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Evaluation of computed tomography findings for success prediction after extracorporeal shock wave lithotripsy for urinary tract stone disease

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Abstract
Purpose Currently, the most widely used method of treatment of urinary tract stones is extracorporeal shock wave lithotripsy (SWL). Patient and stone characteristics are important for SWL success. We evaluated noncontrast computed tomography (NCCT) characteristics of urinary tract stones for the prediction of SWL success.
Methods Records of patients who underwent NCCT before SWL treatment between January 2008 and June 2012 were retrospectively evaluated. Demographic data were recruited from patient files. Hounsfield units (HU), stone size and skin-to-stone distance (SSD) were measured on NCCT. After serial measurements of the highest HU value (HUmax) and lowest HU value (HUmin), HU value was calculated as the average of these two values (HUave). These parameters were compared between successful [stone-free (SF) group] and unsuccessful [residual fragment (RF) group] cases after SWL.
Results A total of 254 patients, 113 kidney stones and 141 ureteral stones, were evaluated. Mean age was 51.0 ± 14.6 (18–87) years, and mean stone size was 10.9 ± 3.7 mm. Stone diameter, HUmax, HUmin and HUave were significantly lower in SF group when compared with RF group for both kidney and ureteral stones ($p < 0.05$). We also found that SSD for kidney stones was predictive for SWL success.
Conclusions We suggest that HUmax, HUmin and HUave values are significant predictors of SWL success for both kidney and ureteral stones. They might be used in daily clinical practice for patient counselling.

Keywords Extracorporeal shock wave lithotripsy (SWL) · Hounsfield units (HU) · Noncontrast computed tomography (NCCT) · Skin-to-stone distance (SSD) · Urolithiasis

Introduction

Since 1980, extracorporeal shock wave lithotripsy (SWL) has become the first-line treatment option for <2 cm kidney stones in adults [1]. In general, factors predicting the success rate of SWL can be divided into stone-related and patient-related factors. Patient-related factors are age, sex, stone laterality (right or left), body surface area and body mass index (BMI). Stone-related factors are stone size, intrarenal stone location, skin-to-stone distance (SSD) and stone fragility [2].

In the last decade, noncontrast computed tomography (NCCT) has become the first choice for diagnosis of kidney stones with high sensitivity and specifity [3]. NCCT enables determination of urinary stone density with the probability of 0.5 % difference ranges [4]. In addition, several studies established that the Hounsfield units (HU) and Hounsfield density (HD) of stones determined by NCCT were highly correlated in terms of fragility with SWL [5–8].

Significance of the aforementioned parameters have not been evaluated in our country, so we aimed to evaluate the predictivity of various HU values in addition to HUave and also SSD for SWL success in a Turkish patient group since racial differences may have an effect on outcomes.

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Materials and methods

After an approval obtained from the Local Ethics Committee, we retrospectively evaluated patient records who have undergone SWL for upper urinary tract stone of 5–20 mm diameter from January 2008 to June 2012. Only patients with documented radiographic evaluation of the urinary tract by NCCT before SWL were included. The exclusion criteria included stones of <5 or >20 mm in diameter, staghorn stones, obstructive and multiple stones, stones requiring drainage, patients with solitary kidney and patients with congenital urinary tract anomalies. All patients with SWL failures underwent ureterorenoscopic treatment for ureteral stones and mini-percutaneous nephrolithotomy or retrograde intrarenal surgery for kidney stones.

