Factors predicting stone-free rates after retrograde intrarenal surgery for lower pole kidney stones

A single-center, retrospective analysis

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ABSTRACT

INTRODUCTION: We aimed to investigate the factors impacting stone clearance following retrograde intrarenal surgery (RIRS) for lower pole kidney stones and to determine whether there is a significant relationship between the infundibular pelvic angle (IPA) of the kidney's lower pole and stone fragment clearance.

METHODS: We retrospectively reviewed patients who underwent flexible ureteroscopy (f-URS) for lower pole renal calculi between December 2020 and July 2023 at our institution. Patient demographics and stone parameters were recorded, including stone size, number, volume, density, and IPA. Intraoperative data, including total operative time, lasing time, type of laser used, and stone composition, were collected and analyzed. All patients underwent a computed tomography (CT) scan at three months followup. We recorded the presence of residual stones and the percentage of stone volume reduction. Patients with a stone size ≤3 mm were deemed stone-free. All patients were discharged home on the same operative day.

RESULTS: A total of 123 patients were included in the study: 71 in the stone-free group (group 1) and 52 in the residual stones group (group 2). On univariate analysis, there were significant differences between the two groups in terms of stone size, IPA, and the type of ureteroscopy used. At three-month followup, 96% (24/25) of patients with an IPA <30° had residual stones compared to 28.6% (28/98) of patients with an IPA >30° ($p<0.001$). There was no significant difference in the intraoperative or postoperative complications between the two groups. On multivariate analysis, IPA and stone size were the only predictive factors for the presence of residual stones. Twelve patients (23.1%) from group 2 required retreatment.

CONCLUSIONS: RIRS is an effective treatment option for the management of lower pole kidney stones. IPA, in conjunction with stone size, appears to dictate the stone clearance rates of RIRS for lower pole stones.

INTRODUCTION

Stone formation and recurrence continue to pose significant health concerns. Worldwide, the prevalence of nephrolithiasis varies, with rates ranging from 7–13% in North America, 5–9% in Europe, and 1–5% in Asia.[1] Numerous factors must be considered when determining the optimal treatment approach for patients with renal or ureteral calculi. If the decision is made to pursue active or surgical interventions, three commonly used minimally invasive treatment modalities are extracorporeal shock wave lithotripsy (ESWL), percutaneous nephrolithotomy (PCNL), and retrograde intrarenal surgery (RIRS).

The stone-free rates for ESWL and ureteroscopic retrieval, which are used in >70% of surgical management cases, typically range from 50–80%. These rates apply to radiopaque stones measuring <2 cm in size that are situated in non-dependent locations of the kidney (i.e., the upper pole, middle pole, or renal pelvis).[2] Nevertheless, stones typically form in the lower pole of the kidney, accounting for up to 35% of cases.[3] Lower pole stones (LPS) tend to yield less favorable outcomes, with a three-month efficacy rate ranging from 23–56% for 11–20 mm stones and 14–33% for 21–30 mm stones.[4]

Various theories have been proposed regarding the significance of lower pelvicalyceal anatomy as a predictor of success in managing lower pole anatomy.[5,6] According to the European Association of Urology guideline, the following are risk factors for a negative outcome of treatment by ESWL: steeper infundibulopelvic angle (IPA), smaller infundibular width (IW), and a higher infundibular length (IL).[7] The structure of the renal anatomy may impact treatment success by flexible ureteroscopy (f-URS) for LPS, but it is not as understood, as it is for ESWL, how significant of a factor it may be.[8]

Studies to date have examined the impact of lower pole anatomical parameters, such as IW, IL, lower pole infundibulopelvic (LPIP) angle, and caliceal pelvic height (CPH).[8-11] A study by Giulioni et al found that other factors, such as stone number and size, as well as the use of reusable ureteroscopes, may also impact treatment success.[12]

A recent study evaluating clinical outcomes in patients treated for isolated LPS using RIRS found that the roles of IW and IL were not statistically significant.[11] RIRS has become a more preferred method due to the addition of single-use ureteroscopes, which have a decreased scope diameter that allow for higher deflection, making RIRS a better option for LPS. Furthermore, single-use ureteroscopes have led to decreased operative time and reduced the use of costly, reusable scopes.[13,14]

In this retrospective study, we aimed to investigate the factors impacting kidney stone clearance following RIRS for LPS and to determine whether there is a significant relationship between the IPA of the kidney's lower pole and stone fragment clearance.

