ORIGINAL PAPER

Performance of 'Triple-D' and 'Quadruple-D' scores compared to a regression-based predictive model for treatment outcomes in extracorporeal shock wave lithotripsy

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Summary *Background: Extracorporeal shock wave lithotripsy (ESWL) is a widely utilized, non-invasive treatment for renal and ureteric stones. Accurate prediction of treatment outcomes is essential for improving patient counseling and optimizing clinical management. Established scoring systems, such as the 'Triple-D' score – which incorporates stone Density, Diameter, and skin-to-stone Distance – and the 'Quadruple-D' score – which adds factors like stone location or hydronephrosis status – are used to stratify patients by risk. However, these tools have limitations in predictive accuracy. This study aimed to evaluate and compare the predictive performances of the Triple-D and Quadruple-D scores against a novel regression-based model for ESWL outcomes.*
Methods: A retrospective study was conducted on 1,000 adult patients treated with ESWL using the Dornier Compact Delta® III Pro lithotripter from May 2022 to November 2023. Key predictors of ESWL failure were identified using multivariable logistic regression with internal validation. Predictive performances were compared using receiver operating characteristic (ROC) analysis, with statistical differences assessed by DeLong's test. Model calibration and clinical utility were examined through calibration plots and decision curve analysis (DCA).
Results: ESWL treatment success was achieved in 87.5% of patients. Independent predictors of failure included prior urologic intervention (adjusted odds ratio [aOR] 2.64, 95% CI 1.75-3.99), multiple stones (aOR 0.45, 95% CI 0.24-0.77), higher stone density (per 100 Hounsfield Units increase; $p < 0.001$), and increased skin-to-stone distance (per cm; aOR 1.18, 95% CI 1.06-1.30). The regression-based model showed superior discrimination (AUC 0.92) compared to the Quadruple-D (AUC 0.81, $p = 0.01$) and Triple-D (AUC 0.72, $p < 0.001$) scores. Calibration and DCA confirmed the model's improved accuracy and clinical benefit.
Conclusions: The regression-based model outperforms existing Triple-D and Quadruple-D scores in predicting ESWL failure, providing enhanced individualized risk stratification. This may facilitate better patient selection and treatment planning. Prospective validation is warranted.

KEY WORDS: *Extracorporeal shock wave lithotripsy; ESWL; Predictive model; Triple-D score; Quadruple-D score; Stone clearance; Kidney stones; Ureteric stones; Logistic regression; Outcome prediction; Predictive scoring systems.*

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INTRODUCTION

Urolithiasis represents a significant public health concern worldwide, with an estimated prevalence of 2–3% and a recurrence rate approaching 50% (1, 2). Treatment modalities for renal and ureteric calculi vary widely, encompassing conservative management, endourological interventions, and open surgical procedures (3-6). Among these, *extracorporeal shock wave lithotripsy* (ESWL) has emerged as a minimally invasive, first-line treatment option, attributable to its proven efficacy and favorable safety profile (7).
Recent technological advances, particularly exemplified by the Dornier Compact Delta® III Pro lithotripter, have enhanced the efficacy of ESWL (7). This device incorporates sophisticated shock wave generation, advanced imaging technologies, and refined patient positioning systems, collectively contributing to improved stone fragmentation, reduced patient discomfort, and expedited recovery. Such innovations have reinforced ESWL's pivotal role in contemporary urologic practice (7, 8).
Despite these advancements, ESWL outcomes remain heterogeneous, influenced by multiple interacting factors. Stone characteristics, including size, density, anatomical location, morphology, and degree of impaction, are primary determinants of treatment success, commonly assessed as stone-free rates (9, 10). Notably, larger or denser stones, particularly those situated in anatomically challenging regions such as the lower renal calyx with unfavorable infundibulo-pelvic angles, demonstrate consistently lower clearance rates and higher failure risks.

Patient-specific factors, including age, body mass index, skin-to-stone distance, presence of hydronephrosis, previous urological interventions, and infection status, further modulate treatment efficacy (7, 11-13).

To enhance pre-treatment risk stratification and individualization management, several predictive scoring systems have been proposed. The '*Triple-D*' score, which integrates stone Density (Hounsfield units), Diameter, and skin-to-stone Distance, and the extended '*Quadruple-D*' score – adding an additional factor such as stone Distribution (location) or hydronephrosis status – are widely utilized for outcome prediction (14, 15). However, their performance in cohorts treated with modern lithotripters like the Dornier Compact Delta® III Pro remains underexplored.

In response to this knowledge gap, the present study retrospectively evaluates ESWL treatment outcomes in a large cohort of 1,000 patients managed with the Dornier Compact Delta® III Pro lithotripter. This investigation aims to compare the predictive accuracy of the Triple-D and Quadruple-D scores against a novel regression-based model derived from comprehensive clinical and radiological data, with the objective of identifying key predictors of treatment failure and improving individualized patient prognostication.

