Original Article

Skin-To-Stone Distance On Computed Tomography KUB: An Independent Predictor Of Stone-Free Status After Shock Wave Lithotripsy

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Abstract

Objective: To evaluate SSD and other factors related to the characteristics of the patient and renal stone to predict the ESWL outcomes in patients with renal stones.

Methods: A cross-sectional study was conducted on 90 patients undergoing ESWL for renal calculi. Pre-procedural CT scans were used to measure SSD, stone size, and CT attenuation values. Patients were followed post-ESWL by ultrasound and X-ray KUB to assess stone-free status. Correlation analysis, independent samples t-tests, chi-square tests, and binary logistic regression were used to assess associations between variables and treatment outcomes.

Results: The mean value of SSD in our cases was 10 ± 0.72 cm, and 57.8% of patients had SSD ≤10 cm. A statistically significant difference in mean SSD was found between the group that was stone-free vs. the group with residual stones ($p < 0.0001$). Logistic regression confirmed SSD as an independent predictor of ESWL success ($p < 0.00001$), with increasing SSD significantly reducing the odds of being stone-free. Stratified analysis showed that 90% of patients with SSD ≤10 cm achieved stone-free status versus only 37.5% with SSD >10 cm ($p < 0.0001$).

Conclusion: SSD is a statistically and clinically significant predictor of ESWL success. An SSD ≤10 cm is strongly associated with favorable outcomes. Given its simplicity, non-invasiveness, and predictive value, SSD should be incorporated into routine pre-ESWL evaluation to guide treatment planning and improve patient selection.

Keywords: Computed tomography. Extracorporeal Shock Wave. Lithotripsy. Renal calculi. Treatment outcome.

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HHM, ZQ, HR - Acquisition, Analysis, Interpretation
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Introduction

Management of renal stone has undergone a lot of changes in recent decades, with minimally invasive techniques shaping management policies. Among these, extracorporeal shock wave lithotripsy (ESWL) has been a procedure of choice for suitable patients, given its non-invasiveness, relatively low complication rate, and feasibility as an outpatient procedure. Despite these advantages, treatment results of ESWL are variable and are dependent on certain factors, i.e., size of stone, the location and composition of the stone. Additionally, the specific anatomic variation in the patients also leads to variable outcomes of ESWL.

In a clinical setting, pretreatment imaging is important for determining the probability of success of the treatment. Nowadays, with the large use of non-contrast-enhanced computed tomography (NCCT), some objective parameters have been proposed to predict the success of ESWL. These include the density of stone (Hounsfield units), stone burden, and recently, skin to stone distance (SSD), which is a rapidly measurable quantification of distance from the skin of the patient and the underlying stone being planned for removal from the kidney.

It is speculated that SSD may impact the fragmentation of stones by altering the energy attenuation of shock waves when passing through body tissues. Increasing evidence indicates that short distances are related to the ESWL success rates, whereas long distances result in decreased fragmentation efficiency as a result of shock wave energy attenuation. According to various authors' reports, a cut-off diameter of ≤10 cm has been advocated, above which the efficiency of ESWL drops substantially, in contrast with the more general anthropometric measure of body mass index (BMI), SSD is a more direct estimate of the site-specific anatomy of the efficiency of energy transmission.

Even if SSD is increasingly recognized as a preoperative parameter in the recent literature, it is not yet integrated into daily practice. Moreover, the majority of published studies are from Western

or East Asian population may reduce the generalizability to other ethnic and geographical populations. Local data on the predictive value of SSD with ESWL outcome South Asian population are relatively lacking.
This research aims to evaluate SSD and other CT-based variables as markers to predict the success of ESWL in the Pakistani population and will add to international evidence. The identification of factors that predict treatment success is imperative to improve patient selection, prevent unnecessary treatment and enhance clinical outcomes.

