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Upper pole calyx fornix subapical puncture in percutaneous nephrolithotomy

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Abstract

Background This study aims to evaluate the effectiveness of upper pole calyx fornix subapical puncture in percutaneous nephrolithotomy (PCNL) compared to traditional middle calyx puncture. The subapical puncture technique offers the advantages of upper pole access while minimizing the risk of pleural injury.

Methods We conducted a retrospective analysis of 194 patients who underwent PCNL at our hospital from May 2022 to November 2023. Patients were divided into two groups based on puncture technique: the Upper-PCNL group ($n = 122$) with upper pole calyx fornix subapical puncture and the Mid-PCNL group ($n = 72$) with middle calyx fornix apex puncture. Data collected included tract establishment time, operative time, stone-free rates, complications, and auxiliary procedures.

Results The Upper-PCNL group demonstrated significantly higher primary stone-free rates (83.6% vs. 69.4%, $P = 0.021$) and shorter operative times (59.99 ± 5.85 min vs. 68.49 ± 6.74 min, $P < 0.001$) compared to the Mid-PCNL group. Tract establishment time was also significantly shorter in the Upper-PCNL group (3.06 ± 0.35 min vs. 3.56 ± 0.66 min, $P < 0.001$). The hemoglobin drop was not significantly different between the groups. Complication rates were minimal and similar between groups. None of the patients in the Upper-PCNL group experienced pleural, liver, or spleen injuries.

Conclusions Upper pole calyx fornix subapical puncture achieved higher stone-free rates and shorter operative times compared to middle calyx puncture, with comparable safety profiles. Prospective trials are needed to validate these findings.

Keywords Percutaneous nephrolithotomy, Upper pole calyx, Subapical puncture, Renal stones, Surgical outcomes

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Introduction

Percutaneous nephrolithotomy (PCNL) is an established minimally invasive procedure for managing large and complex renal calculi. The success of PCNL largely depends on selecting the optimal puncture site, which ensures maximal stone clearance with minimal complications. Traditionally, the puncture site is chosen based on the calyx that offers the most direct and safest access to the stone-bearing area. While middle calyx puncture has been widely used due to its balance between accessibility and safety, upper pole calyx puncture has gained attention for its higher stone-free rates and better overall stone clearance outcomes [1–5].

Despite these advantages, upper pole calyx puncture is associated with a higher risk of pleural injury and other complications due to its higher entry point on the skin [1, 3, 6, 7]. This often necessitates careful navigation to avoid the ribs and pleura, increasing the risk of pleural injury and other complications. To mitigate these risks, we have adopted an alternative approach: puncturing through the side of the upper pole calyx fornix, slightly below the apex. This method aims to lower the skin entry point and improve the angle of access, thereby reducing the risk of pleural injury and enhancing the maneuverability of the nephroscope.

This study aims to compare the outcomes of PCNL using upper pole calyx fornix subapical puncture versus traditional middle calyx fornix apex puncture. By evaluating parameters such as stone-free rates, operative time, complications, and overall surgical efficacy, we seek to determine whether the upper pole calyx fornix subapical puncture approach offers a safer and more effective alternative for PCNL.

Patients and methods

This retrospective study analyzed the clinical data of 194 patients with renal calculi who underwent PCNL at our facility between May 2022 and November 2023. The Institutional Medical Ethics Committee approved the study. All data were collected after the procedures were completed, and no interventions were planned or altered based on the study design.

The patients were divided into two groups based on the puncture path: the observation group ($n = 122$) underwent upper pole calyx puncture, and the control group ($n = 72$) underwent middle calyx puncture. Inclusion criteria included patients diagnosed with renal calculi ≥ 2 cm by abdominal CT, undergoing single-access PCNL, and those with positive urine nitrites or urine culture who received antibiotic treatment 2–5 days before surgery. Exclusion criteria were age < 18 years, abnormal coagulation function, abnormal renal anatomy (such as horseshoe kidney, pelvic ectopic kidney, or double renal pelvis and ureter), severe heart, lung, or liver dysfunction, and those undergoing multi-access PCNL.

