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CT-based body composition parameters as independent predictors for successful shock wave lithotripsy: a retrospective cohort study

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Abstract

Background

Shock wave lithotripsy (SWL) remains an important minimally invasive treatment for renal and ureteral stones. However, reliable predictors of treatment success are lacking. Here, we aimed to identify preoperative predictors of stone-free status after SWL.

Methods

In a retrospective analysis, we evaluated 155 patients with solitary renal or ureteral stones for 15 preoperative variables, including stone characteristics and computed tomography (CT)–based body composition parameters. Patients with residual fragments ≤4 mm were classified as stone-free (SF), whereas those with residual fragments >4 mm were classified as non–stone-free (NSF). Variables significant in univariate analysis were entered into multivariate analyses.

Results

The SF rate was 66% in the overall cohort, and univariate analysis revealed significant associations between SF status and pre-stenting, stone size, maximum and average CT attenuation, visceral and total fat areas, and iliopsoas muscle parameters. Multivariate analysis identified average CT attenuation and iliopsoas muscle area as independent predictors of SWL success. Receiver operating characteristic curve analysis for those parameters was modestly predictive. Subgroup analyses demonstrated distinct predictors by stone location: visceral fat area independently predicted SF status for renal stones, whereas age and iliopsoas muscle area independently predicted SF status for ureteral stones.

Conclusions

Stone characteristics and CT-based body composition parameters were both significantly associated with SWL outcomes. Visceral fat area and iliopsoas muscle area might serve as predictors of treatment success, suggesting that patient-specific anatomic factors influence SWL efficacy. Preoperative body composition assessment with routine CT imaging might improve patient selection for SWL.

Introduction

The global prevalence of urolithiasis has increased significantly in recent years. A systematic analysis reported that incident cases rose to approximately 106 million worldwide in 2021—a 26.7% increase since 2000. Although age-standardized incidence rates have trended downward in some countries, deaths attributable to urolithiasis rose by 60.3% globally during the same period, making urolithiasis a persistent major concern in global health and welfare [1].

Shock wave lithotripsy (SWL) for urolithiasis was pioneered by Chaussy and colleagues in the 1980s. Even as endoscopic surgical procedures have increased in use, SWL has continued to play an important role as a minimally invasive treatment option.

Previous studies have reported several predictors of SWL treatment outcomes, including skin-to-stone distance (SSD), age [2], stone attenuation (< 1,000 HU) on computed tomography (CT) [3], stone size (< 10 mm) [3], body mass index (BMI) [4, 5], and severity of urinary tract obstruction (e.g., presence of severe hydronephrosis) [5, 6]. A large-scale cohort study by Choi et al. demonstrated a bidirectional association between osteoporosis and urolithiasis, with patients having osteoporosis experiencing an increased risk of developing urolithiasis by a factor of 1.36, and patients having urolithiasis experiencing an increased risk of progression to osteoporosis by a factor of 1.26 [7]. Thus, accurate pre-treatment evaluation of ureteral and renal stones is crucial.

Here, we retrospectively compared preoperative factors in patients with ureteric and renal stones who did and did not achieve SF status at initial treatment, with the aim of identifying positive predictive factors for successful stone fragmentation.

Methods

Of 187 patients with a solitary ureteral or renal stone treated between June 2022 and March 2025, 155 who had undergone Computed Tomography (CT) imaging within six months before treatment were enrolled into our retrospective analysis (Online Resource 1). The SF group consisted of 102 patients, and the NSF group consisted of 53 patients. The advantages and disadvantages of SWL and TUL had been explained to each patient, and the initial treatment modality was selected by each patient.

SWL was performed using the Delta III Pro lithotripter (Dornier MedTech, Kennesaw, GA, USA) in our hospital. The shock wave delivery rate was fixed at 60 shocks per minute, and intraoperative targeting was adjusted as needed during treatment. To reduce the risk of complications, the setting parameters were set at 7 power and 2,500 shots for renal and ureteropelvic junction stones, and at 9 and 3,300 for upper, middle, and lower ureteral stones. If adequate fragmentation was attained, treatment was discontinued even if the maximum energy level or shock number

had not been reached. Patient positioning and shock wave direction were adjusted according to stone location and depth. Treatment efficacy was evaluated by plain radiography or CT on the day after SWL and within one month after treatment.

