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ORIGINAL ARTICLE

Prospective Evaluation of CT Parameters as a Predictive Value of Impacted Stone and Ureteric Stricture Post Ureteroscopy (PRECIOUS Study)

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ABSTRACT

Impacted ureteric stones present significant challenges in urological procedures, often leading to complications such as ureteral strictures. This prospective cohort study primarily aimed to evaluate preoperative CT parameters, particularly ureteral wall thickness (UWT) and the Hounsfield Unit Attenuation Ratio (HAB ratio), as predictors of stone impaction and ureteric stricture formation in patients undergoing elective primary ureteroscopy. A total of 24 patients with ureteric stones (18 impacted, 6 non-impacted) underwent primary ureteroscopic lithotripsy (URSL) between August 2023 and August 2024. Results indicated that impacted stones were associated with a significantly higher UWT (2.79 mm vs. 1.97 mm, $p = 0.018$). ROC curve analysis revealed that UWT had strong predictive value for stone impaction, with an area under the curve (AUC) of 0.824 at a threshold of 2.69 mm. UWT and HAB ratio did not predict postoperative ureteric strictures, which occurred 16.7% in impacted stones. These findings suggest that UWT is a valuable predictor for assessing stone impaction but has limited utility in predicting ureteric stricture formation. This study also found that moderate hydronephrosis demonstrated a strong predictive value for impacted stones ($p < 0.001$). and its combination with UWT further enhanced diagnostic accuracy. These results highlight the importance of preoperative UWT assessment in predicting stone impaction and

Keywords: *Ureteral wall thickness, Hounsfield Unit Attenuation Ratio, Impacted Ureteral Stone, Ureteral Stricture*

guiding treatment decisions, such as choosing between extracorporeal shockwave therapy (ESWL) and primary URSL. Due to the small sample size, additional research with larger cohorts and alternative parameters should be explored to improve the prediction of ureteric strictures following surgical intervention.

INTRODUCTION

Impacted ureteric stones occur when a stone becomes lodged within the ureter, obstructing the flow of urine and impeding its natural passage.They are frequently associated with intraoperative difficulty in stone removal, lower stone-free rates with possibility of long-term ureteric strictures (Roberts et al., 1998, Brito et al., 2006).Treatment options such as ureteroscopy (URS) and shock wave lithotripsy (SWL) depend on the characteristics of the stone observed on computed tomography (CT) scans and patient-specific factors. Each treatment modality offers different success rate and associated complications however to date no predictive CT parameters have been incorporated as part of treatment guideline to recommend urologist one treatment to another. In our clinical practice, perioperative parameters and postoperative results differ for impacted and non-impacted ureteral stones. Identification of factors that can accurately stone impaction preoperative accurately helps surgeons to plan better pre-operatively, counselling patients on the outcomes of operation, risks, failure rate, and need for ancillary procedures (Rasheed et al., 2023). Impacted stones cause persistent irritation to the ureteral mucosa at the impaction site resulting in adhesion of stone to the ureteral wall, epithelial hypertrophy, local inflammation and oedema leading to an increase in the ureteral wall thickness (UWT) with resultant susceptibility to fibrosis and stricture formation (Ozbit et al., 2020).

CT attenuation of ureter above and below ureteral stone (HAB ratio) was also reported to be useful to predict impacted stones (Ozbit et al., 2020). HU values measured above the stone are more likely to be lower, closer to liquid density because of urine, whereas HU values below the stones are higher, closer to tissue density due to the lack of urine caused by impaction. As a result impaction stone is expected to have a lower HAB ratio than non-impacted stone.Many retrospective studies have been carried out to predict stone impaction based on preoperative CT characteristics but none studied the relationship between UWT and HAB ratio together to predict stone impaction and subsequent ureteric stricture rate post endourologic treatment prospectively (Legemate et al., 2017, Ozbit et al., 2020). These parameters are useful adjuncts to daily clinical practise to provide better information and tailored treatment modalities to both surgeon and patients during index clinic visit with aims of achieving least complications, complete stone free-rate and need for subsequent auxillary treatments. Our primary objectives include preoperative ureteric wall thickness (UWT) and ratio of Hounsfield Unit above and below (HAB ratio) ureteric stone on pre-operative non-contrasted CT imaging (NCCT) as a predictor of impacted stone and ureteric stricture rate. Secondary objectives includes exploring stone impaction status with degree of hydronephrosis, stone free-rate, length of operative time, length of hospital stay, need for ancillary procedures and complications.

