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ORIGINAL ARTICLE

A prospective comparative study of haemodynamic, electrolyte, and metabolic changes during percutaneous nephrolithotomy and minimally invasive percutaneous nephrolithotomy

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Abstract
Objectives To report the haemodynamic, electrolyte, and metabolic changes of a prospective clinical trial comparing minimally invasive percutaneous nephrolithotomy (MPCNL) with percutaneous nephrolithotomy (PCNL) for renal stones.
Methods In all, 71 patients who had undergone MPCNL (37) or PCNL (34) were prospectively assessed. Heart rate and arterial blood pressure were monitored, and samples for electrolyte estimation and arterial blood gas analysis were drawn at the start, 30th, 60th, 90th, and 120th min of irrigation and 24 h later after both procedures.
Results In the PCNL group, no significant changes occurred in heart rate, arterial blood pressure, electrolytes, and pH. In the MPCNL group, heart rate, arterial blood pressure, and serum sodium levels kept stably during and after irrigation; the decrease in potassium levels was found from the 30th to 120th min of irrigation and did not recovery until 24 h later after operation ($P < 0.05$), but the potassium levels was normal during the entire observation period; the increase in Cl^- levels was noted at the 120th min of irrigation ($P < 0.05$); there was a decreasing trend of pH from the start to the 120th min of irrigation ($P < 0.05$) and 24 h later after operation this trend attenuated ($P < 0.05$); the changes in base excess levels were in accordance with those in pH levels.
Conclusions Although haemodynamic and electrolyte changes remains stable, a trend towards metabolic acidosis is obvious as the irrigation time goes by during MPCNL compared with PCNL. Therefore, arterial blood gases should be monitored during and after MPCNL in patients with prolonged irrigation time.

Keywords Haemodynamics · Electrolytes · Metabolic changes · Percutaneous nephrolithotomy · Irrigation fluid absorption

Introduction

The morbidity of upper urinary tract stones is evolving. Despite the first-line approach for large, multiple, or inferior calyx renal stones according to the European Association of Urology (EAU) guidelines [1], percutaneous nephrolithotomy (PCNL) is associated with significant complications and morbidity [2]. Therefore, a demand for technologic alternatives that can minimize the risks of PCNL exists. Recently, a minimally invasive PCNL (MPCNL) was developed that decreased complications and morbidity, as described by Jackman [3]. It is widely accepted that MPCNL has high efficacy and safety for the management of small renal stones. With the improvement of instrument and technique, Abdelhafez et al. [4, 5] reported that MPCNL was comparable to PCNL in the treatment of stones of >20 mm, including complex staghorn stones. Some studies even declared that this technique had completely replaced PCNL in their department [5, 6].

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It is a well-established fact that there is considerable fluid absorption during PCNL [7]. Absorption of irrigating fluid may take place when there is extravasation of fluid caused by rupture of the renal pelvicaliceal wall [8]. Absorption may also take place via the vessels that open up during tract dilatation and in the kidney during stone fragmentation [7]. Additionally, massive fluid may be rapidly absorbed by leakage of fluid into the peritoneal space [9]. The volume of fluid absorbed increases with the amount of irrigating fluid used, the duration of irrigation, pressure in the pelvicaliceal system, pelvicaliceal perforation, bleeding, and the duration of the procedure, but not with the number of tracts [7]. Staged nephrostomy through the mature dilated tract reduced the amount of fluid absorbed [7]. As compared to PCNL of which percutaneous tract size is greater than or equal to 24F, the percutaneous tract size of MPCNL is less than or equal to 18F. From a technical standpoint, using a smaller-size percutaneous tract than PCNL, the MPCNL has the potential advantages of decreased bleeding and trauma to renal parenchyma [10]. However, to date there are no published data on whether the smaller-size percutaneous tract could promote fluid absorption so as to give rise to certain disturbances in the haemodynamic, electrolyte, and metabolic changes during MPCNL. To address these issues, we report the results of a prospective, nonrandomized study that compared MPCNL with PCNL in 71 patients with renal stones.

Patients and methods

Patients

From July 2011 to April 2013, patients with one or more renal stones >2 cm in our Department of Urology who desired PCNL or MPCNL treatment were invited to participate in the trial. Inclusion criteria were age >18 and <60 year, and ASA classes I and II. Patients with kidney anomalies, uncontrolled coagulopathy, pregnancy, immunodeficiency, hypertension, diabetes mellitus, heart disease, renal insufficiency, and those who had undergone any kind of medical therapy which could affect haemodynamic, electrolyte, and metabolic changes were not included in the study. Additionally, any patients whose intraoperative irrigating time was <60 or >120 min, in whom the number of percutaneous tract was more than one, or who required a blood transfusion, were excluded.

