ORIGINAL ARTICLE

Factors Associated with Stone-Free Outcome after Retrograde Intrarenal Surgery Using Low-Energy Holmium YAG Laser Based on Multivariable Logistic Regression

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Background: Retrograde intrarenal surgery (RIRS) has become an established minimally invasive treatment for kidney stones, particularly in cases where extracorporeal shockwave lithotripsy or percutaneous nephrolithotomy are unsuitable. However, stone-free (SF) outcomes vary, and identifying preoperative factors associated with success remains essential for improving patient selection and surgical planning.

Objective: To identify factors associated with SF outcomes after RIRS and to develop a simple model-based clinical decision rule using preoperative variables.

Materials and Methods: The present study was a retrospective study that included 114 patients who underwent RIRS. Baseline characteristics were compared between SF and non-stone-free (non-SF) groups. All variables were screened using bivariate logistic regression, and those with significant results were included in a multivariable analysis. Model performance was evaluated using standard statistical measures, and a simple decision rule was constructed from key preoperative factors.

Results: Stone diameter was independently associated with SF outcomes (AOR 0.86, 95% CI 0.76 to 0.98, p=0.024). Prior open surgery (AOR 0.09, 95% CI 0.01 to 1.21, p=0.070) and log-transformed estimated blood loss (AOR 0.29, 95% CI 0.07 to 1.11, p=0.071) showed borderline associations. The final model demonstrated good discriminative performance (AUC 0.87) and acceptable calibration (Hosmer-Lemeshow, p=0.47). A simple decision rule incorporating kidney stone diameter and surgical history stratified patients into low- and high-risk groups, with residual fragment rates of 12.0% and 33.7%, respectively.

Conclusion: Preoperative factors, particularly stone diameter and prior surgical history, play a key role in SF outcomes after RIRS. A simple clinical rule based on these variables may support risk stratification and guide patient counseling in routine practice.

Keywords: Retrograde intrarenal surgery; Stone-free rate; Renal calculi; Clinical decision rule; Multivariable logistic regression

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Nephrolithiasis, or kidney stone disease, is a growing global health burden, with prevalence rates ranging from 5% to 10% in many countries and significantly higher in parts of Asia and the Middle East[1-3]. This trend is expected to strengthen due to increasing metabolic risk factors and widespread lifestyle changes. In Thailand, the increasing prevalence of kidney stones shows notable variations in demographics, stone composition, and geographic distribution. Contributing factors include dietary shifts, rising rates of metabolic syndrome, and limited public awareness, particularly in rural areas, where the need for targeted prevention and management strategies is urgent[4-6].

Retrograde intrarenal surgery (RIRS) has become a standard treatment for renal stones due to its minimally invasive nature and favorable safety profile. Low-power Holmium: YAG laser systems are widely utilized in RIRS due to their broad availability, cost-effectiveness, and adequate clinical performance across a range of stone sizes[7]. The success of the procedure is primarily evaluated from the stone-free rate (SFR), which is commonly defined as the absence of detectable fragments or the presence of clinically insignificant residual fragments smaller than 5 mm. The SFR is typically assessed by computed tomography (CT) several

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weeks to months after the procedure[8,9]. Although recent RIRS studies have used stricter thresholds such as 2 mm or CT-negative criteria, multiple study cohorts continue to classify fragments measuring less than 5 mm as clinically insignificant[10-14], reflecting real-world endourological practice in which small residual fragments are asymptomatic and do not require additional intervention. The use of the 5-mm threshold in the present study was therefore consistent with previously published definitions and aligned with the authors' institutional CT protocol, where routine 3 to 5-mm slice thickness did not reliably permit retrospective differentiation of fragments as small as 1 to 2 mm.

Studies have used multivariable logistic regression to identify factors associated with stone-free (SF) outcomes after RIRS. Consistently reported predictors of a higher likelihood of clinically insignificant residual fragments include larger stone size, multiple stones, and lower pole location. Technical factors such as preoperative stenting and the use of suction-assisted devices have also been associated with improved outcomes[15-19].

