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ORIGINAL RESEARCH

Modified Seoul National University Renal Stone Complexity Scoring System for Predicting Stone-Free Status After Extracorporeal Shock Wave Lithotripsy

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Background: Incorporating the modified Seoul National University Renal Stone Complexity (S-ReSC-R) scoring system into the preoperative evaluation of both retrograde intrarenal surgery and percutaneous nephrolithotomy has proven to be highly effective in predicting stone-free status after each procedure.

Objective: This study aimed to validate the S-ReSC-R scoring system in extracorporeal shock wave lithotripsy (ESWL) and compare it with the Triple D score under the same protocol.

Materials and Methods: Data on consecutive patients undergoing ESWL at a tertiary referral center between 2019 and 2021 were retrospectively analyzed. A total of 297 patients who were evaluated with non-contrast CT prior to the procedure and had adequate follow-up data were included in the analysis. The S-ReSC-R score was calculated based on the number of sites affected. Stone-free status was defined as no evidence of residual stones. Receiver operator characteristic (ROC) curves were generated to determine cutoff values for both scoring systems.

Results: The overall stone-free rate (SFRs) after a single session was 60.5%. The average S-ReSC-R score was significantly lower in patients who had successful ESWL than in those with failed ESWL (1.50 vs 2.63, $p < 0.001$). The SFRs were significantly lower with higher S-ReSC-R scores: 72.4% in the low score (1–2) group, 36.0% in the intermediate score (3–4) group, and 10.5% in the high score (5–12) group ($p < 0.001$). Multivariate analyses revealed that both the S-ReSC-R score and the Triple D score independently influenced ESWL success (both $p < 0.001$). The area under the ROC curve for the S-ReSC-R score was 0.767, whereas that for the Triple D score was 0.694.

Conclusion: This study confirms that the S-ReSC-R is a reliable tool for predicting stone-free status after ESWL. Thus, its use in evaluating patients for ESWL is recommended.

Keywords: extracorporeal shock wave lithotripsy, S-ReSC-R, stone-free status, Triple D

Introductions

Nephrolithiasis, or kidney stone disease, is a serious condition that affects approximately 12% of the global population, impacting health-care systems worldwide.[1–3] Symptomatic kidney stone management requires a comprehensive approach that includes both medical and surgical interventions.[4] Unlike surgical interventions, extracorporeal shock wave lithotripsy (ESWL) is a noninvasive modality and has become the preferred treatment for uncomplicated renal and ureteral calculi, typically less than 20 mm, due to its effectiveness, low morbidity, and high patient preference.[5,6] Nevertheless, stone-free rates (SFRs) after ESWL range from 46% to 91%.[7] Therefore, obtaining crucial patient information for preoperative surgical planning should be a mandatory step in determining the probability of procedural success and the necessity of ancillary procedures.

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Various scoring systems for classifying the complexity of renal stones and nomograms that predict outcomes after renal stone surgery have been developed and externally validated.[8] However, limitations exist. The Clinical Research Office of the Endourological Society (CROES) nomogram is complex and requires extensive preoperative data, while the S.T.O.N.E. (stone size, tract length, obstruction, number of involved calices, and essence/ stone density) was validated in a small cohort, potentially limiting its generalizability. For ESWL, Tran et al[9] devised the Triple D scoring system, which is based on CT imaging and takes into account three parameters: stone density, stone volume, and skin-to-stone distance (SSD). Any scoring system must be simple, fast, and accurate to be widely used in daily practice.

The modified Seoul National University Renal Stone Complexity (S-ReSC-R) scoring system is a modified version of the original Seoul National University Renal Stone Complexity system that includes one additional point when the stone located lower calyx is proven to be a precise and rapid assessment in the predictive model for both percutaneous nephrolithotomy and flexible ureteroscopy.[10,11] We hypothesize that the S-ReSC-R is an accurate tool for predicting stone-free rates after ESWL.