The choice of access calyx was determined intraoperatively by the attending urologist based on a comprehensive evaluation of preoperative non-contrast CT imaging, the distribution and burden of stones, renal anatomy, and the proximity of critical adjacent structures (e.g., pleura, liver, spleen). Upper calyx access was preferred when it allowed a direct and safe route to the targeted stone, whereas middle calyx access was chosen when upper pole puncture posed higher anatomical risks. The classification into Upper-PCNL and Mid-PCNL groups was thus based on the calyx selected for initial access and sheath insertion during the procedure.

All procedures were performed under general anesthesia with endotracheal intubation. Patients were initially placed in the lithotomy position for the insertion of an F5 ureteric catheter and an F18 Foley catheter. Subsequently, patients were repositioned to the prone position with the chest and abdomen elevated. After disinfection and draping, artificial hydronephrosis was induced by instilling saline through the ureteric catheter. Under ultrasonographic guidance, the desired calyx was punctured. In the observation group, the puncture needle entered the subapical fornix of the upper pole calyx. In the control group, the needle punctured the apex of the middle calyx fornix. The tract was then dilated to F20 using a fascial dilator. Both groups underwent double-sheath vacuum suction PCNL [8–11].

The double-sheath vacuum suction device utilized consisted of an F20 Y-shaped outer sheath paired with a longer F16 Y-shaped inner sheath. The oblique arms of these sheaths were connected to the perfusion inflow and vacuum suction, respectively. A mini-nephroscope was introduced through the inner sheath. During the procedure, the pneumatic lithotripsy (Swiss Lithoclast) was employed to fragment the stones, with settings of 90% output and 12 Hz frequency [11]. Following the surgery, residual stones were identified using ultrasonography. An antegrade placement of a double-J ureteral stent was then performed. Postoperatively, an abdominal non-contrast CT scan with 2 mm cuts was performed on postoperative days 1–3 to assess the stone-free rate as the primary endpoint. Stone-free data were classified into three grades according to the Endourological Society recommendations: Grade A (no stones), Grade B (≤ 2 mm fragments), and Grade C (2.1–4 mm fragments) [12].

Data were expressed as mean ± standard deviation (SD). Comparisons between groups were made using the chi-square test (Fisher's exact test) for categorical variables and the independent-samples t-test for continuous variables. A P-value < 0.05 was considered statistically significant. Statistical analyses were performed using SPSS version 27 software (IBM Corporation, USA).

Table 1 Baseline characteristics and stone distribution between groups

Parameters	Upper-PCNL group	Mid-PCNL group	*P* value
Number of patients	122	72	-
Age (mean ± SD, years)	44.29 ± 12.76	46.13 ± 13.67	0.346
Male/female	68/54	42/30	0.724
BMI (mean ± SD, kg/m^2)	24.01 ± 2.24	24.36 ± 2.42	0.311
Side (Left / Right)	67/55	40/32	0.931
Stone size (mm)	31.47 ± 8.66	33.43 ± 10.35	0.158
Stone density (Hounsfield units)	997.51 ± 91.13	1005.40 ± 86.81	0.554
Overall hydronephrosis			0.728
No	2	1	
Mild	42	22	
Moderate	50	31	
Severe	28	18	
Target calyx hydronephrosis			< 0.001
No	4	10	
Mild	45	45	
Moderate	51	14	
Severe	22	3	
Stone characteristics, n			0.911
Pelvic stone only	28	17	
Multiple stones	45	25	
Partial staghorn	33	18	
Complete staghorn	16	12	

Results

A total of 194 patients underwent PCNL, with 122 receiving upper pole calyx puncture (Upper-PCNL group) and 72 undergoing middle calyx puncture (Mid-PCNL group). Baseline characteristics, including age, gender, BMI, side of stone, stone size, and stone density, were comparable between groups (Table 1).

There was no significant difference in the overall degree of hydronephrosis between the two groups ($P = 0.728$). However, a significant difference was observed in target calyx hydronephrosis, with the Upper-PCNL group exhibiting more pronounced dilation compared to the Mid-PCNL group ($P < 0.001$). These anatomical differences may influence the ease of tract creation and stone clearance.

Regarding access approach, 71 (58.2%) patients in the Upper-PCNL group underwent intercostal puncture (between the 11th and 12th ribs), and 51 (41.8%) underwent subcostal access. In the Mid-PCNL group, 14 (19.4%) had intercostal and 58 (80.6%) had subcostal access.