MATERIALS AND METHODS

This was a prospective cohort study conducted between 1st August 2023 – 31st August 2024, involving 24 adults (13 males, 11 Females). A minimal sample size 24 was calculated using OpenEpi software, taking mean difference of in UWT between population of having impacted and non-impacted stones to achieve 95% power at an alpha of 0.5 (Rasheed et al., 2023). All urological patients age >18 years old with evidence of a single ureteric stone with size 5mm to 15mm undergoing elective primary ureteroscopic procedures with semi-rigid

URS size 6/7.5Fr Wolf are recruited. Diagnosis and assessment of stones were confirmed with non-contrasted computed tomography urogram, employing 1.25mm slices axial and coronal images. The degree and severity of hydronephrosis were graded according to the Society for Fetal Urology grading system. Demographic data including HU of the stones are recorded.

The definition of impacted calculi requires at least one of the following criteria to be met (Fam et al., 2015): 1. Difficulty encounter in passing standard guidewire or ureteral catheter passed level of calculi in the first attempt ; 2. Moderate to severe hydronephrosis proximal to level of calculi from NCCT ; 3. Stone remain at the same location in the ureter for more than 2 months ; 4. Endoscopic findings of impacted stones, kinks in the ureter, ureteral edema, polyp, and stricture(Yoshida et al., 2017). HU above and below stone measured by calculating the HU from the centre of the ureter, one slice proximal and distal to the stone on axial NCCT image. HAB ratio is calculated as HU above (HA) divided by HU below (HB) (Figure 1-3). UWT measures from the point of highest soft-tissue ureteral wall/ inflammatory oedema surrounding ureteral stone on axial image soft tissue window setting. Retrograde semi-rigid ureteroscopy size 6/7.5Fr Wolf with holmium:YAG 365um laser to assist in fragmentation of the stones. Operations were performed by urologists or trainees at our centre. Laser frequency is set at 6-12Hz and energy limited to 800mJ for all cases (4.8-9.6 Watts). Intra operative ureteral complications will be recorded as per the post ureteroscopic lesion scale (PULS) grade 1 to grade 5. Postoperative complications were recorded using the modified Clavien grading scale, grades 1 through 5.

Stone free is classified based on intraoperative endoscopic findings, KUB x-ray performed post operatively 4 weeks for radiopaque stones. Follow up KUB ultrasound arranged at 3 months post removal of stent if inserted initially to look for presence of moderate to severe hydronephrosis. If present, a follow up CT-IVU will be used for further assessment to confirm formation of ureteric strictures. Children and pregnant ladies, multiple stones within a single ureter, bilateral ureteric stones, patients with preoperative nephrostomy/ stenting, calculus with Hounsfield unit (HU) >1000, renal impairment and sepsis were excluded from this study. The data were recorded and processed using Microsoft Excel. Data analysis done using the SPSS version 22. Categorical data will be analyzed using Chi-square or Mann-Whitney U tests according to impaction status. Univariate analysis and multivariate logistic regression models will be used to identify predictors of stone passage. A value of $P < 0.05$ is considered statistically significant. Ethical MREC permission for pilot research NMRR ID-23-02443-BY7 was granted on 19 October 2023.

RESULTS

A total of 24 patients underwent elective primary ureterolithotripsy during this 1-year study period, stratifying CT parameters and clinical outcomes according to impaction status. A total of 18 patients with impacted stones and 6 with non-impacted stones were analyzed (Table 1).

