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Computer tomography urography assisted real-time ultrasound-guided percutaneous nephrolithotomy on renal calculus

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Abstract

This study aimed to assess the role of pre-designed route on computer tomography urography (CTU) in the ultrasound-guided percutaneous nephrolithotomy (PCNL) for renal calculus.

From August 2013 to May 2016, a total of 100 patients diagnosed with complex renal calculus in our hospital were randomly divided into CTU group and control group (without CTU assistance). CTU was used to design a rational route for puncturing in CTU group. Ultrasound was used in both groups to establish a working trace in the operation areas. Patients' perioperative parameters and postoperative complications were recorded.

All operations were successfully performed, without transferring to open surgery. Time of channel establishment in CTU group (6.5 ± 4.3 minutes) was shorter than the control group (10.0 ± 6.7 minutes) ($P = .002$). In addition, there was shorter operation time, lower rates of blood transfusion, secondary operation, and less establishing channels. The incidence of postoperative complications including residual stones, sepsis, severe hemorrhage, and perirenal hematoma was lower in CTU group than in control group.

Pre-designing puncture route on CTU images would improve the puncturing accuracy, lessen establishing channels as well as improve the security in the ultrasound-guided PCNL for complex renal calculus, but at the cost of increased radiation exposure.

Abbreviations: BUN = blood urea nitrogen, Cr = blood creatinine, CTU = computer tomography urography, PCNL = percutaneous nephrolithotomy, WBC = white blood cell.

Keywords: computer tomography urography, percutaneous nephrolithotomy, ultrasound

1. Introduction

Percutaneous nephrolithotomy (PCNL) has become golden standard in the treatment of complex renal calculus since 1976 when it was initially reported by Fernstrom and Johannson. With the improvement of technologies and instruments of endourology, PCNL is becoming less invasive with fewer postoperative complications, and patients receiving PCNL are having shorter hospital stay and faster recovery.[1,2]

However, compared with traditional open surgery, the operation of PCNL is relatively difficult. For surgeons who are not familiar with PCNL, it has a higher incidence of postoperative complications, including increased blood loss, urinary tract infection, injury of perirenal organs, and so on. In order to complete a successful operation and avoid severe complications, a rational route for PCNL is of great importance.[3–5]

Currently, the combined use of preoperative computed tomography (CT) and intraoperative ultrasound-guided localization significantly improves the safety and efficiency of PCNL.[6,7] On the basis of our experience on PCNL, a prospectively randomized controlled study was designed to investigate the role of pre-designed route on computer tomography urography (CTU) in the ultrasound-guided PCNL. In CTU group, a proper puncturing route was designed on CTU, and the approximate puncturing area was marked on the back, followed by ultrasound-guided PCNL. In the control group, ultrasound-guided PCNL was performed in absence of pre-designed route.

2. Methods

2.1. Patient selection

This clinical trial was approved by our Institutional Review Board, and all the patients signed informed consent before recruitment into this study. PNCL was performed by the same

Editor: Giuseppe Lucarelli.

Y-QF and J-YW equally contributed for this study.

Funding/support: This work was supported by the Science and Technology Planning Project of Guangzhou (201704020052 to Y-QF), the Science and Technology Project of Guangdong (2013B021800084 to Y-QF), and the Fundamental Research Funds for the Central Universities (14YKPY25 to Y-QF).

The authors report no conflicts of interest.

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Medicine (2017) 96:24(e7215)