The tract establishment time was significantly shorter in the Upper-PCNL group (3.06 ± 0.35 min vs. 5.36 ± 0.66 min, $P < 0.001$). Operative time was also reduced (59.99 ± 5.85 min vs. 68.49 ± 6.74 min, $P < 0.001$). Postoperative hospital stay was similar between groups ($P = 0.339$).

Table 2 Intraoperative and postoperative outcomes between groups

Parameters	Upper-PCNL group	Mid-PCNL group	*P* value
Number of patients	122	72	-
Supracostal puncture	71	14	
Infracostal puncture	51	58	
Tract establishment time (mean ± SD, mins)	3.06 ± 0.35	5.36 ± 0.66	< 0.001
Operative time (mean ± SD, mins)	59.99 ± 5.85	68.49 ± 6.74	< 0.001
Postoperative hospital stay (mean ± SD, days)	3.30 ± 0.50	3.24 ± 0.43	0.339
Hemoglobin drop (g/L)	2.13 ± 1.17	2.32 ± 1.1	0.252
Complications (Clavien grade), n (%)			
Transient Fever (grade I)	3 (2.5)	1(1.4)	0.612
Transfusions (grade II)	0	0	-
Fever (grade II)	1 (0.8)	1(1.4)	0.705
Intervention (grade III)	0	0	-
Pleural, liver or spleen injury (grade III)	0	0	-
Primary stone-free rate, n (%)	102 (83.6)	50 (69.4)	0.021
Grade A	53 (43.4)	24 (33.3)	
Grade B	27 (22.1)	15 (20.8)	
Grade C	22 (18.0)	11 (15.3)	
Predominant Stone Composition, n (%)			0.956
Calcium oxalate	80 (65.6)	49(68.1)	
Carbonate apatite	32(26.2)	18(25.0)	
Struvite	7(5.7)	4(5.6)	
Uric acid	3(2.5)	1(1.4)	

The hemoglobin drop showed no significant difference (2.13 ± 1.17 g/L vs. 2.32 ± 1.1 g/L, $P = 0.252$). According to Clavien-Dindo classification, only minor complications (Grade I–II) occurred in both groups, with transient fever (Grade I) reported in 2.5% of patients in the Upper-PCNL group and 1.4% in the Mid-PCNL group ($P = 0.612$), and febrile episodes requiring antibiotics (Grade II) in 0.8% and 1.4% of patients, respectively ($P = 0.705$). No transfusions or major complications (Grade III or higher), including pleural, liver, or splenic injuries, were reported.

The primary stone-free rate was significantly higher in the Upper-PCNL group (83.6% vs. 69.4%, $P = 0.021$). The distribution of stone-free grades (A/B/C) is shown in Table 2. The predominant stone composition did not differ significantly between groups ($P = 0.956$), with calcium oxalate being most common.

Discussion

The preference for upper pole calyx puncture in PCNL is driven by several clinical advantages [1–5]. This approach provides a more direct and straightforward path to the renal pelvis, upper ureter, and lower calyx, facilitating efficient stone removal. Studies have consistently shown that upper pole calyx puncture often results in higher stone-free rates and better overall stone clearance compared to middle and lower calyx punctures [1–3]. The anatomical position allows for improved access to the entire collecting system, including the renal pelvis and upper ureter, which is particularly beneficial in cases of complex and staghorn calculi. Moreover, the upper pole access provides a more favorable angle for instrument manipulation, reducing the need for multiple punctures and auxiliary procedures [4, 5]. While some research suggests that middle calyceal access can effectively target both the superior and inferior calyces [13], this route often creates a sharp, acute angle with these calyces, complicating thorough stone removal efforts [14]. Despite its advantages, upper pole calyx puncture is associated with a higher risk of pleural injury, which can lead to complications such as pneumothorax or hydrothorax [1, 3, 6, 7]. This increased risk is due to the proximity of the upper pole to the diaphragm and pleura. These complications are a significant concern for many urologists and may contribute to the reluctance to choose upper pole calyx puncture as the first-line approach in PCNL.