Although studies have examined factors associated with SF outcomes after RIRS, many have relied on complex scoring systems or required advanced imaging parameters that are not routinely available preoperatively. Existing prediction models also vary in reporting of performance measures, particularly calibration and overall model fit, limiting their applicability in everyday practice. These gaps underscore the need for a pragmatic, preoperatively applicable approach that is both clinically intuitive, and statistically sound to support individualized treatment planning.

To address these limitations, the present study aimed to identify factors associated with SF outcomes following RIRS. Baseline characteristics were compared between SF and non-stone-free (non-SF) groups, and bivariate logistic regression was performed to screen for candidate variables. Significant predictors were then included in a multivariable logistic regression model. Model performance was evaluated using standard statistical metrics, and a simple decision rule was developed based on key preoperative variables to support individualized risk stratification in clinical practice.

Materials and Methods

Study design and ethical approval

The present study was a retrospective study conducted at Sichon Hospital, Nakhon Si Thammarat, Thailand. Ethical approval was obtained from the Human Research Ethics Committee, Office of Disease Prevention and Control 11 Nakhon Si Thammarat, Ministry of Public Health, Thailand (Protocol number NSTPH 158/2568). The present study was registered with the Thai Clinical Trials Registry (TCTR), TCTR20251125009. The need for informed consent was waived due to the retrospective design. All procedures followed the Declaration of Helsinki and relevant ethical guidelines.

Patients and eligibility criteria

The present study included patients aged 18 years or older who underwent RIRS for renal stones at Sichon Hospital between October 2022 and December 2024. Patients were eligible if their medical records were complete, including data on demographics, stone characteristics, treatment outcomes, and complications. Exclusion criteria were incomplete documentation, additional procedures performed during the same admission such as percutaneous nephrolithotomy (PCNL) or open surgery, or clinical conditions that could compromise outcome assessment. One hundred and fourteen eligible patients were consecutively included, in accordance with the retrospective nature of the present study.

All procedures were performed as single-stage RIRS. Some patients underwent bilateral RIRS. However, both renal units were treated within the same operative session, and all analyses were performed on a per-patient basis. No staged or multistage procedures on separate days were conducted in this cohort.

RIRS procedure

Pre-operative ureteral stenting was routinely performed for three to four weeks to allow passive ureteral dilation and facilitate insertion of a 12/14 Fr ureteral access sheath (UAS). This practice was adopted because non-pre-stented ureters in the present study setting frequently did not accommodate the access sheath, whereas short-term pre-stenting reliably permitted atraumatic insertion and reduced ureteric mucosal injury. Post-operative stenting was used only when ureteric mucosal abrasion or risk of acute kidney injury such as solitary functional kidney was present. RIRS was performed using a 20-W Holmium: YAG laser with a 200-µm fiber, typically at 1.0 J/8 Hz for fragmentation and 0.8 J/10 Hz for dusting, with minor adjustments based on stone characteristics. Post-operative care included intravenous (IV) hydration and Foley catheterization until hematuria resolved, which was between 24 and 48 hours. No routine medical expulsive therapy or urinary alkalinization agents were used. Analgesia consisted of oral NSAIDs, with tramadol or IV morphine given when needed.

Data collection

The collected information included patient demographics, stone characteristics, intraoperative parameters, and postoperative data. Patient demographics encompassed age, gender, body mass index (BMI), side of surgery (right, left, or bilateral), preoperative stenting status (yes or no), and postoperative stent placement (yes or no). Stone characteristics included stone diameter, number of stones (single or multiple), stone location (renal pelvis, upper pole, mid pole, lower pole, or multiple calyces), and stone density (Hounsfield unit, HU). In cases with multiple stones, stone diameter was defined as the maximum diameter of the largest stone. Prior stone treatments such as extracorporeal shock wave lithotripsy (ESWL), RIRS, PCNL, or open surgery, as well as preoperative stenting status (yes or no), were also included. Intraoperative data comprised operative time and estimated blood loss (EBL). Postoperative data included analgesic use, categorized as oral analgesic drug or IV opioid, length of stay (LOS), and the occurrence of postoperative fever.

The primary outcome was SF status, assessed by CT at three months postoperatively. SF status was defined as having no residual stone fragment measuring five millimeters or larger. Any remaining fragment smaller than five millimeters was considered a clinically insignificant residual fragment and regarded as SF for the purpose of the present study. Patients who retained any stone fragment measuring five millimeters or larger were classified as having a non-SF outcome. All outcome assessments were based on the treating urologist's documentation, and all data were anonymized prior to analysis.

