Article

A Comparative Study of Retrograde Intrarenal Surgery versus Percutaneous Nephrolithotomy for the Management of Staghorn Renal Calculi

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AIM: The indications for performing retrograde intrarenal surgery (RIRS) have increased. However, no comparative studies have been conducted on the treatment of staghorn renal calculi using RIRS and percutaneous nephrolithotomy (PCNL). We aimed to compare the effectiveness and safety of RIRS and PCNL as treatments for staghorn renal calculi.

METHODS: We conducted a retrospective analysis of patients with staghorn renal calculi who underwent either PCNL or RIRS at our hospital from January 2021 to July 2023. Patients with staghorn renal calculi and renal malformation, as well as those with interrupted treatment or irregular follow-up, were excluded from the study. We compared the perioperative outcomes and complications between the groups.

RESULTS: Fifty patients were included in the RIRS group, whereas 48 patients were included in the PCNL group. 1. No significant differences were observed between the groups regarding the number of complete staghorn calculi, stone size, age, sex, or other demographic characteristics. 2. RIRS was associated with a shorter postoperative hospitalization time (2.14 $\pm$ 0.76 vs. 5.15 $\pm$ 1.98 days, $p < 0.001$). 3. RIRS was associated with a decrease in hemoglobin (0.1 [0, 0.2] vs. 0.65 [0.4, 1] g/dL, $p < 0.001$) and a lower pain score (1 [1, 2] vs. 2 [1, 3], $p = 0.008$). 4. Compared with PCNL, RIRS did not significantly differ in terms of the 1-stage stone-free rate (50% vs. 66.67%, $p = 0.095$) or total stone-free rate (84% vs. 89.58%, $p = 0.415$). 5. The overall complication rate was lower in the RIRS group (10% vs. 16.67%, $p = 0.331$).

CONCLUSIONS: Compared with PCNL, RIRS can reduce bleeding and overall complications, shorten the hospitalization time, and achieve satisfactory stone-free rate. As a result, RIRS can be considered an alternative treatment option for staghorn renal calculi.

Keywords: staghorn renal calculi; percutaneous nephrolithotomy; retrograde intrarenal surgery; stone-free rate; complication

Introduction

Staghorn renal calculi are a specific and complex type of renal calculus characterized by their ability to fill the renal pelvis and branch into all or part of the renal calyces [1]. If the calculi occupy all the calyces or more than 80% of the renal pelvis volume, it is called a complete staghorn renal calculus. Otherwise, it is called a partial staghorn renal calculus. Staghorn renal calculi can cause recurrent pain, urinary tract infections, and even urosepsis, ultimately leading to severe damage to kidney function. Therefore, surgical intervention should be actively considered for all staghorn renal calculi. Owing to the complex morphology of staghorn renal calculi, stone removal is challenging, and postoperative recurrence is common, which is still a significant clinical challenge in urology [2].

Percutaneous nephrolithotomy (PCNL) is currently the preferred treatment for staghorn renal calculi. However, the procedure has significant drawbacks, including invasiveness, postoperative bleeding, infection, prolonged hospitalization, and slow recovery. These drawbacks are especially concerning for elderly patients, as prolonged bed rest after surgery increases the risk of lower limb deep vein thrombosis (DVT) and pulmonary embolism. Retrograde intrarenal surgery (RIRS), a precise and effective minimally invasive procedure, has become the first-line treatment for stones smaller than 2 cm. Recent advancements in RIRS have significantly expanded its indications for treating renal stones larger than 2 cm. Enhanced high-definition ureteroscopes, improved laser technologies such as Holmium: YAG and Thulium fiber lasers, and advanced ureteral access sheaths have collectively contributed to the efficacy of RIRS in managing larger stones. Modern imaging techniques and improved ancillary instruments such as stone baskets and lithotripsy probes have further supported this expanded use. Consequently, RIRS presents a viable and minimally invasive alternative for larger renal calculi, with promising outcomes and manageable complication rates [3]. However, no comparative studies have been conducted on the treatment of staghorn renal calculi via RIRS and PCNL. This study aimed to compare the effectiveness and safety of RIRS and PCNL in managing staghorn renal calculi.