Fig. 1 The upper pole calyx fornix apex puncture can risk pleural injury, whereas the fornix subapical puncture avoids such complications

In PCNL, the fornix puncture technique is widely considered optimal for accessing the renal collecting system. This approach involves puncturing the fornix apex of the renal calyx and aligning the needle parallel to the long axis of the infundibulum [15, 16]. This method can result in a higher skin entry point for the upper pole calyx access, increasing the risk of pleural injury. To mitigate the risks associated with traditional upper pole calyx fornix apex puncture, we have adopted the technique of upper pole calyx fornix subapical puncture. This method involves puncturing the side of the upper pole calyx fornix, slightly below the apex, thereby lowering the skin entry point and reducing the risk of pleural injury (Fig. 1). This approach also improves the angle between the puncture line and the upper body, enhancing the maneuverability of the nephroscope. Although the angle between the puncture line and the long axis of the kidney increases, this method can fully utilize the kidney's own mobility, making it easier to explore the dorsal lower calyx (Fig. 2). The fornix subapical puncture aligns with the "puncture zone" concept, which introduces a broader view of ideal puncture sites. This zone takes into account the anatomy of the infundibulum and allows for flexible adjustment of the puncture site to minimize trauma and optimize access [17]. This concept supports the safety of the calyx fornix subapical puncture approach.

The subapical technique strategically avoids the calyceal infundibulum and renal column, reducing bleeding risk. Despite the more oblique needle trajectory, we observed no increase in hemoglobin drop ($P = 0.252$). In contrast to traditional supracostal apical puncture, which may risk pleural or visceral injury, our method achieved 58.2% intercostal access without complications, benefiting from ultrasound-guided real-time visualization of surrounding structures.

Beyond pleural complications, upper pole puncture has been associated with potential injuries to adjacent organs such as the liver and spleen due to anatomical proximity. Previous studies noted that supracostal upper pole access, particularly when performed without careful image guidance, may increase the risk of hepatic or splenic injury in addition to pleural complications [1–3, 7]. Notably, our study reported no pleural, hepatic, or splenic injuries in either group. This favorable safety profile can be attributed to ultrasound-guided subapical fornix puncture, which enables real-time visualization and avoidance of critical adjacent structures.

Our findings revealed no significant difference in hemoglobin drop between the two groups (2.13 ± 1.17 g/L vs. 2.32 ± 1.1 g/L, $P = 0.252$), demonstrating that both subapical and apical punctures of the calyx fornix maintain equivalent safety profiles. This result aligns with Soares et al. [18], who reported comparable median hemoglobin