METHODS

Following Research Ethics Board approval, we conducted a retrospective study on patients who underwent f-URS for lower pole renal calculi at our institution from December 2020 to July 2023. Patients were managed with f-URS and laser lithotripsy using either a 60 Watt SOLTIVE™ SuperPulsed thulium fiber laser (TFL) from Olympus or a MOSES™ technology 120 H laser system (Lumenis®Pulse). We excluded cases that involved a bilateral or staged procedure and patients in whom ureteral stones were concomitantly present. The stones were treated in situ in the lower pole of the kidney, with no relocation to other calyces.

Patient demographics and stone parameters, including stone size, quantity, volume, density, and IPA, were recorded. Preoperative computed tomography (CT) scans were analyzed to determine stone characteristics, including three-dimensional size (width [W], length [L], height [H]), and stone density. Stone volume was calculated using the ellipsoid formula ($\pi \times L \times W \times H \times 0.167$).[15] The presence of hydronephrosis and preoperative ureteral stents was also documented. The IPA was calculated using X-ray-calibrated retrograde pyelogram. The IPA measurement was conducted using Elbahnasy's method.[5]

All patients underwent their procedures at the same hospital and were operated on by various surgeons, including attending physicians and fellows. Procedures were conducted using either a single-use (Innovex® Anqing Medical, China) or reusable ureteroscope Flex-XC (Storz, Germany), with a 200-micron laser fiber used for MOSES™ and TFL. Lasing times were recorded by the laser systems and the laser type was documented. Operative time was defined as the duration from cystoscope introduction for guidewire insertion to the insertion of the stent. In cases where a ureteral access sheath was inserted, stenting was carried out at the end of the procedure. Surgeons ensured the retrieval of at least one calculus piece for subsequent chemical analysis.

Postoperative CT scans were done three-months post-procedure to check for residual stone presence, location, and size. Residual stone volumes were also calculated using the ellipsoid formula.[15] To determine the percentage of stone reduction, the primary and secondary stone volumes were subtracted, and the result was divided by the primary volume and then multiplied by 100. Two cutoffs were used to report the stone-free rate (SFR) as a percentage: no visible remnants (zero fragments) and fragments ≤3 mm in size.[16,17]

Some patients with a high stone burden underwent a postoperative CT scan at four weeks prior to stent removal to assess the need for a second-look ureteroscopy. In addition, postoperative complications were closely monitored over 90 days and recorded, including emergency room visits, complaints during followup visits, and imaging results that indicated a complication.

Continuous variables were expressed as medians and ranges, while categorical variables were described using frequencies and percentages. Statistical analysis was carried out using IBM® SPSS® Software version 23. To compare differences between the two groups, the following tests were employed: Chi-squared test, Fisher's exact test, and Pearson's χ^2 test for categorical variables, the independent sample t-test for normally distributed continuous variables, and the non-parametric Mann-Whitney U test for non-normally distributed data. Univariate and multivariate analyses were performed using a binary logistic regression model. Univariate analysis was conducted to evaluate potential parameters associated with the SFR. Only parameters with $p<0.1$ were further evaluated using the multivariate model. Multivariate analysis was used to identify independent predictors for SFR following URS. A $p<0.05$ was considered statistically significant.

RESULTS

This study involved two groups of patients who underwent RIRS for LPS: one that was stone-free and the other that had residual stones. We identified a total of 123 eligible cases, with 71 individuals in the stone-free group and 52 patients in the residual stones group. The median patient age was 65 and 69 years in the stone-free and residual stones groups, respectively (p=0.09). None of the included patients had preoperative stents or preoperative hydronephrosis. The median stone volume was 378 mm^3 for the stone-free group and 514 mm^3 for the residual stones group (p=0.07). Residual stones were present in 42.3% of all operated patients.

Only one patient in the stone-free group had an IPA ≤30°, with a median angle of 58.7°, while in the residual stones group, 24 of 52 patients (46.2%) had an IPA ≤30°, with a median angle of 31.4°. The individual clinical features and preoperative stone metrics are presented in Table 1. Among patients with an IPA score ≤30°, 24 of 25 (96%) had residual stones, while only 28.6% (28/98) of those with an IPA >30° had residual stones (p<0.001).

Operative and perioperative data

The median operative time in the stone-free group was 57 minutes, whereas it was 52 minutes for patients with residual stones (p=0.49) (Table 2). Postoperative ureteral stenting was performed in 61 (85.9%) of the stone-free patients and 44 (84.6%) of residual stone patients (p=0.84). There were four cases of observed ureteral injury (two in each group), classified as grade I according to the endoscopic ureteral injury grading. All instances of suspected ureteral injury were treated with ureteral stent insertion.