Received: 9 February 2017 / Received in final form: 23 May 2017 / Accepted: 24 May 2017

http://dx.doi.org/10.1097/MD.0000000000007215

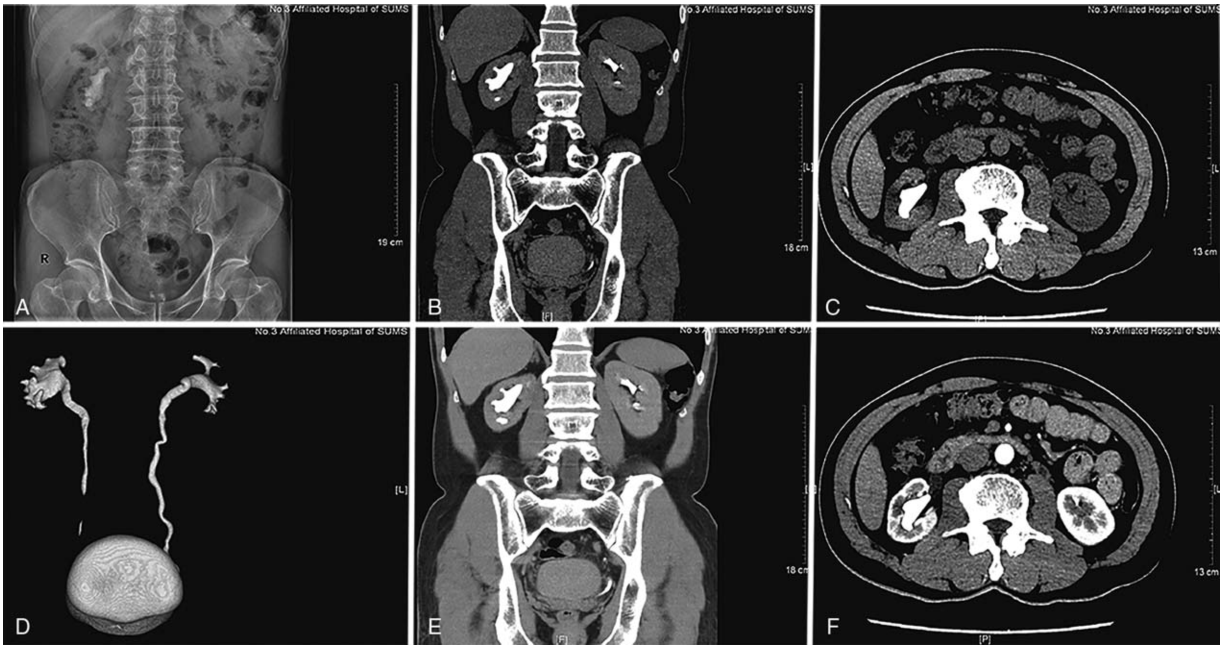

Figure 1. Images before operation. (A) KUB. (B, E) CTU (coronal plane); (C, F) CTU (vertical plane). (D) CTU (water imaging of urinary collection system).

surgical team in this study. From August 2013 to May 2016, a total of 100 patients were enrolled into this study in our hospital, and randomly assigned into 2 groups at a ratio of 1:1. Inclusion criteria included patients were ≥18 years; patients had complex renal calculus including stag horn calculus (involved in the renal pelvis and extended into 2 or more calices) or multiple renal calculus with a maximal diameter >2 cm. Exclusion criteria included patients had a history of PCNL; patients had renal failure or pyonephrosis; patients were pregnant; and patients had concomitant diseases, including severe cardiorespiratory dysfunction, severe blood coagulation dysfunction, and so on that cannot tolerate the operation.

2.2. Preoperative examination

Before operation, all the patients underwent complete preoperative examinations, including physical examination, urinalysis, routine blood examination, detection of blood glucose, blood urea nitrogen (BUN), blood creatinine (Cr), and midstream urine culture, and imaging examinations [such as abdominal ultrasound, combination of renal plain radiograph kidney, ureter, and bladder (KUB), intravenous pyelography (IVP) or CTU]. Besides, whether radionuclide renal dynamic imaging was needed to evaluate the kidney function was determined by the severity of hydronephrosis. Moreover, if urinary tract infection was present, operation should be delayed until it resolved after effective anti-infectious therapy.