The selection between the different techniques was based on a joint decision by surgeons and patients after ethical approval from the institutional review board at our hospital and written informed consent was obtained from all subjects. No crossovers occurred between the treatment groups after allocation. Neither the patient nor the surgeon was blinded as to the type of the procedure performed, but two independent investigators, who did not know which treatment the patients had undergone, performed the data analysis.

Surgical procedures

Each procedure was performed by one of two experienced surgeons (Shuxiong Xu or Hua Shi) in our Department of Urology. Each of the surgeons was skilled in PCNL and MPCNL. Both the procedures were performed under continuous epidural anaesthesia.

Cystoscopy was performed, and a 5F soft ureteric catheter was placed in lithotomy position initially. Percutaneous access was gained under ultrasound guidance with the patient in the prone position. For the PCNL procedure, the nephrostomy tract was sequentially dilated with telescoping Alken metal dilators (Karl Storz, Tuttlingen, Germany) and a 24F working sheath was placed. Using the 20.5F rigid nephroscope, stones were fragmented by combining pneumatic and ultrasound lithotripsy system (Swiss Lithoclast-EMS, Switzerland). For the MPCNL procedure, the tract was dilated by fascial dilators (Cook, Inc.) in a stepwise manner, and a 16F peel-away sheath (Cook, Inc.) was then inserted. Using the 12F rigid nephroscope, stones were fragmented in a drilling fashion [11] using high-power holmium laser lithotriptors (Sphinx, German). Any procedure of which intraoperative irrigation time >120 min were terminated, and the patient underwent second-look PCNL or MPCNL 5–7 days later. A 7F double-J stent was placed in an antegrade position, and a nephrostomy catheter was fixed at the end of both procedures. Sodium chloride (0.9 %) was used for continuous irrigation of kidney, and the volume of fluid absorbed was calculated as described by Mohta [12]. In short, the volumes of total irrigation fluid used and total effluent fluid including the fluid spilt on the floor and the fluid soaking the drapes were measured and the difference between these two was taken as volume of fluid absorbed.

Perioperative assessment

The two groups were compared with regard to age, gender, body mass index (BMI), stone burden, previous documented urinary tract infection (UTI), irrigation duration, duration of operation, duration of anaesthesia, volume of irrigation fluid, volume of fluid absorbed, decrease in haemoglobin, stone-free rate, duration of hospitalization, and complications.

Standard electrocardiographic monitoring and noninvasive blood pressure monitoring was performed in all patients during and for 24 h after the operation., using a modular monitoring system (Siemens SC 7000; Siemens

Medical Solutions, Malvern, PA, USA). With the patient in the supine position on the operating table, baseline heart rate and blood pressure values were determined as the respective means of three consecutive heart rate and blood pressure measurements. The heart rate and blood pressure were measured every 5 min from the beginning of anaesthesia during both procedures and were measured every 1 h for 24 h after both procedures.

Samples for electrolyte estimation and arterial blood gas analysis were drawn at the start (T_0), the 30th min (T_1), the 60th min (T_2), the 90th min (T_3), the 120th min (T_4) of irrigation, and 24 h later (T_5) after both procedures.

The post-operative determination of stone-free status was obtained with plain radiography (KUB) and abdominal ultrasound (US). In a few cases with suspicious or non-conclusive KUB or US findings, noncontrast CT was used. Complications were recorded according to Clavien–Dindo classification.

Statistical analysis

Baseline characteristics and perioperative data between the two groups were compared by means of the paired, Tukey's, and independent *t* tests. Statistical significance was considered at $P < 0.05$ for all analyses.

Results

In the present trial, 71 patients (34 for PCNL and 37 for MPCNL) were included. Table 1 summarizes the clinic data of patients analysed. The mean stone size in the PCNL group was significantly larger than that in the MPCNL group. Although the difference in blood loss did reach statistical significance ($P = 0.015$), all the patients in both arms did not require blood transfusion. There were no other statistically significant differences between the treatment groups in preoperative variables. Although there was no significant difference in the duration of irrigation, operation, and anaesthesia between the two groups, volume of fluid absorbed in the PCNL group was significantly less than that in the MPCNL group. Stone-free rate, duration of hospitalization, and complications were comparable in both arms of study.