We aimed to evaluate the predictive value of the S-ReSC-R scoring system for determining treatment outcomes following ESWL, using stone-free status as the primary endpoint.

Materials and Methods

This was a retrospective observational study approved by the Ethics Committee of Ranong Hospital (no. COA_PHRN013/2564) and conducted in accordance with the principles outlined in the Declaration of Helsinki. Consent for chart review was not required because of the retrospective nature of the study. All data were encrypted and remained confidential.

A total of 332 patients undergoing ESWL for kidney stones at a tertiary hospital between January 2019 and November 2021 were reviewed for inclusion in the study. The inclusion criteria were an age of 18 years or older, previously untreated renal stones greater than 4 mm in size, and available preoperative CT imaging. The exclusion criteria were a stone in a solitary kidney, uncorrectable bleeding disorders, active urinary tract infection, urinary tract obstruction or abnormalities, and pregnancy. Twenty-eight patients were excluded because of insufficient imaging, and seven were excluded due to incomplete clinical data. Thus, 297 patients were included in the analysis.

The data collected included medical history, physical examination, complete blood count, serum biochemical profile, urinalysis, and coagulation profile. Non-contrast CT was used preoperatively to determine the stone characteristics. The largest dimension of a stone visualized on a soft tissue window in a coronal view represented the stone's size. Stone Hounsfield units (HU) were calculated by taking the mean attenuation of three consistent, nonoverlapping regions of interest chosen from stones in bone windows. SSD measurements were performed using axial CT as the average distance from the skin to the surface of the targeted stone at 0°, 45°, and 90° angles.

S-ReSC-R scores were calculated using the method described by Jung et al.[9] The S-ReSC-R score is calculated by summing the points assigned to specific stone locations: renal pelvis (#1); superior and inferior major calyceal groups (#2–#3); and anterior and posterior minor calyceal groups of the superior (#4–#5), middle (#6–#7), and inferior calyx (#8–#9). If a stone is situated in inferior locations (#3, #8–#9), one extra point is added for each site. Thus, the total S-ReSC-R score ranges from 1 to 12 points. A higher score indicates greater stone complexity and may be associated with less favorable procedural outcomes. Based on these scores, the patients were divided into a low score (1–2 points) group, an intermediate score (3–4 points) group, and a high score (5–12 points) group.

Triple D scores were calculated based on the formula devised by Tran et al.[8] Values were calculated for each of the three stone parameters (stone volume, stone density, and SSD). One point was assigned for any parameter that was below the cutoff value (150 μ L for stone volume, 600 HU for stone density, and 12 cm for SSD). Thus, the Triple D score ranged from 0 (worst) to 3 (best).

Before ESWL, urine examinations and cultures were evaluated. If the results indicated urinary tract infection, an antibiotic was prescribed, and the procedure was postponed. Following the standard protocol, all patients underwent ESWL as outpatients in the supine position without anesthesia or sedation. A Siemens Modularis Vario Lithostar electromagnetic lithotripter was used in the procedures. Stone localization and real-time tracking during the procedure were performed using both ultrasound and fluoroscopy. The frequency applied was 60–90 shock waves/min. The total number of shock waves applied in one session ranged from 3000 to 5000, or the session was stopped when significant stone fragmentation was detected. The patients were advised to increase fluid intake and to take analgesics consistently after the procedure. A follow-up X-ray KUB and ultrasonography examination was scheduled four to six weeks later to assess residual fragments. Treatment success was defined as complete stone clearance without any residual fragments.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics for MacOS, version 25.0 (IBM Corp., Armonk, NY, USA). Descriptive variables were represented as numbers and percentages. Associations between continuous variables, such as stone size, HU, SSD, and BMI, were assessed using the Student's *t*-test. Categorical variables, such as gender, stone laterality, and stone location, were compared using the chi-square test. Values of $p < 0.05$ were considered statistically significant. Univariate and multivariate logistic regression analyses were used to identify significant predictors of stone-free status. Receiver operator characteristic (ROC) curves were drawn to assess the predictive ability of the S-ReSC-R and Triple D scoring systems.