2.3. Surgical procedure

In CTU group, CT images were used to design feasible routes on each slice. The optimal puncturing route was determined after comparing the advantages and disadvantages of these routes [8] (Figure 1A–F). Through the rational route, the surgeon conducted PCNL. Of note, the rational route should meet following criteria: the renal parenchyma should be as thin as possible; obvious hydronephrosis (pathological or artificial); the vasculature should be avoided in the route; the removal of calyceal stones should be feasible; and the route has better to be below the 12th lib to avoid the damage to the spleen, liver, and lung. The theoretical rational route was named A, and then another line B was drawn to connect the spinal midline and the puncturing point on the skin (Figure 2).

Thereafter, the surgeon figured out the vertical distance (a) between the puncturing point and the tip of 12th rib through the CT images (usually each CT slice was 0.5 cm), and the horizontal distance (b). Before sterilization, the surgeon drew the surface projection of the 12th and 11th ribs on the back according to CT

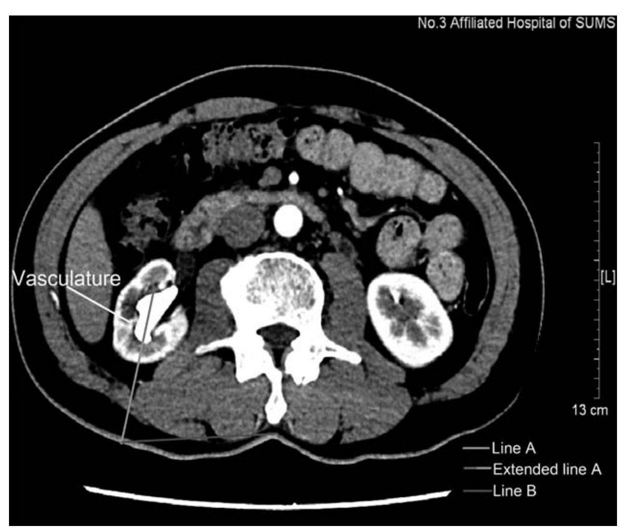

Figure 2. Line A, the puncture line. Extended line A, the maximum puncturing depth. Line B, the line linking the center of spinous process and the puncture point.