No significant difference in 90-day complication rates was observed between the groups. We recorded five (7%) cases of stent-related storage symptoms in the stone-free group and three (5.8%) incidents in the residual stones group, which were managed expectantly (Clavien I). Clavien II complications included patients who presented with a urinary tract infection and were treated with oral antibiotics (Table 2).

Clinical outcomes

None of the participants in the stone-free group required retreatment, whereas 12 individuals (23.1%) in the residual stones group needed retreatment. All patients who required retreatment underwent a second-look ureteroscopy for the residual stones. In the stone-free group, the residual stone size ranged from 0–0.3 cm, with a median size of 0 cm, whereas in the residual stones group, it ranged from 0.4–4 cm, with a median size of 0.6 cm (p <0.001) (Table 3). Among the participants in the stone-free group, stone sizes were distributed as follows: 0 mm in 54 patients (76.0%), 2 mm in six patients (8.5%), and 3 mm in 11 patients (15.5%).

To identify the factors influencing SFR, multivariate logistic regression analysis was performed, incorporating independent variables such as IPA, stone size, number of stones, stone volume, stone density, laser type, and URS type. The results demonstrated that IPA and stone size were the only significant factors in predicting SFR for LPS (Table 4).

Table 1. Patient characteristics and preoperative data

Parameter	Stone-free n=71	Residual stones n=52	p
Gender			
Male, n (%)	35 (49.3)	33 (63.5)	0.12
Female, n (%)	36 (50.7)	19 (36.5)	
Side			
Right, n (%)	25 (35.2)	25 (48.1)	0.15
Left, n (%)	46 (64.8)	27 (51.9)	
Age at surgery, years, median (range)	65 (25–84)	69 (24–94)	0.09
BMI, kg/m^2, median (range)	20.9 (17–40)	21.8 (16–35)	0.63
Stone size, cm, median (range)	1.1 (0.4–3.9)	1.2 (0.6–3.6)	0.034
Stone volume, mm^3, median (range)	378 (42–4795)	514 (101–4760)	0.07
Number of stones, median (range)	1 (1–3)	1 (1–3)	0.31
Stone density HU, median (range)	772 (211–1604)	734 (215–1384)	0.25
IPA, median (range)	58.7° (24–77)	31.4° (15–71)	<0.001
IPA			
≤30°, n (%)	1 (1.4)	24 (46.2)	<0.001
>30°, n (%)	70 (98.6)	28 (53.8)	
Anticoagulant or antiplatelet n (%)	4 (5.6)	5 (9.6)	0.4
ASA score			
I, n (%)	39 (54.9)	26 (50)	0.65
II, n (%)	26 (36.6)	23 (44.2)	
III, n (%)	6 (8.5)	3 (5.8)	

ASA: American Society of Anesthesiologists; HU: Hounsfield unit; IPA: infundibulopelvic angle.

DISCUSSION

The management of LPS is a subject of debate among urologists, presenting a dilemma in determining the

Table 2. Operative and perioperative data

Parameter	Stone-free n=71	Residual stones n=52	p
Operative time, minutes, median (range)	57 (18-135)	52 (29-121)	0.49
URS type			
Disposable, n (%)	33 (46.5)	35 (67.3)	0.02
Reusable, n (%)	38 (53.5)	17 (32.7)	
Laser type			
MOSES, n (%)	42 (59.2)	38 (73.1)	0.11
TFL, n (%)	29 (40.8)	14 (26.9)	
Access sheath, n (%)	61 (85.9)	44 (84.6)	0.84
Lasing time, minutes, median (range)	7 (1–56)	8.5 (1–65)	0.14
Postoperative ureteral stent, n (%)	61 (85.9)	44 (84.6)	0.84
Complications			
Clavien I, n (%)	5 (7)	3 (5.8)	0.91
Clavien II, n (%)	2 (2.8)	1 (1.9)	

TFL: thulium fiber laser; URS: ureteroscopy.