Table 2 shows that not only heart rate and systolic and diastolic blood pressure in the PCNL group kept stably during and after irrigation, but also in the MPCNL group. There were no significant disparities in heart rate and systolic and diastolic blood pressure at any of the time points between the two groups.

Table 3 reveals the changes in electrolyte and metabolic changes for the two groups at the sampling times. Serum sodium levels remained stable at the different sampling times, and the two groups had similar serum concentrations

Table 1 Patient characteristics before, during, and after PCNL and MPCNL

Parameters	PCNL group	MPCNL group	*P* value
Number of patients	34	37	
Age, year	45.3 ± 13.5	50.3 ± 14.8	0.144
Gender F/M, *n*	21/13	24/13	0.786
BMI (kg/m^2)	22.8 ± 1.5	22.7 ± 1.4	0.834
Stone side (R/L), *n*	18/16	22/15	0.580
Stone size, mm	41.4 ± 10.9	33.4 ± 10.3	0.002
Previous documented UTI, *n* (%)	9 (26.5)	10 (27.0)	0.958
Irrigation duration, min	91.0 ± 17.5	98.0 ± 13.0	0.062
Duration of operation, min	110.6 ± 17.0	115.4 ± 13.5	0.188
Duration of anaesthesia, min	121.1 ± 16.9	126.4 ± 13.9	0.152
Volume of irrigation fluid, ml	17,603 ± 2,711	14,204 ± 2,079	0.000
Volume of fluid absorbed, ml	722 ± 163	943 ± 171	0.000
Haemoglobin loss, g/l	9.6 ± 4.0	7.4 ± 3.5	0.015
Stone-free rate, *n* (%)	27 (79.4)	29 (78.4)	0.915
Hospital stay, days	9.3 ± 3.0	9.8 ± 3.4	0.573
Complication, n (%)			
Clavien–Dindo grade II			
Post-operative pyrexia	2 (5.9)	3 (8.1)	0.714
Prolonged nephrostomy drainage	2 (5.9)	1 (2.7)	0.506
Urinary retention	1 (2.9)	1 (2.7)	0.952

PCNL percutaneous nephrolithotomy, *MPCNL* minimally invasive percutaneous nephrolithotomy, *BMI* body mass index, *UTI* urinary tract infection

of sodium during the entire observation period. There were decreases in potassium levels at the T_2, T_3, and T_4 in the PCNL group; the decrease in potassium levels was found earlier at the T_1 and did not recovery until T_5 in the MPCNL group; but the potassium levels in the two groups was normal during the entire observation period. No relevant increase was noted in Cl^- levels until the 120th min of irrigation (T_4) in the two groups ($P < 0.05$), and a significant difference between the groups in Cl^- levels was seen simultaneously ($P < 0.05$). pH was maintained within normal limits throughout the procedure and in the post-operative period in the PCNL group. In the MPCNL group, there was a decreasing trend of pH from the start to the 120th min of irrigation and 24 h later after operation this trend attenuated. Although the pH at 30th min and at 60th min of irrigation was not significantly different from the start of irrigation, there was a statistically significant fall in pH at

Table 2 Heart rate and systolic and diastolic blood pressure of the patients in the two groups

Parameters	T_0	T_1	T_2	T_3	T_4	T_5
Heart rate (beats/min)						
PCNL group	82.3	81.6	85.3	80.2	81.2	83.7
MPCNL group	84.1	80.2	83.1	80.3	81.1	82.5
P value	0.590	0.700	0.526	0.981	0.958	0.716
Systolic BP (mmHg)						
PCNL group	115.7	117.0	121.6	122.0	122.0	126.9
MPCNL group	113.6	120.8	119.5	124.8	124.5	127.1
P value	0.618	0.309	0.623	0.446	0.464	0.964
Diastolic BP (mmHg)						
PCNL group	71.1	72.2	72.2	73.5	74.7	70.5
MPCNL group	69.9	72.7	72.1	74.7	74.9	70.3
P value	0.665	0.838	0.948	0.568	0.911	0.896

PCNL percutaneous nephrolithotomy, *MPCNL* minimally invasive percutaneous nephrolithotomy

