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Evaluating Renal Stone Volume and Size as Predictors of Residual Fragments Post RIRS: A Prospective Study

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What's known on the subject? and What does the study add?

Renal stone size has traditionally been used as the primary predictor for residual fragments after retrograde intrarenal surgery (RIRS), and volume assessment is often overlooked in routine clinical practice. This prospective study highlights that stone volume may be a more accurate predictor of stone burden and residual fragments post-RIRS than stone size alone, suggesting the need for incorporating volumetric analysis into preoperative planning.

Abstract

Objective: To identify a better predictor of renal stone burden among stone volume and stone size, and their predictive efficacy on residual fragments post-retrograde intrarenal surgery (RIRS).

Materials and Methods: This single-center prospective observational study was conducted from July 2023 to December 2024, involving patients undergoing RIRS for renal calculi. Pre-operative renal stone parameters were analyzed on non-contrast computed tomography (NCCT) kidney, ureter, and bladder (KUB) scan. The residual fragments were determined by NCCT-KUB, on the 90th postoperative day. The relationships between possible predictors and the residual fragments were analyzed using a logistic regression model.

Results: According to multivariate analysis, the stone volume (p=0.038) was found to be the only significant independent predictor of residual fragments, while other factors such as stone size (p=0.627), age (p=0.251), location (p=0.506), and body mass index (p=0.69) did not have an impact on stone-free rates post RIRS. The area under curve generated cut-off was 889 mm^3 for stone volume.

Conclusion: Among the parameters of renal stone burden, the stone volume determined by NCCT-KUB was a statistically significant predictor of residual fragments, post-RIRS, compared to stone size.

Keywords: Stone burden, volume, residual fragment, predictor, stone-free rate

Introduction

The global prevalence of renal stone disease is around 12% (1). Non-contrast computed tomography (NCCT) kidney, ureter, and bladder (KUB) is considered the gold standard investigation for renal stone detection as well as further treatment planning (2). Major parameters to consider in NCCT-KUB are stone size, number of stones, location of stones, density of stones, volume of stones, and calyceal anatomy of the kidney. Different treatment options are available for symptomatic renal stone diseases such as percutaneous nephrolithotomy (PCNL), retrograde intrarenal surgery (RIRS), extracorporeal shock wave lithotripsy (ESWL), and laparoscopic interventions. Accurately evaluating a patient's stone burden is a key component in the effective management of urolithiasis. Despite its clinical importance, standardized guidelines for the preoperative assessment of renal stone burden remain lacking. Various parameters such as maximum stone diameter (stone size), cumulative diameter of stones, and stone volume have been utilized in prior studies to quantify and analyze stone burden (3). It is generally presumed that multiplanar measurements of renal stones provide a more comprehensive representation of stone burden, potentially

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offering superior predictive value for postoperative stone-free status. Nevertheless, evidence from existing studies has not consistently supported the superiority of multiplanar assessments over simpler metrics such as cumulative stone diameter (CSD), which remains one of the most frequently reported parameters. Currently, stone size is a major parameter in deciding among different treatment options. According to European Association of Urology and American Urological Association guidelines, RIRS is recommended for renal stones up to 2 cm in size (4).

The stone-free rate is one of the primary objectives for treatment of renal stone diseases. Reported stone-free rates for RIRS vary from 54% to 96% for renal stones smaller than 2 cm (5). Stone size is traditionally used to predict stone-free rates following RIRS, and residual fragments are known to increase morbidity and the likelihood of re-intervention. While linear measurements are commonly employed, volumetric assessment is emerging as a potentially more accurate method for evaluating stone burden. This prospective study compares the effectiveness of stone volume and size as predictors of residual fragments post the RIRS procedure and finds that stone volume more reliably predicts residual fragments. The findings support the integration of volumetric analysis into preoperative planning to enhance the prediction of surgical outcomes.

Materials and Methods

This prospective observational study was conducted over an 18-month period from July 2023 to December 2024, involving a total of 219 patients. Ethics and scientific clearance were obtained from the Institutional Review Board of Hall Clinic under registration no: RHC/BIOPMRFIEC/2022/443, date: 20.07.2023. After obtaining written informed consent, patients who were diagnosed with renal calculus and undergoing RIRS were included. Patients with anatomical anomalies such as cross-renal ectopy, duplicated collecting systems, or pelvic kidneys were excluded from the analysis.