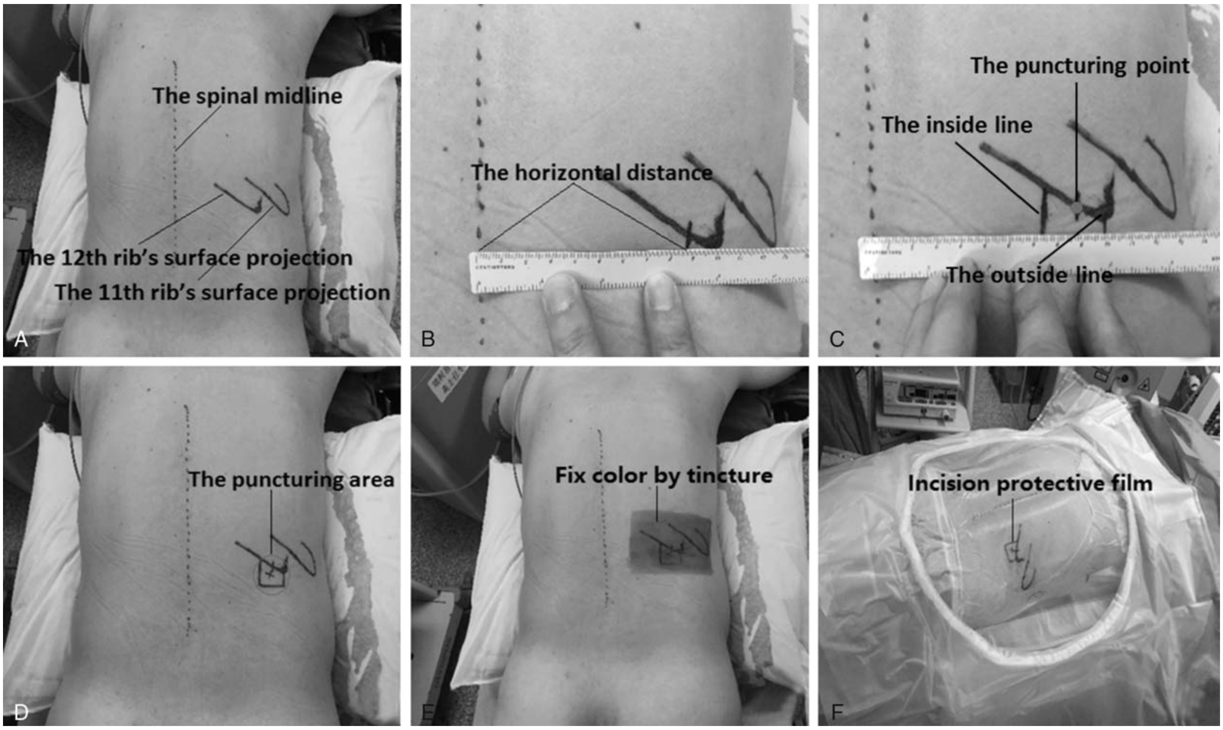

Figure 3. Detail information about the puncturing. (A) Draw the 12th, 11th rib's surface, and spinal middle projection. (B) Measure the horizontal distance as long as B line from the spinal middle and crossing the low surface of 12th rib. (C) Draw the inside line and outside line between the surface puncturing point. (D) Mark the puncturing area. (E) Fix color by tincture. (F) Cover the area by protective film after disinfection.

images and palpation. Then, the puncturing point was marked by measuring vertical and horizontal (a and b) distances from the tip of 12th rib. This point served as the center, and 2 lines 1 to 1.5 cm away from the center that were parallel to the spinal midline and the horizontal line 1 cm below the point were drawn. The area among these 3 lines and lower edge of 12th rib was drawn and the ultrasound probe was placed in this area (Figure 3A–F).

In addition, the patient's kidney was slightly pressed toward the spinal midline because the patient lied in a prone position. Thus, the puncture needle more accurately worked at the inner part of this area. Ultrasound was used to probe the kidney, and a needle was also introduced. An anesthesiologist controlled the patient's breath depth in mechanical ventilation to avoid the kidney's movement caused by breath, which improved the accuracy of puncturing. The length of line A served as the expected depth (minimum puncturing depth), and length of extended line A that approached the opposite renal pelvis wall was used as the maximum puncturing depth. The area between line A and extended line A was used as a practical puncturing place (safe depth).

Under the ultrasound guidance, an 18-gauge coaxial needle was introduced into the fornix of the desired calyx. The efflux of urine or injected fluid from the urethral stent tube came out when the needle was settled successfully. After that, a guidewire was inserted through the needle into the pelvis; the working route for PCNL was established according to the general procedure (Figure 4A–F).

In control group, the surgeon checked and determined the targeted calyx, and the route was determined through preliminary ultrasound examination. The 12th rib projection and puncturing area were not marked on the back as in CTU group, but ultrasound was applied to guide and monitor the puncturing needle. After the placement of a guidewire, a working route for PCNL was established.

All the operations were performed under general anesthesia after endotracheal intubation. After anesthesia, patients lied in a lithotomy position, and the surgeon performed ureteroscopy on the side of renal calculus. Artificial hydronephrosis is a way to lessen the difficulty of renal puncturing, which is especially applied to renal stones in kidney without hydronephrosis. A 5F ureteral stent tube was indwelled to induce artificial hydronephrosis. After that, the patient was placed in a prone position. A coaxial needle was penetrated to the targeted calyx following the aforementioned procedures in both groups. After the needle sheath was withdrawn, the tract was dilated from 6 to 18 F using a fascial dilator over the guidewire. A 12F micro-percutaneous nephroscope (Richard Wolf, Knittlingen, Germany) was inserted into the 18F sheath, and forwarded into the renal collecting system under the TV monitoring. All the stones in each direction were visualized, and then pounded by the VersaPulse PowerSuite 60 Watt Holmium laser (Lumenis 60W, 2 J, 10 Hz, 550 μm fiber). The small fragments would be flushed out with water, while the larger fragments were clipped out with lithotomy forceps.

