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Evaluation of Possible Predictive Variables for the Outcome of Shock Wave Lithotripsy of Renal Stones

Yong Il Park, Ji Hyeong Yu, Luck Hee Sung, Chung Hee Noh, Jae Yong Chung

Department of Urology, Inje University College of Medicine, Seoul, Korea

Purpose: The aim of this study was to evaluate possible predictive variables for the outcome of shock wave lithotripsy (SWL) of renal stones in a single center.
Materials and Methods: Between March 2008 and March 2010, a retrospective review was performed of 115 patients who underwent SWL for solitary renal stones. The patients' characteristics and stone size, location, skin-to-stone distance (SSD), and Hounsfield units (HU) of stone were reviewed. The impact of the possible predictors on the disintegration of the stones was evaluated by logistic regression analysis. Receiver operator characteristic (ROC) curves were generated to compare the predictive powers of the variables.
Results: Seventy-nine patients (68.7%) had successful outcomes, whereas 36 patients (31.3%) had residual stones. Significant differences were found in the mean size and mean HU of the stones (size: 8.34±3.58 mm vs. 13.57±5.41 mm, p<0.001; HU: 675.29±254.34 vs. 1,075.00±290.41, p<0.001). In the unadjusted model, age, stone size, and stone density were significant predictors. In the reduced model, stone density and size were significant predictors for the outcome of SWL. The area under the ROC curve (AUC) was significantly higher for stone density and size than for the other parameters, but the AUC between stone density and size did not differ significantly (stone density: 0.874, stone size: 0.827, p=0.388).
Conclusions: Stone density and size were significant predictors of the outcome of SWL for renal stones less than 2.0 cm in diameter. We should consider HU and stone size when making decisions on the treatment of renal stones.

Key Words: *Kidney calculi; Lithotripsy; X-ray computed tomography*

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Corresponding Author:
Jae Yong Chung
Department of Urology, Sanggye Paik Hospital, Inje University College of Medicine, 761-7, Sanggye 6, 7-dong, Nowon-gu, Seoul 139-707, Korea
TEL: +82-2-950-1137
FAX: +82-2-950-1954
E-mail: chung90@paik.ac.kr

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INTRODUCTION

Extracorporeal shock wave lithotripsy (SWL) has been the most common treatment of choice, especially for small renal stones (<2 cm), since its introduction by Chaussy et al [1]. The effectiveness of SWL on kidney stones varies from 69.5% up to 99% [2-4]. Failure to fragment by SWL could result in unnecessary exposure of the renal parenchyme to shock waves and the requirement for an alternative procedure, which increases medical cost [5]. Therefore, it is important to identify patients who would benefit most from SWL before treatment. There have been many reports on the factors predicting stone disintegration by SWL. In particular, radiographic findings have been studied, such as the skin-to-stone distance (SSD) and the Hounsfield unit (HU) for measuring the density of the stone on noncontrast computed tomography (NCCT) [6,7]. Patient characteristics such as body mass index (BMI) [6] have also been reported as significant predictors of the results of SWL.

In this study, we evaluated possible predictive variables for the outcome of SWL of renal stones to help to better define the indications for SWL treatment and to determine the efficiency with which we can check HU and stone size.

MATERIALS AND METHODS

Between March 2008 and March 2010, 115 patients (71 men and 44 women) with solitary renal stones were evaluated. Patients were included if they had a stone of 0.5-2.0 cm in the longest dimension in a plain film. Patients who had multiple stones on the same side, patients with a stone size $>$20 mm in maximal diameter, patients with radiolucent stones, cases followed up elsewhere, and cases that required a stent or developed steinstrasse and active urosepsis during the therapy were excluded.

NCCT was performed for all patients with a multislice helical computed tomography (CT) scanner (64-channel, multi-detector computed tomography, Aquilion®, Toshiba, Tokyo, Japan). The images were obtained by use of the high-quality mode at 300 mA, 120 kVp, and 5 mm collimation.