If no radiologic changes in stone fragmentation were detected after multiple SWL sessions, conversion to TUL was proposed. However, SWL was continued in patients for whom TUL was considered unfavorable because of insufficient preoperative surgical tolerance. Postoperative imaging with kidney–ureter–bladder radiography or CT was used to assess residual stones. Patients with residual stones or fragments no larger than 4 mm were classified as SF [8, 9], and those with residual stones or fragments larger than 4 mm were classified as non-SF (NSF).

The SF and NSF groups were comparatively evaluated on 15 preoperative variables. That univariate analysis included age, sex, and BMI; past history of urolithiasis; pre-stenting; complications; treatment time; stone street; maximum, average, and minimum CT attenuation in Hounsfield units; SSD, visceral, subcutaneous, and total fat area; osteoporosis; and sarcopenia.

CT-related stone parameters were measured by tracing the stone's contour (maximum axial cross-section) as a region of interest, from which the maximum, minimum, and average attenuation were obtained (Online Resource 2). SSD was determined as the distance at a 45-degree angle from the SWL direction (ventral and dorsal) (Online Resource 3). Sarcopenia was defined as a psoas muscle mass area overimposing the third lumbar vertebra below the sex-specific median size, determined using the formula: length of the major axes × length of the minor axes × π (Online Resource 4) [10, 11].

Irlbeck et al. reported that the visceral fat area at the L3/4 vertebral level had the strongest correlation with the total visceral fat volume, which is used for assessing metabolic syndrome [12]. We therefore measured visceral fat area at L3/4 in our cohort (Online Resource 5). For the evaluation of osteoporosis, we used the technique of Sharma et al., who reported that bone mineral density can be estimated using the average pixel density within elliptical regions of interest placed in the mid-vertebral core of the 11th thoracic vertebra on CT images (Online Resource 6) [13].

Variables observed to be significantly different on univariate analysis were entered into multivariate analyses. All statistical analyses were conducted in the R software application (version 4.4.1: R Foundation for Statistical Computing, Vienna, Austria). Values of $p < 0.05$ were considered significant. This study was approved by the Institutional Review Board of International University of Health and Welfare Nasu Medical Center (Approval No. 24-TC-014) and was conducted in accordance with the Declaration of Helsinki. The requirement for written informed consent was waived by the Institutional Review Board because of the retrospective nature of the study. Instead, an opt-out procedure was implemented by publicly disclosing information regarding the study and providing patients with the opportunity to decline participation.

Results

Table 1 summarizes patient and stone characteristics for the analyzed cohort (124 men, 80%; 31 women, 20%; median age, 56.0 years [range, 24–87 years]). Median height in the cohort was 166.1 cm (range, 145–183 cm), and median BMI was 25.5 (range, 16.6–39.3). Maximum stone size was a median of 10 mm (range, 4–45 mm). Stone locations were the renal pelvis (30%), calyces (10%), and ureteral sites (upper, 36%; middle, 7%; lower, 17%). The SF rate was 66% in the cohort overall, with greater success for ureteral (73%) than for renal stones (55%). Three patients (2%) experienced complications, including renal subcapsular hematoma, pyelonephritis, and back pain.

Table 1
Characteristics of the study patients and their urinary stones

Sex male	**N(%)**
female	**124(80%)**
	31(20%)
Age (median)	56.0 (24–87)
Height (cm) (median)	166.1 (145–183)
BMI (median)	25.5 (16.6–39.3)
Maximum stone size (mm) (median)	10 (4–45)
Stone position R2 / R3	47 (30%) / 16 (10%)
U1 / U2 / U3	56 (36%) / 10 (7%) / 26 (17%)
Stone free rate	Total : 66% Kidney : 55% Ureter : 73%
Complications	3 (2%)
	(renal subcapsular hematoma/pyelonephritis/Back pain)
BMI, body mass index; IQR, interquartile range.	
Variables are presented as medians with interquartile range or as frequencies with percentages.	

Table 2 summarizes the univariate analyses for the overall cohort and the renal and ureteral stone subgroups.