When the stones were difficult to be removed through a single channel, multi-channels were used. At the end of operation, ultrasound was used to detect whether there were residual stone fragments. If there were no residual stone fragments, a 4.7F double-J tube was indwelled for urine drainage, and a 16F urinary catheter was set to artificial renal fistula. In other situation, the operation would be continued.

2.4. Postoperative treatment

All patients were treated with antibiotics 3 to 5 days after surgery, and received liquid diet after anal exsufflation. Abdominal plain X-ray was employed to confirm the position of double-J tube as well as whether there were any residual stones at 1 to 2 days after

Figure 4. Introduction of the coaxial needle into the fornix of the desired calyx through the ultrasound guidance. (A) Use the ultrasound to probe the kidney. (B) Search for the desired calyx. (C) Introduce the 18-gauge coaxial needle into the fornix of the desired calyx. (D) Introduce the guidewire into the pelvis. (E) Dilate the route from 6 to 18F. (F) Pound the kidney stones by holmium laser.

surgery. If the position of double-J tube was correct, and there were no big residual stones (<0.4 cm in diameter), the nephrostomy tube was clamped, and the patient was observed for the following 12 to 24 hours. If there was no any discomfort, the nephrostomy tube was removed, and the patient was asked to visit our hospital to remove the double-J tube under the cystoscopy 3 to 4 weeks after being discharged. In addition, ultrasound examination was performed once every 3 months to exclude the recurrence of renal calculus.

2.5. Statistical analysis

Statistical analysis was done with SPSS version 16.0 (SPSS Inc., Chicago, IL), and comparisons were performed with Chi-square test and independent 2-sample *t* test. A value of $P<.05$ was considered statistically significant.

3. Results

A total of 100 patients with complex renal calculus were recruited into this study, including 50 patients in CTU group and 50 patients in control group. Characteristics for the total group are summarized in Table 1; no significant difference was found between CTU group and control group, including age, gender, body mass index (BMI), and so on. None was lost to follow-up. All the operations were performed successfully, and none was transferred to open surgery. The median time of establishing percutaneous working channel in CTU group was 6.5 minutes, which was significantly shorter than in control group (10.0 minutes) ($P=.002$). The average number of puncturing channel in CTU group (1.02) was smaller than in control group (1.3) ($P<.001$). As compared with the control group (111.7 minutes), the operation time was significantly shortened in CTU group (86.6 minutes; $P<.001$). The number of patients receiving a

Table 1

Characteristics of included patients.

	Group	Statistics		
	CTU (n=50)	**Control (n=50)**		***P***
Gender (M/F)	18/32	20/30	0.170*	.680
Age, y	54.5±17.1	53.8±16.6	0.207†	.835
BMI, kg/m^2	22.7±2.1	22.3±2.7	0.826†	.410
Side of kidney stone (R/L)	36/14	27/23	3.475*	.062
Stone's surface area, mm^2	325.4±124.7	295.5±143.5	1.112†	.268
Renal parenchyma thickness, mm	17.2±4.5	16.2±4.7	1.086†	.279

BMI=body mass index, CTU=computer tomography urography.
* Chi-square test.
† *t* test.

Table 2

Operation-related parameters in each group.

	Group			
	CTU (n=50)	Control (n=50)	Statistics	*P*
Time of establishing channel, min	6.5±4.3	10.0±6.7	3.108a	.002
Average channel number	1.02±0.3	1.3±0.5	3.395a	<.001
Operation time, min	86.6±18.5	111.7±17.3	7.007a	<.001
Terminating cases	0	1	—	—
Blood transplantation	0	2	—	—
Secondary operations	2	4	—	—

t test.
CTU=computer tomography urography.

second operation for residual stones or blood transfusion in CTU group was smaller than in the control group. Operations were terminated for 2 patients in control group because the operative field was unclear due to bleeding during operation; therefore, a fistula tube was placed. And several days later, a second-stage PCNL was performed. None in CTU group developed severe bleeding during or after surgery. None in both groups needed selective renal embolization for hemostasis. Other detailed information could be found in Table 2.