Table 3 Electrolyte and acid–base status in the two groups

Parameters	T_0	T_1	T_2	T_3	T_4	T_5
S. Na^+ *(meq/l)*						
PCNL	140.0 ± 3.1	138.4 ± 4.0	139.6 ± 3.3	139.1 ± 3.1	139.7 ± 2.6	138.6 ± 3.3
MPCNL	139.2 ± 3.5	138.8 ± 3.7	139.1 ± 3.0	138.8 ± 2.8	138.4 ± 3.4	139.1 ± 3.3
P	0.215	0.646	0.521	0.690	0.079	0.581
S. K^+ *(meq/l)*						
PCNL	4.2 ± 0.4	4.1 ± 0.5	4.0 ± 0.4*	3.9 ± 0.4*	3.9 ± 0.4*	4.1 ± 0.3
MPCNL	4.3 ± 0.4	4.1 ± 0.5*	3.8 ± 0.4*	3.8 ± 0.5*	3.8 ± 0.5*	3.9 ± 0.4*
P	0.316	0.387	0.360	0.167	0.224	0.096
Cl^- *(meq/l)*						
PCNL	103.8 ± 4.1	104.7 ± 4.6	104.9 ± 5.0	105.6 ± 4.6	106.5 ± 4.5*	104.8 ± 4.1
MPCNL	104.4 ± 4.3	104.8 ± 4.8	106.1 ± 4.6	106.1 ± 4.1	113.1 ± 6.0*	103.0 ± 6.3
P	0.560	0.904	0.324	0.657	0.000	0.156
pH						
PCNL	7.43 ± 0.11	7.42 ± 0.21	7.42 ± 0.32	7.41 ± 0.31	7.38 ± 0.60	7.40 ± 0.24
MPCNL	7.44 ± 0.12	7.43 ± 0.19	7.39 ± 0.29	7.30 ± 0.30*	7.21 ± 0.55*	7.39 ± 0.23
P	0.728	0.924	0.724	0.129	0.234	0.849
Base excess (mmol/l)						
PCNL	1.68 ± 0.19	1.58 ± 0.19	1.58 ± 0.19	1.52 ± 0.17*	1.52 ± 0.17*	1.62 ± 0.14
MPCNL	1.69 ± 0.18	1.57 ± 0.14*	1.55 ± 0.16*	1.42 ± 0.14*	0.72 ± 0.13*	1.37 ± 0.13*
P	0.920	0.777	0.481	0.009	0.000	0.000

PCNL percutaneous nephrolithotomy, *MPCNL* minimally invasive percutaneous nephrolithotomy

* $P < 0.05$ when compared with the time point of T_0 within each surgical procedure group

90th and 120th min of irrigation as compared to the start of irrigation ($P < 0.05$). No significant differences were noted in pH levels between the two groups. The changes in base excess levels were in accordance with those in pH levels in the MPCNL group, but there were some statistically significant differences in base excess levels at 90th and 120th min of irrigation and 24 h later after both procedures between the two groups ($P < 0.05$). In the study, 3 patients (8.1 %) in the MPCNL group experienced hyperchloremic acidosis, which returned to the normal range after 24 h.

Discussion

In the literature, discussion about haemodynamic, electrolyte, and metabolic changes during PCNL is controversial.

Little is known about these changes during MPCNL. Considering that the irrigation duration, the number of percutaneous tract, and the patient's fragmentation position varied in these studies on PCNL, which might influence the volume of fluid absorbed and subsequent haemodynamic, electrolyte, and metabolic changes, we chose the cases whose irrigation duration was in 60–120 min, who had single fresh percutaneous tract, and whose fragmentation position was prone. Excessive bleeding during the PCNL was reported to be associated with increased fluid absorption [7]. Although the difference in blood loss did reach statistical significance ($P = 0.015$), all the patients in both arms did not require blood transfusion. Therefore, the effect of bleeding on fluid absorption could be neglected in the present study. Our results showed that there was no statistically significant difference in irrigation duration between the two groups, but the volume of fluid absorbed in MPCNL group was significantly more than that in PCNL group (Table 1). For that reducing pressure in the pelvicaliceal system helps prevent fluid absorption [7] and that during MPCNL with 14-, 16-, 18-, and double-16-French percutaneous tracts, the mean intrapelvicaliceal pressure was 24.55, 16.49, 11.22, and 6.64 mmHg, respectively [13], our finding was probably because of increased pressure in the pelvicaliceal system due to the reduced diameter of tract. Unfortunately, pressures in the pelvicaliceal system were not measured during this study.