The patients underwent SWL with the electromagnetic lithotripter (Compact Delta®, Dornier, Wessling, Germany) under fluoroscopy. In each treatment, the maximum number of shock waves was limited to 3,000 (mean shock waves number: 2,900) at a maximum energy of 3.0 kVs increasing gradually from 0.1 kV. Repeated treatment was carried out if inadequate fragmentation was observed. The result of treatment was evaluated by KUB at 1 month after the last lithotripsy. If there were residual fragments larger than 3 mm after three sessions per week, the case was considered as a failure.

Multiple variables including patient characteristics such as sex and age and calculus characteristics such as location, size, density, and SSD were collected. Stone location was categorized as lower calyx and non lower calyx. For the measurement of stone density, three regions of interest with a diameter of 2 mm were drawn on the stone at an axial plane of the NCCT where the stone length was the longest. The mean number of HU calculated from the 3 regions represented the density of the stone on NCCT (Fig. 1). [6]. The SSD was calculated by measuring three distances from the stone to the skin at 0°, 45°, and 90° by using radiographic calipers, and the average of these three values was calculated to represent the SSD for each stone as described in the literature (Fig. 2) [6].

Statistical analysis was performed by using Student's t-test for continuous data and Fisher's exact test or chi-square test for categorical data. We used logistic regression analysis to determine the factors influencing the outcome of treatment. The impacts of variables were assessed by logistic regression analysis and those variables with a significant association with SWL outcome were further evaluated by multivariate (logistic regression) analysis. A 5% level of significance was used for all statistical testing, and all statistical tests were two-sided. Receiver operator characteristic (ROC) curves were generated to compare the predictive power of the variables. Medcalc software ver. 9.6.40 (Medcalc, Mariakerke, Belgium) was used for the data analysis.

RESULTS

The mean age of the patients was 50.5±14.0 years. The mean size and density of the stones were 10.1+5.0 mm and 799.5±321.5 HU, respectively.

Of the 115 patients studied, 79 (68.7%) patients had successful outcomes, whereas 36 (31.3%) patients had residual stones. Between the two groups, significant differences were found in the size and HU of the stones. The mean HU of the success and failure groups were 675.29±254.34 HU and 1,075.00±290.41 HU ($p<0.001$), and the mean sizes of the stone were 8.34±3.58 mm in the success group and 13.57±5.41 mm in the failure group ($p<0.001$), resp-

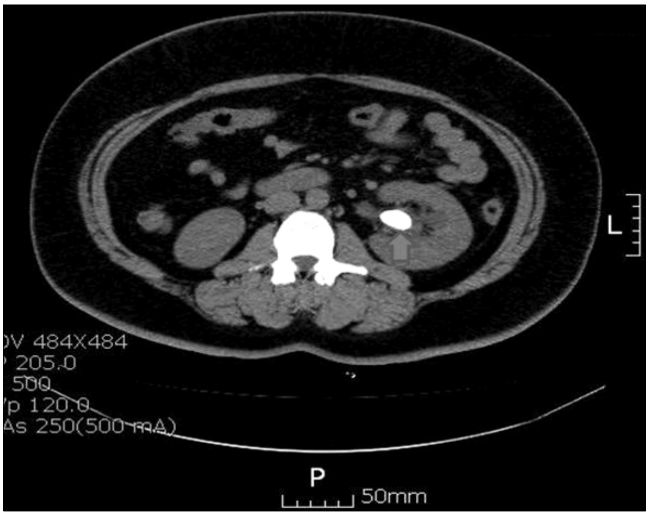

FIG. 1. Three regions of interest with a diameter of 2 mm were drawn on the stone in the axial plane of NCCT where the stone length was the longest. The mean number of HU calculated from the 3 regions represents the density of the stone. NCCT: non-contrast computed tomography, HU: Hounsfield unit.