Patients and methods

Study design

This retrospective cohort study was conducted at *Hazm Mebaireek General Hospital, Hamad Medical Corporation, Doha, Qatar*, spanning from May 2022 to November 2023. A total of 1,000 adult patients (aged 16 years or older) with renal collecting system or ureteric stones measuring no more than 25 mm in greatest dimension underwent extracorporeal shock wave lithotripsy. The study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki and received approval from the institution's Medical Research Center (approval ID: MRC-01-25-167). Given its retrospective design, the requirement for informed consent was waived by the ethics committee, with all patient information handled in accordance with strict confidentiality and data protection protocols.

Inclusion and exclusion criteria

Eligible subjects were adult patients aged 16 years or older presenting with ureteral and/or renal calculi with maximum diameters under 25 mm. Stone size was predominantly assessed using non-contrast *computed tomography* (CT) (16), regarded as the reference standard for stone characterization. In cases involving multiple stones, measurements were based on the largest stone.

The following exclusion criteria were applied:

- Active urinary tract infection (UTI) or urosepsis,
- Use of active anticoagulation therapy, including warfarin with international normalized ratio (INR) > 2.0 or direct oral anticoagulants,
- Pregnancy,
- Untreated bleeding diathesis,
- Poorly managed hypertension,
- Known aortic aneurysms,
- Bilateral ureteric stones,
- Presence of a solitary functioning kidney, and
- Renal impairment defined as *estimated glomerular filtration rate* (eGFR) below 60 mL/min/1.73 m^2.

Pre-treatment assessment

All patients underwent a standardized preprocedural evaluation comprising detailed medical history review, comprehensive physical examination, and laboratory testing including urinalysis, urine culture and sensitivity, complete blood count, coagulation profile, blood urea nitrogen, and serum creatinine. Imaging protocols incorporated abdominal plain radiographs, ultrasonography, and standardized non-contrast CT scans with a slice thickness of approximately 3 mm to accurately determine stone size, anatomical location, *skin-to-stone distance* (SSD), and stone density expressed in *Hounsfield Units* (HU). CT imaging was performed in all subjects barring contraindications.

ESWL procedure

Extracorporeal shock wave lithotripsy was carried out using the Dornier Compact Delta® III Pro lithotripter, with the maximum power setting of 15 kV. Patients were positioned supine, and sedation and analgesia were administered according to institutional protocols, typically employing intravenous midazolam and fentanyl. The initial energy level was set at 8 kV and incrementally increased in a stepwise manner, adapted to patient tolerance to optimize fragmentation efficiency. Kidney stones were localized and monitored using real-time ultrasonography, whereas fluoroscopy was utilized to guide treatment of ureteric calculi. Procedures were performed by experienced technologist to minimize inter-operator variability (7). Details including the average number and range of shock waves delivered per session are reported in the Results section.

Post-treatment follow-up and outcome assessment

Patients underwent radiologic evaluation at 2 weeks post-procedure utilizing plain abdominal radiographs to assess initial fragmentation. Repeat ESWL sessions were scheduled within 4 weeks in cases showing inadequate fragmentation, defined as absence of fragmentation or presence of residual fragments exceeding 4 mm. Treatment success was defined as complete radiographic clearance of stones on follow-up imaging (plain radiograph, ultrasound or CT scan as determined by the clinician) within a 3-month period. Persistence of stones or fragments larger than 4 mm beyond this period was classified as treatment failure. Additional clinical outcomes including pain episodes, hospital admissions, postoperative complications, and ancillary intervention requirements were also documented.

Data collection

Data were gathered through a structured, self-designed questionnaire, which was pilot tested to ensure clarity and reliability, combined with detailed patient interviews and rigorous review of medical records by trained independent reviewers. Variables collected included sociodemographic data (age, sex, *body mass index* [BMI]), comorbid conditions, prior radiological interventions, and anticoagulant use. Stone characteristics included size, location, SSD, density (HU), and presence of hydronephrosis. Treatment variables recorded encompassed number of shock waves delivered, energy settings, frequency, analgesia usage, patient pain tolerance, fluoroscopy time and radiation dose, treatment duration, and number of ESWL sessions. Treatment outcomes captured were stone clearance status, complications, postoperative emergencies, and the necessity for additional procedures. Data consistency and accuracy were confirmed through an inter-rater agreement of 98.2% between two independent reviewers, with any discrepancies adjudicated by a senior consultant urologist.

Evaluation of Predictive Models for Treatment Outcomes

To elucidate predictors of ESWL treatment failure and improve prognostic accuracy, the predictive capabilities of the established '*Triple-D*' and '*Quadruple-D*' scoring systems were compared to a bespoke regression-based model developed from this patient cohort. The '*Triple-D*' score consists of stone Density (HU), stone Diameter (mm), and skin-to-stone Distance (mm). The '*Quadruple-D*' score adds a fourth component (Distribution), in this study defined as stone location (lower renal calyx versus alternative sites), to enhance predictive utility (15). The regression model was constructed via multivariable logistic regression with backward elimination and underwent internal validation through k-fold cross-validation to ensure robustness.