Materials And Methods

This was a cross-sectional observational study carried out at the Department of Radiology, Institute of Urology and Transplantation, Rawalpindi, during 12 months from May 2023 to April 2024. The aim was to investigate whether patient and stone-related factors, with a focus on skin-to-stone distance (SSD), serve as independent predictors of outcome after extracorporeal shock wave lithotripsy (ESWL).
A sample size of 86 was calculated by the WHO sample size calculator, taking a confidence interval 95%, 5% precision and 8% prevalence of renal calculi in South East Asian countries. The study included 90 adult patients presenting with single symptomatic radio-opaque renal stones of less than 30 mm in diameter. In addition, the study exclusion was based on abnormal renal functions as well as the anatomic abnormalities or obstruction of the distal urinary tract. Precluded patients included those with impaired renal function tests, pregnancy and patients who weighed over 125 kg, diagnosed with staghorn calculi or who had undergone previous open, percutaneous and/or endoscopic urologic procedures (e.g., double-J stent insertion or nephrostomy tube placement). Patients who were not willing to undergo ESWL or refused to accept the necessary imaging protocols were also excluded.
Informed consent was received from all participants after approval by the local ethics committee. Demographic information, clinical history, physical examination and laboratory findings were recorded. All patients had NCCT within 2 weeks before ESWL. Imaging acquisition was executed in a 160-slice multi-detector CT scanner (Aquilion Prime SP; Canon Medical Systems, Japan) in the range from the upper poles of the kidneys to the urinary bladder. Imaging parameters were 120 kV, 40 mAs and a slice thickness of 0.5 mm. The images were reconstructed in the axial, coronal and sagittal planes and in 3D when necessary.
The CT scans were interpreted by 2 senior radiologists independently. Collected data consisted of stone location, largest stone diameter (in mm), and mean CT attenuation (in h.) units (in Hounsfield units, H.U.). The SSD was calculated by measuring the distance between the centre of the stone and the skin surface at 0°, 45°, and 90° angles, and the mean value of these three measurements was used as the SSD.
Extracorporeal shockwave lithotripsy was performed using a Siemens electromagnetic lithotripter in a day care setting in all patients. For procedural consistency, the same trained technician conducted all sessions. Patients were in the prone position, and stone localization was done with fluoroscopy, with or without ultrasonography guidance. Power was incrementally apportioned to shock wave energy for the duration of the session. The frequency remained constant, and between 3,000 and 4,500 shocks were given per session, according to stone size, site and patient tolerance. The patients were closely observed via monitoring of their vital signs from the beginning of the procedure till the time of discharge, and were instructed to take oral hydration and analgesics upon discharge.
Subsequent imaging, including ultrasound and X-ray KUB at day 14 for initial fragment clearance, and at 4 weeks, finally on X-ray KUB and ultrasound KUB. Repeat CT was performed in a limited number of cases as per requirement. Stone-free status was defined with no remaining fragments visualized on imaging. Visible fragments were considered as residual stones.
The data were extracted and analyzed by SPSS. The continuous variables (age, stone size, CT density, SSD and number of shocks) were described by the mean ± standard deviation, and the descriptive analysis of categorical variables was shown in frequencies and proportions. Correlations between continuous variables were analyzed using Pearson's correlation coefficient. Group comparisons (stone-free vs residual) were made by independent samples t-tests and chi-squared tests. Binary logistic regression was used to analyze the predictive ability of SSD. P-value <0.05 was regarded as statistically significant.

Results

Overall, ninety patients were treated by ESWL. The mean age was 40.2 ± 12.7 (range:13– 69) years. The study included 56 male patients (62.2%) and 34 female patients (37.8%). The mean size of the renal stones turned out to be 12.1 ± 5.2 (range: 6-28) mm; thus, the majority of the subjects had small to medium-sized stones that were amenable to ESWL. Stone laterality distribution was the same right and left kidneys (50% each).

Table 1: The characteristics of CT and ESWL showing the CT density (HU) and number of shocks administered (n=90)

CT and ESWL characteristics	Mean ± SD; n(%)
CT Density (HU)	886.5 ± 176.1 (351-1400)
SSD (cm)	10.0 ± 0.72 (8.2-11.6)
No. of Shocks	3508 ± 338 (3000-4500)

The lower pole was the most common location of the stone (31.1%), followed by the upper pole (25.6%) and the mid pole (23.3%). Less common sites were the PUJ (11.1%) and pelvis (8.9%). The average CT attenuation was 886.5 ± 176.1 HU, which indicated a diversity of stone compositions (Table 1). The average SSD was 10.0 ± 0.72 (range: 8.2-11.6) cm. Mean number of shocks/session was 3508 ± 338. The SSD of> than 10 cm was reported as one of the independent factors for stone-free treatment response in other studies. This implies that most of this group was on the favorable side for the success of ESWL. Over half the patients (57.8%) had a 10 cm or < SSD (table 2, figure 1).

Table 2: Describing the characteristics of stones in terms of location, side of stone and skin-to-stone distance (n=90)

Stone characteristics		**n (%); (mean ± SD)**
Stone side(n%)	Right	45 (50.0%)
	Left	45(50.0%)
Skin-to-Stone Distance (n%)	≤ 10 cm	52 (57.8%)
	> 10 cm	38 (42.2%)
Mean SSD by Stone Location (mm) (mean ± SD)	Lower pole28 (31.1%)	9.88±0.66
	Upper pole 23 (25.6%)	10.27± 0.67
	Mid pole 21 (23.3%)	10.04± 0.70
	PUJ 10 (11.1%)	10.28±0.62
	Pelvis 8 (8.9%)	10.46±0.41

Regarding the location of stones, the stones in the renal pelvis had the highest mean SSD (10.46 ± 0.41 cm), followed by the pelvi-ureteric junction (PUJ) stone (10.28 ± 0.62 cm) and upper pole stones (10.27 ± 0.67 cm). In comparison, lower pole stones had the least average SSD at 9.88 ± 0.66 cm, and mid pole stones were 10.04 ± 0.70 cm.