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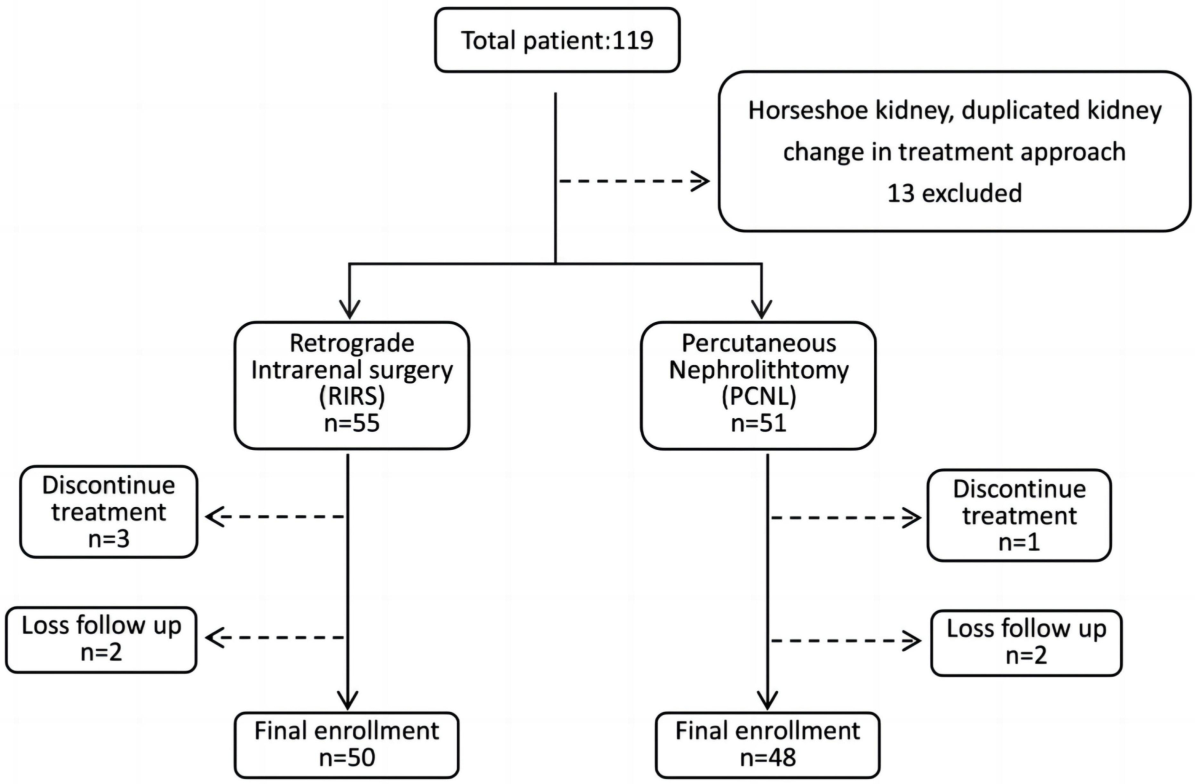

Fig. 1. Flowchart of patient enrollment.

Materials and Methods

Patients

A retrospective analysis was conducted on patients who were diagnosed with staghorn renal calculi at our hospital and scheduled for surgery between January 2021 and July 2023. The study included 119 patients who underwent either PCNL or RIRS. The exclusion criteria included horseshoe kidneys and duplicated kidneys, interrupted treatment, and loss to follow-up, as depicted in Fig. 1. Ultimately, 50 patients were in the RIRS group and 48 patients were in the PCNL group.

All patients underwent comprehensive preoperative evaluations, including routine blood tests, urinalysis, urine culture, kidney function tests, coagulation function tests, and computer tomography (CT) scans. Patient information, such as age, sex, body mass index (BMI), medical history, staghorn renal calculus type, and maximum calculus diameter, was recorded.

