

Predicting the Outcome of Renal Stones Treated by Shock Wave Lithotripsy on the Basis of CT Morphodensitometry

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Abstract

Background: Shock wave lithotripsy (SWL) is a non-invasive treatment for selected renal calculi, but treatment success varies according to stone and renal anatomical characteristics. Computed tomography (CT) provides objective information on stone density and collecting-system anatomy that may improve prediction of SWL outcome. The objective is to evaluate the utility of CT urography/CT morphodensitometry in predicting the outcome of SWL for renal stones, with particular emphasis on Hounsfield unit (HU) density, stone size, location, infundibulum length, and infundibulopelvic angle. **Material and Methods:** This hospital-based prospective observational study was conducted in the Department of Urology, Pt. B.D. Sharma PGIMS, Rohtak, from January 2024 to December 2025. Adults with renal stones up to 20 mm who were suitable for SWL were enrolled consecutively. Pre-treatment CT urography/CECT KUB was used to assess stone size, location, density, infundibulum length and infundibulopelvic angle. SWL was delivered using an electromagnetic lithotripter, with a maximum of 3000 shocks per session. Success was defined as stone-free status or residual fragments <4 mm after treatment; residual fragments ≥4 mm after three sessions or need for ancillary stone-removal procedures was considered failure. Univariate analysis, ROC analysis and backward stepwise multivariable logistic regression were performed. **Results:** Among 100 patients, 79 (79.0%) achieved successful SWL and 21 (21.0%) failed. Mean stone size was 12.82 ± 4.24 mm and mean stone density was 717.83 ± 209.56 HU. On univariate analysis, sex (P=0.036), stone location (P=0.036), calyceal versus non-calyceal location (P=0.001), stone density (P=0.001), infundibulum length (P=0.015 for categorical analysis; P=0.006 for mean comparison), and infundibulopelvic angle (P=0.005 for categorical analysis; P=0.035 for mean comparison) were associated with outcome. Age, stone size, number of sittings and number of shocks were not significant. ROC analysis showed the greatest discriminatory ability for stone density, with an AUC of 0.926 (95% CI 0.847–0.999; P=0.001) at an optimal cut-off of 775 HU. On multivariable analysis, non-calyceal location (OR 2.966, 95% CI 1.487–6.889; P=0.013) and stone density <800 HU (OR 7.748, 95% CI 3.794–23.448; P=0.001) remained independent predictors of success. Overall, 21% of patients experienced a recorded complication, most commonly hematuria (8%), Steinstrasse (7%) and pain (6%). **Conclusion:** CT morphodensitometry provides clinically useful information for predicting SWL outcome. Stone density was the strongest predictor, followed by stone location. Patients with lower-density and non-calyceal stones were more likely to achieve successful SWL. CT-derived anatomical parameters may provide additional information for patient selection, although their independent predictive value was not retained after multivariable adjustment. **Keywords:** Renal Calculi, shock wave lithotripsy, SWL, computed tomography, CT morphodensitometry, Hounsfield units, stone density, infundibulopelvic angle.

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INTRODUCTION

Urolithiasis is a common clinical problem with substantial geographic variation in prevalence. The thesis source reports prevalence estimates of approximately 7–13% in North America, 5–9% in Europe and about 1% in Asia, with a considerable burden of disease in India. Recurrent stone disease may be associated with infection, renal impairment and repeated interventions, making appropriate treatment selection important.^[1-3]

Imaging plays a central role in diagnosis, treatment planning and follow-up. Non-contrast CT is highly accurate for stone detection and provides more precise stone-size assessment than plain radiography or ultrasonography. CT also permits quantitative characterization of calculi using attenuation values expressed in Hounsfield units (HU).^[4-6]

SWL remains an important non-invasive treatment for appropriately selected renal calculi. Nevertheless, its efficacy is variable. Treatment outcome is influenced by stone size,

location, composition and density, as well as renal collecting-system anatomy and patient-related factors. Lower-pole and calyceal stones may be more difficult to clear because fragmentation alone does not guarantee dependent fragment clearance.^[7-9]

Stone attenuation on CT has been repeatedly investigated as a surrogate for stone hardness and a predictor of SWL response. Previous studies cited in the thesis have reported poorer outcomes with higher stone attenuation, while other CT-derived

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parameters, including stone location, stone burden and renal anatomy, may contribute to prediction.^[10]

The present study was designed to evaluate CT urography/CT morphodensitometry as a pre-treatment tool for predicting SWL outcome in patients with renal stones. Particular emphasis was placed on stone density, location, size, infundibulum length and infundibulopelvic angle.^[11]

Aim and Objectives

Aim: To predict the outcome of renal stones treated by SWL on the basis of CT morphodensitometry.