Statistical analysis

All analyses were performed using Python version 3.12. A p-value of less than 0.05 was considered statistically significant for all assumption and univariate tests. Descriptive statistics summarized patient demographics, stone characteristics, intra-operative parameters, and postoperative information. The Shapiro-Wilk test was used to assess the normality of continuous variables. Depending on distribution, SF and non-SF groups were compared using either the independent samples t-test or Mann-Whitney U test, while categorical variables were analyzed using the chi-square test or Fisher's exact test, as appropriate. To meet the assumptions of the chi-square test, particularly the requirement for minimum expected cell counts, some categorical variables were grouped prior to analysis. Grouping decisions were based on data distribution and made before conducting inferential testing.

Bivariate logistic regression was performed to examine crude associations between predictors and the outcome. Tested assumptions included outliers such as standardized residuals and influence statistics, linearity in the logit with the Box-Tidwell test, and perfect separation. Predictors with p-value of less than 0.05 in the bivariate analysis were selected for inclusion in the multivariable model. Categorical variables were entered into the multivariable model if any of their dummy-coded levels showed statistical significance with p-value of less than 0.05 in the bivariate analysis. All levels were retained to preserve the integrity of the variable and to ensure unbiased estimation. Multicollinearity among all selected predictors, including dummy-coded categorical variables, was assessed using the variance inflation factor (VIF). Adjusted odds ratios (AORs) were then estimated to evaluate independent associations with SF status. Model performance was evaluated using the area under the receiver operating characteristic curve (AUC) for discrimination, the Hosmer-Lemeshow test for calibration, and Nagelkerke's R^2 for overall model fit.

Results

Comparison between SF and non-SF groups

One hundred and fourteen patients who underwent RIRS were included in the analysis. Of these, 81 (71.05%) were classified as SF and 33 (28.95%) as non-SF. To meet the assumptions of the chi-square test, some categorical variables were grouped before analysis such as side of surgery that was categorized as right, left or bilateral, prior stone treatments as none, ESWL, or other including RIRS, PCNL, and open surgery, and stone location as renal pelvis, single calyx in upper, mid, or lower, or multiple calyces.

A p-value of less than 0.05 was considered statistically significant. Statistically significant differences were observed between groups in stone diameter, operative time, EBL, stone location, and number of stones (Table 1). Variables such as prior

Table 1. Baseline characteristics of patients by kidney stone-free (SF) postoperative status

