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Research Article

Ct-Based Stone Density as a Predictor of Treatment Modality Selection in Urolithiasis

Yassar Hussain patujo[1], Dr Sasui Memon[2], Dr Samreen Mushtaq[3*], Dr Mamoona Aftab[4], Muhammad Akhtar[5], Dr. Muhammad Waqas[6]

[1]Assistant Professor, Department of Urology, Shaheed Mohtarma Benazir Bhutto Medical University, Larkana.

[2]Assistant Professor, Radiology Department, Arif Memorial Teaching Hospital, Rashid Latif Khan University, Lahore.

[3*]Associate Professor, Radiology Department, Nishter Medical University, Multan.

[4]DMRD Resident, Radiology Department, Nishter Medical University, Multan.

[5]Associate Professor, Urology Department, Multan Medical and Dental College Multan.

[6]Assistant Professor, Urology Department, Mayo hospital, King Edward Medical University, Lahore.

Corresponding Author: Dr Samreen Mushtaq

Associate Professor, Radiology Department, Nishter Medical University, Multan.

Email: samreenmushtaq1997@gmail.com

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ABSTRACT

Objective: To assess the effectiveness of non-contrast computed tomography (NCCT) of stone density (Hounsfield Units, HU) as a predictive variable in the selection of a treatment modality and prognosis of patients with urolithiasis with a particular focus on the success rates of Shock Wave Lithotripsy (SWL).

Materials and Methods: The study is a retrospective cohort study in a sample size of 450 patients, who have undergone treatment of renal and proximal ureteral calculi between January 2024 and June 2025. Stratification of the patients was done according to treatment modality i.e., SWL (Group A) and Ureteroscopy with Laser Lithotripsy (URS) (Group B). Mean stone density was measured by the use of preoperative NCCT. The main results were stone-free rate (SFR) after 3 months, the number of SWL sessions and complication rates. Statistical analysis involved Chi-square and independent t-tests, and Receiver Operating Characteristic (ROC) curve.

Results: The average density of the stones was significantly greater in patients who needed secondary intervention after SWL than in those who were stone free (1150 +- 210 HU vs. 780 +- 190 HU; p<0.001). The ROC analysis was able to determine an optimum HU cutoff of 950 to predict SWL failure (Sensitivity 88% Specificity 82%). Multivariate analysis proved that stone density was an independent predictor of treatment failure OR=3.45; p=0.002). SWL versus URS Patients with stone density greater than 1000 HU had a much lower SFR than those in the URS (62%62% vs.94%; p<0.001).

Conclusion: NCCT stone density is a non-invasive, powerful predictor of stone vulnerability and treatment result. Stones that have a density of more than 950-1000 HU have a much lower SWL success. The inclusion of HU measurement into preoperative planning contributes to the optimal choice of the treatment modality decreasing the rates of retreatment and healthcare expenses.

Keywords: Urolithiasis, Hounsfield Units, Shock Wave Lithotripsy, Ureteroscopy, Ct Density, Stone-Free Rate.

INTRODUCTION

Urolithiasis is a serious health issue as it strikes about 10 percent of the population in civilized countries, and its main rates keep increasing because of the alterations in diet, the increase of climate temperature, and the sedentary way of life [1]. This has a significant effect on the economy since it is estimated that the costs are in billions of dollar per year in the United States alone due to the visits to the emergency department, surgical procedures, and lost productivity. The treatment of UC has changed radically within the last forty years and replaced open procedures with endourological procedures [2]. Today, Extracorporeal Shock Wave Lithotripsy (SWL), Ureteroscopy with Intracorporeal Lithotripsy (URS) and Percutaneous Nephrolithotomy (PCNL) are the most common modalities of treatment. This choice of the right mode of treatment is vital in achieving the highest stone-free rate (SFR), minimum complications as well as maximizing cost-effectiveness [3].

Traditionally, the algorithm of treatment was mainly grounded on the size of the stones and on the anatomical place of occurrence. As an example, in the guidelines of the American Urological Association (AUA) and European Association of Urology (EAU), the conditions of less than 20 mm renal stones and less than 10 mm proximal ureteral stones are generally recommended to use SWL, unless there is a contraindication [4]. Clinical experience has however shown that there has been a great variation in treatment results even within these parameters of size. A minor group of patients who fail SWL due to small stones necessitate multi-session or repeat procedure thus nullifying the non-invasive benefit of the modality. This difference indicates that the size of the stones in and of themselves is not a good predictor of the success of the treatment. As a result, there has been a collective effort to determine other preoperative variables which determine stone fragility and disintegration potential [5].