Table 2
Univariate analysis of 19 preoperative variables in 155 patients by stone-free (SF) or non–stone-free (NSF) status after shock wave lithotripsy

Stone size : less than 4mm=SF group □over 4 mm□NSF group									
	Overall cohort			**Renal stone cohort**			**Ureter stone cohort**		
	SF group N=102	NSF group N=53	P value	SF N = 36	NSF N = 28	P value	SF group N=102	NSF group N=53	P value
	Mean(SD)	Mean(SD)		Mean(SD)	Mean(SD)		Mean(SD)	Mean(SD)	
Age	56.59 (15.06)	58.28 (12.97)	0.488	56.67 (14.35)	52.57 (10.44)	0.209	56.55(15.55)	64.68(12.70)	0.022*
BMI	24.99 (3.91)	26.03 (3.50)	0.104	25.63 (5.06)	26.84 (1.92)	0.237	24.64(3.10)	25.13(4.56)	0.553
Sex	1.25 (0.43)	1.11(0.32)	0.052	1.25 (0.44)	1.14 (0.36)	0.298	1.24(0.43)	1.08(0.28)	0.084
Past history	0.45 (0.50)	0.43 (0.50)	0.841	0.64 (0.49)	0.36 (0.49)	0.025*	0.35(0.48)	0.52(0.51)	0.138
Pre-stenting	0.20 (0.40)	0.40(0.49)	0.007*	0.28 (0.45)	0.43 (0.50)	0.214	0.15(0.36)	0.36(0.49)	0.029*
Complications	0.05 (0.21)	0.06 (0.23)	0.219	0.03 (0.17)	0.00 (0.00)	0.382	0.02(0.12)	0.12(0.33)	0.03*
Treat time	57.75 (7.20)	54.77 (13.43)	0.075	55.14 (8.24)	51.79 (14.42)	0.245	59.17(6.18)	58.12(11.62)	0.580
Maximum stone size	10.52 (6.39)	14.65 (9.25)	0.001*	12.70 (9.23)	18.15 (11.22)	0.037*	9.33(3.66)	10.72(3.67)	0.109
SSD(Skin-to-stone distance) (mm)	100.21 (23.48)	94.91 (23.57)	0.185	97.27 (27.45)	86.07 (20.04)	0.075	101.82(21.07)	104.8(23.63)	0.561
Maximum CT attenuation value	1190.27 (359.67)	1342.68 (294.04)	0.01*	1218.11 (339.57)	1356.89 (226.54)	0.067	1175.09(371.83)	1326.76(359.29)	0.083
Minimum CT attenuation value	252.06 (118.10)	294.23 (149.63)	0.057	233.50 (118.28)	316.21 (132.44)	0.011*	262.18(117.67)	269.6(166.08)	0.812
Average CT attenuation value	789.73 (253.03)	950.72 (277.16)	0.001*	799.12 (237.46)	1020.50 (257.47)	0.001*	784.61(262.77)	872.56(282.51)	0.166
Visceral fat area	152.22 (77.72)	200.03 (72.38)	0.001*	156.38 (84.18)	219.44 (50.49)	0.001*	146.92(55.92)	130.95(86.22)	0.302
Subcutaneous fat area	148.04 (58.27)	143.49 (68.45)	0.665	150.09 (63.12)	154.68 (46.27)	0.748	149.96(74.53)	178.3(86.91)	0.126
Total fat area	300.27 (113.95)	343.52 (126.22)	0.032*	306.47 (131.61)	374.11 (68.66)	0.016*	296.89(104.01)	309.25(164.02)	0.67
Bone density	145.43 (48.05)	143.97 (47.46)	0.857	141.47 (39.05)	136.10 (37.65)	0.582	147.6(52.47)	152.79(55.97)	0.68
Iliopsoas muscle length	40.31 (7.00)	43.20 (7.31)	0.017*	40.40 (5.92)	42.91 (7.11)	0.128	40.25(7.56)	43.53(7.66)	0.069
Iliopsoas muscle width	21.19 (7.52)	23.24 (6.23)	0.09	20.22 (7.77)	22.67 (6.25)	0.179	21.71(7.39)	23.88(6.28)	0.198
Iliopsoas muscle area	2721.64 (1137.39)	3222.43 (1111.60)	0.01*	2630.67 (1132.12)	3128.81 (1070.14)	0.079	2771.26(1145.83)	3327.29(1169.29)	0.043*

BMI, body mass index; SSD, skin-to-stone distance; CT, computed tomography; .

