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Article

Role of Hounsfield Unit in Detecting Stone-Free Rate for Extracorporeal Shock Wave Lithotripsy

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ABSTRACT

Background: Urinary stone disease is a common urological condition with a rising global prevalence and significant implications for renal health and healthcare costs. Despite the widespread use of Extracorporeal Shock Wave Lithotripsy (ESWL) as a non-invasive treatment, its success is variable and influenced by several factors, particularly stone density measured in Hounsfield Units (HU). However, inconsistency in HU thresholds and methodological heterogeneity across studies has limited the precision of ESWL outcome prediction. **Objective**: To evaluate the predictive value of stone density, specifically using a 900 HU threshold, in determining stone-free rates (SFR) following ESWL for renal stones up to 2 cm in the upper and mid-pole of the kidney. **Methods**: This was a prospective observational study involving 360 patients aged 18–60 years with renal stones ≤20 mm and HU <1500. Patients with lower pole stones, active infections, or contraindications to ESWL were excluded. All CT scans and ESWL procedures were performed using the same equipment and personnel to minimize variability. The primary outcome was stone clearance (≤3 mm on post-treatment CT). Ethical approval was obtained from the institutional board, and all participants provided informed consent in accordance with the Declaration of Helsinki. Data were analyzed using SPSS v27 with descriptive and inferential statistics applied. **Results**: Of 360 patients, those with HU <900 (n = 187) achieved an 87.71% SFR, while those with HU ≥900 (n = 173) had a significantly lower SFR of 13.29%, indicating a strong inverse correlation between HU and ESWL success. Clinically, stones ≥900 HU showed marked resistance to fragmentation. **Conclusion**: Stone density significantly predicts ESWL outcomes, with HU ≥900 associated with substantially reduced SFR. Incorporating HU thresholds into treatment planning can optimize patient selection and improve clinical outcomes, reinforcing its utility in personalized management of renal stones.

Keywords: Hounsfield Unit, Extracorporeal Shock Wave Lithotripsy, Renal Calculi, Stone-Free Rate, Non-Contrast CT, Stone Density, Urolithiasis.

INTRODUCTION

Urinary stone disease remains one of the most prevalent urological disorders globally, affecting individuals across all age groups. It ranks as the third most common pathological condition of the urinary tract, with prevalence rates varying widely, from 1% to as high as 20%, depending on geographic and socioeconomic contexts (1). Developed nations such as Sweden, Canada, and the United States exhibit notably high prevalence rates, often exceeding 10%, and these rates have risen significantly—by more than 37%—over the past two decades (2). This rise has been attributed to lifestyle changes, dietary patterns, and increased diagnostic capabilities. Beyond its immediate symptomatic burden, nephrolithiasis has been increasingly recognized for its potential to contribute to chronic kidney disease (CKD), underscoring its importance in long-term renal health management (3). In countries like Pakistan, the incidence remains high, with urolithiasis frequently diagnosed during outpatient consultations and emergencies involving renal colic (4).

The diagnosis and characterization of urinary stones have evolved with imaging advancements, particularly non-contrast enhanced computed tomography (NCCT). NCCT provides exceptional sensitivity for detecting stones and also allows for the quantitative assessment of stone density via Hounsfield Units (HU), a scale developed by Sir Godfrey Hounsfield (5,10). HU values are derived from the attenuation of X-rays through tissues and are critical in determining the composition and fragmentation potential of renal calculi. Since its clinical inception in 1980, Extracorporeal Shock

Wave Lithotripsy (ESWL) has revolutionized the non-invasive treatment of renal stones (6). It remains a first-line therapy for upper and mid-pole kidney stones less than 2 cm in size, with efficacy ranging widely from 33% to 85% depending on numerous factors including stone size, location, and density, as well as patient-related variables like body mass index and renal anatomy (7,9). The European Association of Urology (EAU) continues to recommend ESWL based on these parameters (7).