Statistical analysis

All statistical analyses were conducted using IBM SPSS Statistics version 22 (*IBM Corp., Armonk, NY, USA*). Continuous variables demonstrating normal distribution are reported as means ± *standard deviation* (SD), while non-normally distributed data are summarized as medians with *interquartile ranges* (IQR). Categorical variables are presented as frequencies and percentages. Bivariable analyses employed chi-square or Fisher's exact tests for categorical data and independent t-tests or Mann-Whitney U tests for continuous variables, as applicable.

Variables with a p-value less than 0.20 in bivariable analyses or with established clinical relevance were included in multivariable logistic regression models to identify independent predictors of ESWL failure. Model calibration was evaluated using the Hosmer-Lemeshow goodness-of-fit test (p > 0.05 indicating acceptable fit), and model discrimination was assessed through the area under the receiver operating characteristic curve (AUC). Variables exhibiting multicollinearity (*variance inflation factor* [VIF] ≥ 5), sparse data (cell counts under 5), or excessive missingness (> 15%) were excluded from analyses. Missing data were handled using complete-case analysis due to minimal missingness (< 5%).

Comparisons of predictive performance among the '*Triple-D*', '*Quadruple-D*', and regression-based models were performed using ROC curve analyses, with differences between AUC values assessed via DeLong's test. Statistical significance was defined as a two-tailed p-value less than 0.05. *Decision Curve Analysis* (DCA) was conducted to evaluate the clinical utility of these scores by comparing the net benefits across different threshold probabilities (17). Importantly, all analyses conformed to the *Transparent Reporting of a multivariable prediction model for Individual Prognosis Or Diagnosis* (TRIPOD) guidelines to ensure transparent and reproducible reporting of predictive modelling methodologies and results (18).

RESULTS

Patient and stone characteristics

Table 1 presents the demographic and clinical characteristics of the 1,000 patients who underwent extracorporeal shock wave lithotripsy. The median age was 37.0 years (*interquartile range* [IQR]: 32.0-44.2), with a predominance of male patients (99.7%). Left-sided stones occurred more frequently (54.7%) than right-sided stones. The median *body mass index* (BMI) was 26.0 kg/m² (IQR: 24.0-29.0). Most patients (79.0%) had no comorbidities; diabetes mellitus and hypertension were present in 7.5% and 9.6% of patients, respectively. Prior urologic interventions were reported in 36.6%, and 10.8% had

Table 1.
Patient and stone characteristics according to ESWL outcome (n = 1000).

Characteristic	Total (n = 1000)	Stone Clearance Yes (n = 875)	Stone Clearance No (n = 125)	p-value
Age, median (IQR), years	37.0 (32.0-44.2)	37.0 (32.0-44.0)	38.0 (30.0-45.0)	0.951
Male, n (%)	997 (99.7)	870 (99.7)	127 (100)	1.000
Left-sided stones, n (%)	547 (54.7)	484 (55.4)	63 (49.6)	0.255
BMI, median (IQR), kg/m²	26.0 (24.0-29.0)	26.0 (24.0-29.0)	27.0 (24.0-30.0)	0.099
Prior urologic intervention, n (%)	366 (36.6)	303 (34.7)	63 (49.6)	0.002*
Multiple stones, n (%)	202 (20.2)	186 (21.3)	16 (12.6)	0.030*
Stone density, median (IQR), HU	1000.0 (760.0-1200.0)	980.0 (750.0-1200.0)	1100.0 (911.5-1250.0)	< 0.001*
Stone-to-skin distance, median (IQR), cm	9.0 (8.0-11.0)	9.0 (8.0-11.0)	10.0 (9.0-12.0)	< 0.001*
Stone location (kidney), n (%)	591 (59.1)	523 (59.7)	68 (54.4)	0.034
Comorbidities (e.g., diabetes, hypertension), n (%)	200 (20.0)	170 (19.4)	30 (24.0)	0.123
Triple-D score, median (IQR)	1020.0 (782.0-1224.0)	1000.0 (762.0-1213.0)	1123.0 (930.5-1267.0)	< 0.001*
Quadruple-D score, median (IQR)	1021.0 (783.0-1226.0)	1001.0 (763.0-1215.0)	1125.0 (932.5-1269.0)	< 0.001*

**BMI: body mass index; HU: Hounsfield units; IQR: interquartile range. Bold indicates statistical significance (p < 0.05).*

Table 2.
Multivariate logistic regression analysis of predictors of ESWL failure.