In this study, a horseshoe kidney was defined as a congenital condition in which the two kidneys are fused at their lower poles, forming a U-shaped or horseshoe-like structure [4]. A duplicated kidney was defined as a congenital anomaly where one or both kidneys had two ureters instead of one [5]. A decrease in hemoglobin was defined as the difference between the preoperative hemoglobin level (g/dL) and the first postoperative day's hemoglobin level. Stone-free status was determined by the presence of residual stones less than 2 mm in size on a CT scan conducted three months postoperatively. Postoperative fever was characterized by a body temperature above 38.0 °C. The numeric rating scale (NRS) is a tool used to measure pain intensity, typically on an 11-point scale ranging from 0 to 10. On this scale, 0 represents no pain, whereas 10 indicates the worst possible pain. We assessed postoperative pain using the NRS and defined an NRS score $\leq$3 as an acceptable level of pain [6].

PCNL Technique

After general anesthesia, the patient was placed in a prone split-leg configuration, and an Fr 6 ureteral catheter was introduced into the ureter to instill water and distend the renal pelvis and calyces. Guided by ultrasound, an 18-gauge puncture needle was used to puncture the target calyx. Successful puncture was confirmed when urine flowed out. Following the guidance of a guidewire, the tract was gradually dilated, and an Fr 18 peel-away sheath was left in place. Pneumatic ballistic or holmium laser lithotripsy was used to fragment the stones, and the stone fragments were flushed out. Multiple access tracts might be established depending on the intraoperative situation. In cases of suspected residual stones, a flexible ureteroscope may be inserted through the peel-away sheath for inspection and further lithotripsy [7]. If a postoperative CT scan revealed residual stones, staged percutaneous PCNL was performed.

RIRS Technique

The patient was placed in the lithotomy position after receiving general anesthesia. Guided by a guidewire, a ureteroscope (Fr 6/7.5) was maneuvered to the upper segment of the ureter. Under guidewire guidance, a ureteral access sheath (Fr 12/14) was inserted just below the ureteropelvic junction. A flexible ureteroscope (Fr 8.7) was introduced through the access sheath. The laser energy was set to 0.3–0.6 J with a frequency of 50 Hz to achieve the powderization effect for stone fragmentation. Stone fragments larger than 2 mm were retrieved using a stone retrieval basket, whereas fragments smaller than 2 mm were allowed to pass naturally. After the surgery, a double-J stent (Fr 5) was placed [8]. Follow-up examinations were conducted, and if no significant residual stones were found, the double-J stent was removed 2–4 weeks postoperatively. Upon postoperative follow-up, if significant residual stones were detected, the patient would undergo a second stage of RIRS.

Statistical Analysis

In this study, the sample size was calculated based on the total stone-free rate. Preliminary results indicated an incidence rate of 0.89 for both the experimental (RIRS) and control (PCNL) groups. Using a two-sided alpha of 0.05 and a power of 0.8, the sample size ratio was set at 1:1 with an equivalence margin of 0.2. The calculation was performed using PASS 11 software (NCSS Statistical Software, Kaysville, UT, USA). To account for a 10% loss to follow-up, a minimum of 94 patients were included, and 47 patients were included in each group. Ultimately, 50 patients were included in the RIRS group, and 48 were included in the PCNL group, resulting in a total of 98 patients. Continuous variables that followed a normal distribution were reported as means ± standard deviation and were analyzed using *t* test, whereas variables that did not follow a normal distribution were presented as medians and interquartile ranges and analyzed using the Mann–Whitney U test. Categorical variables were presented as frequencies and percentages and analyzed chi-squared test. When any expected count was less than 5, Fisher's exact test was utilized. A *p* value of less than 0.05 was considered statistically significant. Statistical analyses were performed using SPSS version 26.0 (IBM Corporation, Armonk, NY, USA).

Results

The patient enrollment process is illustrated in Fig. 1. A total of 98 patients were included in this study. The RIRS group consisted of 50 patients, whereas the PCNL group included 48 patients.