The average ureteral wall thickness (UWT) was significantly higher in the impacted group 2.79 mm [1.49–4.0] compared to the non-impacted group 1.97 mm [1.45–2.59] , with a p-value of 0.018. The degree of hydronephrosis differed significantly between the impacted and non-impacted groups ($p < 0.001$). In the impacted group, 66.7% of patients exhibited moderate hydronephrosis, while 33.3% had severe hydronephrosis. Conversely, in the non-impacted group, 66.7% had mild hydronephrosis, with only 16.7% showing severe hydronephrosis and 16.7% moderate hydronephrosis. These findings highlight that impacted stones are associated

Table 1: Patient characteristics, CT Parameters and operative outcomes stratified by impaction status

	Impacted Stone (n=18)	Non-Impacted (n=6)	P-value
BMI	27.1, (17.8 - 43.0)	27.5, (18.3 - 35.0)	0.887[a]
UWT	2.79 (1.49 - 4.0)	1.97 (1.45 - 2.59)	0.018[a]
HA	9.61 (1.83 - 23.0)	6.52 (1.7 - 14.6)	0.280[a]
HB	31.76 (10.0 - 45.1)	19.58 (6.10 - 47.3)	0.052[a]
HAB	0.31 (0.06-0.72)	0.40 (0.08 - 0.66)	0.387[a]
Stone Size (mm)	10.4 (0.7-16.3)	10.8 (6.82-13.1)	
Stone density (HU)	918.1 (660 - 998)	794.7 (379 - 989)	0.194[a]
Degree of hydronephrosis, n (%)			< 0.00[b]
Mild	-	4 (66.7)	
Moderate	12 (70.6)	1 (16.7)	
Severe	6 (33.3)	1 (16.7)	
Location of stone, n (%)			0.600[b]
Proximal	7 (38.9)	3 (50.0)	
Middle	7 (38.9)	1 (16.7)	
Distal	4 (22.2)	2 (33.3%)	
Operative Times (mins)	53.2 (25 - 73)	37.3 (17 - 67)	0.102[a]
Post Ureteric Lesion Scale (PULS)			0.449[b]
1	14	6	
2	2	-	
3	2	-	
Duration of Impaction (Days)	145.4 (10-514)	83.8 (24-233)	
Mean stone free rate, n (%)	18 (77.8)	6 (66.7)	0.625[a]
Stricture, n (%)	3 (16.7)	-	
Length of stay, days	2.17	2.00	0.323[a]
Modified Clavien-Dindo			1.000[b]
I	17	6	
II	1	-	

a : Mann-Whitney U Test
b : Chi-square test

BMI = Body Mass index, UWT = Ureteral Wall Thickness, HA = Hounsfield unit above,
HB = Hounsfield unit below, PULS = Post Ureteric Lesion Scale
Data presented as no. (%) or mean(range)

with more severe degrees of hydronephrosis and increased UWT compared to non-impacted stones.

Receiver operating characteristic (ROC) curve analysis demonstrated strong predictive value for both ureteral wall thickness (UWT) and hydronephrosis in determining stone impaction, with UWT cutoff value of 2.69mm (AUC, 0.824; sensitivity,55.6%; specificity 100%) and grade 2 hydronephrosis (AUC, 0.806; sensitivity, 100%; specificity, 66.7%) (Figure 3,4). Average HA (9.61 vs. 6.52) and HB (31.76 vs. 19.58) were greater in the impacted group than in the non-impacted group; however, these differences were not statistically significant (p = 0.280 and p = 0.052, respectively). Similar, HAB ratio were lower in impacted group (0.31 vs. 0.40), but there was no discernible difference (p = 0.387). Separate univariate logistic regression analyses were conducted on other preoperative CT parameters to predict impaction and ureteral strictures.. Among all variables analyzed for stone impaction, only degree of hydronephrosis showed a statistically significant association (p = 0.028). A higher degree of hydronephrosis increases the odds of stone impaction by approximately 13 times. None of the variables analyzed were significantly associated with ureteric stricture (Table 2).