Primary objective: To assess the value of CT urography as a possible predictor of renal stone disintegration by SWL.

Secondary objectives: (1) To investigate the correlation between HU values and SWL success; and (2) to assess the effect of CT-determined stone size, location, stone volume/density, infundibulum length and infundibulopelvic angle on SWL outcome.

MATERIALS AND METHODS

Study design and setting: A hospital-based prospective observational study was conducted in the Department of Urology, Pt. B.D. Sharma Post Graduate Institute of Medical Sciences, Rohtak, Haryana. The study period was January 2024 to December 2025. The source thesis describes consecutive enrolment of eligible participants.

Participants: Adults aged ≥ 18 years with renal stones up to 20 mm who were willing to undergo SWL and were considered suitable for SWL were eligible.

Exclusion criteria were abnormal renal anatomy or function, stones in a calyceal diverticulum, pregnancy, bleeding diathesis, severe renal impairment/CKD stage 4 or higher, sepsis, renal cancer, obstruction distal to the calculus, unwillingness to undergo SWL, medical conditions contraindicating SWL or interfering with CT interpretation, and ESWL failure.

Pre-treatment assessment and CT morphodensitometry

All patients underwent clinical evaluation and routine laboratory and radiological assessment. The protocol included ultrasonography of the abdomen, chest radiography, X-ray KUB and CECT KUB/CT urography. CT-derived parameters included stone size, stone location, stone density in HU, infundibulum length and infundibulopelvic angle. Imaging was performed using a 64-slice multidetector CT scanner.

SWL protocol: SWL was performed on an outpatient basis

using a Sonolith iMove (EDAP TMS) electromagnetic lithotripter. Stone localization was achieved with ultrasound or C-arm fluoroscopy according to the study protocol. Patients were kept nil per oral for at least 4 hours. Pre-procedural DJ stenting was performed in patients with stone size >10 mm and in those with a solitary functioning kidney. Patients were treated in the prone position without anaesthesia or analgesia. Up to 3000 shocks were delivered per session at 10–12 kV and 65–100 shocks/min. NSAIDs and empirical antibiotics were prescribed after each session.

Follow-up and outcome definition: X-ray KUB and/or ultrasonography was performed two weeks after each SWL session. Repeat treatment was given when follow-up imaging showed inadequate fragmentation. NCCT KUB was used when X-ray KUB/ultrasound demonstrated incomplete fragmentation, radiolucent stones or clinically insignificant residual fragments. SWL was considered failed when residual fragments ≥ 4 mm persisted after three sessions or when an ancillary procedure was required. Success was defined as stone-free status or residual fragments <4 mm.

Sample size and sampling: Based on an expected success proportion of 80% from the study by Rathee et al., a minimum sample size of 96 was calculated using 15% relative precision, 5% alpha error and 80% power. The final study included 100 patients. Consecutive sampling was used.

Statistical analysis: Categorical variables were evaluated using the chi-square test, while continuous variables were compared using the independent-samples t-test. ROC curve analysis was used to determine the discriminatory performance and optimal cut-offs of CT-derived predictors using Youden's index. Backward stepwise multivariable logistic regression was used to identify independent predictors of SWL success. Statistical significance was set at $P < 0.05$. Analyses were performed using SPSS version 24.0 (IBM, USA).

RESULTS

The study included 100 patients. The age range was 18–70 years; 56 patients (56.0%) were male and 44 (44.0%) were female. The most frequent age groups were 18–30 years and 61–70 years, each accounting for 26%. Mean stone size was 12.82 ± 4.24 mm, and 74% of stones were ≥ 10 mm. Calyceal stones accounted for 58%, with upper calyceal stones being the most frequent individual location (28%). Mean stone density was 717.83 ± 209.56 HU.