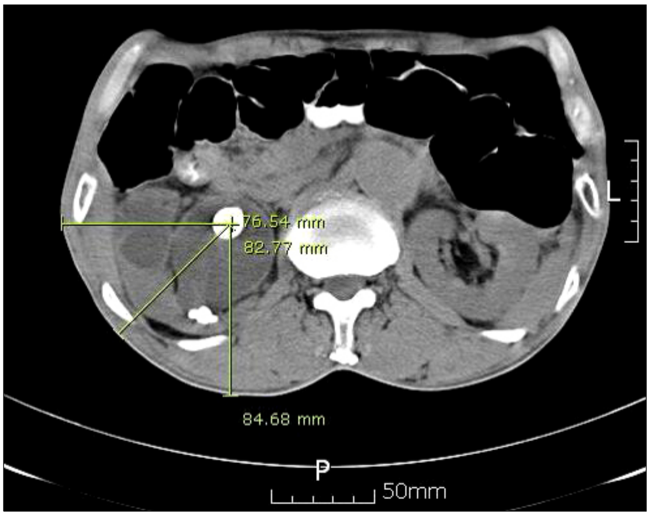

FIG. 2. Measurement of the skin-to-stone distance at 0°, 45°, and 90° on an axial scan of NCCT. NCCT: non-contrast computed tomography.

ectively. However, patient age, SSD, and location of lower calyceal stones did not differ significantly between the two groups (Table 1).

In the univariate analysis, stone density and stone size were significant predictors of the outcome of SWL (Table 2). There were no significant differences in the prediction

TABLE 1. Comparisons of characteristics between the shock wave lithotripsy success and failure groups

Parameter	Success (%)	Failure (%)	Total	p-value
No. of patients				
Sex[a]	79 (68.7)	36 (31.3)	115	-
Female	32 (72.7)	12 (27.3)	44	0.463
Male	47 (66.2)	24 (33.8)	71	
Age[b] (yr)				
Mean	48.76±12.44	53.83±16.01		0.067
<40	16 (72.7)	6 (27.3)	22	
40-49	22 (78.6)	6 (21.4)	28	
50-59	32 (80.0)	8 (20.0)	40	
≥60	9 (36.0)	16 (64.0)	25	
Stone[b] density (HU)				
Mean	675.29±254.34	1,075.00±290.41		<0.001[c]
<599	34 (97.1)	1 (2.9)	35	
600-799	25 (89.3)	3 (10.7)	28	
800-999	12 (46.2)	14 (53.8)	26	
≥1,000	8 (30.8)	18 (69.2)	26	
Stone size[b] (mm)				
Mean	8.34±3.58	13.57±5.41		<0.001[c]
<6.0	23 (100.0)	0 (0.0)	23	
6.0-7.99	25 (86.2)	4 (13.8)	29	
8.0-9.99	13 (59.1)	9 (40.9)	22	
10.0-14.99	12 (57.1)	9 (42.9)	21	
≥15.0	6 (30.0)	14 (70.0)	20	
Skin-to-stone distance[b] (mm)				
Mean	95.46±20.78	98.40±23.48		0.501
<80.0	21 (67.7)	10 (32.3)	31	
80.0-99.9	26 (74.3)	9 (25.7)	35	
100.0-119.9	22 (75.9)	7 (24.1)	29	
≥120.0	10 (50.0)	10 (50.0)	20	
Stone location				
Others	60 (68.2)	28 (31.8)	88	0.830
Lower calyx	19 (70.4)	8 (29.6)	27	

HU: Hounsfield units, [a]: chi-square test, [b]: Student's t-test, [c]: $p<0.05$

TABLE 2. Influence of patient and stone characteristics on failure of disintegration by shock wave lithotripsy

	Unadjusted model OR	Adjusted model OR	Reduced model OR
Sex			
Female	1.000	1.000	-
Male	1.362 (0.596-3.110)	1.506 (0.486-4.661)	
Age	1.030 (0.998-1.063)	1.033 (0.988-1.080)	1.034 (0.989-1.080)
Stone density	1.005 (1.003-1.007)[a]	1.005 (1.003-1.007)[b]	1.005 (1.002-1.007)[c]
Stone size	1.277 (1.150-1.419)[a]	1.147 (1.012-1.300)[b]	1.147 (1.014-1.298)[c]
Skin-to-stone distance	1.006 (0.988-1.025)	1.004 (0.979-1.031)	1.003 (0.977-1.031)
Stone location			
Others	1.000	1.000	-
Lower calyx	0.902 (0.352-2.310)	1.367 (0.375-4.980)	

OR: odds ratio, Adjusted model: adjusted for sex, age, stone density, stone size, skin-to-stone distance, and stone location, Reduced model: adjusted for all confounders after analysis of unadjusted model, [a]: $p<0.05$ in unadjusted model, [b]: $p<0.05$ in adjusted model, [c]: $p<0.05$ in reduced model of outcome of SWL according to SSD or lower calyceal stone location.