The correlation analysis revealed SSD to have a positive correlation with the stone size (r = +0.21, p = 0.048), that is, a slightly deeper position in the body for larger stones. No other significant associations were found. Particularly, SSD did not significantly correlate with CT density (r = −0.02, p 0.839). Similarly, SSD wasn't significantly correlated with the number of shocks delivered during the procedure (r = +0.05, p = 0.620), which means SSD is an independent variable and is not related to them originally (Table 3).

Table 3: Correlation Matrix between Continuous Variables.

Comparison	**Correlation (r)**	**p-value**
SSD vs Stone Size	+0.21	0.048
SSD vs CT Density	−0.02	0.839
SSD vs Shocks	+0.05	0.620
Stone Size vs Shocks	+0.18	0.086
Stone Size vs CT Density	−0.12	0.266
CT Density vs Shocks	−0.04	0.690

Moreover, the stone size also demonstrated a weak, but non-statistically significant, relationship when studied in relation to the number of shock waves delivered (r = + 0.18, p = 0.086), suggesting that larger stones might demand higher energy to be crushed; however, it was not statistically significant. There was a slight negative correlation between the size of stones and CT density (r = −0.12, p = 0.266), indicating that the larger stones may have a slightly lower density; however, this was not significant. There was no significant correlation between CT density and shock number (r = −0.04, p = 0.690; table 4)

Table 4: Logistic Regression: Predicting Stone-Free Status Using SSD (n=90).

Variable	**Coefficient (β)**	**Std. Error**	**z**	**p-value**
Intercept	32.07	7.08	4.53	<0.00001
SSD	−3.12	0.70	−4.46	<0.00001

***(Independent Samples t-Test; significant p<0.05)**

The independent samples t-test found a significant difference in mean SSD between the two groups. The cases that reached the stone-free status had a mean SSD of 9.72 ± 0.45 cm, and the cases with residual stone had a larger value of mean SSD, that is, 10.41 ± 0.49 cm (p < 0.0001). Furthermore, analysis via a binary logistic regression model showed SSD to be a statistically significant negative predictor regarding the successful ESWL treatment (β = −3.12, p < 0.00001). The probability of being stone-free decreased 7% for each 1 cm increase in SSD. Patients were classified according to SSD into two groups: ≤10 cm and >10 cm. In the SSD ≤10 cm group, 45 out of 50 (90%) were stone free, in contrast to the >10 cm group, of who m only 15 out of 40 (37.5%) were stone free (p<0.0001).

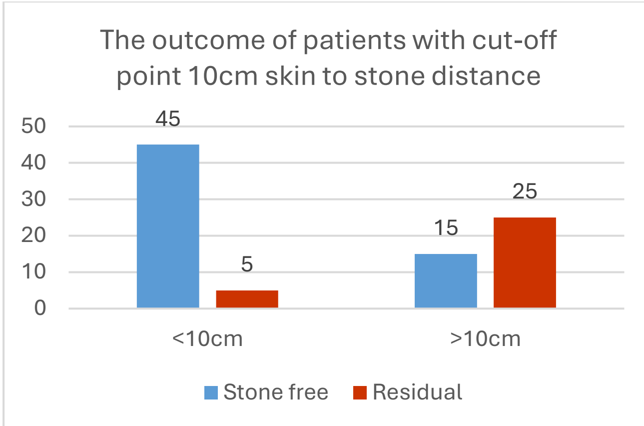

Figure 1: Bar graph representing SSD Stratification (≤10 cm vs. >10 cm) vs. Outcome (n=90).

Discussion

This study focused on the prognostic significance of SSD and other radiological parameters in patients with renal stones, with the success rate of ESWL. Study results demonstrated that SSD is a strong and independent predictor of ESWL success. The SSD ≤10 cm revealed a stronger association with stone-free status than SSD >10 cm. This finding demonstrates the strong relationship of low SSD with ESWL outcome. Estimates of the mean SSD of the stone-free group are lower, indicating that it is easier for the shockwave to propagate its energy to the vicinity of the skin surface. This is in agreement with the previous publications on the application of SSD as a non-invasive imaging marker for treatment planning.2,3,

The results of the analysis via the binary logistic regression model demonstrated that SSD turned out to be a significant negative predictor for the success of ESWL treatment. Also, the probability of being stone-free decreased by 7% for each one cm increase in SSD. Hence, proving that the SSD was independently associated with a stone-free outcome. The difference in rate to be stone-free between the group having SSD ≤10 cm was quite remarkable; hence, SSD may be considered a very useful tool to choose patients who might benefit from ESWL. This is in line with the adjunctive use of SSD as a quantitative clinical decision-making tool, rather than as a descriptive metric. The CUA-Canadian Urology Association guidelines also declared a <10 cm SSD to be an indicator of a favorable outcome.