NCCT images using 2-mm sections with the liver's dome as cranial border and pubis joint as caudal border at 100 mA 120 kV (Brilliance 64, Philips®, Best, the Netherlands) were taken. HU values were measured in the largest diameter of the stone (longitudinal or transverse) with bone window and large magnification. After serial measurements of the highest HU value (HUmax) and lowest HU value (HUmin), HU values were calculated as the average (HUave) of these two values. The HD was calculated as the HUmax divided by stone size [9]. The average SSD for kidney stones was determined as previously described by Pareek et al. [10] and briefly calculated by using measurements in the coronal plane, sagittal plane and at 45° between these two planes from the center of the stone to the skin on NCCT. All measurements were calculated by radiologists. All treatments were performed with Elmed Lithotripsy® (Elmed, Ankara, Turkey) Systems. Stone fragmentation was monitored by fluoroscopy throughout the procedure. Processing began with 13 kV and frequency of 60/min, and sessions were completed with maximum 20 kV and 2000 shocks. After each session, location and fragmentation of stones were followed with kidney-ureter-bladder (KUB) plain abdominal radiograph. Time interval between the sessions was 1 week, and the SWL success was evaluated by radiographic imaging (KUB, intravenous urography or NCCT) 6 weeks after the last session and defined as stone-free. Efficiency quotient (EQ) was calculated as originally described [11]. Then, aforementioned parameters were compared between stone-free patients (SF group) and patients who have residual fragments after last SWL session (RF group). Thereafter, stones with >750 and ≤750 HUave values were compared regarding SWL success [6].

Statistical analysis

Data were analyzed using the Statistical Package for Social Sciences, version 15.0 (SPSS, Chicago, Ill) software program. Independent Student's *t* test analysis was used for comparing demographic and radiologic parameters between SF and RF groups. Data were given as mean ± SD. Bivariate correlations between possible predictive parameters for SWL success were compared by using Pearson's correlation test. Statistical significance was defined as $p < 0.05$.

Results

A total of 254 patients (157 men and 97 women) were included. Mean age was 51.0 ± 14.6 (18–87) years, and mean stone size was 10.9 ± 3.7 mm for the whole group. Stone localization and stone side and average SWL sessions are given in Table 1. Considering the stone localization, there were 113 patients with kidney stones and 141 patients with ureteral stones. Stone localizations were 21 lower pole (8.3 %), 10 middle calyx (3.9 %), 8 upper pole (3.1 %), 74 renal pelvis (29.2 %), 58 proximal ureter (22.8 %), 35 mid-ureter (13.8 %) and 48 distal ureter (18.9 %).

When we compare patients in SF and RF groups, we determined that factors affecting SWL success for both kidney and ureter stones were stone diameter, HUmax, HUmin and HUave (Tables 2, 3). For patients with kidney stones, increasing SSD and BMI was also another factor decreasing SWL success rates. In correlation analysis, we see that all these factors were correlated with SWL success (Table 4). Further analysis regarding the cutoff HUave value 750 HU, we found that SWL success for kidney stones was 50 and 20.2 % for ≤750 HU and >750 HU groups, respectively ($p < 0.05$). Stone diameters did not differ between these two groups (12.2 ± 4.6 mm vs. 12.3 ± 4.2 mm, $p = 0.544$). For ureteral stones, SWL success were 75.6 and 42.1 % for stones ≤750 HU and >750 HU HUave values, respectively ($p < 0.05$). However, there was also significant difference in terms of stone diameter between these two groups (8.1 ± 3.5 mm for ≤750 HU vs. 9.8 ± 3.4 mm for >750 HU, $p < 0.05$).

Discussion

SWL has gained much popularity for the last three decades as an alternative to surgical management with high success rates. However, there are some factors affecting the success of SWL which are the stone size, stone density and configuration previously evaluated with KUB abdominal plain radiograms. Several reports indicated that stone density lower than bone on KUB is an augmenting factor for SWL success [12–16]. However, effective measurement of the size of stone and evaluation of density may not be done truly sometimes because of bowel gases [5]. Today, most

Table 1 Patient and stone characteristics of the study population. Data regarding SWL sessions were also provided