In the multivariable analysis taking all factors into account, stone density and size were strongly associated with the outcome of SWL (Table 2). No other factors were significant. When sex and lower calyceal stone location were eliminated in the reduced model, stone density and size were still significant predictors of the outcome of SWL (Table 2).

The ROC curves of all parameters were obtained for the prediction of an unsuccessful outcome of SWL (Fig. 3). Stone density showed that 863 HU was the ideal cutoff value for the prediction of failure of SWL with sensitivity of 86.1% and specificity of 79.2% (95% confidence interval) (Table 3). Stone size showed that 8.5 mm is the ideal cutoff value for the prediction of failure of SWL with sensitivity of 83.3% and specificity of 70.1% (95% confidence interval) (Table 3). In the comparison of ROC curves to test the statistical significance of the difference among the areas under different ROC curves, the area under the ROC curve (AUC) was significantly higher for stone density and size than for the other parameters, but the AUC between stone density and size did not differ significantly (stone density: 0.874; stone size: 0.827, p=0.388) (Fig. 3).

DISCUSSION

Although NCCT has become the most sensitive and accurate imaging modality for the diagnosis of urinary calculi [8-12], the intravenous pyelogram (IVP) is still widely used in Korea. Until 2 years ago, the Korean health insurance review agency prohibited the use of computed tomography as the initial imaging modality in the diagnosis of stone disease. However, IVP has many limitations in detecting urinary calculi owing to the interference with bowel gas or bony structures, and it also exposes patients to a risk of renal insufficiency and allergy by administration of contrast material [13]. Also, IVP has a limitation in diagnosis of radiolucent and small stones.

By contrast, NCCT is noninvasive and it can detect not only radiolucent and small stones but also other diseases of the urinary tract and other organs (e.g., renal mass, duplicated ureter, bladder mass, gall bladder stone, etc.) [14]. NCCT can precisely localize the site of the stone without the use of contrast. Besides, recent studies have used high-resolution CT protocols to predict the outcome of SWL. For example, Gupta et al concluded that the worst outcome was in patients with a calculus density >750 HU and a stone diameter of >1.1 cm, because 77% of those patients needed more than three sessions of SWL and the clearance rate was 60% [15].

The factors associated with the outcome of SWL have been discussed in many studies over the past decade [16-21]. Stone characteristics, such as size and location, have been reported as significant predictors of the results of SWL by other authors [22,23]. However, lower calyceal stone location was not a significant predictive variable in this study. This is because of the different patient populations in the studies. Also, the definition of success of SWL in our study was to fragment the stones into pieces of less than 3 mm and not to excrete them all. This may be another explanation for the difference in results.

There have been reports that the composition of the stones is related to the fragmentation of the stone by SWL [24]. However, knowing the stone composition before treatment is difficult and may not be sufficient to allow for prediction of the response to SWL. Therefore, pre-SWL radiographic examination should focus on those radiographic characteristics that can influence SWL outcome rather than stone composition.

We also found that the density of the stone was a significant predictor of SWL outcome. To date, a few studies have reported that stone density is a significant predictive factor for SWL outcome. For example, Pareek et al found that the mean HU values of stones were significantly higher in patients with residual stones [25,26], and Joseph et