Predictor	β Coefficient	Standard error	p-value	Exp (β) [OR]	95% CI for Exp (β)
Prior urologic intervention	0.97	0.21	< 0.001*	2.64	1.75-3.99
Multiple stones	-0.80	0.27	0.003*	0.45	0.24-0.77
Stone density (per 100 HU)	0.07	0.01	< 0.001*	1.07	1.05-1.09
Stone-to-skin distance (per cm)	0.17	0.05	0.002*	1.18	1.06-1.30
Stone location (kidney vs ureter)	-0.12	0.20	0.547	0.89	0.58-1.37
Comorbidities	0.30	0.23	0.201	1.35	0.85-2.15
Triple-D score (per 10 points)	0.077	0.015	< 0.001*	1.08	1.05-1.11
Quadruple-D score (per 10 points)	0.086	0.016	< 0.001*	1.09	1.06-1.12

**Bold indicates statistical significance (p < 0.05).*

undergone previous double-J stenting. The median stone size was 9.0 mm (IQR: 7.0-10.0), median density was 1000.0 *Hounsfield units* (HU) (IQR: 760.0-1200.0), and hydronephrosis was present in 55.3% of cases. Stones were mostly renal (59.1%) or ureteral (40.7%), with a median stone-to-skin distance of 9.0 cm (IQR: 8.0-11.0).

ESWL procedure
The mean power applied was 6.6 ± 1.2 kV (range: 2.0-10.0), with an average of 3,314 shock waves administered per session over a mean duration of 44.0 ± 5.1 minutes. Ultrasound guidance was utilized in 50.3% of procedures and fluoroscopic guidance in 49.7%. The majority of patients (89.6%) tolerated the procedure well, with analgesia primarily consisting of midazolam/morphine (61.2%) or fentanyl (37.2%).

Treatment outcomes
Initial ESWL success was achieved in 80.5% of patients, increasing to 87.5% after repeat sessions (mean number of treatments 1.2). Success rates differed by stone location: 78.2% for renal stones (lower calyx: 76.0%, mid calyx: 80.6%, upper calyx: 81.3%, renal pelvis: 82.4%) and 83.1% for ureteral stones (proximal ureter: 82.0%, distal ureter: 83.7%). Treatment failure occurred in 12.5% (n = 125) and required additional procedures including semirigid ureteroscopy (5.4%), flexible ureteroscopy (0.7%), and percutaneous nephrolithotomy (0.4%). Postoperative complications were rare (4.6%), mainly renal colic (4.2%). A single case of bowel perforation (0.1%) underscored the importance of clinical vigilance.

Predictors of ESWL failure
Univariate analysis demonstrated significant associations of ESWL failure with prior urologic intervention (p = 0.002), fewer multiple stones (p = 0.030), higher stone density (p < 0.001), and longer stone-to-skin distance (p < 0.001). Stone location was not significantly associated with failure (p = 0.547). Multivariate logistic regression confirmed prior intervention (*adjusted odds ratio* [aOR] 2.64; 95% confidence interval [CI] 1.75-3.99; p < 0.001), fewer multiple stones (aOR 0.45; 95% CI 0.24-0.77; p = 0.003), increased stone density (per 100 HU increase; aOR 1.07, 95% CI 1.05-1.09; p < 0.001), and increased stone-to-skin distance (per cm; aOR 1.18; 95% CI 1.06-1.30; p = 0.002) as independent predictors (Table 2). Also, the Triple-D score was significantly associated with ESWL failure, with an adjusted odds ratio of 1.08 (95% CI: 1.05-1.11) per 10-point increase (p < 0.001). Similarly, the Quadruple-D score demonstrated a significant association, with an adjusted odds ratio of 1.09 (95% CI: 1.06-1.12) per 10-point increase (p < 0.001). These results indicate that higher Triple-D and Quadruple-D scores were strongly predictive of increased risk of ESWL failure.

Comparison of predictive models
Receiver operating characteristic (ROC) analyses (Figure 1) revealed the regression-based model had superior discriminative ability with an *area under the curve* (AUC) of 0.92 (95% CI 0.89-0.95), significantly outperforming the Quadruple-D score (AUC 0.81, 95% CI 0.77-0.85; p = 0.01 *vs* regression) and the Triple-D score (AUC 0.72, 95% CI 0.68-0.76; p < 0.001 vs regression) (Table 3).

Table 3.
Predictive model performance for ESWL treatment failure.

Model	AUC (95% CI)	Sensitivity % (95% CI)	Specificity % (95% CI)	Accuracy % (95% CI)	p-value vs Regression Model (DeLong's test)
Triple-D score	0.72 (0.68-0.76)	68.5 (63.1-73.3)	65.2 (59.7-70.4)	66.8 (63.2-70.2)	< 0.001
Quadruple-D score	0.81 (0.77-0.85)	75.4 (70.5-79.7)	74.1 (69.0-78.7)	74.8 (71.7-77.6)	0.01
Regression-based model	0.92 (0.89-0.95)	87.3 (83.4-90.5)	85.6 (81.2-89.1)	86.7 (84.1-89.0)	Reference

**AUC: Area Under the Receiver Operating Characteristic Curve; CI: Confidence Interval. Bold indicates statistical significance (p < 0.05).*