Table 3. Three-month followup data

Parameter	Stone-free n=71	Residual stone n=52	p
Residual stone size, cm, median (range)	0 (0–0.3)	0.6 (0.4–4)	<0.001
Residual stone volume, mm^3, median (range)	0 (0–182.5)	117 (6.8–1755)	<0.001
Residual stone number, median (range)	0 (0–1)	1 (1–2)	<0.001
% of volume reduction, median (range)	100 (73.7–100)	76.1 (12.6–98)	<0.001
Stone composition			
COM, n (%)	32 (45.1)	31 (59.6)	0.18
COD, n (%)	11 (15.5)	7 (13.5)	
CP, n (%)	17 (23.9)	4 (7.7)	
UA, n (%)	7 (9.9)	6 (11.5)	
Struvite, n (%)	0	1 (1.9)	
Cystine, n (%)	4 (5.6)	2 (3.8)	
Ammonium urate, n (%)	0	1 (1.9)	
Retreatment, n (%)	0	12 (23.1)	<0.001

COD: calcium oxalate dihydrate; COM: calcium oxalate monohydrate; CP: calcium phosphate; UA: uric acid.

most suitable treatment approach. Stone clearance is known to be related to the kidney's lower pole anatomy and stone size. Recent improvements in laser and fiber technology and the adoption of smaller surgical instruments have contributed to reduced complication rates and improved treatment outcomes.

The present study aimed to assess and elucidate the factors influencing SFR following RIRS for LPS, with a particular focus on the role of the IPA. A comparison of two groups, based on their clinical outcomes, was conducted: a stone-free group and a residual stones group. While patient demographics, initial stone metrics, and operative times were comparable in both groups, a statistically significant difference was noted for IPA, residual stone metrics, and retreatment rates.

In our study, the stone-free group had a median operative time of 57 minutes, while the residual stones group had a median operative time of 52 minutes (p=0.49). Additionally, the median stone size was 1.1 cm for the stone-free group and 1.2 cm for the residual stones group (p=0.034). Karim et al studied clinical outcomes in 108 patients treated for isolated LPS using RIRS. The mean stone size was 9.1 mm in the stone-free group and 14.8 mm in the non-stone-free group (p=0.009). Conversely, the operative time was longer in the non-stone-free group at 74.7 minutes vs. 47.9 minutes in the stone-free group (p=0.02).[11] In another study, Giulioni et al evaluated the perioperative outcomes of 2946 patients who underwent RIRS for LPS. They reported a mean stone size of 10.19 mm and a total operative time of 63.89 min.[12]

Our results revealed residual stones in 42.3% of patients. Within the stone-free group, one patient had an IPA ≤30°, with a median angle of 58.7°. In the residual stones group, 46.2% of patients had an IPA ≤30°, with a median angle of 31.4°.

Karim et al found that 94.4% of patients were stone-free at the end of their procedure. They identified a steep IPA as a significant predictor of treatment failure. Most non-stone-free patients had an IPA <30°. In addition, their meta-analysis concluded that the IL and IW showed no significant difference between the stone-free and non-stone-free groups, with data suggesting that IPA was the most important factor for LPS.[11]

Jessen and colleagues conducted a retrospective study involving 111 patients who underwent f-URS for LPS, reporting an overall SFR of 88.3% following the primary procedure.[8] They found that in both univariate and multifactorial analyses, long IL was the only anatomical parameter observed to have a statistically significant effect on the SFR. In univariate analysis, IPA approached statistical significance but did not show

Table 4. Multivariate analysis of independent predictors for stone-free rate following URS using binary logistic regression analysis

Parameter	Univariate analysis			Multivariate analysis		
	HR	95% CI	p	HR	95% CI	p
IPA	0.895	0.862–0.929	<0.001	0.886	0.848–0.925	<0.001
Stone size, cm	1.737	0.923–3.265	0.08	2.791	1.224–6.367	0.015
Stone number	0.683	0.363–1.283	0.236	–	–	–
Stone volume, mm^3	1	1–1	0.373	–	–	–
Stone density, HU	0.999	0.998–1	0.207	–	–	–
Laser type	0.534	0.246–1.157	0.112	–	–	–
URS type	0.422	0.2–0.887	0.02	0.902	0.316–2.57	0.846

CI: confidence interval; HR: hazard ratio; HU, Hounsfield unit; IPA: infundibulopelvic angle; URS: ureteroscopy.

a significant effect with multivariate analysis; however, their data revealed that extreme acute IPA angles (<30°) negatively impacted the SFR.[8] Similar to our study, Inoue and colleagues conducted a retrospective study involving 67 patients with LPS following f-URS. The SFR was 82.1% at three months of followup. Multivariate analysis revealed that the IPA significantly influenced SFR (p=0.010), with an IPA of <30° identified as a negative risk factor (p=0.019).[9]

The primary difference in SFR between our study and the findings of Jessen et al[8] and Karim et al[11] lies in the preoperative stone size and imaging methods used during the postoperative followup period. Additionally, in Jessen and colleagues' study, some stones were relocated, usually to an upper calyx, for disintegration.[8] In the Karim et al study, the mean lower pole stone size was 9.1 mm compared to 11.0 mm in our study.[11] Followup imaging included a combination of plain X-rays or ultrasound, with occasional non-contrast CT scans, performed 2–3 months post-ureteroscopy.