Patients arriving at the urology department with clinical suspicion of renal stone disease were evaluated with a thorough history and detailed systemic examination. Demographic parameters were also considered, such as age, gender, and body mass index (BMI). NCCT-KUB was performed as a pre-operative workup in each patient. Pre-operative computed tomography (CT) scan parameters were considered, such as stone size, number of stones, total volume of stones, location of stone, density of stone (in Hounsfield unit), laterality of stone, number and anatomical details of calyces, and whether the patient was pre-stented. Stone size was assessed using the maximum linear diameter in cases of a single stone, while the CSD was used for multiple stones. Stone volume was calculated using the ellipsoid formula: (length × width × height × π × 1/6) (Figure 1). All measurements, including stone length, width, and height, were obtained from NCCT scans using digital calipers within the SYNAPSE-PACS software system.

During RIRS, standard operative procedures were followed, with all intraoperative parameters kept constant, including 35W TFL laser (IPG photonics), 200 µm laser fiber size, and standard UAS sheath of 9.5/11.5F. Securing the access sheath was straightforward for all the patients. After laser lithotripsy, each calyx was checked for complete dusting of stone. A Double-J (JJ) stent was placed in all patients after endoscopy, and the stent was removed 3 to 4 weeks postoperatively when we were certain that the bypass was no longer necessary. All major or minor intra-operative and post-operative complications were taken into consideration along with the total operation time. Postoperatively, the stone clearance rate was documented, using NCCT-KUB on the 90^{th} postoperative day. For stone size, 4 mm was accepted as the cut-off level of significance (6).

Statistical Analysis

Data were recorded using a predesigned proforma and analyzed in Microsoft Excel and IBM SPSS Statistics for Windows, version 25. Descriptive statistics included mean ± standard deviation for quantitative variables and frequencies with percentages for categorical data. Normality was assessed using the Shapiro-

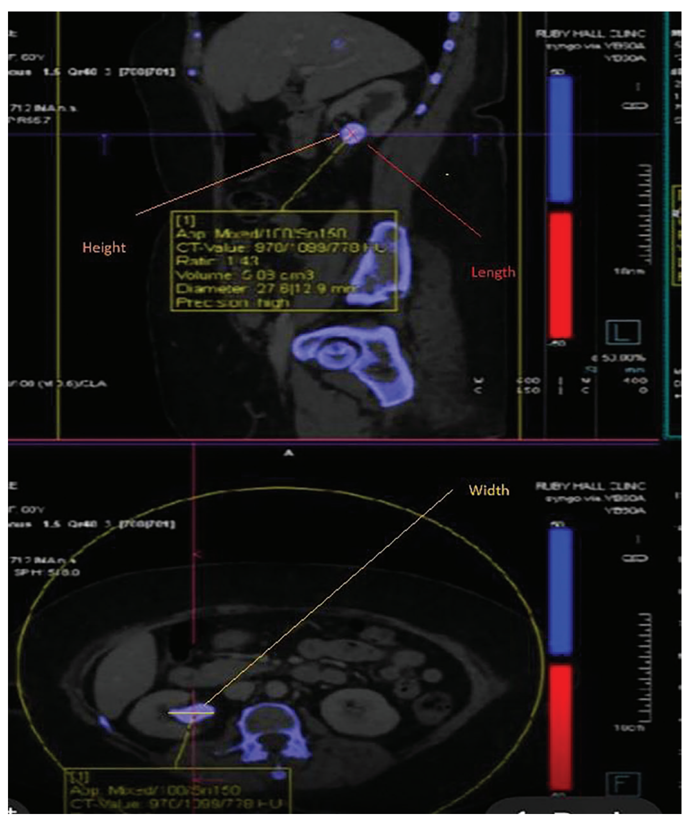

Figure 1. NCCT-KUB image of renal stone

NCCT: Non-contrast computed tomography, KUB: Kidney, ureter, and bladder

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Wilk test. The chi-square test evaluated associations between qualitative variables, while the Mann-Whitney U test compared quantitative variables. Logistic regression was used for predictive analysis. A p-value <0.05 was considered statistically significant, with additional tests applied as appropriate.