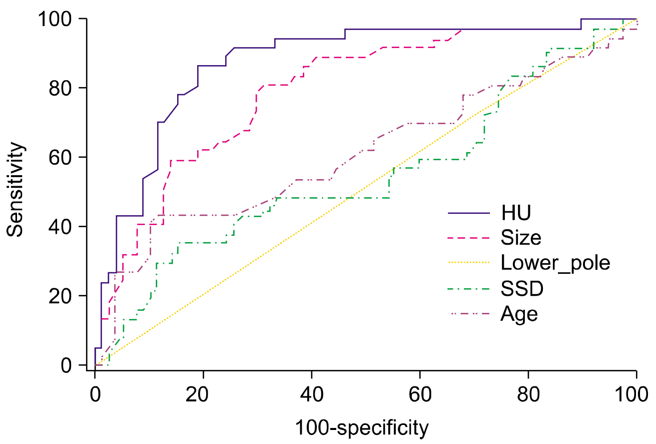

FIG. 3. Comparison of ROC curves to test the statistical significance of the difference between the area under different ROC curves. In pairwise comparison of all predictors for the outcome of shock wave lithotripsy, stone density and stone size was not different (AUC difference: 0.0465, p=0.388). ROC: receiver operator characteristic, AUC: area under the ROC curve.

TABLE 3. Comparison of receiver operating characteristic curve analysis for the prediction of outcome of shock wave lithotripsy

	AUC	Sensitivity	Specificity	Criterion
Stone density[a]	0.874	86.1%	79.2%	>863 HU
Stone size[a]	0.827	83.3%	70.1%	>8.5 mm
Age[a]	0.635	44.4%	89.6%	>59 yr
SSD[a]	0.533	33.3%	83.1%	>112 mm
Sex[b]	0.528	66.7%	39.0%	-
Lower calyceal stone[b]	0.512	77.8%	24.7%	-

AUC: area under the receiver operating characteristic curve, SSD: skin-to-stone distance, [a]: continous variables, [b]: categorical variables al found a positive correlation between the number of shock waves required to treat a stone and its HU value [27]. Wang et al suggested cutoff values (the stone density >900 HU and volume >700 mm^3) for predicting SWL failure [28]. In the present study, the cutoff value was >863 HU, which is lower than the cutoffs reported in other studies. El-Nahas et al suggested that the differences in the cutoff values that predicted extracorporeal SWL failure may be due to different inclusion criteria, the use of different CT protocols, or the measurement of different endpoints (e.g., failure of disintegration, the need for multiple sessions, or rate of residual stones) in these studies [7].

Several patient characteristics have been suggested to influence SWL results. Abe et al reported that older patients are likely to have difficulty in successful SWL [29]. In the univariate and multivariable analysis in the present study, however, age was not a significant factor. Abdel-Khalek et al also showed that age is not a significant predictor of SWL outcome [19]. Other studies have reported that higher BMI and SSD are significant predictors for SWL failure [6,30]. In the present study, SSD did not reach statistical significance even in the univariate analysis. Our patients' relatively lower SSD than those of Western patients could be the reason for that. Also, we could not get exact information on the patients' BMI for many patients in real practice. Therefore, we did not consider BMI as a patient characteristic. However, because this study was performed retrospectively and the number of patients studied was not large enough, further studies with large numbers of patients and a standardized CT protocol are needed to clarify this important point.

CONCLUSIONS

NCCT is noninvasive and useful for obtaining a lot of information about the patient and urinary calculi. In this study, stone density and size were significant predictors of the outcome of SWL for renal stones less than 2.0 cm in diameter. We should consider HU and stone size when making decisions on the treatment of renal stones.

Conflicts of Interest

The authors have nothing to disclose.

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EDITORIAL COMMENT

This article was a retrospective review to evaluate possible predictive variables for the outcome of shock wave lithotripsy (SWL) of renal stones in a single-center experience. The authors confirmed other previous results [1,2] with their qualified data from 115 patients (71 men and 44 women) with solitary renal stones. As the authors suggested in this article, until 2 years ago, the Korean health insurance review agency prohibited the use of computed tomography as the initial imaging modality in the diagnosis of stone disease. These authors' efforts to collect pure data in order to predict the outcome of SWL under such difficult Korean medical circumstances have provided us valuable data. However, there may still be some conflicting parameters for predicting the outcome of SWL, such as the skin-to-stone distance (SSD), body mass index (BMI), and stone location (lower calyx). Besides, there were some weak points in this study. It was performed retrospectively in a single center and the number of patients studied was not large enough. Further prospective, multicenter study with large numbers of patients and a standardized CT protocol are needed to clarify these important points.

Sang Don Lee
Department of Urology,
Urological Science Institute,
Pusan National University School of
Medicine, Pusan, Korea

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