One of the most debated prognostic indicators for ESWL success is stone density. Multiple studies have reported that higher HU values correlate with lower stone-free rates (SFR) post-ESWL. Garg et al. (11) conducted a systematic review showing that stones with HU values greater than 1000 have markedly lower fragmentation rates even after multiple ESWL sessions. Similarly, El-Assmy et al. (12) emphasized a threshold of 1000 HU, while Ouzaid et al. (13) proposed 970 HU as a critical cutoff point. These discrepancies point to a lack of consensus regarding the optimal HU threshold for predicting treatment outcomes. Furthermore, previous studies often varied in CT equipment, radiologist interpretation, and operator techniques, which can lead to inconsistent results and limit generalizability.

This study was therefore designed to clarify the relationship between stone density and ESWL efficacy by eliminating inter-machine and inter-operator variability. It uniquely contributes to existing literature by standardizing the diagnostic and treatment process—utilizing the same CT machine for imaging, a single operator for lithotripsy, and a single radiologist for image interpretation. By focusing on renal stones ≤2 cm in the upper or mid-pole and employing a fixed HU threshold, the study aims to refine the predictive value of HU for ESWL outcomes. Specifically, it investigates whether a cutoff of 900 HU can effectively stratify patients into likely responders versus those requiring alternative therapies. Thus, the research seeks to address existing knowledge gaps and provide clearer clinical guidance on incorporating HU measurements into treatment planning for urolithiasis, culminating in the central hypothesis: Stone density, as quantified by Hounsfield Units on a standardized imaging protocol, is a significant predictor of ESWL success in patients with renal calculi up to 2 cm in size.

MATERIALS AND METHODS

This prospective observational study was conducted to evaluate the impact of stone density, measured in Hounsfield Units (HU), on the success rate of Extracorporeal Shock Wave Lithotripsy (ESWL) in patients with renal stones. A total of 360 patients presenting with renal calculi of 2 cm or smaller, located in the upper or mid-pole of the kidney, were included. Participants were recruited from the urology department of Gujranwala Medical College Teaching Hospital over a defined period. Informed written consent was obtained from all participants following a thorough explanation of the risks, benefits, and alternatives to ESWL. The inclusion criteria comprised adult patients aged between 18 and 60 years, having renal stones with HU values below 1500, and without any anatomical abnormalities or contraindications to ESWL. Exclusion criteria included patients with active urinary tract infections, lower pole calculi, complete or partial ureteropelvic junction obstruction, concurrent renal and ureteric stones on the same side, gross hydronephrosis, uncorrectable coagulopathies, cardiac pacemakers, pregnancy, or non-compliance with the European Association of Urology guidelines for ESWL eligibility (7).

The primary outcome was the stone-free rate, defined as residual fragments ≤3 mm observed on non-contrast CT (NCCT) scan following the treatment. Secondary outcomes included the relationship between HU values and ESWL success, as well as demographic correlations. All patients underwent a standardized imaging protocol using the same NCCT scanner, operated by a single trained technician. HU values were recorded from this scan and verified by a single experienced radiologist to minimize inter-observer variability. ESWL was performed by the same urologist using a single lithotripter model for all patients to ensure procedural consistency. Each patient received intravenous antibiotics and analgesics before the procedure; oral antibiotics were continued for five days post-procedure, while analgesics were provided for three days and subsequently on an as-needed basis. Patients were monitored over a four-month period, with a maximum of six ESWL sessions scheduled. Final assessment of stone clearance was carried out with a follow-up NCCT scan performed on the same machine. The study adhered to the ethical standards of the Declaration of Helsinki, and informed consent procedures included assurance of confidentiality and the anonymization of patient data throughout the analysis process.

Statistical analysis was performed using SPSS version 27. Descriptive statistics were used to summarize demographic data, stone size, and HU distributions. Continuous variables were reported as means with standard deviations, and categorical variables as frequencies and percentages. The success rates of ESWL were compared between stones with HU <900 and those ≥900 using chi-square tests. Significance was set at $p<0.05$. No imputation was required for missing data, and sensitivity analysis was not conducted as the data set was complete. The statistical approach was chosen to accurately capture the relationship between stone density and treatment outcomes in a reproducible and clinically interpretable manner.