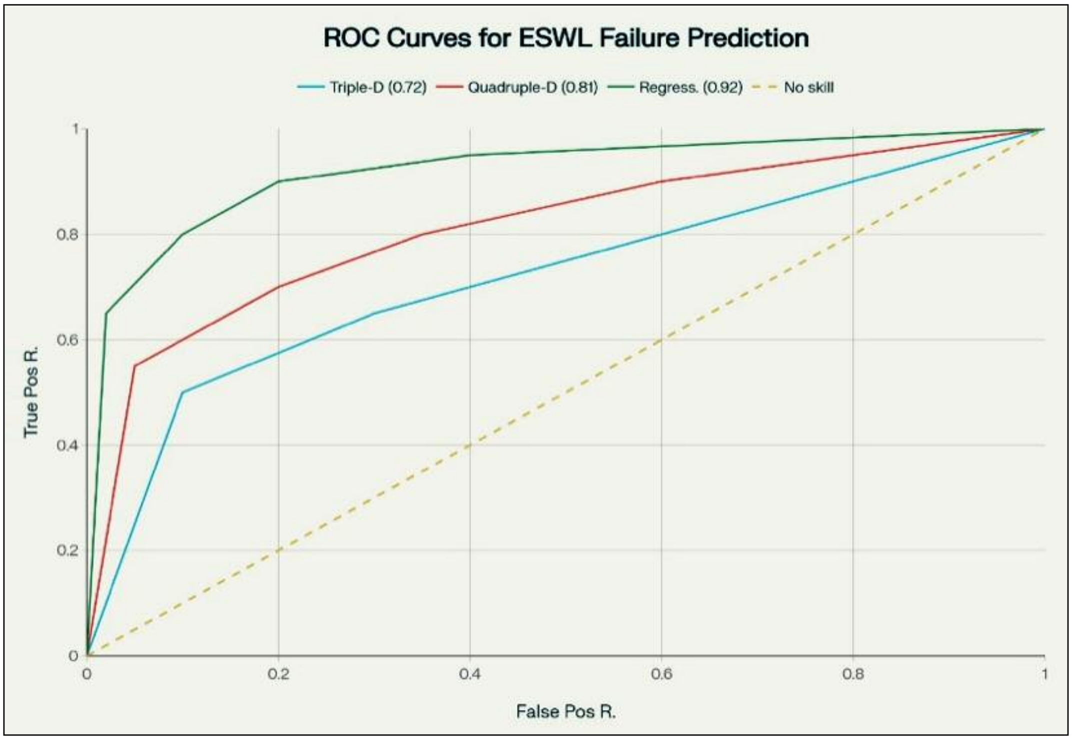

Figure 1.
Receiver Operating Characteristic (ROC) Curves Comparing Predictive Models for ESWL Treatment Failure.
ROC curves depict the discriminative ability of the regression-based model (blue line, AUC = 0.92, 95% CI 0.89–0.95), the Quadruple-D score (green line, AUC = 0.81, 95% CI 0.77–0.85), and the Triple-D score (orange line, AUC = 0.72, 95% CI 0.68–0.76).
The regression-based model significantly outperformed both scoring systems (p = 0.01 vs. Quadruple-D and p < 0.001 vs. Triple-D, DeLong test).