Results

In our study, 219 patients were included, with a gender distribution of males (54.8%) and females (45.2%). The mean age was 37.19 years, with a range from 20 to 58 years, indicating a predominantly young adult cohort. The average BMI was 22.7 (±2.1). The most frequent presenting complaint was flank pain (50.7%), followed by dysuria (16.4%) and backache (11%). The duration of complaints varied widely from 0 to 90 days, with a mean duration of 15.63 days. Additionally, 16.4% of the patients had a JJ ureteral stent placed prior to the procedure; this was done in anticipation of the potential complexity of the procedure. This may come across as a possible selection bias.

A total of 219 patients underwent RIRS, out of which 201 (91.8%) were stone-free on post-operative day 90, while 18 (8.2%) had residual fragments. For analysis, patients were categorized into two groups: Those with residual fragments and those without residual fragments at postoperative day 90. Out of the 219 patients undergoing RIRS, only 12 (5.5%) patients had complications. All of them were Clavien-Dindo grade I (10 were post-operative fever and 2 were post-operative pain).

The multivariate logistic regression revealed that volume (mm^3) is statistically significantly independent predictor of residual fragments (p-value=0.038).

No statistically significant differences were observed in patient demographics such as age (p=0.226), BMI (p=0.069), and stone characteristics in NCCT-KUB such as laterality (p=0.455), pre-stenting status (p=0.107), number of stones (p=0.545), density (p=0.251), or location (p=0.506) between the two groups. As predictors of stone burden, two parameters were observed, which stone size has shown an insignificant impact (p=0.374), but stone volume has shown a significant impact (p=0.038) on residual fragments post RIRS (Tables 1-3, Graphs 1-3). The surgical duration was observed to be significantly higher among the residual fragments group.

The ROC curve indicates that the "volume (mm^3)" variable is a statistically significant and a discriminator with fair to good performance for the condition being tested. The test has an AUC of 0.746, which suggests it has a reasonable ability to distinguish between the two groups.

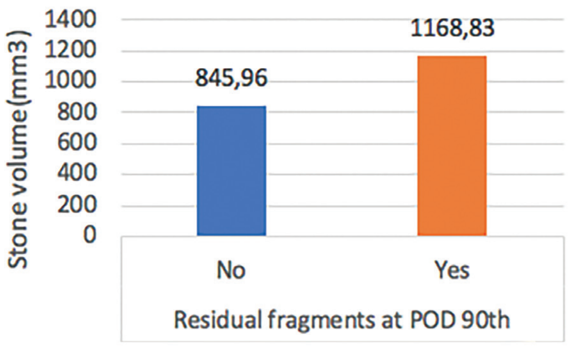
Table 1. Impact of variables, including patient demographics and stone characteristics, on residual fragments post retrograde intrarenal surgery

Variables	Residual fragments at postoperative day 90th		p-value
	No	Yes	
Patients (n)	201	18	
Age	36.94±7.78	40±7.59	0.226
Gender			0.805
Male	111	9	
Female	90	9	
BMI	22.98±2.09	24.33±1.51	0.69
Laterality of stone			0.455
Right	102	12	
Left	99	6	
Pre-stented			0.107
Yes	30	6	
No	171	12	
Number of stones	1.67±0.64	1.83±0.41	0.545
Stone volume (mm^3)	845.96±385.51	1168.83±214.49	0.038
Stone size (mm)	14.58±3.8	16±2.28	0.374
Stone density (Hounsfield unit)	999.84±178.62	1086.33±114.1	0.251
Stone location			0.506
Lower poler	39	3	
Non-lower poler	162	15	
Surgical duration (minute)	79.70±18.83	98.33±16.02	0.022

Table 2. Multivariate analysis of different parameters with residual stone fragments				
	B	S.E.	Sig.	Exp(B)
Age years	0.136	0.112	0.226	1.145
BMI	0.982	0.539	0.069	2.669
Pre-stented YN (1)	-3.178	1.971	0.107	0.042
Location (1)	-1.051	1.579	0.506	0.350
Duration	0.122	0.062	0.050	1.129
Size mm cumulative stone burden	0.123	0.254	0.627	1.131
Volume mm^3	0.005	0.002	0.038	1.005
Constant	-46.051	19.925	0.021	0.000