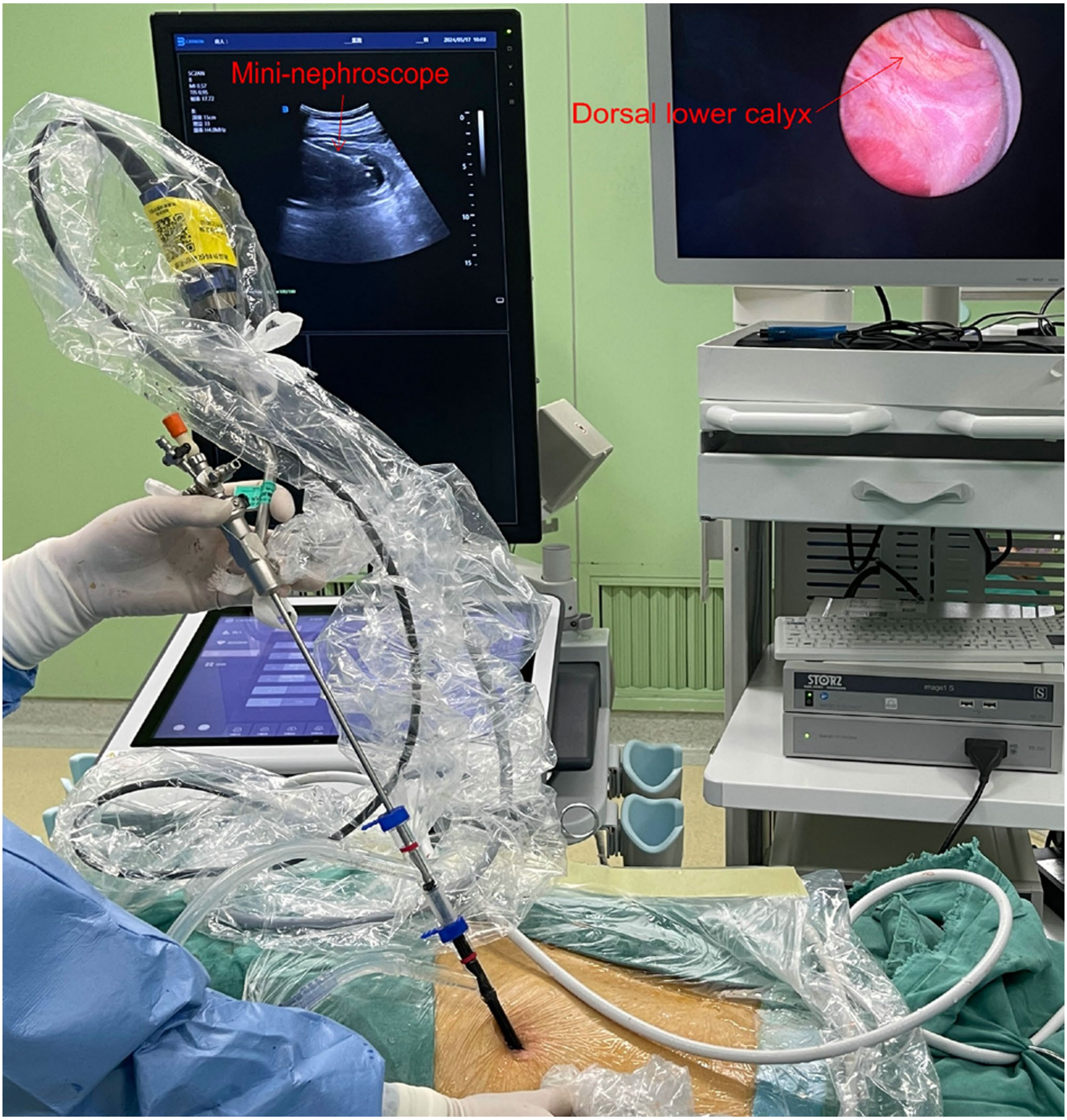

Fig. 2 Utilizing the kidney's own mobility, the mini-nephroscope can easily explore the dorsal lower calyx through the upper pole access

decreases of 6.5 and 6.0 for upper and non-upper pole access, respectively.

The significantly shorter tract establishment time in the upper pole calyx puncture group (3.06 ± 0.35 min vs. 5.36 ± 0.66 min, $P < 0.001$) can be attributed to the distinctive anatomical features of the upper pole calyx, which typically presents a larger, funnel-shaped internal space compared to the inferior and middle calyces, facilitating puncture and tract establishment (Fig. 3).

Our analysis revealed that while overall renal hydronephrosis showed no significant difference between groups ($P = 0.728$), target calyx hydronephrosis was significantly greater in the Upper-PCNL group compared to the Mid-PCNL group ($P < 0.001$). This anatomical distinction likely contributed to the substantially shorter tract establishment time observed in the upper pole group. The more dilated calyx provides a clearer target for puncture, enhances ultrasound visualization, and reduces