Table 1: Overall SWL outcome

Outcome	n	%
Success	79	79.0
Failure	21	21.0
Total	100	100.0

Successful SWL was achieved in 79% of patients, while 21% experienced treatment failure. Thus, approximately four out of five patients achieved the predefined successful outcome. Age was not significantly associated with SWL outcome ($P=0.986$). The distribution of successful and failed treatments was broadly similar across age groups. Sex showed a statistically significant association with SWL

outcome on univariate analysis ($P=0.036$), with males comprising a larger proportion of failures. Sex was not retained as an independent predictor in the multivariable model.

Comorbidity was not significantly associated with SWL outcome on univariate analysis ($P=0.157$).

Table 2: Association between stone size and SWL outcome

Stone size	Failure n (%)	Success n (%)	Total n (%)
<10 mm	5 (23.8)	21 (26.6)	26 (26.0)
≥10 mm	16 (76.2)	58 (73.4)	74 (74.0)
Total	21 (100.0)	79 (100.0)	100 (100.0)
Mean ± SD (mm)	13.95 ± 4.71	12.52 ± 4.08	12.82 ± 4.24
Categorical P		0.797	
Mean comparison P		0.170	

Inference: Neither categorical stone size nor mean stone size differed significantly between successful and failed cases

(P=0.797 and P=0.170, respectively). Stone size was therefore not a significant predictor in this dataset.

Table 3: Association between individual stone location and SWL outcome

Location	Failure n (%)	Success n (%)	Total n (%)
Lower calyx	4 (19.0)	15 (19.0)	19 (19.0)
Upper calyx	8 (38.1)	20 (25.3)	28 (28.0)
Middle calyx	7 (33.3)	12 (15.2)	19 (19.0)
Renal pelvis	2 (9.5)	32 (40.5)	34 (34.0)
Total	21 (100.0)	79 (100.0)	100 (100.0)
Chi-square		P=0.036	

Stone location was significantly associated with SWL outcome (P=0.036). Renal pelvic stones were more frequent

among successful treatments, whereas upper- and middle-calyceal stones were more frequent among failures.

Table 4: Calyceal versus non-calyceal stone location

Location	Failure n (%)	Success n (%)	Total n (%)
Calyceal	19 (90.5)	39 (49.4)	58 (58.0)
Non-calyceal	2 (9.5)	40 (50.6)	42 (42.0)
Total	21 (100.0)	79 (100.0)	100 (100.0)
Chi-square		P=0.001	

Calyceal versus non-calyceal location was strongly associated with SWL outcome (P=0.001). Non-calyceal

stones were disproportionately represented among successful cases.

Table 5: Association between stone density and SWL outcome

Stone density	Failure n (%)	Success n (%)	Total n (%)
<800 HU	2 (9.5)	74 (93.7)	76 (76.0)
≥800 HU	19 (90.5)	5 (6.3)	24 (24.0)
Total	21 (100.0)	79 (100.0)	100 (100.0)
Mean ± SD (HU)	1004.24 ± 172.36	641.70 ± 142.00	717.83 ± 209.56
Categorical P		0.001	
Mean comparison P		0.001	

Stone density was one of the strongest univariate predictors. Most successful treatments involved stones <800 HU, whereas most failures involved stones ≥800 HU. Both

categorical and mean comparisons were highly significant (P=0.001).

Table 6: Association between infundibulum length and SWL outcome

Infundibulum length	Failure n (%)	Success n (%)	Total n (%)
<3.0 mm	8 (38.1)	53 (67.1)	61 (61.0)
≥3.0 mm	13 (61.9)	26 (32.9)	39 (39.0)
Total	21 (100.0)	79 (100.0)	100 (100.0)
Mean ± SD (mm)	3.15 ± 0.47	2.71 ± 0.68	2.80 ± 0.66
Categorical P		0.015	
Mean comparison P		0.006	

Shorter infundibulum length was associated with better SWL outcome on univariate analysis. Both categorical and

continuous comparisons were statistically significant.