In our series of 90 patients, 57.8% had an SSD of ≤10 cm and among this group, 90% were stone-free after ESWL. On the other hand, only 37.5% of patients with SSD >10 cm were free of stone. This agrees with the outcome reported by Erhan Erdugan et al., who identified that increased density of stone, longer SSD, and increasing age group can reduce the success rate of ESWL. Similarly, a regional study conducted at Hayatabad Medical Complex, Peshawar, by Islam et al found that a mean SSD of 10.9 was associated with a favorable outcome as compared to a mean SSD of 14.8cm. Our study results show the mean SSD in the stone-free outcome to be 9.7cm Vs. 10.4 cm in residual outcome ($p < 0.0001$; Fig. 1).

By multivariable logistic regression analysis, we concluded that SSD independently predict the successful treatment following adjusting for other factors, regardless of CT attenuation value and stone size. We also found a weak but statistically significant association between the SSD and the size of the stone ($r = 0.21$, $p = 0.048$), which may also imply that deeper stones are slightly larger. However, no robust association was determined between SSD and CT density and the number of shocks delivered. However, an Islamabad study by Iqbal et al concluded that the variation coefficient of stone density (VCSD), a useful CT-based parameter, can be utilized to gauge stone fragility and hence the prediction of SWL outcomes. This is another evidence for SSD as a separate anatomical factor in ESWL success. An Arab based study by Ahmed S-El-Abd et al concluded that ESWL has excellent results for stones <1cm in size.

These disparities are clinically important since a lower SSD has been shown to predict good results after ESWL. Ahmadullah et al conducted a study at SIUT Karachi and found a mean SSD of 69mm in patients with favorable stone clearance. The study also stated that high BMI and obesity contributed to higher SSD. The phenomenon whereby SSD in the lower pole was relatively lower, despite the anatomical difficulties of fragment extraction, indicates that SSD should be regarded as one of the determining factors in the choice of ESWL, among other factors. Bajaj et al used high-volume ESWL to demonstrate the real-world outcomes to conclude ESWL as an effective way for managing upper tract calculi. Taken together, this variant highlights the need for personalized choice of treatment, taking into account the stone location and the features of the patient's imaging. In our experience, in view of this study, we suggest that with the diligent selection of the patients, ESWL should still be considered as an effective tool while managing the calculi of the upper renal tract.

Considering the stone size, the SSD was positively correlated to the size of stones (r = +0.21, p value = 0.048), that is, a slightly deeper position in the body for larger stones. This correlation isn't very strong, but it does suggest that increased stone size is associated with increased probability of a longer SSD. This relationship could affect the ESWL efficacy because a larger SSD might decrease the transmission of shock wave energy.
Taken together, these findings highlight SSD and stone size as the two most important anatomic variables, and that a significant multivariate relation between them enhances the basis that ESWL is key, with SSD a major parameter used in the consideration of patient eligibility and in the prediction of ESWL treatment outcome. The SSD's independence of CT density and of the number of the CT shocks lends further support to its clinical power as an independent imaging parameter.
The strength of the present study is the prospective study design with standardized imaging and uniform ESWL protocol by the same technician. Nevertheless, it has the limitation of this as a single-centre-based study, with a relatively smaller sample size, and not including some types of stones, including stag horn calculi, so the results may not be generalized.
Recent progress in endourological methods, such as Retrograde Intrarenal Surgery (RIRS) and the Percutaneous Nephrolithotomy (mini-PCNL), has extended the indications for renal stone management strategies. However, this study also upholds the lasting value of ESWL, particularly in patients who have favorable anatomy, in terms of shorter SSD and smaller stone size. The simplicity, non-invasiveness, and economy of ESWL provide us a useful option in cases with SSD ≤10 cm, so-called, as appropriate stone size, although an appropriate estimation of stone size is necessary.
Lastly, this investigation corroborates SSD as a powerful, easily reproducible, and independent predictor of ESWL treatment outcome. The addition of SSD to standard pre-treatment assessment could offer an invaluable role for better patient selection, achieving better outcomes, and minimizing the requirement for repeated intervention

Conclusions

This study highlights that Skin-to-Stone Distance (SSD), a simple CT-derived metric, can help identify patients most likely to benefit from Extracorporeal Shock Wave Lithotripsy (ESWL). Given that over 56% of patients had an SSD ≤10 cm, and the majority had stones ≤15 mm, ESWL remains a highly viable first-line treatment in appropriately selected cases, supporting its continued clinical utility alongside retrograde intrarenal surgery and percutaneous nephrolithotomy.

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