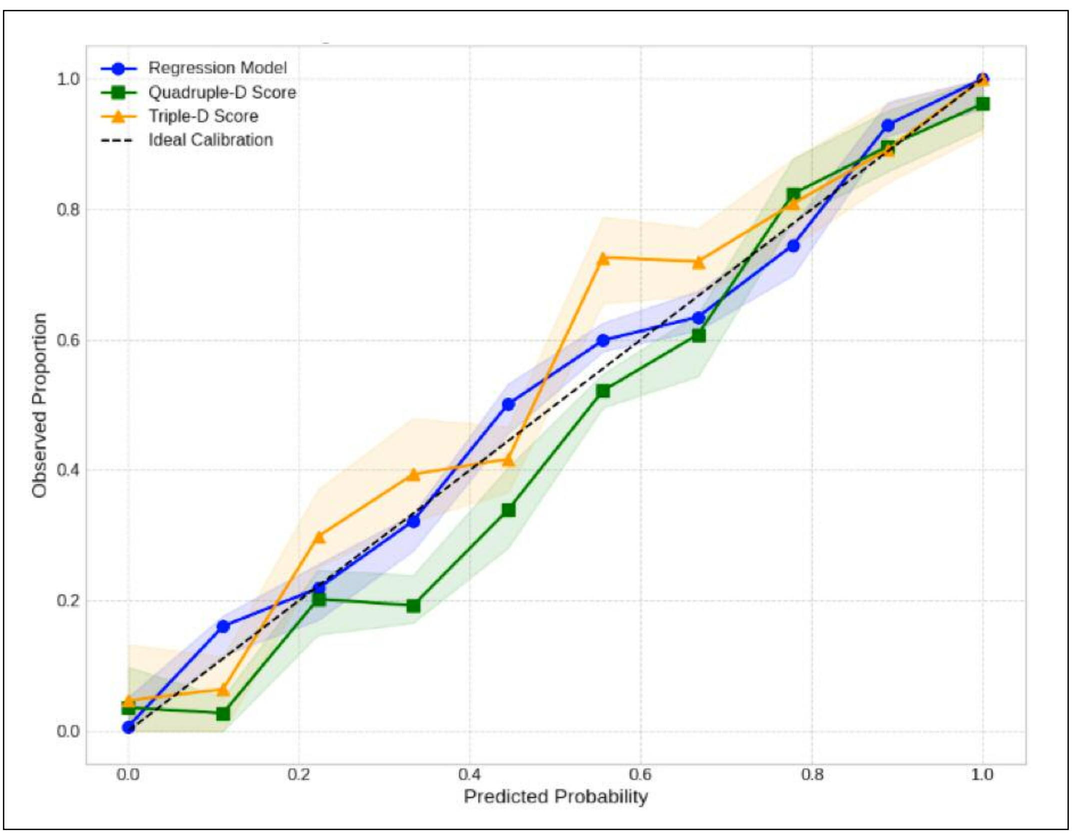

Figure 2.
Calibration Plots of Predicted Versus Observed ESWL Failure Probabilities for the Triple-D, Quadruple-D, and Regression-Based Models.
Calibration curves illustrate the agreement between predicted probabilities of treatment failure and actual observed outcomes for each model. The regression-based model demonstrated the closest alignment to ideal calibration (diagonal line), outperforming both the Triple-D and Quadruple-D scores, suggesting better predictive accuracy.

Calibration plots (Figure 2) demonstrated excellent agreement between predicted and observed failure probabilities for the regression model. Decision curve analysis (Figure 3) further showed the regression model provided superior net benefit across clinically relevant threshold probabilities compared to other models. Logistic regression curve (Figure 4) illustrated a clear positive relationship between the regression score and probability of ESWL failure.

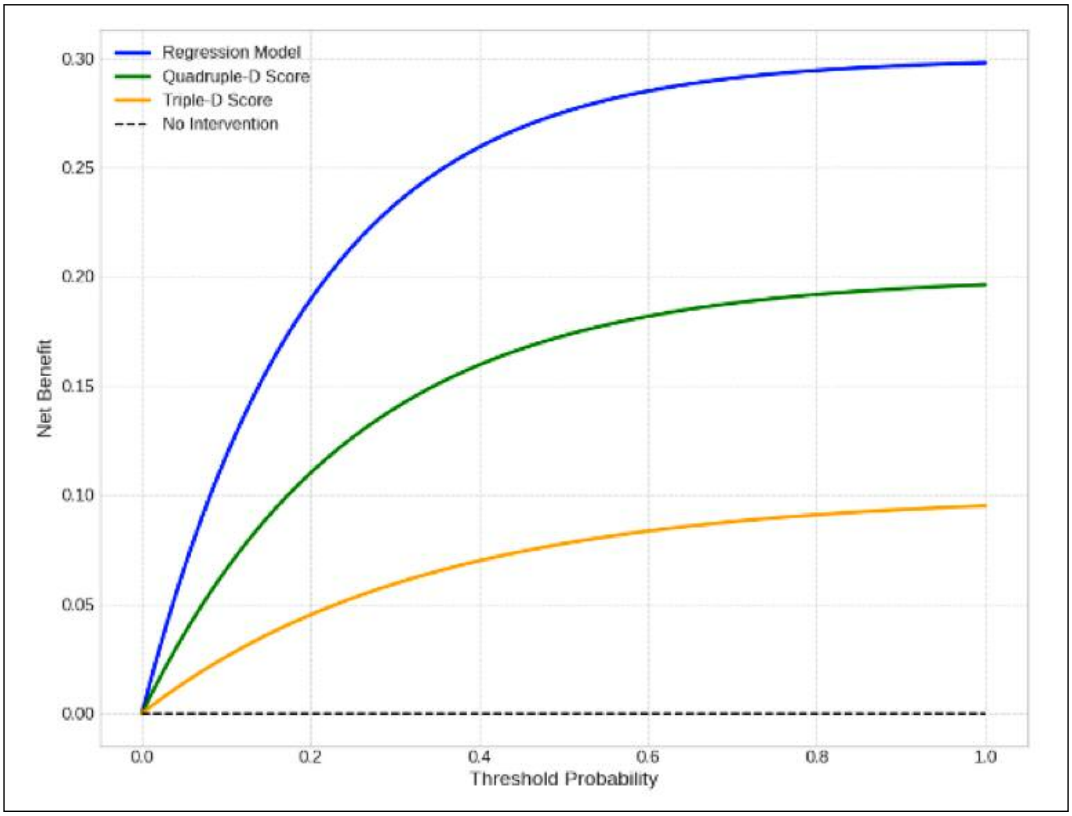

Figure 3.
Decision Curve Analysis (DCA) for the Regression-Based Model and Traditional Scoring Systems.
The DCA graph compares the net clinical benefit of the regression model (blue), Quadruple-D score (green), and Triple-D score (orange) across a range of clinically relevant threshold probabilities for ESWL failure.
The regression-based model provides greater net benefit over a broad range of thresholds, indicating superior clinical utility in guiding treatment decisions.