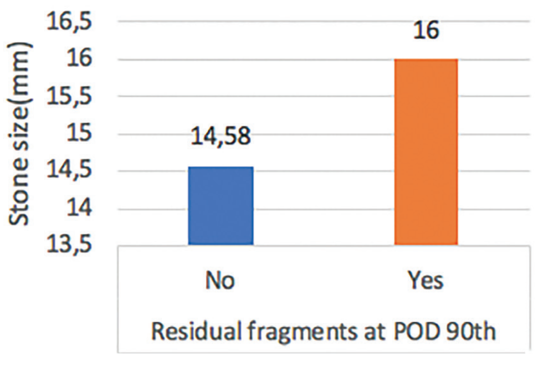
BMI: Body mass index

Table 3. For Youden's index	
Youden index J	0.5224
Associated criterion	>889
Sensitivity	100
Specificity	52.24



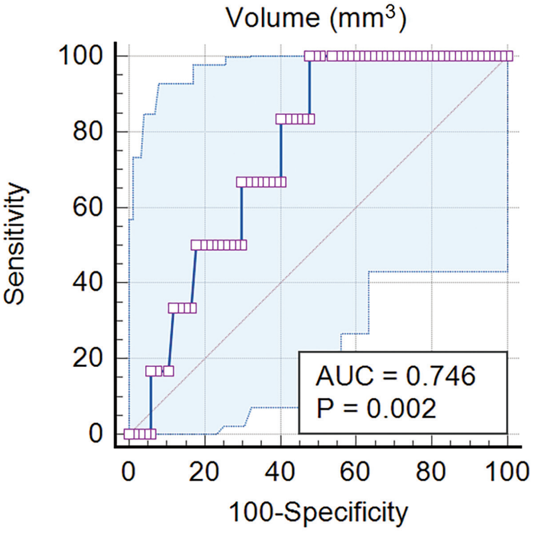
Graph 1. Stone volume as predictor of residual fragments post RIRS

RIRS: Retrograde intrarenal surgery, POD: Postoperative day



Graph 2. Stone size as predictor of residual fragments post RIRS

RIRS: Retrograde intrarenal surgery, POD: Postoperative day



Graph 3. ROC curve for stone volume

AUC: Area under curve, ROC: Receiver operating characteristic

Discussion

Stone burden remains one of the most critical factors influencing the choice of surgical intervention in the management of urolithiasis. Traditionally, it has been assessed using maximum stone diameter in case of single stone, or CSD in case of multiple stones, both of which are widely endorsed in current urological guidelines (4). This method is the simplest and most easily obtained among parameters used to assess stone burden; however, it does not account for stone width and depth. Additionally, these are linear measurements that fail to accurately represent the true stone burden, especially considering the irregular shape of most renal stones. Other factors that were conventionally used for predicting renal stone clearance are infundibulopelvic angle (IPA) and infundibular length. The reproducibility of IPA measurements has also been called into question. Rachid Filho et al. (7) examined the intra-observer and inter-observer variations of IPA measurements

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using the Elbahnasy, Sampaio, and Gupta measurement method. They found significant inter-observer variations, with the Sampaio method producing the widest variations between observers. This suggests that routine use of IPA in daily clinical practice may be problematic, therefore, they have not been used in the present study. In contrast, stone volume, derived from the multiplanar reconstructions on NCCT, offers a more comprehensive and accurate representation of the actual stone mass (3). Despite this, it remains uncertain whether this more precise measurement leads to improved prediction of clinical outcomes and post-RIRS residual fragments.

In our cohort, patients with higher stone volumes (1168.83 $mm^3 \pm 214.49$ mm^3) were more likely to retain residual fragments, even when stone diameters were within the traditionally acceptable range (≤20 mm). This suggests that stone volume may better represent procedural complexity, and potential for incomplete stone clearance. Furthermore, volume estimation can help guide clinical decision-making, such as anticipating the need for staged procedures, considering adjunctive therapies, or choosing alternative modalities like PCNL in selected cases with large-volume stones, despite a relatively small maximal diameter. Stone volume has emerged as a more reliable predictor of operative time in RIRS compared to other burden estimation methods. Larger stone volumes typically require longer fragmentation and retrieval times, which can extend surgical duration significantly. Prolonged operative times not only increase the risk of complications but may also contribute to surgeon fatigue, particularly in high-volume or complex cases. This fatigue can potentially impact surgical precision and efficiency, further influencing outcomes. Moreover, extended procedures may raise the likelihood of residual stone fragments, especially when complete clearance becomes difficult due to limited visibility in longer cases. Therefore, accurate preoperative assessment of stone volume is critical for surgical planning, better intraoperative decision-making, and minimizing residual stone rates in high-risk patients.

