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ARTICLE

Evaluation of the relation between size of stone and its attenuation measured by Hounsfield units and the total laser energy required to fragment it

A prospective study investigating how stone size and HU affects the total LASER energy (TLE) used when managing ureteric stones less than 2 cm

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ABSTRACT

Background: Anticipating the total laser energy (TLE) of Holmium YAG laser required for ureteroscopic (URS) lithotripsy is essential to guide urologists in selecting the optimal fiber size. This study aimed at evaluating the relationship between stone size and stone attenuation measured by HU as predictors for the TLE during the procedure.

Methods: We conducted an observational prospective cohort study of patients undergoing URS lithotripsy at the Urology department of Ain Shams University Hospitals from September 2018 to September 2019 with the use of a holmium YAG laser as the lithotripsy method. Patients' demographic and clinical characteristics, stone location, stone size, stone attenuation measured by HU from the non-contrast CT, TLE, and procedure time were recorded. Data were analyzed using Jamovi software (version 2.0 for macOS).

Results: Forty patients were included in the study (22 males and 18 females) with a mean age of 57.8 years. The mean stone size was 9.8 mm^3, the mean HU was 858.8 units, and the mean TLE was 3.5 KJ. Both stone size and stone attenuation measured by HU were positively correlated with TLE ($r = 0.81$ and 0.84, respectively; $p < 0.001$ for both). Further, regression analysis showed that both variables could significantly predict the TLE ($ß = 0.001$ and 0.71, respectively).

Conclusions: Both stone attenuation, as measured by HU, and stone size positively correlate with TLE required for URS lithotripsy. Therefore, both HU and stone size can predict the TLE, which will be helpful to guide the urologist in selecting the optimal fiber size for the procedure.

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Introduction

Ureteroscopy (URS) is one of the main management strategies of ureteric calculi [1]. With the advances in laser techniques and the introduction of the Holmium: Yttrium–Aluminum–Garnet (Ho:YAG), the efficacy of URS has improved significantly over the past decades [2]. Although more advanced types of laser have been developed recently, we chose the Ho:YAG laser for this study because of its availability and spread in our country. URS is more preferred than shock wave lithotripsy (SWL) because it is associated with a higher stone clearance rate, is less affected by patient habitus, and can be used when SWL is contraindicated [3–7].

The selection of the type of procedure, including ESWL, URS, percutaneous nephrolithonomy, open or laparoscopic surgery for each patient is important to increase the success of the procedure and reduce the costs, times, and complications of the surgery [8]. In addition, the literature reported that stone size, number of stones, stones' location, Hounsfield unit (HU), and composition might affect the choice of the treatment procedure as well as the outcome [9–13].

The Ho:YAG laser is the most widely studied laser in urology and represents the gold standard method used in URS for stone lithotripsy [14–18]. This will probably soon be replaced by the recently introduced thalium fiber laser, as mentioned before [19]. Its wavelength of 2,140 nm provides efficient fragmentation and safety, making it a widely accepted multipurpose tool for performing a variety of endourological procedures and, in particular, stones. However, despite the established success of the Ho:YAG in stone lithotripsy, urologists sometimes experience difficulty with stone fragmentation; therefore, some stones might be associated with incomplete clearance, procedural complications, and more total laser energy, which make the cost-effectiveness of the procedure questionable.

Molina et al. [20] evaluated the association of preoperative non-contrast CT (NCCT) stone characteristics, laser settings, and stone composition with cumulative Ho:YAG laser time and laser energy; they found that Ho:YAG cumulative

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laser energy and total time are significantly affected by stone dimensions, hardness measured in HU by using non-contrast CT, location, fiber size, and laser power. Kidney location, laser fiber size, and laser power have more influence on the final laser energy than on the total laser time. Further, calcium phosphate stones required less laser energy to fragment.