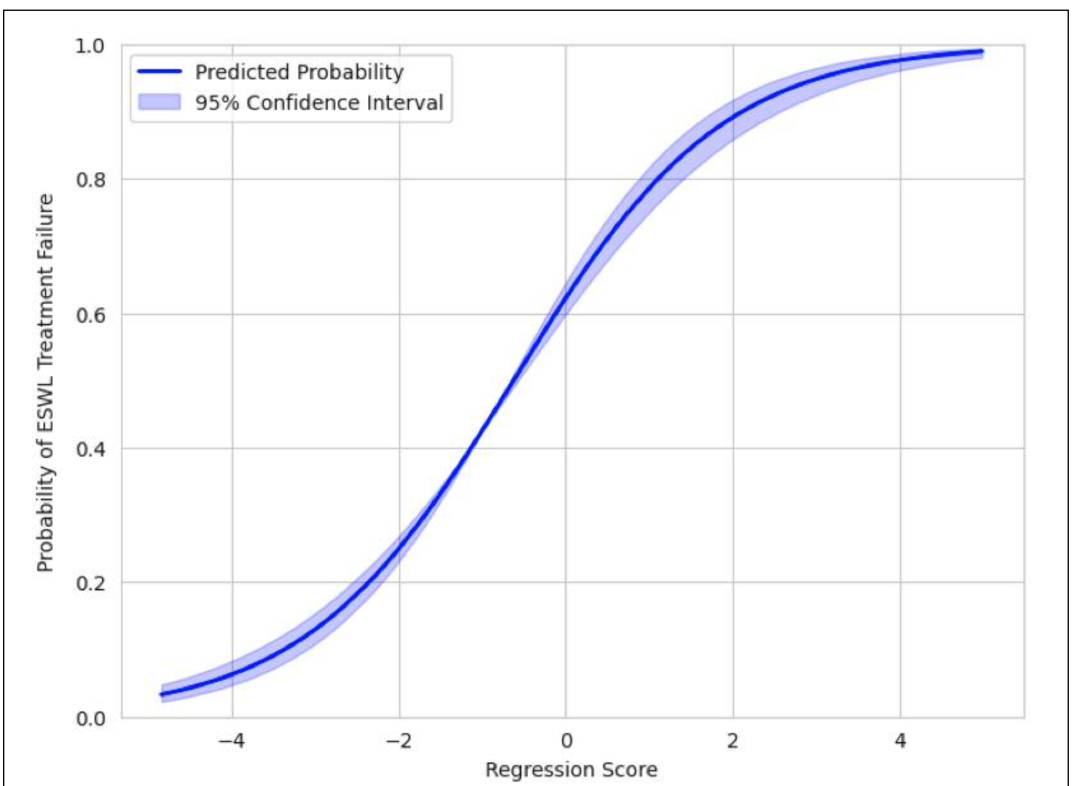

Figure 4.
Logistic Regression Curve Depicting the Relationship Between Regression Score and Probability of ESWL Treatment Failure.
A smooth logistic curve demonstrates the positive association between the calculated regression-based score and the predicted probability of ESWL failure. Shaded areas represent 95% confidence intervals, highlighting increasing failure risk with higher model scores.

Discussion

Extracorporeal shock wave lithotripsy remains a cornerstone in the management of renal and ureteric stones, favored for its non-invasive nature and favorable safety profile (19-21). However, treatment outcomes vary substantially across patients, highlighting the need for reliable predictive models to guide individualized treatment selection and optimize patient care.

In this study, the regression-based predictive model demonstrated superior discriminative ability (AUC = 0.92) compared to the established Triple-D (AUC = 0.72) and Quadruple-D scores (AUC = 0.81). This improved performance likely reflects the model's incorporation of a broader range of clinically relevant variables beyond the traditional scores, including prior urologic interventions, stone density measured in Hounsfield units, stone number, and skin-to-stone distance. This comprehensive multivariable approach enables a more nuanced risk stratification, facilitating better identification of patients at elevated risk of ESWL failure and supporting more tailored treatment decisions.

Consistent with the literature, higher stone density and greater skin-to-stone distance were strongly associated with lower ESWL success rates, reflecting the deleterious effects of stone hardness and energy attenuation on fragmentation efficacy (7, 22-24). Prior urologic interventions also independently predicted failure, possibly indicating more complex stone disease or altered anatomy (9). Interestingly, the presence of multiple stones was linked to reduced odds of failure, a finding reported in some prior studies, potentially relating to smaller individual stone sizes or more vigilant management in such cases. Further investigation is warranted to clarify this association.