Baseline characteristics	Overall (n=114)	SF (n=81)	Non-SF (n=33)	p-value
Sex; n (%)				0.98[t]
Male	52 (45.6)	37 (71.1)	15 (28.9)	
Female	62 (54.4)	44 (71.0)	18 (29.0)	
Age (years); mean±SD	56.5±12.81	55.4±13.11	59.1±11.86	0.15[m]
Side of surgery*; n (%)				0.50[c]
Right	60 (52.6)	41 (68.3)	19 (31.7)	
Left	50 (43.9)	37 (74.0)	13 (26.0)	
Bilateral	4 (3.5)	3 (75.0)	1 (25.0)	
BMI (kg/m^2); median (range)	25.1 (22.52 to 28.85)	25.3 (23.4 to 28.4)	24.6 (22.4 to 30.7)	0.89[m]
Prior stone treatments*; n (%)				0.06[c]
None	54 (47.4)	43 (79.6)	11 (20.4)	
ESWL	23 (20.2)	17 (73.9)	6 (26.1)	
RIRS	15 (13.1)	11 (73.3)	4 (26.7)	
PCNL	17 (14.9)	8 (47.1)	9 (52.9)	
Open surgery	5 (4.4)	2 (40.0)	3 (60.0)	
Preoperative stenting; n (%)				0.35[f]
No	14 (12.3)	12 (85.7)	2 (14.3)	
Yes	100 (87.7)	69 (69.0)	31 (31.0)	
Postoperative stent placement; n (%)			0.09c	
No	74 (64.9)	57 (77.0)	17 (23.0)	
Yes	40 (35.1)	24 (60.0)	16 (40.0)	
Stone diameter (mm); median (range)	14.0 (12.0 to 19.0)	13.0 (10.0 to 16.0)	19.0 (14.0 to 23.0)	<0.001[m]
Stone location*; n (%)				0.023[c]
Renal pelvis	42 (36.8)	36 (85.7)	6 (14.3)	
Upper pole	7 (6.1)	4 (57.1)	3 (42.9)	
Middle pole	11 (9.7)	7 (63.6)	4 (36.4)	
Lower pole	31 (27.2)	21 (67.7)	10 (32.3)	
Multiple calyces	23 (20.2)	13 (56.5)	10 (43.5)	
Number; n (%)				0.033[c]
Multiple	48 (42.1)	29 (60.4)	19 (39.6)	
Single	66 (57.9)	52 (78.8)	14 (21.2)	
Stone density (HU); median (range)	953.5 (677.0 to 1,323.0)	863.0 (618.0 to 1,263.0)	1,077.0 (841.0 to 1,459.0)	0.05[m]
Operative time (minutes); median (range)	90.0 (65.0 to 135.0)	75.0 (50.0 to 100.0)	140.0 (100.0 to 180.0)	<0.0012
EBL (mL); median (range)	2.0 (2.0 to 3.0)	2.0 (2.0 to 2.0)	3.0 (2.0 to 3.0)	<0.001[m]
LOS (days); median (range)	4.0 (4.0 to 5.0)	4.0 (4.0 to 5.0)	4.0 (4.0 to 5.0)	0.40[m]
Analgesic use; n (%)				0.51[f]
Oral analgesics	81 (71.1)	59 (72.8)	22 (27.2)	
Intravenous opioid	33 (28.9)	22 (66.7)	11 (33.3)	
The occurrence of postoperative fever; n (%)				0.32[c]
No	102 (89.5)	74 (72.6)	28 (27.4)	
Yes	12 (10.5)	7 (58.3)	5 (41.7)	

SF=stone-free; BMI=body mass index; ESWL=extracorporeal shock wave lithotripsy; RIRS=retrograde intrarenal surgery; PCNL=percutaneous nephrolithotomy; EBL=estimated blood loss; LOS=length of stay

* Variables grouped prior to analysis, (t) Result of independent samples t-test, (m) Result of Mann-Whitney U test, (c) Result of chi-square test, (f) Result of Fisher's exact test

stone treatments, stone density, and postoperative stent placement also demonstrated trends toward group differences.

Bivariate logistic regression

Bivariate logistic regression was performed to explore unadjusted associations between individual predictors and SF status following RIRS. Continuous variables were assessed for distributional characteristics and outliers. To reduce skewness, EBL and LOS were transformed using the natural logarithm of each value plus one. All variables met the assumptions of linearity in the logit and absence of perfect separation.

Several variables were significantly associated with SF outcomes. Among continuous predictors, larger stone diameter, longer operative time, and higher EBL were associated with greater likelihood of achieving SF status, while stone density showed a borderline association. For categorical variables, patients with multiple stones had lower SFRs than those with a single stone. Stones located in multiple calyces were less favorable than those in the renal pelvis, and prior PCNL treatment was associated with poorer outcomes compared with no prior treatment. Other variables including age, BMI, LOS, gender, side of surgery, stent placement, analgesic use, and postoperative fever were not significantly associated with the outcome (Table 2, 3).

Table 2. Bivariate logistic regression for continuous variables

Baseline characteristics	OR	95% CI (lower to upper)	p-value
Age	0.98	0.95 to 1.01	0.17
BMI	0.98	0.90 to 1.06	0.56
Stone diameter	0.83	0.76 to 0.90	<0.001
Stone density	0.99	0.98 to 1.00	0.05
Operative time	0.97	0.96 to 0.99	<0.001
Log (EBL+1)	0.12	0.03 to 0.46	0.002
Log (LOS+1)	0.93	0.20 to 4.26	0.93

OR=odds ratio; CI=confidence interval; BMI=body mass index; EBL=estimated blood loss; LOS=length of stay

Multivariable logistic regression

Multivariable logistic regression was conducted to identify independent predictors of SF status. Prior to model fitting, multicollinearity was assessed using VIF. Although stone diameter and operative time exhibited VIF values slightly above the conventional threshold of 10, at 12.1 and 10.4, respectively, both were retained in the model due to their clinical relevance and the absence of substantial collinearity.