As for the postoperative complications, there were 4 patients (8%) with residual stones in control group, of whom extracorporeal shock wave lithotripsy (ESWL) was performed in 2 patients and a second operation in remaining 2. In CTU group, there were only 2 patients (4%) with residual stones, and a secondary operation was performed. In addition, sepsis was observed in 2 patients of control group at 3 to 4 days after surgery and resolved after intensive anti-infection as well as steroid therapy. In CTU group, none developed sepsis.

Furthermore, 2 patients in control group and 1 in CTU group developed peri-renal hematoma after surgery, which resolved after conservative treatment by adjusting the position of nephrostomy tube. Patients in both groups had no abdominal organ injury, hemopneumothorax, or severe arteriovenous fistula that needed selective renal artery embolization (Table 3).

4. Discussion

The key of PCNL is the establishment of operation route, and thus to establish a safe and efficient route has been focused in the field of PCNL.[9] Traditional percutaneous nephroscopy is performed under the guidance by X-ray in which the renal calculi were localized and working tract was established. This achieves accurate localization, clear imaging, and lower incidence of residual stones.

However, iatrogenic X-ray radiation significantly limits its wide clinical application.[10] Ultrasound has no radiation and can be employed to position the renal calculi. Thus, it has been widely used to aid nephroscopy. However, it is a long learning curve for doctors to study characteristics of kidney under the ultrasound, and thus, there is usually a higher incidence of complications when the operators are beginners due to their misjudgments.[11,12]

Table 3

Complications of percutaneous nephrolithotomy.

	Group	
Complications	CTU (n=50)	Control (n=50)
Residual stones	3	4
Sepsis	0	2
Intervention embolization	0	0
Perirenal hematoma	1	2
Hemopneumothorax	0	0
Abdominal organs injury	0	0

CTU=computer tomography urography.

In recent years, along with the technological improvement of CT and magnetic resonance imaging (MRI), some investigators apply intraoperative CTU or MRU to establish the tract. It is a helpful tool for intraoperative orientation and pretreatment decision-making in selected cases. The 2016 EAU guideline also indicates that preoperative planning using CT resulted in easier access as well as shorter operating times. Of note, these techniques need special equipment and have a high medical cost. Thus, they are only employed in researches and have not been applied widely in clinical practice.[13–15] In the present study, CT was used before surgery to display the renal anatomy, size, and shape, to detect kidney stones, and determine the distribution of renal vasculatures, which provide important information for the surgical design and evaluation for complex PCNL. Thus, a route could be designed before surgery to trace the kidney stones on CT images.

To design a puncturing route on CT images is the first step, but to implement this theoretical route accurately in a patient is much more difficult. Some investigators reported that the 11th intercostal space or the intersection point of the lower edge of 11th rib and infrascapular line could be used as the puncturing sites, and this area should be marked with colloidal particle that contained diatrizoate on patient's skin before CT. When CT scanning finished, the particle would be seen on images as a marker.

The level of colloidal particle and stone was recorded, respectively; the colloidal particle was taken as a puncturing point on the skin, and then the distance between it and collecting system and the angle between theoretical puncturing line and skin were measured.[16] Liu et al[17] reported a technique of localization on the basis of 2 points, which did not need marking with colloidal particle before CT scanning. Through CT images, the skin puncturing point (first point), targeted calyx (second point), and the puncturing angle were determined.

Before puncturing, under the X-ray's guidance, the surgeon adjusted the patient's breath to make the first point and targeted calyx in a line. Then, the surgeon adjusted the needle to the targeted calyx.[17] In the present study, the preoperative CT 3D images were analyzed to understand the anatomy, stones distribution, and important surrounding organs of kidney with stones. Moreover, the renal artery was clearly displayed on CTU in arterial phase. Thus, the risk for bleeding due to the damage to parenchyma artery is reduced.