	Kidney stone ($n = 113$)	Ureteral stone ($n = 141$)	Total ($n = 254$)
Gender			
Male	73	84	157
Female	40	57	97
Stone side			
Left	70	58	128
Right	53	73	126
Stone location	Renal pelvis: 74	Proximal ureter: 58	254
	Upper pole: 8	Mid-ureter: 35	
	Middle calyx: 10	Distal ureter: 48	
	Lower pole: 21		
Mean age (years)	49.9 ± 14.1 (18–80)	51.1 ± 14.9 (18–87)	51.0 ± 14.6 (18–87)
Mean BMI (kg/m^2)	27.4 ± 2.8 (19–44)	28.2 ± 3.3 (19–46)	27.8 ± 3.1 (19–46)
Average SWL session	2.78 (1–3)	2.57 (1–3)	2.66 (1–3)
Average shock wave/SWL session	2,000	2,000	2,000
Mean SWL frequency (shock wave/min)	60	60	60
Fluoroscopic exposure time (min)	1.9	1.7	1.8
Stone free (%)	33 (29.2)	72 (51.1)	105 (41.3)
Efficiency quotient (EQ)	0.17	0.34	0.26

BMI body mass index, *SWL* extracorporeal shock wave lithotripsy, *EQ* efficiency quotient

Table 2 Comparison of possible success predictors between SF and RF group in kidney stones

	Kidney stones		
	SF group ($n = 33$)	RF group ($n = 80$)	*p* value
Mean age (years)	48.3 ± 13.7	54.0 ± 14.5	0.061
BMI (kg/m^2)	26.2 ± 2.1	28.1 ± 3.3	0.023
HUmin (HU)	707.4 ± 224.7	857.6 ± 309.2	0.006
HUmax (HU)	1,047.0 ± 338.1	1,270.7 ± 278.7	0.002
HUave (HU)	877.3 ± 268.2	1,064.2 ± 264.5	0.001
Stone diameter (mm)	10.1 ± 4.4	13.0 ± 4.1	0.003
SSD (mm)	88.4 ± 16.7	98.7 ± 25.7	0.015
HD	113.0 ± 58.6	108.1 ± 44.5	0.682

SF stone free, *RF* residual fragment, *BMI* body mass index, *HUmin* minimum hounsfield units, *HUmax* maximum hounsfield units, *HUave* average hounsfield units, *SSD* skin-to-stone distance, *HD* hounsfield density

patients with nephrolithiasis are now evaluated with NCCT instead of KUB and IVU [6]. NCCT is a noninvasive radiologic imaging modality, which determines the stone density and anatomical relationships better than KUB. Predictors of SWL success provided by NCCT are mostly stone density, stone location and SSD [6, 10]. As mentioned previously, NCCT is more sensitive than KUB abdominal plain graphies for determining the stone density [4, 17].

Joseph et al. reported that higher HU values needed increasing number of pulses for stone clearance with SWL and success rates are lower for high HU values. They proposed surgical treatment with a cutoff stone density value denser than 950 HU according to their results [5]. In another study considering the SWL session number for stone clearance, Gupta et al. [6] demonstrated that 80 % of stones ≤750 HU need <3 SWL sessions with a stone-free rate of 88 %, whereas 72 % of stones >750 HU need more than three sessions with a stone-free rate of 60 %. When we compare stone clearance rates for stones ≤750 HUave and >750 HUave in our study, it is clearly seen that denser stones are more resistant to SWL. Relatively, low success rates in our study when compared with the aforementioned study may be attributed to definition of different success criteria. Ouzaid et al. [18] defined 970 HU as cutoff HU value and gave that clearance rates for stones <970 HU was 96 %, whereas 38 % stone-free rates was documented for stones ≥970 HU in the same study.

Factors predicting SWL success rates in our study are presented as stone size, HUmin, HUmax and HUave for kidney and ureteral stones; additionally, SSD and BMI for kidney stones. A cutoff value of 10 cm was proposed for SSD in terms of predicting SWL success by Pareek et al. [10]. Another study presented SSD as an important parameter for predicting SWL success rates for calyxeal stones [2]. In our study, there was a significant difference between SSD values; RF group have significantly higher SSD values compared to SF group.