Stone diameter was independently associated with reduced odds of achieving SF status (Table 4). EBL and prior open surgery demonstrated trends toward negative associations, while other predictors were not significantly associated with the outcome.

Model performance

The performance of the multivariable logistic regression model was evaluated using standard metrics of discrimination, calibration, and overall model fit. The model demonstrated excellent discrimination ability with an AUC of 0.87 (Figure 1). Calibration assessed by the Hosmer-Lemeshow goodness-of-fit test yielded a non-significant result (χ^2=7.59, df=8, p=0.47), indicating good agreement between predicted probabilities and observed outcomes. The model also showed strong explanatory power, as reflected by a Nagelkerke's R^2 of 0.92, indicating that a substantial proportion of the variance in SF status was accounted for by the included predictors.

Table 3. Bivariate logistic regression for categorical variables

Baseline characteristics	Reference category	Comparison group	OR	95% CI (lower to upper)	p-value
Sex	Male	Female	1.01	0.45 to 2.27	0.98
Side of surgery	Right	Left	1.32	0.57 to 3.04	0.52
		Bilateral	1.39	0.14 to 14.25	0.78
Prior stone treatments	None	ESWL	0.72	0.23 to 2.27	0.58
		RIRS	0.70	0.19 to 2.64	0.60
		PCNL	0.23	0.07 to 0.73	0.012
		Open surgery	0.17	0.03 to 1.15	0.07
Preoperative stenting	No	Yes	0.37	0.08 to 1.76	0.21
Postoperative stent placement	No	Yes	0.45	0.19 to 1.03	0.06
Stone location	Renal pelvis	Upper pole	0.22	0.04 to 1.25	0.09
		Middle pole	0.29	0.06 to 1.31	0.10
		Lower pole	0.35	0.11 to 1.10	0.07
		Multiple calyces	0.22	0.07 to 0.72	0.012
Number	Multiple	Single	2.43	1.07 to 5.56	0.035
Analgesic drug use	Oral analgesics	Intravenous opioid	0.75	0.31 to 1.79	0.51
The occurrence of postoperative fever	No	Yes	0.53	0.16 to 1.81	0.31

OR=odds ratio; CI=confidence interval; ESWL=extracorporeal shock wave lithotripsy; RIRS=retrograde intrarenal surgery; PCNL=percutaneous nephrolithotomy

Table 4. Multivariable logistic regression showing adjusted odds ratios (AOR) for baseline characteristics with p<0.05 in bivariate analysis

Baseline characteristics	Reference category	Comparison group	AOR	95% CI (lower to upper)	p-value
Stone diameter	-	-	0.86	0.76 to 0.98	0.024
Operative time	-	-	0.99	0.97 to 1.00	0.12
Log (EBL + 1)	-	-	0.29	0.07 to 1.11	0.071
Prior stone treatment	None	ESWL	0.87	0.18 to 4.30	0.87
		RIRS	0.34	0.07 to 1.78	0.20
		PCNL	0.41	0.09 to 1.87	0.25
		Open surgery	0.09	0.01 to 1.21	0.070
Stone location	Renal pelvis	Upper pole	0.97	0.05 to 17.27	0.99
		Middle pole	1.30	0.17 to 9.97	0.80
		Lower pole	0.81	0.18 to 3.63	0.79
		Multiple calyces	1.22	0.18 to 8.13	0.84
Number	Multiple	Single	2.90	0.72 to 11.64	0.13

AOR=adjusted odds ratio; CI=confidence interval; EBL=estimated blood loss; ESWL=extracorporeal shock wave lithotripsy; RIRS=retrograde intrarenal surgery; PCNL=percutaneous nephrolithotomy