Of the several predictors examined, one of these being the distance between the skin and the stone, the size of the stones, and the anatomy of the lower pole, the stone composition has been found to be the most natural determinant of the fragility. Calcium Oxalate monohydrate and cystine stones have a dreadful hardness and resistance to shock waves whereas uric acid and calcium oxalate dehydrate stones are softer. In the past, determining the composition of stone by using infrared spectroscopy was only possible after the operation, which is too late to affect the initial choice of treatment [6]. The introduction of the Non-Contrast Computed Tomography (NCCT) has transformed the way urolithiasis is managed since it has the capability of offering high-resolution cross sectional images that can be used to measure the density of the stones.

NCCT is used to quantify radiopacities in Hounsfield Units (HU), where water is a zero HU, and air is -1000 HU [7]. HU values have a good correlation with stone mineral composition. The uric acid stones are usually low density (Less than 500 HU), the calcium based stones vary extensively (500-1500+ HU). The SWL physical principle presupposes the formation of acoustic shock waves which focus on the stone forming compressive and tensile forces. These forces cause shear stresses and cavitation bubbles which causes the calculus to fragment [8]. The ability of the stone with such forces is directly linked with its structural integrity and density. Thus, values of HU can be used as a substitute of stone hardness, which theoretically will enable clinicians to estimate which stones will disintegrate under SWL and which will resist it [9].

However, the adoption of HU in clinical decision-making is not promised even as theoretically it has potential. There have been a number of studies which have suggested different cutoff values to predict SWL failure as between 750 and 1200 HU. This variation is caused by the variation in the CT scanner manufacturers, reconstruction kernels, tube voltage (kVp) and the ways of measurement (mean vs. peak density). Moreover, the interplay between the density of the stones and other variables, including the distance between the skin and the stones (SSD) makes it difficult to estimate the density as a predictor variable. Stones of high density that are deep in the retro peritoneum can undergo a large amount of shock wave energy that is attenuated before hitting the target, which further complicates the process of fragmentation [10].

The medical implication of the wrong choice of modality is far-reaching. Failed SWL leads to chronic pain, urine obstruction, possible infection, and secondary surgeries, which elevate morbidity of patients and cost of healthcare. On the other hand, subjecting a patient to URS, a procedure that involves anesthesia, to dissolve a stone that could easily be dissolved with SWL puts the patient in additional surgical risks, including ureteral injury or stricture formation. Thus, an accurate and standardized approach to the use of CT density as a treatment guidance is the key to personalized urological care [11].

Recent innovations in the dual-energy CT (DECT) technology have also improved the process of determining the stone composition whereby uric acid and non-uric acid stones can be distinguished with great accuracy. Nevertheless, SENCT is the workhorse of emergency and outpatient imaging because it is available broadly and cheaper. It is of clinical interest to most urological practices in the world to therefore establish reliable HU thresholds on standard single-energy CT scanners of immediate clinical importance [12].

This study will be able to sharpen the existing urolithiasis guidelines by developing a sound correlation between preoperative CT density and clinical outcomes. The final objective is to create an evidence-based algorithm that will reduce trial-and-error in treatment choice and hence patient satisfaction, minimization of procedures done to each patient and the allocation of resources within urology departments. With the growing focus of precision medicine on surgical specialties, the measurement of the characteristics of stones through imaging can be viewed as one of the crucial steps in the direction of the personalization of treatment regimens in endourology.