The basic clinical data of the two groups, including age, sex, BMI, diabetes status, hypertension status, antiplatelet medications, anticoagulant medications, history of kidney open surgery, staghorn renal calculi type, maximum stone diameter, stone size and hydronephrosis, were not significantly different (Table 1). The numbers of complete staghorn renal calculi in the RIRS group and PCNL group were 20 (40%) and 26 (54.17%), respectively. The stone sizes in the RIRS and PCNL groups were 699.83 (440.78, 992.24) mm^2 and 791.28 (589.34, 1249.33) mm^2, respectively, with no statistically significant difference (p = 0.112). Positive urine cultures were detected in 12 patients in the RIRS group and 16 patients in the PCNL group. These patients received appropriate antimicrobial treatment based on antibiotic sensitivity testing results and underwent surgery after negative follow-up urine cultures.

Table 2 compares the perioperative parameters between the groups. The numbers of surgeries in the RIRS group and PCNL group were 1 (1, 2) and 1 (1, 2), respectively (p = 0.174). The two groups had similar total operative times and mean operative times. Compared with the PCNL group, the RIRS group had a shorter postoperative hospital stay (2.14 ± 0.76 vs. 5.15 ± 1.98 days, $p < 0.001$). Compared with PCNL, RIRS was associated with a smaller decrease in hemoglobin (0.1 [0, 0.2] vs. 0.65 [0.4, 1] g/dL, $p < 0.001$) and a lower postoperative pain score on the first day (1 [1, 2] vs. 2 [1, 3], p = 0.008).

Table 2 also compares the incidence of complications between the two groups. In the RIRS group, there were 4 patients with fever, whereas there were 5 patients in the PCNL group. The PCNL group included one case each of pseudoaneurysm, blood transfusion, and pneumothorax. In the RIRS group, 1 patient who underwent emergency ureteroscopic lithotripsy had a clinically significant steinstrasse. The incidence of complications was greater in the PCNL group than in the RIRS group, but the difference was not significant.

Table 3 compares the stone-free rates between the groups. After the first-stage surgery, the stone-free rate in the RIRS group was 50%, whereas it was 66.67% in the PCNL group (p = 0.095), with no statistically significant difference. After second-stage surgery, the stone-free survival rate was 68% in the RIRS group and 83.33% in the PCNL group (p = 0.078). Following third-stage surgery, the stone-free survival rate was 78% in the RIRS group and 89.58% in the PCNL group (p = 0.121). The total stone-free rate in the RIRS group was similar to that in the PCNL group (84% vs. 89.58%, p = 0.415).

Discussion

If left untreated, patients with staghorn renal calculi may progress to chronic kidney failure and life-threatening sepsis, with a 10-year mortality rate of up to 28% [9]. Therefore, it is essential to actively treat renal calculi in clinical practice. The treatment goals are to effectively clear stones, prevent stone recurrence, manage urinary tract infections, and protect renal function. Owing to its high stone clearance efficacy, multichannel PCNL remains the preferred treatment approach. However, PCNL is associated with potential complications, such as bleeding, septicemia, renal function impairment, pneumothorax, and colonic injury

Table 1. Demographics and baseline characteristics of the patients.

Parameters	RIRS	PCNL	$t/Z/\chi^2$	p value
Number of patients	50	48		
Age, year	54.58 ± 13.30	57.81 ± 8.58	1.435	0.155
Male, n (%)	30 (60.00%)	23 (47.92%)	1.440	0.230
BMI (kg/m^2)	25 (23.00, 27.00)	24.3 (23.00, 26.00)	–1.718	0.086
Diabetes mellitus, n (%)	17 (34.00%)	14 (29.17%)	0.265	0.607
Hypertension, n (%)	22 (44.00%)	15 (31.25%)	1.694	0.193
CRF, n (%)	15 (30.00%)	17 (35.42%)	0.327	0.568
Antiplatelet drug, n (%)	8 (16.00%)	5 (10.42%)	0.664	0.415
Anticoagulant drug, n (%)	3 (6.00%)	0 (0.00%)	1.293	0.255
Previous open surgery, n (%)	4 (8.00%)	5 (10.42%)	0.004	0.949
History of SWL, n (%)	13 (26.00%)	12 (25.00%)	0.013	0.910
Positive urine culture, n (%)	12 (24.00%)	16 (33.33%)	1.045	0.307
Complete staghorn calculi, n (%)	20 (40.00%)	26 (54.17%)	1.973	0.160
Hydronephrosis, n (%)	37 (74.00%)	38 (79.17%)	0.364	0.546
Right side, n (%)	26 (52.00%)	22 (45.83%)	0.373	0.542
Solitary kidney, n (%)	5 (10.00%)	2 (4.17%)	0.531	0.466
Stone diameter (mm)	41.16 ± 11.99	45.06 ± 11.12	–1.668	0.099
Stone size (mm^2)	699.83 (440.78, 992.24)	791.28 (589.34, 1249.33)	–1.588	0.112
CTmax	1029.22 ± 287.11	1110.42 ± 428.24	1.098	0.275