Results

Among the 297 patients, 156 were male, and 141 were female. The procedure was successful in 62.3% (185/297) of the patients and unsuccessful in 37.7% (112/297). In the univariate analysis, there were no significant differences between the two groups in terms of age, gender, stone laterality, stone density, or SSD. Conversely, statistically significant differences were observed in stone size, presence of a lower pole stone, and mean S-ReSC-R score (all $p < 0.001$; Table 1).

Table 1 Baseline Demographic and Clinical Characteristics of the Study Cohort

Patient Characteristics	Overall (n= 297)	Stone Free (n= 185)	Not Stone Free (n= 112)	p-Value
Age (year) (mean ± SD)	53.1 ± 10.4	52.6 ± 10.8	54.1 ± 9.8	0.231
Gender: n (%)				
Male	156 (52.5)	96 (51.9)	60 (53.6)	0.779
Female	141 (52.5)	89 (48.1)	52 (46.4)	
BMI (kg/m^2): (mean ± SD)	24.5 ± 3.9	24.4 ± 4.0	24.6 ± 3.7	0.580
eGFR (mg/dL): (mean ± SD)	83.1 ± 24.7	84.6 ± 24.9	80.3 ± 24.0	0.134
Stone laterality: n (%)				
Right	138	87	51	0.803
Left	159	98	61	
Stone location: n (%)				
Lower pole	77 (25.9)	31 (16.8)	46 (41.1)	<0.001*
Other	220 (74.1)	154 (83.2)	66 (58.9)	
Stone size (mm) (mean ± SD)	7.55 ± 2.28	6.82 ± 1.69	8.74 ± 2.60	<0.001*
Skin-to-stone distance (mm) (mean ± SD)	9.4 ± 0.9	9.4 ± 0.8	9.4 ± 1.1	0.490
Stone density (Hounsfield unit) (mean ± SD)	812.4 ± 159.1	802.1 ± 168.1	829.3 ± 142.1	0.137
Number of shockwave (impulses) (mean ± SD)	4632.3 ± 557.4	4601.6 ± 544.2	4683.0 ± 577.3	0.223

(*Continued*)

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Table 1 (Continued).

Patient Characteristics	Overall (n= 297)	Stone Free (n= 185)	Not Stone Free (n= 112)	p-Value
S-ReSC-R score (mean ± SD)	1.9 ± 1.3	1.5 ± 0.8	2.7 ± 1.6	<0.001*
Triple D score (mean ± SD)	1.5 ± 0.6	1.7 ± 0.6	1.1 ± 0.5	<0.001*

Notes: *Statistically significant.
Abbreviations: BMI, body mass index; eGFR, estimated glomerular filtration rate; SD, standard deviation; S-ReSC-R, modified Seoul National University Renal Stone Complexity.

The SFRs were significantly lower with higher S-ReSC-R scores ($p < 0.001$). The low score (1–2) group had an SFR of 72.4% (165/228), the intermediate score (3–4) group had an SFR of 36.0% (18/50), while the high score (5–12) group had an SFR of 10.5% (2/19). The SFRs determined by the individual S-ReSC-R scores differed significantly ($p < 0.001$) from those obtained using the three-tier S-ReSC-R classification (Table 2).

As shown in Table 3, multivariate logistic stepwise regression revealed significant inverse associations between the SFR and both the S-ReSC-R score ($p < 0.001$) and the Triple D score ($p < 0.001$). The ROC curves drawn to assess the accuracies of the S-ReSC-R and Triple D scoring systems in predicting stone-free status are shown in Figures 1 and 2,

Table 2 Stone-Free Rates Following ESWL by Individual S-ReSC-R Scores and Low, Intermediate, and High Score Groups

Individual S-ReSC-R Score	SFR (%)	Score Group	SFR (%)
1	84.0 (126/150)	Low (1–2)	72.4 (165/228)
2	50.0 (39/78)		
3	36.8 (14/38)	Intermediate (3–4)	36.0 (18/50)
4	33.3 (4/12)		
5	11.1 (1/9)	High (5–12)	10.5 (2/19)
6	14.3 (1/7)		
7	0.0 (0/3)		
Linear-by-linear association	$p < 0.001$*		$p < 0.001$*

Notes: *Statistically significant.
Abbreviations: S-ReSC-R, modified Seoul National University Renal Stone Complexity; SFR, stone-free rate.