The impacted group had a longer average operative time compared to the non-impacted group (53.2 minutes vs. 37.3 minutes, p = 0.102) and also higher stone-free rate (77.8% vs. 66.7%, p = 0.625). Our reduced stone-free rate in the non-impacted group can be attributable to stone repulsion during ureterolithotripsy, which require adjunct treatments (n = 6). A greater number and higher severity of post-ureteric lesion scales were observed in the impacted group, as expected (p = 0.449). Ureteric stent was placed for all patients undergone primary URSL and the average length of hospital stay is 2.13 days. There was no difference in overall highest Clavien-Dindo complications between the groups (p = 1.000).

Follow-up ultrasound was performed 3 months post-stent removal (ROS) to assess

Table 2: Multivariable Logistic Regression Analysis of factors affecting stone impaction and ureteric strictures.

Variables	Stone Impaction			Ureteric Stricture		
	OR	95% CI	P-value	OR	95% CI	P-value
UWT	8.97	2.35 - 83.10	0.0535	0.997	0.989 - 1.006	0.554
Degree of Hydronephrosis	13.61	1.33 - 139.48	0.028	4.040	0.56 - 29.07	0.166
HAB ratio	0.11	0.001 - 13.88	0.372	0.198	0.001 - 62.444	0.581
Stone Density	1.01	0.999 - 1.012	0.122	1.000	0.994 - 1.007	0.88
Operative times	1.05	0.993 - 1.118	0.083	1.046	0.971 - 1.126	0.24
Stone size	0.97	0.726 - 1.291	0.825	1.058	0.674 - 1.662	0.806

OR = Odd Ratio, CI = Confidence Interval
UWT = Ureteral Wall Thickness, HAB = Hounsfield above and below calculi

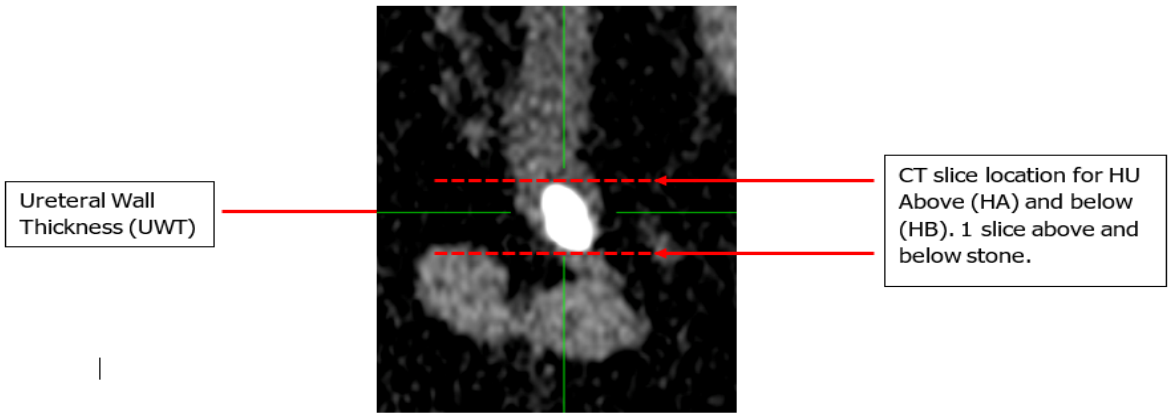

Figure 1: NCCT scan coronal view to depict points of measurement.