The distance between puncturing point and spinal midline (line B) was helpful to mark the approximate working area on the skin, and the distance between puncturing point and 12th rib (distance a, b) could make this area more precise. On the basis of CT-designed area on the skin, ultrasound could quickly locate the punctured area, which shortened the scanning time as well as narrowed the scanning area. Targeted calyx would be figured out rapidly with ultrasound. Then, surgeons adjusted the patient's breath to keep the targeted calyx on the theoretical puncturing line (line A). Then, puncturing began. The measurement of punctured angle was unnecessary.

When it was difficult to puncture the targeted calyx, the surgeon could count the slices from targeted calyx to the upper pole or lower pole of the kidney to correct the theoretical puncture line under the ultrasound guidance. Obviously, this method decreases the exposure of surgical staff to X-ray and utilizes the precise localization of CT. Furthermore, it helps to monitor the depth and direction of puncturing needle, which is important for the successful PCNL. With the assistance of CTU and ultrasound, the operation time was shortened, and the complications also decreased.

Available studies indicate that the incidence of postoperative complications after PCNL was 21.5%, and the most common complications are urinary tract infection, fever (>38.5°C) (10.5%), bleeding (7.8%), blood transfusion (5.7%), renal pelvis perforation (3.4%), and pleural effusion (1.8%). According to the Clavien–Dindo classification, the incidence of complication could be classified as level I (11.1%), level II (5.3%), level IIIa (2.3%), level IIIb (1.3%), level IVa (0.3%), level IVb (0.2%), and level V (0.03%).[18] Septicemia was diagnosed in only 2 patients in this study. It occurred 3 to 4 days after surgery, but resolved after treatment with antibiotics to which the pathogens were sensitive as shown in bacterial culture. Longer operation time, increased bleeding, and a secondary puncturing channel for these 2 patients may increase the risk of septicemia. None suffered from septicemia in CTU group.

Urinary-related septicemia and septic shock are the most common postoperative severe complications, and usually cause a high mortality. Therefore, preoperative urine and midstream urine culture is necessary. If the urine examination shows white blood cell (WBC), especially in those positive for urine culture, preoperative anti-infection therapy is of great importance. Surgeons should remember that low-pressure perfusion and shortening operation time as much as possible are equally significant.[19] In addition, smooth drainage and intensive anti-infection therapy after surgery are also important for the prevention of postoperative complications.

Bleeding is another common postoperative complication, and in case of severe bleeding, the patient probably needs selective renal artery embolization, or even renal resection.[20] The increased number of puncturing tracts in control group may be the cause of increased bleeding, but the damage of arteries would also work. Increased bleeding may also lead to septicemia, for blood is a good medium for the growth of bacteria. To prevent severe bleeding as well as septicemia, the key point is to design a rational puncture route on CT images, which may avoid the damage to major blood vessel. When severe bleeding occurs, the surgeons should stop the operation and take measures to ensure patient's safety.

Although the pre-designing puncture route on CTU images could improve the efficacy and safety of PCNL for complex renal calculus, some limitations of CTU guide puncturing as well as our study should be taken into consideration. One of the most important one is that patients in CT guidance group were previously exposed to x-rays during CT scan. Further studies that compared the x-ray dosages in the 2 settings should be performed. But taking reason that iterative reconstruction is applied in CT in our hospital, the radiation exposure would be less than standard CTU. At the same time, our study only focuses on patients who suffer from complex renal calculus, so the benefit of CT guidance was obvious. But for patients who suffer from simple renal calculus, the requirement for CT guidance should be taken into further consideration. Last but not the least, although we compared most of important related parameters between these 2 groups, some parameters including number of stones and shape of stones were not compared during our study, and this may miss some important information.

All in all, pre-designing puncture route on CTU images may improve the puncturing accuracy and safety in the ultrasound-guided PCNL for complex renal calculus. This technique used in PCNL may also shorten the time of successfully establishing working track and the operation time, reduce the risk for hemorrhage as well as lower the possibility of residual stones.

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