The effects of different energy settings, frequency, and fiber diameters on stone fragmentation by Ho:YAG laser were investigated in an ex-vivo study by Kuo et al. [21]. They found that increasing the energy with the small fibers resulted in more fragmentation ($p < 0.05$). Also, increasing the frequency up to 10 Hz increased the stone fragmentation but this relationship reached a plateau for the small fibers; increasing the frequency above 10 Hz did not result in more fragmentation ($p < 0.05$). The authors reported that, except when the energy setting was more than 1.0 J, there were no significant differences in the stone fragmentation produced by the small vs. large fibers. The literature supports that appropriate fiber selection and energy/frequency settings is important for several reasons: (1) to enable accessing most of the stones throughout the urinary tract, (2) to maximize fiber life, (3) to decrease the operation time, and finally (4) to reduce the overall costs of the operation [22].

The literature showed that NCCT is a valuable tool for predicting the stone clearance rates after SWL and URS [9,12,13]. Predictors of the success of stone lithotripsy have been extensively studied in the past decade; however, factors affecting the total laser energy of the Ho:YAG in stone lithotripsy were poorly studied. Therefore, we conducted this prospective study to investigate the association between preoperative NCCT characteristics, including stone size represented by the maximum diameter in millimeters and attenuation measured by HU and the total laser energy in patients undergoing URS with Ho:YAG.

Methods

To write this manuscript, we followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement guidelines as the standard reporting guidelines for observational cohort studies. The ethics committee of Ain Shams University Hospital approved this study on July 11, 2018 (IRB approval, no 166/2018).

Study design, setting, and duration

We conducted an observational prospective cohort study of patients undergoing URS lithotripsy at the Urology department of Ain Shams University Hospitals from September 2018 to September 2019 with the use of a holmium YAG laser as the lithotripsy method.

Study participants and variables

We included patients who had: (1) ureteric stones, (2) stone size from 5 mm to 20 mm, (3) normal renal function, and (4) patients who achieved stone free status after the operation. We excluded patients with the following conditions: (1) previous ESWL on the same stone, (2) ureteral stricture, (3) untreated urinary tract infection, and (4) pregnancy.

Data of the baseline characteristics, preoperative non-contrast CT findings including stone size by maximum diameter in millimeters, and stone attenuation values measured using average Hounsfield units (HUs) were recorded for all patients.

URS procedures

All patients were selected according to the previously mentioned inclusion and exclusion criteria and were informed about the study details. Written consent to be included in this study after the explanation of the study procedure and follow-up course was obtained from all patients. A complete history was taken from all patients and a physical examination was done.

Preoperative investigations were done as follows:

1. Laboratory investigations including complete blood count, liver function tests, kidney function tests, prothrombin time and coagulation, random blood glucose, AIDS antibodies, and hepatitis viral markers of HBV and HCV viruses. Electrocardiography of patients older than 40 years old was done.
2. Radiological investigations including CT without contrast to estimate stone size, stone attenuation measured by HU, presence of hydronephrosis, tissue rim sign and laterality of the stone and plain X-ray was done to assess the radio-opacity of stones. Consultation of internal medicine, cardiology, and anesthesiology specialists was done. We finally analyzed the data of 40 URS procedures (40 patients) that achieved stone-free status.

Surgical technique

All URS procedures were performed by two experienced surgeons, the URS procedure standardized in the study setting, Ain Shams university hospital, was as follows:

Preoperative prophylactic antibiotic was given within 1 hour before the operation and the dose was calculated according to body weight. Patients were placed in the lithotomy position under spinal anesthesia. Diagnostic cystoscopy with identification of the ureteric orifices and a 0.03 inch hydrophilic guide wire was gently placed into the renal pelvis by using a 22 Fr rigid cystoscope. Balloon dilatation of the intra mural portion of the ureter was done with a 9 Fr balloon dilator. Then, we passed a semi-rigid ureteroscope (6.5 Fr/8 Fr; Storz, Germany) over a guide wire, and the intra-ureteral space was directly confirmed. We localized the stone and the non-impacted stones were engaged in a Boston zero tip dormia basket. At a maximum average power of 30 W, we used a 200-µm laser fiber for stone fragmentation using a Ho:YAG laser (Ain shams university hospital). The initial laser settings were 0.5 J of energy at a rate of 5 Hz. The energy output was maintained at minimal settings for fragmentation of stones and then the rate was gradually increased at the discretion of each surgeon (the maximum energy and rate settings were 1.0 J and 10 Hz, respectively). The goal of the procedure was to fragment each stone into very small particles that did not require extraction. Although we used a retrieval basket device (zero-tip; Boston Scientific, in 21 URS procedures (52.5%), the use of a basket was restricted to prevent stone migration. We extracted a small piece from each patient for stone analysis for the future follow-up and treatment of the patient. Finally, a 6 Fr double-pigtail ureteral stent was placed routinely and removed using a rigid cystoscope within 4–10 weeks after surgery. Post-operative NCCT was done after 1 month and 2 months if needed to confirm stone-free status and exclude any complications before stent removal.

Follow-up

All patients were followed for 2 months. A NCCT was done after 1 month and 2 months to confirm the stone-free status and to record any related complications before stent removal.

Sampling method and sample size calculation

We employed a convenience sampling method within the study period of September 2018 to September 2019. All eligible patients in the study setting within the study period were considered for inclusion in this study. The sample size was calculated to detect an expected correlation coefficient of 0.62 between the stone attenuation measured by HU and the total laser energy as reported by Ofude et al. [13]. Assuming a 5% margin of error and 90% statistical power, a minimum sample size of 23 was sufficient to find a correlation coefficient of 0.62 between the two variables, stone attenuation measured by HU and the TLE. Sample size calculation was based on the methods of Negida [22].

Statistical analysis

Categorical data were described as frequency and percentages, while continuous data were described as mean and standard deviation. The association between categorical variables was tested by the Chi-square test. We considered a *p*-value $\leq$ 0.05 as statistically significant. All analyses were performed using SPSS version 26 software.

Results

Characteristics of the study population

Out of the 45 cases operated on during the study duration, 40 patients met the inclusion criteria and were included in the study and the final analysis. Twenty-two of them were men and 18 of them were women with a mean age of 57.8 years. The average BMI for the study population was 25.4 (SD = 1.3) Kg/m^2. The characteristics of the stone and the URS procedures are summarized in Table 1.

Table 1. Descriptive statistics of the study population.

Variables	Descriptive statistics ($n = 40$ patients)
Age (years)	57.8 (5.4), range (49.0–68.0)
Sex	
Males	22 (55.0%)
Females	18 (45.0%)
BMI (Kg/m^2)	25.4 (1.3), range (23.5–28.0)
Size of the stone (mm^3)	9.8 (2.4), range (6.0–14.0)
Operation time (min)	58.8 (16.0), range (40.0–90.0)
HFUs	858.8 (302.3), range (390.0–1400.0)
TLE (KJ)	3.5 (2.3), range (0.5–7.0)
Side	
Left	18 (45.0%)
Right	22 (55.0%)
Site	
Distal	5 (12.5%)
Mid	35 (87.5%)
Tissue rim sign	
Yes	15 (37.5%)
No	25 (62.5%)
Hydronephrosis	
No	26 (65.0%)
Yes	14 (35.0%)
Impacted	
No	28 (70.0%)
Yes	12 (30.0%)

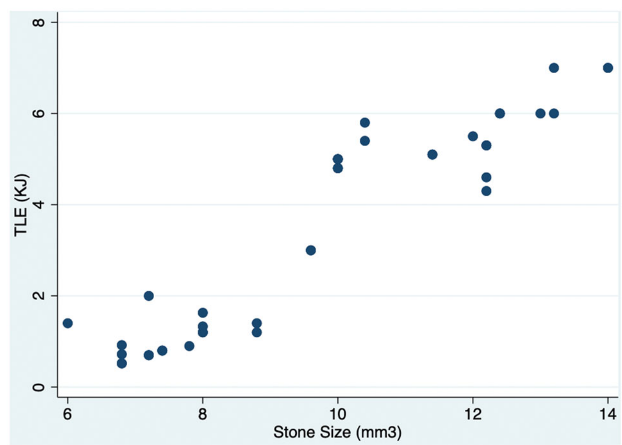

Figure 1. Shows a scatter plot of the correlation between stone size and TLE.