Variables are presented as means ± standard deviation (SD)

* Significant result.

In the overall cohort, pre-stenting, larger stone size, higher maximum and mean CT attenuation, greater visceral and total fat areas, and larger iliopsoas muscle length and area were significantly associated with non–stone-free (NSF) status. Strong correlations were observed between maximum and mean CT attenuation (r = 0.88), visceral and total fat areas (r = 0.89), and iliopsoas muscle length and area (r = 0.75) (Online Resource 7–9). To minimize multicollinearity and improve clinical applicability, mean CT attenuation, visceral fat area, and iliopsoas muscle area were selected for multivariable analysis together with pre-stenting and maximum stone size. Multivariable logistic regression identified mean CT attenuation (OR 0.99, p = 0.045) and iliopsoas muscle area (OR 0.99, p = 0.044) as independent predictors of stone-free status (Table 3). ROC analysis demonstrated modest predictive performance for both variables (AUC 0.659 and 0.663, respectively), with optimal cut-off values of 1,102 HU and 3,504 mm² (Online Resource 10 and 11).

Table 3
Multivariate logistic regression analysis for stone-free status after shock wave lithotripsy in 155 patients of overall and subgroup cohort

Overall cohort			
Variable	OR	95%CI	p Value
Pre-Stenting	0.49	0.21–1.13	0.092
Maximum size	0.97	0.91–1.02	0.198
Average CT attenuation value	0.99	0.997–0.999	0.045*
Visceral fat area(L3–4)	0.996	0.990–1.000	0.088
Iliopsoas muscle area(L3)	0.999	0.9993–0.9999	0.044*
Renal stones cohort			
Past history	2.74	0.75-10.576	0.130
Maximum stone size	0.98	0.92–1.05	0.633
Minimum CT attenuation value	1.00	0.994–1.01	0.981
Average CT attenuation value	0.99	0.994–1.00	0.098
Visceral fat area(L3–4)	0.99	0.980–0.99	0.037*
Ureteral stones cohort			
Age	0.94	0.89–0.98	0.006*
Pre-Stenting	0.44	0.13–1.56	0.199
Complications	0.22	0.01–2.80	0.293
Maximum stone size	0.91	0.79–1.05	0.218
Iliopsoas muscle area(L3)	0.99	0.998–0.999	0.004*
CT, computed tomography.			
Data are presented as odds ratios (ORs) with 95% confidence intervals (CIs). Variables reaching p < 0.05 in the univariate analysis were included in the multivariate analysis. A two-sided p value less than 0.05 was considered statistically significant.			
* Significant result.			

Among patients with renal stones, prior urolithiasis, stone size, minimum and mean CT attenuation, visceral fat area, and total fat area differed significantly between the SF and NSF groups (Table 2). Visceral fat area showed a strong correlation with total fat area (r = 0.89; Online Resource 12), and only visceral fat area was included in the multivariable model. Multivariable analysis identified visceral fat area as the only independent predictor of stone-free status (OR 0.99, p = 0.037; Table 5). ROC analysis yielded an AUC of 0.724 with an optimal cut-off value of 185 cm² (Online Resource 14).

Among patients with ureteral stones, age, pre-stenting, complications, and iliopsoas muscle area differed significantly between the SF and NSF groups (Table 2). Multivariable analysis demonstrated that age (OR 0.94, p = 0.006) and iliopsoas muscle area (OR 0.99, p = 0.004) were independent predictors of stone-free status (Table 3). ROC analysis showed modest predictive performance for both age (AUC 0.667; cut-off 65.5 years) and iliopsoas muscle area (AUC 0.659; cut-off 3,281 mm²) (Online Resource 15 and 16).

Discussion

In this retrospective analysis, we revealed three principal findings. First, stone characteristics, particularly CT attenuation, strongly correlated with treatment outcomes. Second, body composition parameters, including visceral fat and iliopsoas muscle area, were significantly associated with SWL success. Third, those associations differed depending on stone location, suggesting distinct mechanisms underlying SWL efficacy in renal and ureteral stone treatment.