While the Quadruple-D score offered improved predictive accuracy over Triple-D by adding factors such as stone location, it did not reach the accuracy of the regression model. This underscores the advantage of multivariable regression frameworks that better capture complex predictor interactions compared to additive scoring systems (25-27). The regression model also exhibited excellent calibration and demonstrated superior clinical net benefit over a range of decision thresholds, as evidenced by calibration plots and decision curve analysis. Moreover, the logistic regression curve linking model scores with predicted failure probabilities provides an intuitive tool for clinicians to communicate individualized risk estimates, enhancing shared decision-making.

Our findings are consistent with recent evidence from *Ipek et al.*, who reported that the *Mayo Adhesive Probability* (MAP) score, which incorporates perinephric fat characteristics, outperformed Triple-D and Quadruple-D scores in predicting stone-free status post-ESWL (AUC 0.82 vs. 0.72 and 0.64, respectively) (15). Similarly, *Coskun et al.* demonstrated modest discriminative ability of Triple-D and Quadruple-D scores (AUCs ~0.63-0.67), mirroring the limited accuracy we observed with these scores (14). Variability in patient populations, lithotripter technology, and outcome definitions may explain differences in absolute AUC values across studies, but the consistent pattern of enhanced prediction with multivariable or anatomically enriched models supports advancing beyond simple composite scores. Incorporating a wider array of clinical, anatomical, and procedural factors within predictive modeling frameworks holds promise for improving ESWL outcome prediction and fostering precision medicine approaches in urolithiasis management (7, 14, 15).

Clinical Utility of the Regression-Based Predictive Model

The regression-based predictive model for ESWL outcomes offers a robust tool for enhancing clinical decision-making through individualized risk assessment. By delivering more precise predictions of ESWL success or failure, the model enables clinicians to tailor treatment strategies favoring alternative interventions such as ureteroscopy or percutaneous nephrolithotomy in patients at high risk of failure, while confidently recommending ESWL for those predicted to have favorable outcomes (28, 29). Integration of this model into clinical workflows, potentially via electronic health records, can facilitate real-time risk estimation, supporting shared decision-making and improving patient counseling. Furthermore, the logistic regression curve linking model scores to failure probabilities provides an intuitive framework for communicating personalized risk to patients, thereby managing expectations and guiding treatment choices (20, 30). Overall, this model promises to optimize patient selection, reduce unnecessary procedures, and enhance outcomes; however, further validation in varied clinical contexts is warranted to confirm its generalizability and practical applicability.

Study limitations

Despite the strengths of this large retrospective cohort and comprehensive analysis, certain limitations merit acknowledgment. First, the retrospective study design inherently risks biases related to data completeness and patient selection. Although data accuracy and consistency were verified by independent reviewers, residual confounding from unmeasured variables cannot be excluded. Second, although the regression model displayed strong internal validity through cross-validation, external validation in diverse patient populations and clinical settings is essential to confirm its generalizability and robustness. Third, important factors such as patient pain

DECLARATIONS

Ethical approval and consent for participate: *The study adhered to the principles of the Helsinki Declaration and was approved by the Ethics Committee of Hazm Mebaireek General Hospital, Hamad Medical Corporation, Doha, Qatar (ID MRC-01-25-167).*

Availability of data and material: *Data supporting this study were submitted and published in Mendeley Data with the reference: Salah, Morshed; Ahmed, Faisal (2025), "Performance of 'Triple-D' and 'Quadruple-D' Scores Compared to a Regression-Based Predictive Model for Treatment Outcomes in Extracorporeal Shock Wave Lithotripsy: A 1000-Treatment Series Using the Dornier Compact Delta III Pro", Mendeley Data, V2, doi: 10.17632/3y5s2f3py6.2.*

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tolerance and operator technique, which may influence ESWL outcomes, were not quantitatively captured or incorporated into the predictive models. Additionally, heterogeneity in imaging modalities and acquisition protocols could affect measurement consistency for stone characteristics such as density and skin-to-stone distance. Finally, the study was conducted at a single center using a specific lithotripter model (*Dornier Compact Delta® III Pro*), which may limit extrapolation to other clinical environments or device types. Future prospective, multicenter studies are warranted to externally validate this model and assess its integration and impact within clinical workflows.

Conclusions

This study demonstrates that a regression-based predictive model incorporating multiple clinical and radiological variables significantly outperforms established Triple-D and Quadruple-D scoring systems in predicting failure of extracorporeal shock wave lithotripsy. The enhanced predictive accuracy, excellent calibration, and superior clinical net benefit suggest that this model may provide a valuable tool for individualized risk stratification in patients with renal and ureteric stones. Implementation of such a tool could facilitate informed patient counseling, optimize treatment selection, and ultimately improve clinical outcomes. External validation and prospective evaluation will be important next steps to confirm these findings and support widespread clinical adoption.

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