Correlation between HU and TLE

The mean total laser energy used in the study population was 3.5, while the mean HU was 858 units. Correlation analysis showed the following statistically significant correlations: (1) a positive strong correlation between stone size and TLE ($r = 0.934$, $p < 0.001$, Figure 1), (2) a positive strong correlation between HU and TLE ($r = 0.843$, $p < 0.001$, Figure 2), and (3) a positive strong correlation between TLE and operation time ($r = 0.85$, $p < 0.001$, Figure 3). The correlation matrix between the study variables is shown in Table 2.

Prediction of the TLE

The linear regression analysis showed that both HU and stone size were strong predictors of the TLE ($p = 0.013$ and $p < 0.001$, respectively). The R^2 value for this regression was 89%, which means this regression relationship could explain 89% of the variances in the studied sample. The regression results are shown in Table 3.

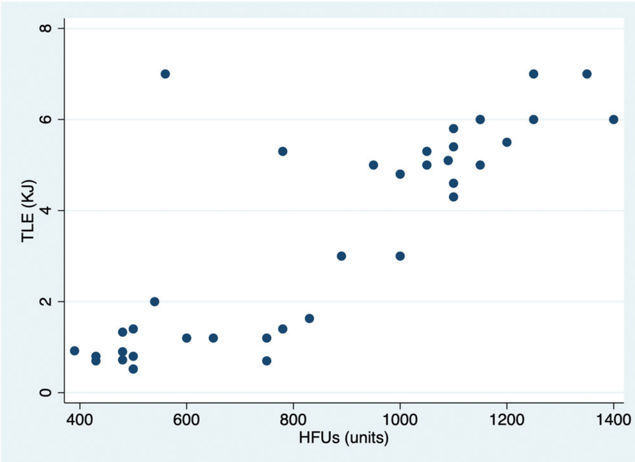

Figure 2. Shows a scatter plot of the correlation between TLE and HFUs.

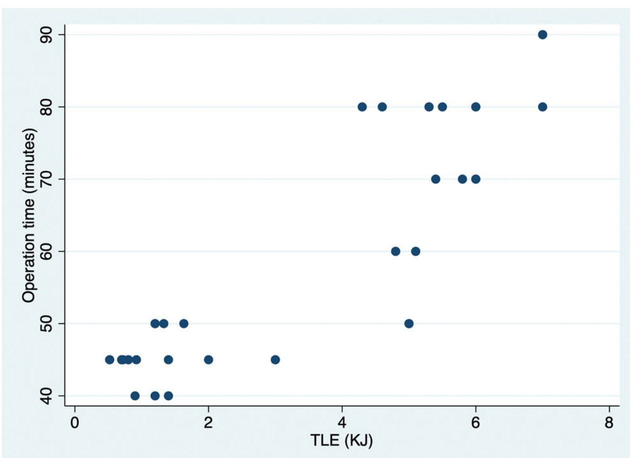

Figure 3. Shows a scatter plot of the correlation between operation time and TLE.

Table 2. The correlation coefficients and the *p*-values for the correlation between stone size, age, BMI, and the procedure parameters (HFUs, TLE, and operation time).