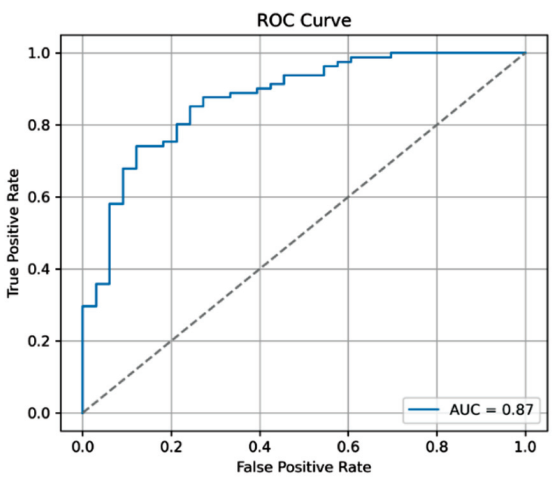

Figure 1. The receiver operating characteristic (ROC) curve demonstrating the discriminative performance of the multivariable logistic regression model (AUC=0.87).

Simple decision rule

To support clinical decision-making, the authors developed a simple rule using preoperative factors that were significant in the multivariable model. Stone diameter and prior open surgery were selected, as both can be assessed before the procedure. Although EBL showed a borderline association, it was excluded due to its intraoperative nature and limited preoperative applicability. The cutoff of 11 mm was chosen because it lay close to the central tendency of stone diameter in the present cohort and provided a clear separation between SF and non-SF outcomes. Patients were classified as high-risk if they had both a stone diameter of 11 mm or larger and a history of prior open surgery for kidney stones. The high-risk group had a non-SF rate of 33.7%, compared with 12.0% in the low-risk group (Table 5). This rule may help identify patients at increased risk of residual stones and guide preoperative planning.

Table 5. Stone-free outcomes according to the decision rule

Risk group	Criteria	SFR (%)	Non-SFR (%)
Low-risk	Either stone diameter <11 mm or no prior open surgery	88.0	12.0
High-risk	Stone diameter ≥11 mm and prior open surgery	66.3	33.7

SFR=stone-free rate

Discussion

Key findings

The present study identified three preoperative factors associated with SF outcomes following RIRS, stone diameter, prior open stone surgery, and EBL. Among these, stone diameter was statistically significant, while the other two showed trends toward significance. The multivariable logistic regression model demonstrated excellent predictive performance, with an AUC of 0.87 and a Nagelkerke's R^2 of 0.93. Based on these findings, a simple preoperative decision rule using stone diameter and prior surgical history was developed to stratify patients into two risk groups. Patients classified as high risk, defined by a stone diameter of 11 mm or greater and prior open stone surgery, had a non-SF rate of 33.7%, compared to 12.0% in the low-risk group. This tool may assist urologists in anticipating surgical outcomes, guiding treatment selection, and informing postoperative planning.

Interpretation of factors

Stone diameter was the most influential factor associated with SF outcomes. This finding aligns with clinical experience. Larger stones, particularly those exceeding 11 mm, are more difficult to completely fragment and remove during RIRS due to anatomical limitations and technical constraints. The history of prior open stone surgery is often reflected in altered intrarenal anatomy, such as calyceal distortion or fibrosis, which can impede endoscopic access and reduce procedural efficacy. Although EBL is recorded intraoperatively, its association with residual stones may reflect case complexity and surgical difficulty. Together, these factors offer a valuable insight into the need for preoperative risk assessment and treatment planning.

Perioperative characteristics of the cohort

The perioperative characteristics of the present cohort reflect the workflow of a community hospital. The mean hospital stay of approximately four days results from admission one day before surgery and 24 to 48 hours of postoperative observation, as day-surgery RIRS is not implemented in this setting. The high rate of pre-stenting relates to previous difficulties with inserting the UAS, four weeks of pre-stenting reliably dilated the ureter and facilitated atraumatic UAS placement. Consequently, postoperative stenting was often unnecessary because the pre-dilated ureter and the dusting technique minimized ureteral edema and allowed adequate drainage.