Data are presented as the median (IQR 25–75), mean ± SD, and frequency (percentage), as applicable.
BMI, body mass index; CRF, chronic renal failure; IQR, interquartile range; SD, standard deviation; SWL, shock wave lithotripsy; RIRS, retrograde intrarenal surgery; PCNL, percutaneous nephrolithotomy; CTmax, maximum CT value.

[10]. A comprehensive systematic review encompassing nearly 12,000 patients revealed the complication rates associated with percutaneous nephrolithotomy (PCNL). The findings indicate that the incidence of fever is 10.8%, the need for blood transfusion is 7%, thoracic complications occur in 1.5% of cases, sepsis in 0.5%, organ injury in 0.4%, embolization in 0.4%, urinoma in 0.2%, and mortality in 0.05%. Notably, PCNL procedures involving multiple tracts are associated with a heightened risk of postoperative complications, including pleural damage, infections, and an increased need for transfusions [11].

RIRS has now become the first-line choice for treating renal stones smaller than 2 cm [2]. With advancements in endoscopic equipment and techniques, more studies have reported experiences with RIRS for managing renal stones exceeding 2 cm in size. For example, studies have shown that in the treatment of renal stones larger than 2 cm, the perioperative complication rate is significantly lower in the FURSL group (13.5%) than in the mini-PCNL group (23.7%). Additionally, the hospital stay was significantly shorter in the FURSL group (1.3 days) than in the mini-PCNL group (2.5 days). While the stone-free rate (SFR) was lower in the FURSL group (81.1%) than in the mini-PCNL group (89.5%), this difference was not statistically significant [12].

The guidelines indicate that RIRS for treating staghorn renal calculi is only suitable for specific patients, such as those with a solitary kidney who strongly request RIRS or patients who cannot withhold anticoagulant medications. Compared with PCNL, RIRS reduces the risk of complications related to percutaneous access, such as bleeding and adjacent organ injury, making it a safer option. Therefore, some clinical centers have started to explore RIRS to address staghorn renal calculi. For example, Lai *et al.* [13] used flexible ureteroscopy to treat 30 cases of staghorn renal calculi in solitary kidneys. The stone-free rate for a single RIRS session was 53.3%, whereas the total stone-free rate after multiple RIRS procedures reached 86.7%. There was one case of ureteral steinstrasse and one case of perirenal abscess postoperatively [13]. Yang *et al.* [14] treated 43 patients with staghorn renal calculi with RIRS, with a first-stage stone-free rate of 72.1% and a final stone-free rate of 88.4% after multiple-stage RIRS. Similar to the PCNL group, the RIRS group achieved an 84% stone-free rate after multiple-stage procedures, while the overall complication rate was 10%. Zhu *et al.* [15] reported 54 cases of RIRS for treating staghorn renal calculi, with a first-stage stone-free rate of 33.3% and a complete stone-free rate of 83.3%. The overall incidence of complications was 35.2%. Together, the findings from the literature and this study suggest that multiple-stage RIRS for the treatment of staghorn renal calculi can achieve a stone-free rate similar to that of PCNL. With negative pressure ureteral access sheaths and more efficient lasers, the number of surgical procedures required for RIRS to treat staghorn renal calculi may further decrease, leading to higher stone-free rates.