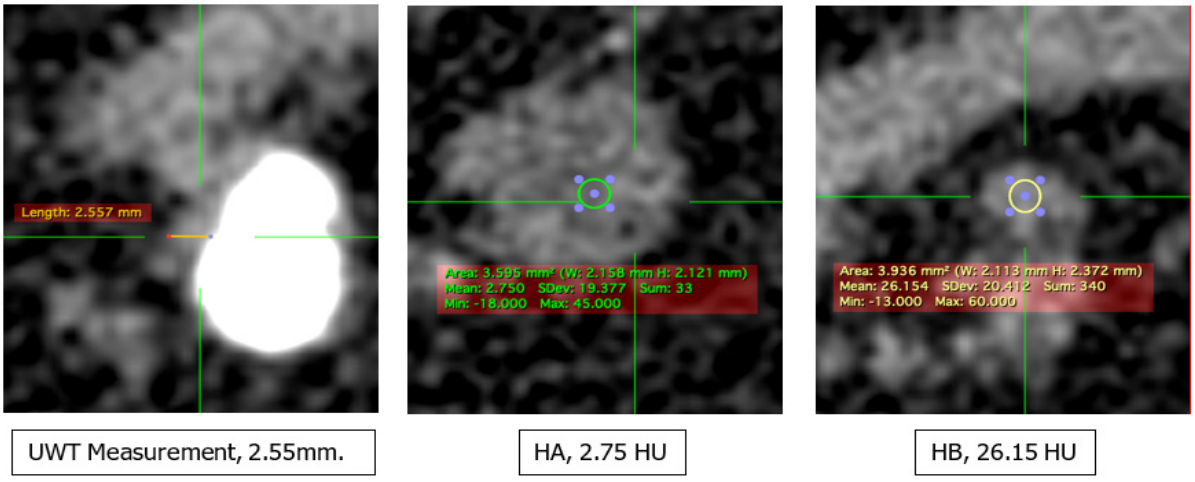

Figure 2: NCCT scan axial view depicting ureteral wall thickness measurement, Hounsfield unit 1 slice above and below stone measured on center of ureter.

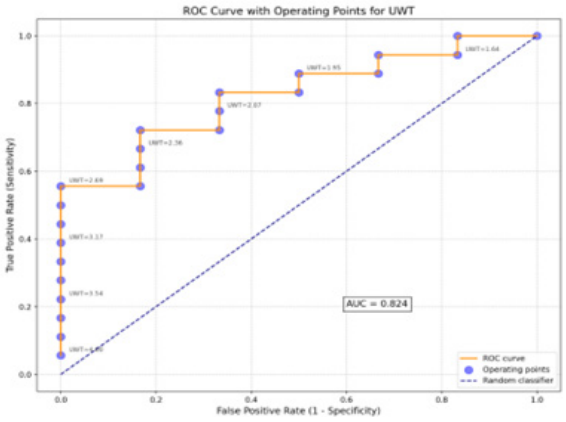

Figure 3: ROC Curves for UWT

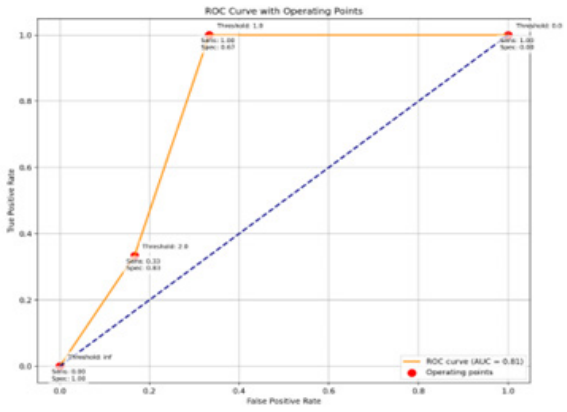

Figure 4: ROC Curves for Degree of Hydronephrosis

hydronephrosis (HN), followed by CT IVU to confirm ureteric strictures. 6 patients were excluded from the follow-up ultrasound assessment as they required additional treatment i.e repeat ureterolithotripsy (URSL). These patients were excluded as this cohort of patients may significantly influence the final study of stricture formation resulting from repeated endoscopic interventions.