Table 3 Multivariate Analysis of Stone-Free Status Predictors

Variable	OR	95% CI	*p*-Value
Stone size	0.03	0.01–1.07	0.189
Lower pole stone	0.14	0.04–1.28	0.060
S-ReSC-R score	0.14	0.06–0.21	< 0.001*
Triple D score	0.20	0.17–0.28	< 0.001*

Notes: *Statistically significant.
Abbreviation: S-ReSC-R, modified Seoul National University Renal Stone Complexity.

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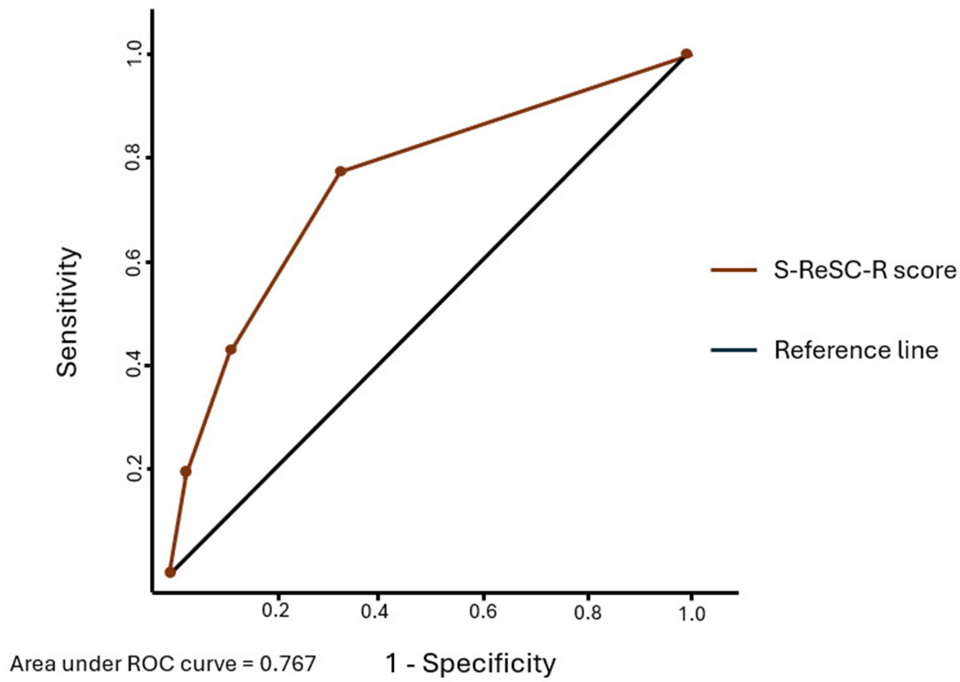

Figure 1 ROC curve of the S-ReSC-R score.
Abbreviations: ROC, receiver operator characteristic; S-ReSC-R, modified Seoul National University Renal Stone Complexity.