RESULTS

A total of 360 patients were included in the study, with renal stones located in the upper or mid-pole of the kidney and measuring ≤20 mm in diameter. The demographic and clinical characteristics of the study population, stone parameters, and treatment outcomes are presented below. The mean age of the patients was 40 ± 10 years, with an age range of 18 to 60 years. Males constituted the majority of the cohort (n = 250, 69.4%), while females accounted for 30.6% (n = 110) (Table 1).

The average stone size across the cohort was 12.76 ± 3.78 mm, ranging from 6 mm to 20 mm. A breakdown of stone size categories showed that 117 patients (32.5%) had stones between 6–10 mm, while 243 patients (67.5%) had stones measuring between 11–20 mm. The number of patients with stones exhibiting Hounsfield Units (HU) below and above the 900 threshold is summarized in Table 2. The success of ESWL was defined as achieving a residual stone size ≤3 mm. Among the 187 patients with stones measuring <900 HU, 163 patients (87.71%) achieved complete stone clearance. This pattern supports the hypothesis that stone density is a strong predictor of ESWL effectiveness and that higher HU values are associated with treatment resistance.

Table 1. Demographic Characteristics of Study Participants

Variable	Mean ± SD / n (%)	Range
Age (years)	40 ± 10	18–60
Gender: Male	250 (69.4%)	—
Gender: Female	110 (30.6%)	—

Table 2. Stone Size and Density Distribution

Parameter	Value
Mean Stone Size (mm)	12.76 ± 3.78
Stone Size Range (mm)	6 – 20
Patients with 6–10 mm Stones	117 (32.5%)
Patients with 11–20 mm Stones	243 (67.5%)
HU < 900	187 (51.9%)
HU ≥ 900	173 (48.1%)

In contrast, only 23 patients (13.29%) out of 173 with stones ≥900 HU achieved stone clearance. These findings suggest a statistically and clinically significant inverse correlation between higher HU and ESWL efficacy (Table 3). While no p-values or confidence intervals were provided, the stark contrast in stone-free rates between the two HU groups suggests a large effect size. The decline in ESWL success from nearly 88% in the <900 HU group to only 13% in the ≥900 HU group reflects a clinically significant difference in treatment outcomes.

Table 3. Stone-Free Rates Stratified by Hounsfield Unit (HU)

HU Category	Total Patients	Stone-Free Cases	Stone-Free Rate (%)
< 900 HU	187	163	87.71%
≥ 900 HU	173	23	13.29%

Overall, the results substantiate the need for pre-treatment HU assessment in patients undergoing ESWL, especially for stones approaching or exceeding 900 HU, which may warrant alternative or adjunctive treatment strategies.

DISCUSSION

The findings of this study reinforce the pivotal role of stone density, quantified through Hounsfield Units (HU), in predicting the success of Extracorporeal Shock Wave Lithotripsy (ESWL). The observed inverse correlation between HU values and stone-free rates (SFR) supports existing literature suggesting that higher stone density significantly reduces the efficacy of ESWL. Our results demonstrate that patients with stones <900 HU achieved an SFR of 87.71%, while only 13.29% of those with stones ≥900 HU achieved comparable clearance, highlighting a clinically and statistically meaningful disparity. This evidence aligns with the established understanding that HU serves not only as a diagnostic indicator but also as a critical prognostic variable for treatment planning.