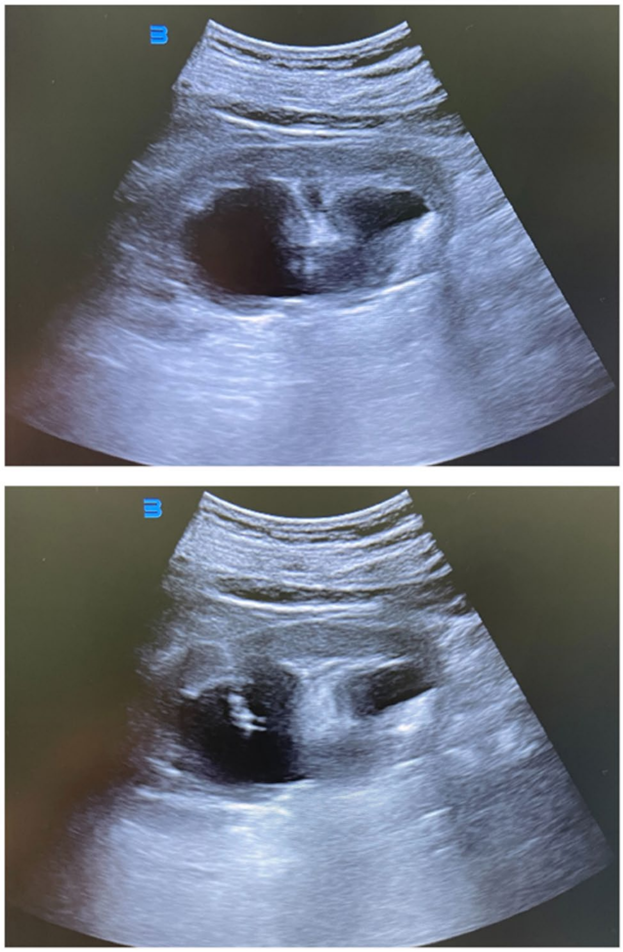

Fig. 3 Kidney stones often lead to a larger, funnel-shaped internal space of the upper calyx (top image). Ultrasound-guided upper pole calyx fornix subapical puncture (bottom image)

parenchymal resistance—particularly important when artificial hydronephrosis may be less effective in kidneys with thick parenchyma [19–21].

Furthermore, the operative time was significantly shorter in the upper pole calyx fornix subapical puncture group (59.99 ± 5.85 min vs. 68.49 ± 6.74 min, $P < 0.001$). In comparison to Nottingham et al. [3], our mean operative times were shorter. This efficiency is likely due to the favorable anatomical and functional attributes of the upper pole access, which provide a more straightforward route to the renal pelvis and upper ureter, enabling quicker and more effective stone removal.

Our study also found that the primary stone-free rate was significantly higher in the upper pole calyx puncture group compared to the middle calyx puncture group (83.6% vs. 69.4%, $P = 0.021$), which aligns with existing literature [22] and supports Ma et al.'s [1] meta-analysis conclusion that superior calyceal access provides better stone clearance (OR: 0.64, 95% CI, 0.47–0.88, $P = 0.006$). Our stone-free rate is comparable to recent studies by Kucukyangoz et al. [2] and Van der Jeugt et al. [23], who reported 88% and 85% success rates respectively using upper pole access approaches.

Importantly, none of the patients in the upper pole calyx puncture group experienced pleural, liver, or spleen injuries. This outcome is likely related to the subapical puncture technique, which lowers the risk of such injuries by avoiding critical structures. Through comparing the PCNL surgical outcomes of patients in the upper pole calyx puncture group and the middle calyx puncture group, we found that the subapical puncturing of the calyx fornix is equally effective and safe as puncturing through the apex.

To our knowledge, this is the first study to systematically evaluate upper pole calyx fornix subapical puncture as a distinct and standardized technique in PCNL. Unlike non-papillary puncture, which typically refers to access through the infundibulum or renal pelvis [24], our technique represents a modified form of upper pole access that preserves the anatomical advantages of upper pole entry while minimizing the risk of pleural injury.

This study has several limitations. First, as a single-center retrospective study, selection bias cannot be completely ruled out. Second, the follow-up period was relatively short, limiting our ability to assess long-term outcomes. Third, the experience of the surgeons might influence the results, and the learning curve was not analyzed in this study. Fourth, the sample size was relatively small, which may affect the statistical power of our findings. Future research should include prospective randomized controlled trials, multicenter studies, and long-term follow-up to validate these findings.

Conclusion

In this single-center retrospective study, upper pole calyx fornix subapical puncture in PCNL demonstrated higher primary stone-free rates and shorter operative times compared to middle calyx puncture. The technique showed comparable safety profiles with no increased risk of complications.

Author contributions

TZL and BL developed the protocol, analyzed the data, and wrote the manuscript. YZ and BL developed the protocol and collected the data. WW and YZW supervised the data analysis and manuscript preparation. YTZ developed the protocol. XHW supervised the project. ZHW supervised the data analysis and manuscript preparation. All authors read and approved the final manuscript.

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Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request. All data were de-identified to protect patient privacy.

Declarations

Ethics approval and consent to participate
This retrospective study was approved by the Medical Ethics Committee of Zhongnan Hospital of Wuhan University (Approval Number: 2023228 K). The study adhered to the principles outlined in the Declaration of Helsinki. The requirement for written informed consent was waived by the ethics committee due to the retrospective nature of the study. All patient data were anonymized before analysis.

Consent for publication
Written informed consent was obtained from the patient for publication and any accompanying images. A copy of the written consent is available for review by the Editor-in-Chief of this journal on request.

Competing interests
The authors declare no competing interests.

Clinical trial number
Not applicable.

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