Major drawbacks of the present study include retrospective analysis of nonrandomized patients and limited number

Table 3 Comparison of possible success predictors between SF and RF group in ureteral stones

Ureteral stones	SF group	RF group	p value
Stone localization			
Proximal ureter	51.7 % ($n = 30$)	48.3 % ($n = 28$)	
Mid-ureter	42.9 % ($n = 15$)	57.1 % ($n = 20$)	
Distal ureter	56.2 % ($n = 27$)	43.8 % ($n = 21$)	
Mean age (years)			
Proximal ureter	51 ± 13.2	51.7 ± 15.3	0.849
Mid-ureter	45.3 ± 12.8	47.4 ± 17.2	0.698
Distal ureter	47.9 ± 13.9	55.3 ± 16.8	0.106
Humin (HU)			
Proximal ureter	737.3 ± 254.7	834.4 ± 266.8	0.162
Mid-ureter	625.9 ± 245.1	854.6 ± 237.4	0.009
Distal ureter	679.1 ± 195.4	868.7 ± 223.5	0.003
Humax (HU)	978.2 ± 324.2	1,148.4 ± 291.9	0.041
Proximal ureter			
Mid-ureter	861.6 ± 301.1	1,199.2 ± 180.2	0.000
Distal ureter	1,000.1 ± 304.2	1,187.5 ± 228	0.023
HUave (HU)	857.8 ± 282	991.5 ± 265.7	0.069
Proximal ureter			
Mid-ureter	743.9 ± 269.7	1,027 ± 186.9	0.001
Distal ureter	839.8 ± 236.5	1,028.2 ± 215.8	0.007
Stone diameter (mm)			
Proximal ureter	8.8 ± 2.6	11 ± 4	0.017
Mid-ureter	8.8 ± 4.8	10.6 ± 3.9	0.227
Distal ureter	8.3 ± 2.8	8.6 ± 2.8	0.632
HD			
Proximal ureter	114.4 ± 41.1	113 ± 36	0.891
Mid-ureter	115.6 ± 49.2	124.2 ± 39.5	0.568
Distal ureter	127.1 ± 43.4	144.6 ± 36.7	0.146

SF stone free, *RF* residual fragment, *HUmin* minimum hounsfield units, *HUmax* maximum hounsfield units, *HUave* average hounsfield units, *HD* hounsfield density

Table 4 Correlation analysis of possible success predictive parameters for SWL

	SF			
	Kidney stones ($n = 113$)		Ureteral stones ($n = 141$)	
	p value	R	p value	R
HUmin	0.014	−0.231[a]	0.000	−0.331[b]
HUmax	0.000	−0.325[b]	0.000	−0.365[b]
HUave	0.001	−0.305[b]	0.000	−0.365[b]
Stone diameter	0.001	−0.297[b]	0.009	−0.220[b]
SSD	0.039	−0.196[a]	–	–
HD	0.641	−0.045	0.453	−0.064

SF stone free, *HUmin* minimum hounsfield units, *HUmax* maximum hounsfield units, *HUave* average hounsfield units, *SSD* skin-to-stone distance, *HD* hounsfield density

[a] Correlation is significant at the 0.05 level

[b] Correlation is significant at the 0.01 level

of patients; lack of metabolic workup, stone analysis of most patients and auxiliary re-treatment rates for renal and ureteral stones are also missing. Evaluation of patients with KUB after SWL may also have an adverse effect on outcomes since sensitivity and specificity of these methods vary. Further prospective-randomized trials may enlighten these findings.

In conclusion, as a gold standard diagnostic method for the urinary tract stone disease, NCCT also gives valuable information in terms of prediction of success before SWL. Definitive stone size measurement and stone location, enabling calculation of HUave value as stone density parameter and SSD measurements, are well-documented success predictors of NCCT. With this study, we provided that all these parameters are also significant for Turkish patient population. We recommend NCCT evaluation and measurement of these parameters for all patients with urinary tract stone disease in order to predict SWL success.

Conflict of interest The authors declare that they have no conflict of interest.

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