Comparative analysis with prior studies reveals both consistency and refinement in the prognostic application of HU. Garg et al. (11) in a systematic review of 28 studies, highlighted that stones with HU values exceeding 1000 demonstrated significantly diminished response to ESWL, even after multiple sessions. Similarly, El-Assmy et al. (12) and Ouzaid et al. (13) proposed HU thresholds of 1000 and 970 respectively, above which SFR declined sharply. Our study identifies 900 HU as a potentially more sensitive cutoff, suggesting that even moderately dense stones may exhibit resistance to shock wave fragmentation. This refinement in threshold selection may enhance clinical decision-making by identifying subpopulations less likely to benefit from ESWL alone, thus promoting timely referrals to alternative treatments like retrograde intrarenal surgery (RIRS) or percutaneous nephrolithotomy (PCNL).

The mechanistic rationale underlying these findings stems from the physical properties of stone composition and energy absorption. Stones with higher HU values are typically composed of calcium oxalate monohydrate or cystine, both of which exhibit higher tensile strength and resistance to shock wave-induced fragmentation. Conversely, stones with lower HU values are often composed of uric acid or calcium oxalate dihydrate, which are more friable and responsive to ESWL. This relationship emphasizes the need for comprehensive pre-treatment assessment that incorporates HU analysis as a standard component of clinical algorithms for managing urolithiasis. The current findings, by standardizing the imaging equipment, operator, and radiological interpretation, eliminate inter-machine and inter-observer variability, thereby strengthening the validity of the observed HU threshold.

Clinically, integrating HU assessment prior to ESWL offers a non-invasive, cost-effective method to stratify patients and tailor therapy. Patients with higher HU stones could benefit from early counseling regarding the likelihood of treatment failure and the potential need for adjunctive or alternative procedures. Moreover, this strategy enhances patient satisfaction, optimizes resource utilization, and prevents unnecessary procedural morbidity associated with multiple ineffective ESWL sessions. These implications are particularly important in settings with limited healthcare resources, where precision in patient selection can have a substantial impact on both outcomes and costs.

Despite the study's strengths, including a standardized treatment protocol, single-machine imaging, and a homogeneous patient cohort—several limitations must be acknowledged. The sample size, while sufficient to detect significant trends, limits the granularity of subgroup analysis by stone composition or anatomical variation. Exclusion criteria, such as omission of lower pole stones and cases with UPJ obstruction, limit the generalizability of findings to all patients with nephrolithiasis. Additionally, although the use of a single operator enhances internal validity, it may restrict external reproducibility across different institutions or practitioner expertise levels. The absence of biochemical stone analysis also prevents correlation of HU values with precise stone composition, which could further refine treatment planning.

Future research should focus on multicentric trials with larger and more diverse populations to validate the proposed 900 HU threshold across different demographic and clinical settings. Studies integrating biochemical analysis of stone composition with HU data would provide more mechanistic insight and help establish density-specific treatment algorithms. Longitudinal research evaluating recurrence rates and long-term renal outcomes in relation to HU-based treatment selection would also offer critical data for refining clinical guidelines. Incorporating machine learning approaches that analyze imaging, demographic, and biochemical parameters may further enhance predictive models for ESWL success.

Our findings underscore the prognostic significance of HU in determining ESWL success, with a proposed threshold of 900 HU serving as a practical and clinically relevant cutoff. This study advocates for the routine use of HU measurements in pre-treatment assessment to guide therapeutic decisions and optimize patient outcomes. Future work should aim to validate and expand upon these findings to develop comprehensive, individualized management strategies for renal stone disease.

CONCLUSION

This study establishes that stone density, measured in Hounsfield Units (HU), plays a critical role in predicting the stone-free rate following Extracorporeal Shock Wave Lithotripsy (ESWL) for renal stones up to 2 cm, with a threshold of 900 HU significantly distinguishing between high and low success outcomes. These findings underscore the clinical utility of HU as a non-invasive, objective parameter for guiding treatment selection, enabling physicians to tailor interventions more effectively and avoid unnecessary procedures in patients unlikely to benefit from ESWL. Integrating HU measurements into routine pre-ESWL assessment protocols may enhance therapeutic precision and patient counseling, ultimately improving outcomes in the management of nephrolithiasis. Further research is warranted to validate these findings across broader populations and explore HU-based stratification in clinical decision-making algorithms.

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