Table 7: Association between infundibulopelvic angle and SWL outcome

Infundibulopelvic angle	Failure n (%)	Success n (%)	Total n (%)
<70°	12 (57.1)	20 (25.3)	32 (32.0)
≥70°	9 (42.9)	59 (74.7)	68 (68.0)
Total	21 (100.0)	79 (100.0)	100 (100.0)
Mean ± SD (°)	78.19 ± 16.43	85.43 ± 13.05	83.91 ± 14.05

Categorical P		0.005	
Mean comparison P		0.035	

A wider infundibulopelvic angle was associated with successful SWL on univariate analysis. Both categorical and mean comparisons were statistically significant.

The number of sittings was not significantly associated with final SWL outcome ($P=0.419$).

Number of shocks was not significantly associated with treatment success ($P=0.138$).

No complication was recorded in 79% of patients. Hematuria was the most frequently recorded complication (8%),

followed by Steinstrasse (7%) and pain (6%). The percentages represent the thesis' recorded complication categories; because categories may not be mutually exclusive, they should not be summed as a composite complication rate without verification of the raw dataset.

Most patients did not require an ancillary procedure. DJ stenting was the most frequent ancillary intervention, followed by ureteroscopy and PCNL.

Table 8: ROC analysis of CT-derived predictors

Parameter	Optimal cut-off	AUC $\pm$ SE	95% CI	P-value
Stone size	12.0 mm	0.600 $\pm$ 0.076	0.450–0.750	0.161
Stone location	Calyceal	0.706 $\pm$ 0.057	0.594–0.817	0.004
Stone density	775 HU	0.926 $\pm$ 0.040	0.847–0.999	0.001
Infundibulum length	2.7 mm	0.696 $\pm$ 0.055	0.587–0.804	0.006
Infundibulopelvic angle	89°	0.642 $\pm$ 0.080	0.485–0.798	0.047

Stone density had the highest discriminatory performance (AUC 0.926), indicating strong predictive ability. Stone location and infundibulum length demonstrated moderate

predictive performance, while the infundibulopelvic angle showed modest predictive ability. Stone size did not significantly discriminate between success and failure.

Table 9: Diagnostic efficacy of CT-derived predictors

Parameter	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
Stone size	66.7	40.5	22.9	82.0	46.0
Stone location	90.5	50.6	32.8	95.2	59.0
Stone density	90.5	89.9	70.4	97.3	90.0
Infundibulum length	80.9	48.1	29.3	90.5	55.0
Infundibulopelvic angle	76.2	46.8	27.6	88.1	53.0

Stone density was the most accurate CT-derived predictor, with sensitivity 90.5%, specificity 89.9%, PPV 70.4%, NPV

97.3% and overall accuracy 90.0%.

Table 10: Multivariable logistic regression for SWL success

Predictor	Reference	OR	95% CI	P-value
Location: non-calyceal	Calyceal	2.966	1.487–6.889	0.013
Stone density: <800 HU	≥ 800 HU	7.748	3.794–23.448	0.001

Model covariates: age, sex, stone size, infundibulum length and infundibulopelvic angle were included in the backward stepwise model. The dependent variable was binary SWL outcome (0=failure, 1=success).

Inference: After adjustment, non-calyceal location and stone density <800 HU remained independently associated with SWL success. Patients with stones <800 HU had approximately 7.75-fold higher odds of success, while non-calyceal stones had approximately 3-fold higher odds of success compared with their respective reference categories. Age, sex, stone size, infundibulum length and infundibulopelvic angle were not independently significant in the final multivariable model.

DISCUSSION

The present prospective study evaluated whether CT morphodensitometry can help predict the outcome of SWL in patients with renal stones. The overall success rate was 79%, with failure in 21% of patients. This result is within the

range reported in the literature cited in the thesis, including approximately 68% success in studies by Rasheed et al. and Rathee et al. Differences between studies may reflect variation in patient selection, stone characteristics, treatment protocols, lithotripter systems and operator experience.^[12,13]

The principal finding was the strong relationship between stone density and SWL outcome. Stones <800 HU constituted 93.7% of successful cases but only 9.5% of failures. Mean stone density was also substantially lower in successful than failed cases (641.70 $\pm$ 142.00 HU versus 1004.24 $\pm$ 172.36 HU). ROC analysis identified 775 HU as the optimal threshold, with an AUC of 0.926 and 90.0% overall accuracy. In multivariable analysis, density <800 HU remained the strongest independent predictor, with an OR of 7.748.^[14,15]