Some studies showed that there was no significant change in heart rate and arterial blood pressure during and after irrigation during PCNL [12, 14, 15]. Atici et al. [16] also reported that heart rate remained constant, but at the same time they reported that systolic and diastolic blood pressures were significantly higher during PCNL compared to post-procedure levels because of some hormonal and autonomic changes caused by renal dilation and irrigation. Mohta et al. [12] presumed that the details of intraoperative and post-operative sedation and analgesia in the study by Atici et al. could also have been a reason for lower post-operative values. However, there was no direct proof to support it. In the current study, not only heart rate and systolic and diastolic blood pressure in the PCNL group kept stably during and after irrigation, but also in MPCNL group. Although the volume of fluid absorbed was more in the MPCNL group, probably it was not enough to improve haemodynamic imbalance during and after the operation.

Atici et al. [16] measured serum sodium levels and potassium levels preoperatively, at 15th min and at 60th min of irrigation during the PCNL and found that serum sodium levels were significantly decreased in each stage of measurement and potassium level significantly decreased at the 60th min of irrigation compared to pre-operative level. They attributed hyponatremia and hypokalemia to renal tubular dysfunction due to mechanical irritation of kidneys. However, more studies demonstrated that serum sodium levels and potassium levels did not change significantly during PCNL [12, 14, 15, 17]. Our results showed that serum sodium levels did not change significantly during or after PCNL, which were in concordance with the later several studies [12, 14, 15, 17]. Similarly, changes of sodium in the MPCNL group were comparative to that in PCNL group. However, there were decreases in potassium levels at the 60th, 90th, and 120th min of irrigation in the PCNL group; the decrease in potassium levels was found earlier at the 30th min of irrigation and did not recovery until 24 h later after operation in the MPCNL group; but there were no statistically significant differences in potassium levels between the groups. It was worthy to be noted that the potassium levels in the two groups was normal during the entire observation period. Our irrigation fluid that included no potassium but isotonic sodium maybe one possible explanation for the unchanging of sodium levels and the decrease in potassium levels.

The decrease in carbonate and base excess levels may cause severe metabolic acidosis leading to death in patients during and after PCNL, especially in prolonged procedures [18]. In the study by Mohta et al. [12], there were no significant changes in bicarbonate and base excess, but a significant fall in pH was seen after PCNL. Maximum fall in bicarbonate values, pH and base excess occurred in the patient with maximum duration of irrigation, i.e. 120 min. Atici et al. [16] reported that the carbonate and base excess levels significantly decreased at the 15th and 60th min of irrigation compared to pre-irrigation values. In contrast to the above reports, our trial presented that there were no significant changes in base excess and pH during and after PCNL. But in the MPCNL group, significant decreases were seen in base excess and pH during and after operation. Possible explanation is that Cl^-, which is high to 154 mmol/l in sodium chloride (0.9 %), can be largely absorbed into the blood circulation following by irrigation fluid, resulting in plasma Cl^- increasing, plasma HCO_3^- transferring into intracells, plasma H^+ concentration increasing, and causing hyperchloremic acidosis in serious case. In the current study, 3 cases of hyperchloremic acidosis were seen in the MPCNL group, which returned to the normal range after 24 h. No statistically significant differences in the duration of operation and anaesthesia were found in the two groups, so that the effect of the duration of operation and anaesthesia on acid/base status could also be neglected.

Although our study is the first report about haemodynamic, electrolyte, and metabolic changes so far to compare PCNL with MPCNL, it is not devoid of limitations. The main shortcomings of the present study are the lack of randomized allocation of the patients to the study groups, and the few patients enrolled. In the present study, the PCNL group included patients with larger volume stones comparing with the MPCNL group, which may have negatively influenced the rate of complications. The method of calculating the volume of fluid absorbed was a limitation as it was a very inexact means of calculation. In this study, the mean hospital stay was longer in each arm than those obtained in other countries. Our longer nephrostomy tube indwelling time, at least 5 days (data not shown), was most likely the reason. Moreover, most patients in China do not leave the hospital until they can return to normal activities. Therefore, their hospital stay was longer. In addition, in the trial design, the procedures were performed under epidural anaesthesia, which might have made patients nervous, potentially affecting patients' heart rate and blood pressure evaluations.

In the present trial, the smaller-size percutaneous tract could promote fluid absorption during MPCNL compared with PCNL. Although haemodynamic and electrolyte changes remain stable, a trend towards metabolic acidosis is obvious as the irrigation time goes by. Therefore, arterial blood gases should be monitored during and after MPCNL in patients with prolonged irrigation time.

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