Table 2. Comparison of the perioperative data between the RIRS and mPCNL groups.

	RIRS	PCNL	$t/Z/\chi^2$	*p* value
Operation number	1 (1.00, 2.00)	1 (1.00, 2.00)	–1.36	0.174
Puncture number		2 (1.00, 2.00)		
Nephrostomy tubeless, n (%)		4 (8.33%)		
Mean operation duration (minute)	110.08 ± 23.84	120.45 ± 43.13	1.465	0.147
Total operation duration (minute)	149.5 (108.50, 276.25)	175 (111.75, 238.50)	–0.281	0.779
Postoperative hospitalization (day)	2.14 ± 0.76	5.15± 1.98	9.857	<0.001*
Postoperative 1st day VAS in pain	1 (1.00, 2.00)	2 (1.00, 3.00)	–2.644	0.008▲
Mean drop in hemoglobin (g/dL)	0.1 (0.00, 0.20)	0.65 (0.40, 1.00)	–7.858	<0.001▲
Overall complication, n (%)	5 (10.00%)	8 (16.67%)	0.946	0.331
Fever, n (%)	4 (8.00%)	5 (10.42%)	0.004	0.949
Need for blood transfusion, n (%)	0 (0.00%)	1 (2.08%)		0.490
Renal pseudoaneurysm, n (%)	0 (0.00%)	1 (2.08%)		0.490
Pneumothorax, n (%)	0 (0.00%)	1 (2.08%)		0.490
Steinstrasse, n (%)	1 (2.00%)	0 (0.00%)		1.000

Data are presented as the median (IQR 25–75), mean ± SD, or frequency (percentage), as applicable.

Note: * denotes the *t* test; ▲ indicates the Mann–Whitney U test.

VAS, visual analog scale.

Table 3. Comparison of the stone-free rate (n, %).

		Stone-free rate *p* value				
	Number	1st surgery	2nd surgery	3rd surgery	4th surgery	Total
RIRS	50	25 (50.00%)	34 (68.00%)	39 (78.00%)	42 (84.00%)	42 (84.00%)
PCNL	48	32 (66.67%)	40 (83.33%)	43 (89.58%)		43 (89.58%)
χ^2		2.796	3.114	2.405		0.664
p value		0.095	0.078	0.121		0.415

Compared with the PCNL group, the RIRS group had significantly lower pain scores on the first day after surgery. Although the RIRS group required more surgical procedures than the PCNL group, the RIRS patients experienced less discomfort and faster recovery, leading to significantly shorter postoperative hospital stays and overall hospitalization durations than the PCNL group. The longer hospital stay in the PCNL group was due primarily to the placement of the nephrostomy tube. Study has shown that tubeless PCNL is the most important factor in reducing hospitalization time [16]. In practice, we evaluate the presence of significant residual stones, collecting system perforation, and severity of bleeding before determining the need for a nephrostomy tube. In our study, four patients did not have a nephrostomy tube, and they experienced significantly reduced discomfort, allowing them to be discharged within two days after surgery. Therefore, through more precise puncture, more efficient stone fragmentation, and gentler manipulation, the chance of performing tubeless PCNL increases, leading to shorter hospital stays and reduced hospitalization costs.

The main complications associated with PCNL are often related to renal parenchymal and adjacent structure injuries, including significant bleeding requiring blood transfusion, sepsis, colon injury, hemothorax, fever, and urinary tract infections. One of the most critical complications is severe bleeding, which necessitates blood transfusion, with incidence rates reported to vary between 0.8% and 45% [17]. In severe cases of bleeding, embolization or even nephrectomy may be necessary. In this study, one patient (2.2%) in the PCNL group experienced significant postoperative bleeding, which was diagnosed as a pseudoaneurysm on angiography and was treated with selective arterial embolization and blood transfusion.