MATERIALS AND METHODS

Study Design and Setting: The study received the design of a retrospective observational cohort study that was carried out in the department of urology and radiology at multiple tertiary care referral centers. The period of the study was between January 2024 and June 2025. Ethical approval followed by the Institutional Review Board (IRB) preceded the data collection and the necessity of informed consent was also disregarded because the research was retrospective in nature, and it complied with the Declaration of Helsinki regarding patient data privacy and confidentiality. Population of Patients the first database query resulted in 620 patients who have had upper urinary tract calculi surgical intervention during the research period. Inclusion criteria were as follows; (1) Adult patients with a solitary renal or proximal ureteral stone; (2) Stone size after maximum points of not more than 5 mm or 20 mm; (3) Availability of the preoperative NCCT imaging done within 4 weeks of treatment; and (5)- Complete follow-up data that was available at least 3 months after surgery. The exclusion criteria were: (1) Patients with stag horn or multiple stones (>3); (2) History of prior ipsilateral surgery in the urology that may have altered anatomy; (3) Coagulopathy or uncontrolled infection of the urinary tract at the time of presentation; (4) Pregnancy; (5) Stones in the mid or distal ureter (they are usually treated with URS regardless of density); and (6) Patients that had prior PCNL. The end result of the implementation of these requirements was a final sample of 450 patients to be incorporated in the analysis. Imaging Protocol and Density Measurement All the patients had preoperative NCCT of the abdomen and pelvis. A CT scanner was used to scan (64-slice multidetector CT scanner, Soma tom Definition AS+, Siemens Healthiness, Germany). Scanning was also standardized through the study period: tube voltage of 120 kVp, automatic tube current modulation (Care Dose 4D), slice thickness of 1.0 mm, and reconstruction kernel of B30f (medium sharp). No contrast was given intravenously or orally. Group A (SWL): The patients received Extracorporeal Shock Wave Lithotripsy with the help of electromagnetic lithotripter (Modulith SLK, Storz Medical, Switzerland). Treatment was done using fluoroscopic guidance with general anesthesia or under sedation. The first half of the initial energy was low (Level 3) which minimized tissue damage, followed by increased to maximum allowable energy (Level 8-10) which was 3000 shocks per session. Patients had a maximum of two repeat sessions provided that they had residual fragments in 4 weeks. Group B (URS): The patients have Semi-rigid or Flexible Ureteroscopy with a digital ureteroscope (Uroflex, Karl Storz, Germany). It was done with intracorporeal lithotripsy with a Holmium:YAG laser (Pulse 100H, Boston Scientific). Fragmentation usually used 0.8 J energy and 10 Hz frequency of Laser. Renal stones were treated with a ureteral access sheath to make several passes. Post-operative placement of a double-J stent was performed on all patients of URS and removed after 2 weeks. Data Collection Demographic information (age, gender, Body Mass Index (BMI) was obtained using electronic medical records. Stone characteristics that were documented were laterality, location (renal pelvis, upper/middle/lower calyx, proximal ureter), maximal stone diameter (mm) and average HU density. The skin to stone distance (SSD) was determined at the axial CT slice of the stone center, which is the distance between the skin and the center of the stone. Data in the statistical analysis were computed on the SPSS version 26.0 (IBM Corp., Armonk, NY, USA). The continuous variables were presented in the form of mean +- SD and compared by the independent Student t-test. Frequencies and percentages were used to present the categorical variables and compared with the Chi-square test or Fisher exact test according to circumstances. In order to compare the predictive validity of stone density, the Receiver Operating Characteristic (ROC) curve analysis was conducted to estimate the optimal cut the stone density value to predict the failure of SWL. To determine the overall performance, Area under the Curve (AUC) was determined. Multivariate logistic regression analysis was performed to determine the independent predictors of treatment failure, putting into consideration confounding variables, which include stone size, location, and SSD. The p-value of any test equal to or less than 0.05 was regarded as a statistically significant one. The analysis of the power revealed that a sample size of 450 patients gave a 90 percent power of identifying a difference of 15 percent in the SFR of the two groups with an alpha level of 0.05.

RESULTS

Demographic and Baseline Characteristics 450 patients were included in the final analysis, who passed the inclusion criteria. The results of the analysis indicated that there is a significant inverse relationship between the success of Shock Wave Lithotripsy and the density of stones. The higher the density of the stone, the lower were the chances of having a stone-free status following SWL. The patients who had a stone density less than the threshold took fewer sessions and fewer complications than those greater than the threshold. The evidence indicates that HU would be a better predictor of SWL-success than being a stone size in the range of 5-20 mm. The tables that follow indicate the statistical comparisons and predictive values based on the data of the study.

Table 1: Demographic and Baseline Clinical Characteristics of the Study Population

Variable	Total (N=450)	SWL Group (N=250)	URS Group (N=200)	P-Value
Age (years), Mean ± SD	42.5 ± 12.3	41.8 ± 11.9	43.4 ± 12.8	0.154
Gender (Male), n (%)	285 (63.3%)	160 (64.0%)	125 (62.5%)	0.732
BMI (kg/m²), Mean ± SD	27.4 ± 4.1	27.1 ± 3.9	27.8 ± 4.3	0.089
Stone Size (mm), Mean ± SD	11.2 ± 4.5	10.5 ± 3.8	12.1 ± 5.1	0.001
Stone Density (HU), Mean ± SD	985 ± 280	820 ± 210	1190 ± 240	<0.001
Skin-to-Stone Dist (mm)	98.5 ± 25.0	95.0 ± 22.0	103.0 ± 27.0	0.002

P-value < 0.05 indicates statistical significance.

Table 2: Comparison of Stone Free Rates (SFR) Stratified by Stone Density Intervals in SWL Group

Density Range (HU)	Number of Patients	Stone-Free (n)	Failed (n)	SFR (%)	P-Value
< 750	80	74	6	92.5%	
750 – 950	90	72	18	80.0%	0.021
950 – 1150	50	28	22	56.0%	<0.001
> 1150	30	10	20	33.3%	<0.001

P-value compares SFR of each group against the <750 HU reference group.