Out of 18 cases, 4 patients (22.2%) had neither a stricture nor an impacted stone identified intraoperatively. In 11 patients (61.1%), an impacted stone was observed during surgery, but no stricture was present. Additionally, 3 patients (16.7%) had both an impacted stone and a stricture intraoperatively. Three patients (16.7%) who underwent ultrasonography (USG) assessment three months after retrograde intrarenal surgery (ROS) showed moderate to severe hydronephrosis, with confirmatory CT scans revealing ureteric strictures at the previous stone impaction sites. Similarly, a previous retrospective study by Brito et al. (2006) reported a 14.2% incidence of ureteric strictures in 42 patients treated for impacted ureteral calculi.

The duration of stone impaction was significantly longer in the impacted group compared to the non-impacted group (145 days vs. 83 days). Similarly, the mean stone density was higher in the impacted group (918.1 vs. 794.7), though this difference was not statistically significant ($p = 0.194$). The multivariable logistic regression analysis revealed that stone density had no statistically significant association with either stone impaction or ureteric stricture. For stone impaction, the odds ratio (OR) was 1.01 (95% CI: 0.999–1.012, $p = 0.122$). Similarly, for ureteric stricture, the OR was 1.000 (95% CI: 0.994–1.007, $p = 0.88$) (Table 2).

DISCUSSION

The primary objective of this prospective study involved prediction of stone impaction and ureteric stricture post-primary ureterolithotripsy using preoperative CT parameters. Our prospective study found that higher UWT and grade of hydronephrosis (moderate) are significantly associated with impacted stones found intraoperatively, resulting in longer operative times (53.2 minutes vs. 37.3 minutes) ($p = 0.102$). Our cohort noted a lower HAB within the impacted group compared with the non-impacted group, however not statistically significant (0.31 vs. 0.40, p-value = 0.387).

In previous retrospective study, thicker UWT, a higher grade of hydronephrosis, and a lower HAB ratio are frequently found in stone-impacted groups (Deguichi et al., 2022). HAB ratio was also an independent predictor of stone impaction with an optimal cutoff value of 0.3. One study also reported the equivalent of HAB ratio to UWT in terms of prediction of stone impaction (Özbir et al., 2020). Impacted stones are known to cause chronic inflammation of the ureteric mucosa, interstitial fibrosis, and thickening of the urothelium. The longer operative durations observed in the affected group may result from multiple attempts at guidewire placement beyond the impacted stone prior to initiating primary ureteroscopy (URS). Additionally, significant lasering time was required to fragment stones from altered mucosa caused by edema, polyps, kinking, or adherence. Preoperatively, a higher degree of hydronephrosis also concurred with our intraoperative findings of stone impaction and was consistent with previous findings (Tran et.al., 2019, Iwahashi et al., 2019). This is expected due to poor urinary passage by the obstructing calculi.

With the average ureteral wall thickness (UWT) cut-off value of 2.69 mm and moderate hydronephrosis, the combined logistic regression model incorporating both parameters achieved an overall accuracy of 88%, with particularly strong performance in identifying impacted stones (sensitivity

94%, specificity 89%). These findings suggest that while both parameters independently provide robust prediction of stone impaction, their combined use offers superior diagnostic accuracy, with UWT excelling at ruling in impaction (high specificity) and hydronephrosis at ruling out impaction (high sensitivity).

Notably, there were no cases where patients had stricture without stone impaction. All patients with stricture (n=3) had impacted stone intraoperatively suggesting a potential relationship between these conditions. Stricture only occurs in conjunction with stone impaction (100% of stricture cases had impaction. Subgroup analysis for those who developed stricture revealed longer mean operative time (59mins vs 46 mins, p-value=0.102), ureteral edema, kinking and angulation. Univariate logistic regression analysis did not find statistically significant (OR 1.046, 95% CI 0.971 - 1.126, p-value = 0.24). Limited working space due to impacted stone and ureteral factors i.e edema, kinking and angulation may lead to higher chance of ureteral mucosal injury during initial guidewire advancement and prolong lasering time contributing development of ureteral stricture long term. Long-term stone impaction often leads to ureteral lesions, including inflammatory polyps and strictures (Mugiya et al., 2004; Xi et al., 2009). Changes occurring within the ureter as a result of stone impaction causing decreased blood flow due to the pressure exerted and long period of impaction resulting ureteral tortuosity above the stone. Edematous ureter, in conjunction with the shape and dimensions of the obstructing stone, leads to inadequate saline irrigation flow and increases the risk of ureteral perforation during manipulation and fragmentation of the stone.