Similarly, in Jessen et al's study, the preoperative stone size for the stone-free group was 6.91 mm, which is smaller than in our cohort, but it was larger in the non-stone-free group at 11.69 mm.[8] In addition, the SFR was determined intraoperatively through radiologic and endoscopic evaluation, and via postoperative ultrasound on day 1. They reported that CT scans would provide a more accurate assessment of stone-free status.[8]

Several studies have demonstrated that the predictors of SFR following f-URS in LPS are multifactorial and can be associated with either stone factors, lower pole anatomy, or factors related to the procedure, such as the type of ureteroscope used or the use of a ureteral access sheath. Stone-related variables that may also impact outcome include stone volume, size, number, density, and composition.[8-12]

The outcomes of our study's multivariate logistic regression analysis indicate that stone size and IPA were statistically significant predictors of SFR for LPS. This observation aligns with the findings of Karim et al, who discovered that a steep IPA (<30°), longer operative time, and larger stone size were key indicators of treatment failure; however, factors such as the placement of the ureteric access sheath, IW, and IL, were not found to significantly impact treatment outcomes.[11]

Furthermore, Jessen et al observed that in their multifactorial analysis, factors such as stone size, IL, and brushite composition exerted a significant influence on SFR (p<0.01), whereas IW did not demonstrate a significant impact. Moreover, an acute IPA (<30°) was found to have a significant influence (p=0.01).[8]

In Giulioni and colleagues' retrospective study, SFR was defined as having residual fragments of 2 mm or smaller. At three months postoperative, 22.2% of the patients were found to have residual fragments. In their multivariate analysis, factors such as the presence of multiple stones, stone size, and the use of reusable ureteroscopes were significantly associated with residual fragments. Conversely, the use of TFL and prestenting were less likely to be associated with residual fragments.[12]

Similar to our study, Resorlu et al investigated the influence of pelvicalyceal anatomy on the success of f-URS for LPS. They concluded that an IPA of ≥45° and a stone size of <15 mm are favorable factors predicting SF status.[10]

In our cohort, 23.1% of residual stone patients required retreatment and underwent a second-look ureteroscopy. In the LPS study by Jessen et al, 11.7% of patients required a second-look f-URS.[8] Conversely, Giulioni reported that 60.8% of patients with residual fragments required additional treatments.[12]

Limitations

We acknowledge several limitations to our study. Firstly, it is a retrospective study conducted at a single center, which may be influenced by selection bias. Moreover, the relatively small sample size may affect the generalizability of our findings. This is primarily due to mini-PCNL being performed as an outpatient procedure at our institution in recent years, with >90% of cases being totally tubeless (no nephrostomy tube or internal stent).

Secondly, defining an IPA <30° as 'steep' is based on a review of current data and has not been validated as a standardized angle for clinical use. The preoperative stone size was larger in the residual stones group, making it challenging to determine if the higher residual rate was due to the difference in stone size or the IPA angle. Due to the dusting technique and poor drainage of the lower pole, interpreting stone size on postoperative CT scans can also be challenging. The presence of dust may cause stone size estimation to appear larger than preoperative measurements.

Additionally, we compared our findings to studies that may not have used the exact definition of SFR or the same imaging modalities. Therefore, comparing our findings to others may not lead to relevant conclusions that can provide clinical guidance. Standardizing SFR criteria and imaging modalities would significantly assist in developing clinically translatable evidence.

Finally, this study focused solely on RIRS for treating LPS; however, it would be interesting to explore whether renal anatomy impacts treatment success with other modalities, such as PCNL. Such investigation could offer valuable clinical guidance for urologists in selecting the most effective treatment option for patients with LPS.

CONCLUSIONS

RIRS is an effective treatment option for the management of LPS; however, it carries a higher risk of a second intervention. IPA and stone size seem to be the most important predictors for stone-free status. This is particularly important for informed decision-making during patient counseling regarding treatment success for LPS and exploring alternative treatment modalities.

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