Comparison with previous studies and existing predictive models

The association between stone diameter and SF outcomes after RIRS has been well established. Pattarawongpaiboon & Usawachintachit[13] identified stone size as a significant predictor, with smaller stones linked to higher SFRs. Ergani & Kozacıoğlu[15] reported that both stone volume and maximum diameter were significantly associated with residual fragments. Similarly, Maugeri et al.[20] found that larger stones were correlated with lower SFRs. The present study found that stone diameter was the only statistically significant preoperative factor in SF outcomes. Prior open or percutaneous stone surgery has been associated with lower SFRs after RIRS. Güzel et al.[21] reported significantly reduced SFRs in patients with prior surgery, due to altered renal anatomy and scar tissue impeding endoscopic access. The present study found a similar trend, with prior open surgery associated with decreased SFRs. Taken together, stone diameter and prior open surgery are fully preoperative and clinically relevant, particularly in regions where previous open nephrolithotomy may affect renal anatomy and endoscopic access. These two variables provide practical predictors for real-world RIRS practice.

Although EBL showed a borderline association, it is an intraoperative measure and unsuitable for preoperative prediction, so it was not included in the decision rule. In the authors' center, the routinely documented value of approximately 2 mL reflects the fact that true blood loss during RIRS is extremely small and cannot be accurately quantified under continuous irrigation. Therefore, this measurement should not be interpreted as a meaningful continuous variable.

Compared with predictive systems such as the S.T.O.N.E. and Resorlu-Unsal scores, which require multiple anatomical and radiologic measurements, the present study model uses only two readily available preoperative variables, with stone diameter and prior open surgery. With an AUC of 0.87, it provides a simple and practical tool for preoperative risk stratification without the need for complex imaging-based scoring.

Clinical relevance and application

Preoperative assessment of stone diameter and prior surgical history can help identify patients at higher risk of residual fragments after RIRS. By integrating these variables into a simple decision rule, urologists can stratify patients and tailor surgical planning accordingly. This approach may inform the choice of surgical technique, improve operative efficiency, and facilitate clearer communication of expected outcomes with patients.

Strengths and limitations

The present study has strengths. SF status was objectively assessed using CT to ensure accurate outcome classification. The authors identified preoperative clinical factors that are routinely available and translated them into a simple decision rule applicable in real-world practice. The use of multivariable logistic regression enabled robust evaluation of independent associations, and the model demonstrated strong discriminative ability. In addition, the alignment of the present study findings with those of prior studies supported their clinical relevance.

However, the retrospective, single-center design may limit generalizability. The sample size may not have been sufficient to detect smaller effects, and certain factors such as stone composition, calyceal anatomy, or surgeon experience were not included. External validation is warranted before the decision rule can be widely implemented.

Future research

Future studies should aim to externally validate the proposed decision rule in larger and more diverse patient populations to confirm its generalizability. Prospective, multicenter studies that incorporate additional factors such as stone composition, pelvicalyceal anatomy, and surgeon experience may further improve risk prediction. Moreover, the application of machine learning techniques could enhance predictive performance by identifying complex, nonlinear relationships and uncovering additional influential factors beyond those detected by traditional models. To improve transparency and clinical applicability, explainable artificial intelligence approaches such as SHapley Additive exPlanations could also be employed to quantify and visualize the contribution of each feature to the predictions of the model. These advancements may contribute to more personalized treatment planning and improved surgical outcomes for patients undergoing RIRS. In addition, future research may focus on the development of a web-based or mobile application to operationalize the decision rule, facilitating its integration into routine clinical workflows.

Conclusion

The present study identified stone diameter as the key preoperative predictor of SF outcome following RIRS, with prior open surgery showing a borderline association. Based on these findings, a simple decision rule using only stone diameter and surgical history was developed to stratify patients by the likelihood of residual fragments. Its reliance on readily available preoperative information makes the rule practical for routine clinical use and may assist urologists in counseling and planning individualized treatment.

What is already known about this topic?

SF outcomes after RIRS are influenced by stone size and surgical history. However, clinicians still lack a simple and evidence-based rule to predict surgical success before the procedure.

What does this study add?

This study introduces a novel and easy-to-use preoperative decision rule, derived from multivariable modeling. It accurately stratifies patients by risk (AUC 0.87) and provides a practical tool for surgical planning and personalized patient counseling.

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Authors' contributions

AS: conception and design, administrative support, provision of study materials or patients, collection and assembly of data, data analysis and interpretation, manuscript writing, and final approval of the manuscript. KC: conception and design, collection and assembly of data, data analysis and interpretation, manuscript writing, and final approval of the manuscript.

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Conflicts of interest

The authors declare no conflicts of interest.

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