control intractable bleeding [22]. In the present study, the data indicated that 12 (4.0%) patients with massive haemorrhage received a blood transfusion, and 5 of them (1.7%) underwent renal arterial embolization, which well coincided with previous reports. It is generally believed that patients with stones with nil and mild hydronephrosis are more prone to severe bleeding due to the relatively thick renal cortex [23]. Kim *et al.* proposed that the absence of hydronephrosis was a major risk factor for blood transfusion when performing PCNL. They pointed to the fact that the calyceal fornix may be missed in the absence of hydronephrosis, and puncture through the infundibulum or directly into the renal pelvis may occur, resulting in massive bleeding. Additionally, without hydronephrosis, repeated attempts may be necessary to puncture the desired calyx, which can be a risk factor for bleeding in PCNL. Moreover, the absence of hydronephrosis affords less space for manipulation within the kidney, leading to traumatic injury of the renal vascular system [24]. In another study, no correlation was detected between renal parenchymal thickness and postoperative bleeding [25]. In contrast to previously published literature, the results acquired from our study showed that postoperative haemoglobin drop and blood transfusion rate were statistically higher in the group with severe hydronephrosis than in other cohorts (p = 0.011 and p = 0.043, respectively), suggesting that patients with severe hydronephrosis were more inclined to encounter bleeding complications in our study population. The reasons for this contradictory result included some aspects as follows: First, the renal parenchyma becomes thinner due to the presence of severe hydronephrosis. It has been validated that bleeding is very common in patients with renal cortical thickness less than 4 mm because the thin renal cortex has difficulty shrinking and healing [26]. On the other hand, once the main renal blood vessels are injured, the distended pelvicalyceal system caused by severe hydronephrosis provides space for intrarenal haematoma formation, increasing the blood loss of MPCNL. Second, severe hydronephrosis also offers increased manoeuvrability within the collecting system. When stones were split and stone fragments scatter into other remote calyces, the surgeon unconsciously manipulates with high-angled instrument movements for detection and removal of stone debris, which may tear the neck of the calyx and further traumatize renal vessels that lie close to the infundibulum, leading to haemorrhage. Third, as stated above, a prolonged operation time is an important factor that increase the rates of complications and blood transfusions according to the literature. In separate studies, Kukreja *et al.*, Vorrakitpokatorn *et al.*, and Akman *et al.* reported that operative duration was closely associated with postoperative blood loss, and transfusion requirement in PCNL [11, 27, 28]. Because the operative time in the group with severe hydronephrosis was more prolonged than in the other 3 cohorts in our study, the amount of blood loss as well as blood transfusion rate increased correspondingly. In our single-centre experience, we hold the opinion that careful reading of imageology data including KUB, ultrasonography, and CT images before operation, the optimal puncture route of MPCNL designed upon pelvicalyceal anatomy, precise puncture performed under the B ultrasonic and/or C-arm guidance, and the operator's rich experience and excellent surgical skills will greatly contribute to less traumatic vasculature injury and reduce haemorrhage complication accordingly.

We recognize that this retrospective study carries several limitations: First, some factors that may affect OT and SFR of MPCNL have not been included and evaluated in this study, such as skin-to-stone distance, mobility of kidney, diameter of calyceal infundibulum, angle between calyces, angle between calyx tract with pelvis, etc. Second, because of the retrospective nature of the study, there is inevitable selection bias. Third, as the resolution of an X-ray scan is relatively limited, the plain KUB used for confirming stone clearance may overestimate the true SFR, leading to another source of bias. Fourth, the current study reports the experience of our single medical centre. For a better understanding of the outcomes, a prospective, randomized, multi-centre study with a larger sample size will be needed to verify our observations.

Conclusions

Based on the results of the current study, we demonstrate that severe hydronephrosis is a significant risk factor that can lead to longer operation time and lower stone clearance rate during MPCNL. Severe hydronephrosis also significantly correlates with increased risk of bleeding and blood transfusion rate in some cases. Accordingly, we take the view that severe hydronephrosis is an influential factor that should not be ignored when performing MPCNL.

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Conflict of interest

The authors declare no conflict of interest.

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