Another patient developed immediate dyspnea and chest pain following the removal of the nephrostomy tube. Suspecting pneumothorax, we promptly packed the nephrostomy site with Vaseline gauze and applied a pressure dressing. A bedside chest X-ray revealed mild pneumothorax. After the administration of oxygen, the patient's symptoms improved. A follow-up chest X-ray one week later revealed complete resolution of the pneumothorax. Pneumothorax is commonly caused by the puncture tract passing through the parietal pleura and diaphragm. It is crucial to carefully design the puncture tract to avoid the pleura and diaphragm. Additionally, immediately sealing the nephrostomy site after tube removal is essential to prevent air from entering the pleural cavity. Compared with PCNL, RIRS has a significantly lower probability of encountering the aforementioned complications owing to the avoidance of percutaneous puncture and tract creation.

Our study cohort had a low incidence (8%) of postoperative fever; all patients recovered after receiving appropriate antibiotic treatment. Postoperative infection is a common complication following stone surgery. During the operation, continuous saline infusion ensures a clear operative field, which can lead to increased intrarenal pelvic pressure (IPP). When intrapelvic pressure exceeds 27.2 cm H_2O, fluid in the renal pelvis can flow back into the bloodstream via renal pelvic veins, lymphatics, and tubules [18]. Elevated IPP has been linked to postoperative fever, systemic inflammatory response syndrome (SIRS), and urinary sepsis [19]. Adequate perfusion can be ensured while maintaining a low intrapelvic pressure IPP if the ratio of the outer diameter of the flexible ureteroscope to the inner diameter of the ureteral access sheath (endoscope–sheath diameter ratio, RESD/REUS) is less than 0.75 [20]. With the use of even finer flexible ureteroscopes and flexible ureteral access sheath with negative pressure at the tip in clinical practice, the IPP during RIRS can be further reduced, which may lead to a further decrease in the incidence of postoperative infections.

Mariani [21] reported that 18.7% of patients with renal calculi larger than 4 cm experienced mild steinstrasse after RIRS. The incidence of steinstrasse in our RIRS cohort was 2%, and patients with a solitary kidney developed anuria and required emergent ureteroscopy for stone clearance. The risk of a steinstrasse can be significantly reduced by fragmenting larger residual stones into smaller particles (<2 mm) during RIRS. Therefore, using a low-energy and high-frequency powder lithotripsy mode should be the preferred method for RIRS of staghorn renal calculi. Our center's experience in preventing steinstrasse is as follows: 1. Patients are instructed to undergo preoperative pulmonary function training. 2. Anesthesia is administered via low tidal volume and high-frequency ventilation. 3. The low-energy, high-frequency mode is employed during the stone fragmentation procedure. 4. Negative pressure is used to suction the powder formed during the procedure. 5. A stone retrieval basket is used to extract fragments. 6. Finally, a popcorn mode is applied to further fragment the slightly larger stones. 7. A stone positioning bed is used to assist with stone passage. These adopted techniques potentially help control the incidence of steinstrasse syndrome in our study cohort.

This study has some limitations that should be considered when interpreting the results. First, as a retrospective study, it inherently carries the risk of selection bias. Second, the follow-up period for patients after the procedure was not sufficiently long to evaluate long-term complication rates, such as those related to renal function. These limitations highlight the need for further large-sample prospective studies to provide more robust data and address the issues mentioned above.

Conclusions

While PCNL is now the first-line treatment for staghorn renal calculi, our study demonstrated that multisession RIRS is a similarly effective but safer alternative to PCNL for managing staghorn renal calculi. Compared with PCNL, RIRS also significantly reduced postoperative pain, hospitalization duration, and bleeding complications.

Availability of Data and Materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Author Contributions

XX, SCL, GGW: conceived the study. FHX, YJ, LX, ZQL: data acquisition and statistical analysis. XX, SCL, GGW: completed the manuscript text with the supervision of LX. All authors have been involved in revising it critically for important intellectual content. All authors read and approved the final manuscript. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

The study protocol complied with the Declaration of Helsinki and was approved by the Medical Ethics Committee of The University of Hong Kong-Shenzhen Hospital (No. hkuszh2023178). The need for informed consent was waived by the Medical Ethics Committee of The University of Hong Kong-Shenzhen Hospital because of retrospective study design.

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Conflict of Interest

The authors and contributor declare no conflict of interest.

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