Stone attenuation has consistently been reported as a reliable predictor of SWL outcomes. Previous studies have reported that stones with lower Hounsfield units are more susceptible to fragmentation, reflecting differences in stone composition and internal structure. In our study, maximum and average CT attenuation were both significantly lower in the SF group in the overall and renal stone analyses, with the multivariate analysis revealing average CT attenuation as an independent predictor in the overall analysis. Those findings are consistent with earlier reports and reinforce the importance of CT-based stone characterization in clinical decision-making. The ROC curve in our cohort demonstrated modest discriminative ability (AUC: 0.65), indicating that although CT attenuation is useful, it should not function as a sole predictor [14, 15].

The novel aspect of our study is the evaluation of body composition through CT imaging. Visceral fat area was observed to be significantly correlated with SWL outcomes, particularly in patients with renal stones, for whom it emerged as an independent predictor. Previous studies reported an association between abdominal fat distribution and outcomes in SWL. However, none suggested that fat area alone was an independent predictor of successful stone fragmentation [16, 17]. One possible explanation is the role of acoustic impedance mismatch during shock wave propagation. Shock waves generated during SWL must pass through multiple tissue layers before reaching a stone. Increased visceral fat might alter energy transmission, either by attenuating shock wave energy or by increasing dispersion, thereby reducing fragmentation efficiency. In contrast, subcutaneous fat area was not associated with treatment outcomes, suggesting that internal body composition rather than external body habitus plays a more critical role in clinical outcomes. Another important observation is the strong association between iliopsoas muscle area and SWL outcomes. A larger iliopsoas muscle area was consistently associated with poorer treatment outcomes and was identified as an independent predictor in both our overall and ureteral stone analyses. That observation has not previously been widely reported and might reflect the influence of muscle tissue on shock wave transmission. The acoustic impedance and attenuation coefficient is higher for skeletal muscle than for adipose tissue, which might contribute to greater reflection and dissipation of shock-wave energy. Although that mechanism remains speculative, differences in tissue composition might partly explain the observed association between iliopsoas muscle area and SWL outcomes [18].

In the ureteral stone subgroup, age was revealed to be an independent predictor. Aging is associated with alterations in tissue elasticity, water content, fibrosis, and muscle composition, all of which might influence shock wave propagation and focal energy delivery to a stone.

The clinical implications of our findings are noteworthy. Preoperative CT imaging is routinely performed in patients undergoing SWL, and assessment of body composition parameters incurs no additional cost or radiation exposure. Incorporating the visceral fat and iliopsoas muscle areas into the preoperative evaluation might improve patient selection, potentially identifying patients who are less likely to benefit from SWL and for whom alternative treatments such as ureteroscopy might be more appropriate.

Some limitations of our research should be acknowledged. First, given a retrospective analysis conducted at a single institution, with SWL delivered using a single instrument, the generalizability of our findings might be limited. Patient selection and treatment protocols can vary across institutions, potentially affecting SWL outcomes. Second, the sample size was relatively limited, which might have reduced the statistical power required to detect significant associations for some variables. Factors that demonstrated borderline significance might potentially have reached statistical significance in a larger cohort. Third, although body composition was evaluated based on CT-based measurements, other potentially relevant factors—including shock wave energy settings, stone composition, and operator-related factors—were not addressed in this study. Fourth, because pediatric patients were not included in this cohort, the findings are limited to adult populations and may not be generalizable to children. Future prospective and multicenter studies with larger sample sizes are needed to confirm our observations and further clarify the role of body composition in predicting SWL outcomes.

Conclusions

In this retrospective study of patients receiving SWL for ureteral and renal stones, CT attenuation and body composition parameters, particularly visceral fat and iliopsoas muscle area, correlated significantly with SWL outcomes. Those observations suggest that not only stone characteristics, but also patient-specific anatomic factors influence treatment success. Further prospectively designed studies with larger cohorts are warranted to validate our results and to develop more accurate predictive models for SWL outcomes.

Declarations

Author Contribution

All authors reviewed the manuscript.

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