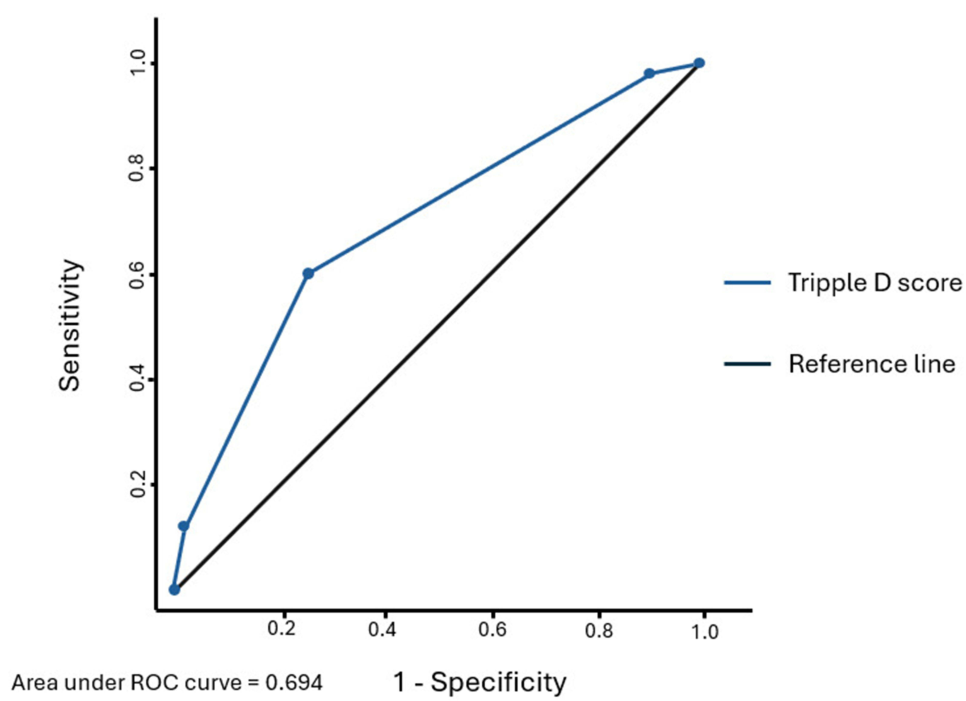

Figure 2 ROC curve of the Triple D score.
Abbreviation: ROC, receiver operator characteristic.

respectively. While both scoring systems exhibited high predictive accuracy, the S-ReSC-R system had a higher area under the curve (AUC) than the Triple D system (0.767 vs 0.694).

Discussion

The use of ESWL in the management of urolithiasis marks a significant milestone in urology. Since its introduction in 1980, it has been established as the primary modality for renal calculus management.[12] However, SFRs after ESWL vary widely, depending on several factors. To obtain the best results, ensure safety, and reduce re-treatment rates, a combination of technological advancements, improved procedural techniques, and proper patient selection is essential. Advanced lithotripters equipped with expanded focal zones and automatic image-based renal stone tracking mechanisms enhance the accuracy of shock wave delivery to the target while reducing potential harm to adjacent renal parenchymal tissue.[13,14] Notably, lowering the shock wave rate has proven beneficial for fragmenting stones, especially those exceeding 1 cm in size.[15] Li et al[16] showed that ESWL at a rate of 60–90 shock waves/min outperformed a rate of 120 shock waves/min in terms of fragmentation. A gradual increase in the device's energy voltage, termed "ramping", not only reduces the risk of tissue injury but also augments stone fragmentation.[17]

Proper patient selection is also crucial for the success of ESWL. The key selection factors are stone size, stone location, SSD, and Hounsfield units. A larger stone size is associated with a higher risk of ESWL failure. In a study of 2954 patients with single or multiple radiopaque renal stones undergoing ESWL monotherapy, Abdel-Khalek et al[18] reported success rates of 89.7% for stones of <15 mm and 78% for stones of >15 mm ($p < 0.001$). Similarly, in a study of 427 patients with renal stones, Al-Ansari et al[19] reported success rates of 90% for stones of ≤10 mm and 70% for stones of >10 mm ($p < 0.05$). Our multivariate analysis confirms that stone size is an independent predictor of ESWL success.