	Size of stone	HFUs	TLE	age	BMI
HFUs					
Pearson's *r*	0.816	—			
p-value	<0.001	—			
TLE					
Pearson's *r*	0.934	0.843	—		
p-value	<0.001	<0.001	—		
Age					
Pearson's *r*	−0.195	−0.138	−0.124	—	
p-value	0.227	0.395	0.447	—	
BMI					
Pearson's *r*	0.395	0.436	0.331	−0.229	—
p-value	0.012	0.005	0.037	0.155	—
Operation time					
Pearson's *r*	0.906	0.669	0.85	−0.261	0.442
p-value	<0.001	<0.001	<0.001	0.104	0.004

Discussion

Significance of the study

The gold standard treatment of urinary calculi is the endoscopic URS. With the advances in endoscopic design and miniaturization, urologists can now access the calculi throughout the collecting system for fragmentation into extractable or passable pieces. The Ho:YAG laser is the most studied and widely used type for endoscopic stone lithotripsy. This study aimed at evaluating the association between preoperative NCCT characteristics and total laser energy use in the Ho:YAG laser lithotripsy. This study reflects real-world data from our center's experience within the period September 2018 to September 2019. The study participants consisted of 40 patients who were treated with URS Ho:YAG at our center. The study expands the literature by corroborating the findings of Molina et al. [19] confirming that stone attenuation measured by HU positively correlates with the total laser energy used in Ho:YAG. Our results are important to guide urologists about the selection of the fiber size that provides the energy required to fragment the stones.

Table 3. Results of the regression analysis.

Predictor	Estimate	*t*	*p* value	Standardized estimate	Lower	Upper
Intercept	−5.05	−9.36	<0.001			
HFUs (units)	0.001	2.6	0.013	0.243	0.054	0.433
Stone size (mm^3)	0.71	7.87	<0.001	0.735	0.546	0.925

Summary of key findings and previous studies

Our results showed preoperative NCCT characteristics as stone attenuation measured by HU and stone size positively correlates with the total laser energy used in Ho:YAG. Therefore, this preoperative measure can be used to expect the anticipated total energy used and, therefore, determine the optimal fiber size.

It is evident that literature data on the role of preoperative NCCT characteristics in predicting the TLE of Ho:YAG is scarce and limited. A few observational studies have examined this relationship so far. In a previous retrospective study by Ofude et al. [13], the TLE positively correlated with stone volume ($r = 0.72$) and stone attenuation measured by HU ($r = 0.62$). Molina et al. [20] retrospectively reviewed 100 patients who underwent ureteroscopy and Ho:YAG laser lithotripsy; they found that stone volume and stone composition correlated with laser energy. Further, the multivariate analysis showed a significant association between laser time, stone volume, and HU. Moreover, similar findings were reported for other lithotripsy techniques as ESWL; Ouzaid et al. [11] investigated the relationships between stone attenuation measured by HU and ESWL outcomes; they found that stone attenuation was a predictor of the treatment outcome.

Recently, the Size, Topography, Obstruction, Number, and Evaluation of HU (S.T.O.N.E.) scoring system has been proposed as a novel prognostic surgical classification for urolithiasis in predicting success rate and complications [23]. Our findings expand the utility of this score by emphasizing the role of stone size and HU not only for predicting the success rate of the procedure but also in expecting the TLE required for the procedure, which would help the urologist when planning for the procedure. In another study, HUs were a significant predictor of success rate and included in the

S3HoCKwave score for prediction of failed shockwave lithotripsy in upper urinary tract calculi [19].

Our study has several strength points including the prospective nature of the study, and the relatively large sample size ($n = 40$ patients). The limitation of our study is that we conducted a single center evaluation and studied one type of lasers. This work has direct implications in urological practice. The larger the stone attenuation HU, the larger the TLE that will be required for URS lithotripsy procedure and therefore, a larger fiber size should be used.

Author conclusion

Both stone attenuation measured by HU and stone size are positively correlated with total laser energy required for ureteroscopic lithotripsy. This finding will be helpful to guide the urologist for selecting the optimal fiber size for the procedure.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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