While the large majority of patients (N=11) had impacted stones but no ureteral stricture, these cohort of patients have shorter mean operative time (53mins), combination of smaller ureteroscope size 6/7.5Fr and lasering energy restricted to maximum of 9.6 Watts may have contributed to lower risk of ureteral stricture formation. Although stone impaction is not a causation for ureteral stricture in our study, stone impaction, severe hydronephrosis and ureteric angulation/kinking resulted in one patient failure to stent requiring nephrostomy and another had ureteric perforation (<50%, PULS 3) complication post primary URSL. Primary URSL was performed to create channel in aiding stent placement, subsequently requiring another repeat URSL to clear of residual stone fragments. Ureteral perforations have 75-80% risk of developing ureteral strictures (Brito et al., 2006, Robert et al., 1998). Systemic literature review reported ureteral perforation and mucosal damage are main predictors of ureteral strictures after ureteroscopic treatment of impacted stones (Tonyali et al., 2023).

This study has a number of limitations. This prospective study has a relatively small cohort in to draw broad conclusion. We only collected 24 patients in the duration 1 year which was the minimal sample required to achieve 95% power at an alpha of 0.5 (Rasheed et al., 2023). The limited sample size was due to the stringent inclusion criteria that focused on CT characteristics to avoid potential influence. While this approach minimized confounding factors, it also reduced the diversity of the sample and limited the applicability of the findings to a wider range of clinical scenarios. We also acknowledged this study involved procedures performed by both urologist and trainees. Variability in surgical expertise and technique could influence outcomes such as operative time, complications, and stone-free rates, introducing potential bias. Larger multi-institutional cohort might result in more representative results. The duration of stone impaction was calculated based on the date of diagnosis from preoperative non-contrasted CT scans rather than the date of symptom onset. This may not accurately reflect the true duration of impaction, potentially affecting

the analysis of its impact on outcomes such as ureteric stricture formation. Lastly, long follow-up period might provide better insight in the long-term risk of stricture formation albeit no specific timeframe has been recommended.

CONCLUSION

This investigation emphasises the significance of preoperative CT parameters, specifically hydronephrosis grading and ureteral wall thickness (UWT), in the prediction stone impaction in patients undergoing primary ureterolithotripsy. The combined use of UWT (cut-off value 2.69 mm) and moderate hydronephrosis demonstrated high diagnostic accuracy for identifying impacted stones but was not effective in predicting ureteral stricture formation. The clinical relevance of these preoperative markers was further substantiated by the discovery that all cases of ureteric strictures were associated with impacted stones in the study. CT imaging parameters serve as a valuable tool for urologist in determining the appropriate treatment modality during the initial consultation, enabling them to offer patients informed counsel regarding the potential complications associated with elective endoscopic treatment for ureteral calculi. This includes the prediction of stone impaction and its possible subsequent complications, such as ureteral perforation, strictures, stent failure necessitating nephrostomy insertion, and the potential need for secondary treatment. If primary ureterolithotriopsy were chosen as a treatment modality for impacted stone, we recommend limited lasering energy to a maximum of 9.6W, short operative time <60mins, and use of smaller URS scope 6/7.5Fr to reduce stricture rate. Alternatively, extracorporeal shock wave lithotripsy (ESWL) could be offered to disimpact and followed by URS later possibly lower down complications rate. Nevertheless, this pilot study requires an additional follow up research with larger cohorts is required to verify these findings and enhance predictive models for long-term outcomes, including stricture formation.

CONFLICT INTEREST

The authors do not have any conflict of interest to declare.

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