The location of kidney stones, particularly those situated in the lower pole, also plays a crucial role in the success of ESWL. Lower pole stones present a distinct challenge due to their relatively low clearance rates, which range from 47% to 75%.[20] Tarawneh et al[21] reported an ESWL success rate for lower calyceal stones of only 47%, which was significantly lower than that for stones in other locations (79%; $p = 0.012$). Similarly, Samir et al[22] found that a lower calyceal location was an independent predictor of ESWL success ($p = 0.017$). In line with these results, a statistically significant difference in SFRs between lower pole and non–lower pole stones was observed in our study ($p < 0.001$), confirming the significant influence of a lower pole location on ESWL outcomes. We believe that scoring systems in which stone location plays an important role, such as the S-ReSC-R system, are suitable for predicting tone-free status after ESWL.

ESWL failure has also been associated with a greater SSD, especially in Western populations. Pareek et al[23] found that an SSD of up to 10 cm was a powerful predictor of stone-free status. This is because with greater SSDs, shock waves travel longer distances, which results in shock wave attenuation. However, studies involving Asian populations have reported contradictory results. Because Asian populations have thinner bodies than Western populations, it has been argued that SSD cannot be applied to Asian patients.[24] Our results are in line with those of other studies, without significant differences in both groups. Thus, the SSD may not be universally applicable as a predictor of stone-free status following ESWL.

Stone fragility is determined by the stone's composition and mineral content. Several studies have examined the relationship between stone density on radiological imaging and stone composition, suggesting that stone density can predict stone characteristics.[25,26] In our study, the mean stone density did not differ significantly between the successful and unsuccessful ESWL groups. However, 71.1% of the patients with a stone density below 500 HU had favorable treatment outcomes, compared to only 47.4% of those with a stone density above 500 HU. Different studies have proposed varying stone density thresholds. Gupta et al[27] reported optimal ESWL outcomes with a mean stone density of ≤750 HU. Similarly, a prospective study of 50 patients with urinary stones reported that a threshold of 970 HU had high specificity and sensitivity in predicting ESWL success.[28]

Cutting-edge technologies such as artificial intelligence and virtual reality are increasingly becoming integral to a range of surgical procedures and assist in predictive analyses of various interventions.[29–31] Despite these advancements, numerous regions around the world still lack internet access, highlighting disparities in access to technology. Traditional tools, such as scoring systems and nomograms, have been developed using multiple clinical variables to assess procedural complexity and predict outcomes. However, nomograms have not been widely adopted in clinical practice due to their complexity and lack of practicality. Clinical scoring systems are generally easy to use and require minimal training and no specialized software, which has made them more popular in routine practice. Tran et al[9] introduced the Triple D scoring system, a straightforward system based on CT imaging that evaluates three stone-related parameters. However, it does not fully account for stone location, particularly a lower pole location, an important variable considered in other scoring systems, such as the S-ReSC-R system.

In our cohort of 297 patients undergoing ESWL, we found that the S-ReSC-R score was significantly associated with stone-free status in both univariate and multivariate logistic regression analyses ($p < 0.001$). The score demonstrated better discriminative performance than the Triple D score, with an AUC of 0.767 compared to 0.694. This finding supports the clinical utility of incorporating stone location, as accounted for in the S-ReSC-R system, when predicting ESWL outcomes. As a practical and efficient tool, the S-ReSC-R scoring system has been applied to various surgical treatments, including flexible ureteroscopy and percutaneous nephrolithotomy. Therefore, its application to ESWL is reasonable.

Our research has certain limitations. First, the sample size was small. Moreover, because of the study's retrospective nature, patients with missing CT scans were excluded, as without CT images, stone attenuation and SSD could not be measured. Second, although metabolic evaluation is an important parameter for assessing stone disease outcomes, such data were not included in this study. However, to the best of our knowledge, this is the first study to validate the S-ReSC-R score for the ESWL procedure. We believe that our findings provide a strong foundation for future research on the clinical applications of this system.

Conclusion

Our study demonstrates that the S-ReSC-R score is a reliable predictor of ESWL outcomes. Thus, the S-ReSC-R scoring system is a valuable tool for clinical planning in patients undergoing ESWL, offering both simplicity in calculation and proven effectiveness.

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Disclosure

The authors declare that they have no competing interests in this work.

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