These findings are consistent with previous CT-based studies. Gupta et al. reported better clearance and fewer sessions with lower attenuation stones, while El-Nahas et al. identified high stone density as an independent predictor of SWL failure. Perks et al. similarly reported an association between stone attenuation and fragmentation. Abdelaziz et al. found lower mean attenuation

among successful cases and reported poorer outcomes with high-density stones. The present study therefore adds further support for routine consideration of CT attenuation when selecting patients for SWL.^[16,17]

Stone location was the second independent predictor. Non-calyceal stones had approximately three times the odds of successful treatment compared with calyceal stones after adjustment. On univariate analysis, renal pelvic stones were particularly frequent among successful treatments, whereas upper- and middle-calyceal stones were more frequent among failures. This finding is biologically plausible because fragmentation must be followed by effective passage of fragments; dependent calyceal anatomy may impede clearance. The result is consistent with previous work identifying renal stone location, especially lower-pole/calyceal anatomy, as an important determinant of SWL outcome.^[18,19]

Infundibulum length and infundibulopelvic angle were significantly associated with outcome on univariate analysis. Successful cases had shorter mean infundibulum length and wider mean infundibulopelvic angle. These parameters may facilitate movement of fragments from calyces toward the renal pelvis. However, neither parameter remained independently significant after multivariable adjustment, suggesting that their apparent effects may overlap with other stone and anatomical characteristics, particularly location and density.^[20]

Stone size was not a significant predictor in this study. Neither the categorical comparison (<10 versus ≥10 mm) nor mean stone size differed significantly between success and failure. ROC analysis also showed poor discrimination (AUC 0.600; P=0.161). This finding differs from some published series in which stone size or stone-burden measures were important predictors. The discrepancy may be related to the restricted inclusion range of stones up to 20 mm, sample size, and correlations between stone size and other CT parameters.^[21]

Age and number of shocks or sittings were not significantly associated with final outcome. Sex was significant on univariate analysis, but it did not remain an independent predictor in the multivariable model. Similarly, comorbidity was not significantly associated with SWL success.^[22]

The complication profile was relatively limited in the recorded data, with no complication recorded in 79% of patients. Hematuria, Steinstrasse and pain were the principal recorded complications. Ancillary procedures were required in a minority of patients, most commonly DJ stenting, followed by ureteroscopy and PCNL. These findings support the generally acceptable safety profile of SWL while emphasizing that treatment failure may require additional intervention.^[23]

The study has several strengths, including prospective data collection, consecutive enrolment, assessment of multiple CT-derived parameters, ROC-based determination of cut-offs, and multivariable analysis. Important limitations include the single-centre design and sample size of 100, which may limit generalizability and statistical power. BMI, skin-to-stone distance, hydronephrosis and stone composition were not evaluated, despite their potential

influence on SWL outcome. The study also did not directly compare SWL with ureteroscopy or PCNL. Finally, the manuscript retains the source thesis' definition of success and its reported complication categories; these should be cross-checked against the final database before journal submission.^[24]

Clinical Implications: CT morphodensitometry may help clinicians identify patients most likely to benefit from SWL. In particular, stone density appears to provide the greatest predictive value, while stone location adds independent information. Patients with high-density stones and challenging calyceal locations may require counselling regarding a lower probability of SWL success and consideration of alternative modalities when clinically appropriate.

CONCLUSION

In this prospective study of 100 patients with renal stones, SWL achieved an overall success rate of 79%. CT-derived stone density was the strongest predictor of treatment success: stones <800 HU had substantially greater odds of successful SWL, and a density threshold around 775 HU demonstrated excellent discriminatory performance. Non-calyceal location was also independently associated with success. Infundibulum length and infundibulopelvic angle were significant on univariate analysis but not after adjustment. Age, stone size, number of sittings and number of shocks were not significant predictors. These findings support the use of CT morphodensitometry as an adjunct to clinical assessment and patient counselling before SWL.

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Conflicts of interest

There are no conflicts of interest.

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