In our study, we calculated stone volume using the ellipsoid formula (length × width × height × π × 1/6). All measurements, including stone length, width, and height, were obtained from NCCT scans using digital calipers within the SYNAPSE-PACS software system. Automated or semi-automated volume calculation using widely available DICOM viewers can facilitate its use in clinical practice without significantly increasing interpretation time or cost.

However, to date, no studies have established a specific cut-off value for stone volume in the context of RIRS. In our study, we identified a single cut-off point, 890 mm^3 (as per the calculated Youden's index), as the most effective threshold for predicting RIRS outcomes and positively predicting residual fragments post-RIRS.

Our study supports prior literature that advocates for the integration of stone volume measurement into routine preoperative planning. In a prospective study by Merigot de Treigny et al. (8), suggested 3 formulas for stone burden estimation. They are the (1) CSD, (2) Ackermann's formula, and (3) the sphere formula. They suggested that if stones are below 20 mm, all three methods approximate stone burden correctly. However, for stones above 20 mm, the calculation of volume is recommended. However, no prospective study has compared the cumulative stone burden and stone volume on the prediction of residual fragments post-RIRS. There are different methods for estimating stone volume using CT images including 3D reconstruction of the stone to measure axis lengths and then applying an ellipsoid formula to estimate volume. Using stone volume instead of axial measurements may be a better predictor of treatment outcome, as small differences in manual axis measurements may lead to much larger volume changes. This may be more applicable with increasing stone size, as found by Finch et al. (9). As maximum stone diameter increases, stone volume estimation using ellipsoid volume equations becomes less accurate.

Yamashita et al. (10) reported that stone volume did not independently predict the stone-free rate in cases of ureteral stones, although it did serve as a predictor for renal stones. They suggested that this discrepancy might be due to the generally smaller size of ureteral stones.

In the above articles, it is implied that stone volume may not be a universally reliable predictor of outcomes across all stone sizes and anatomical locations.

Geraghty et al. (11) in their meta-analysis observed that in the case of PCNL, stone volume was not as reliable a predictive factor of residual stone prediction as it was in the case of RIRS and ESWL. This may be partly explained by the fact that more complex or irregularly shaped stones often have a lower volume than ellipsoid-shaped stones with the same maximum diameter, yet these complex stones are associated with a higher likelihood of residual fragments following the procedure.

Study Limitations

Our study has several strengths. The study is a prospective observational analysis evaluating predictors of residual fragments after RIRS, with 100% of assessments performed using NCCT-KUB. All scans were reviewed by a senior radiologist blinded to surgical outcomes, using optimized settings including magnification, bone window, and 3D reconstruction. To ensure procedural consistency, all surgeries were performed by experienced urologists using the same type of flexible nephroureteroscope and disposable instruments. The study, conducted in a high-volume reference center with high-quality imaging, reflects an ideal clinical setting. However, validation in other centers with varying expertise, equipment, and surgical protocols is necessary to confirm its broader relevance.

Conclusion

Among the parameters of renal stone burden, the stone volume determined by NCCT-KUB was a statistically significant predictor of residual fragments post-RIRS compared to stone size. The shortcoming of the present study is that the stone volume correlation to the operative planning has not been evaluated. The current study indicates that, in future cases, stone volume estimation can be used to predict the possibility of residual fragments after RIRS and to explore possible alternatives.

Ethics

Ethics Committee Approval: Ethics and scientific clearance were obtained from the Institutional Review Board of Hall Clinic under registration no: RHC/BIOPMRFIEC/2022/443, date: 20.07.2023.

Informed Consent: Patient consent was obtained.

Footnotes

Authorship Contributions

Surgical and Medical Practices: J.K., A.T., C.R., Concept: J.K., A.T., C.R., Design: J.K., A.T., C.R., Data Collection or Processing: J.K., A.T., C.R., Analysis or Interpretation: J.K., A.T., C.R., Literature Search: J.K., A.T., C.R., Writing: J.K., A.T., C.R.

Conflict of Interest: No conflict of interest was declared by the authors.

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