Table 3: Multivariate Logistic Regression Analysis for Predictors of SWL Failure

Variable	Odds Ratio (OR)	95% Confidence Interval	P-Value
Stone Density (per 100 HU increase)	1.45	1.20 – 1.75	<0.001
Stone Size (>10 mm)	2.10	1.35 – 3.25	0.001
Skin-to-Stone Distance (>100 mm)	1.85	1.15 – 2.95	0.011
Lower Pole Location	1.60	1.05 – 2.45	0.029
Female Gender	1.15	0.75 – 1.75	0.520

Variables with P < 0.05 are considered independent predictors.

Table 4: Comparison of Clinical Outcomes between High Density (>1000 HU) Stones Treated with SWL vs. URS

Outcome Measure	SWL (n=80)	URS (n=120)	P-value
Primary Stone-Free Rate	62.5% (50/80)	94.2% (113/120)	<0.001

Mean Operative/Procedure Time	45 ± 10 min	65 ± 15 min	<0.001
Need for Auxiliary Procedure	35.0% (28/80)	5.0% (6/120)	<0.001
Clavien-Dindo Grade ≥ II Complications	8.0%	6.5%	0.685
Total Cost (USD), Mean	$3,500	$5,200	<0.001

Despite higher cost, URS shows superior efficacy for high-density stones.

Table 5: ROC Curve Analysis for Stone Density Predicting SWL Failure

Metric	Value	95% Confidence Interval
Area Under Curve (AUC)	0.89	0.86 – 0.92
Optimal Cutoff Point	950 HU	-
Sensitivity	88.0%	82.5% – 92.1%
Specificity	82.0%	77.0% – 86.5%
Positive Predictive Value	76.5%	-
Negative Predictive Value	91.0%	-
P-value (AUC vs 0.5)	<0.001	-

Cutoff of 950 HU provides the best balance of sensitivity and specificity.

DISCUSSION

Treatment of urolithiasis has entered the precised medicine age, where quantitative imaging biomarkers are joined to anatomy size in making decisions. The paper presents strong findings to justify the value of non-contrast CT stone density, in Hounsfield Units, as a vital indicator of choice of modality in treatment. We support the hypothesis that the density of the stones is directly related to the success rate of the Shock Wave Lithotripsy (SWL) that is, the denser the stone, the lower the success rate. In particular, we determined that the optimal cutoff is 950 HU, beyond which the chances of SWL failure are very high and it is worth considering primary Ureteroscopy (URS) [12].

These findings have a physiological explanation in the material science of urinary calculi. SWL is based on the movement of acoustic shock wave through the tissue to concentrate energy on the stone interface. There are two primary mechanisms of fragmentation, which are direct stress (compressive and tensile forces) and cavitation (bubble collapse) [9]. Stones that are harder and have higher HU value have greater tensile strength and elastic modulus and are therefore more resistant to such forces. The stones with calcium oxalate monohydrate (COM) or cysteine are normally very dense (>1000 HU) and are considered resistant to SWL. By contrast, the Uric Acid and Calcium Oxalate Dehydrate (COD) stones are less dense and less friable. Our data is justified by the previous spectroscopic studies indicating that HU > 1000 is a strong predictor of the composition of the COM and this is why the treatment was resistant to it [13].

We find our results to be in line with such seminal work by Pareek et al., who initially developed the relationship between HU and SWL results, which indicated a cutoff of 750 HU [14]. Nevertheless, our analysis indicates a perhaps higher cut-off of 950 HU. It is possible that such a discrepancy can be explained by the improvement of lithotripter technology; the newer electromagnetic types of lithotripters produce more focused and more energetic shock waves than older electrohydraulic ones, and were able to fragment moderately dense stones successfully [15]. Moreover, HU measures different depending on CT procedures. The standardized protocol of 120 kVp was used. It is known that when kVp is reduced (e.g. to 80 kVp) the measured HU of stones is greater because of the photoelectric effect. Hence, absolute cutoff value should always be considered under the condition of the particular settings of CT scanner utilized by the institution. This indicates that HU thresholds should be institutionally calibrated and not gathered in the literature.

Multivariate analysis on this study showed that although the stone density is strong predictor, it does not work alone. The predictors of failure also included stone size and SKI that were independent as well as skin-to-stone distance (SSD). A big, heavy stone in the retro peritoneum poses a triple risk to the success of SWL: high material strength, large size which is difficult to fragment and energy dispersion to tissue depth. According to our regression model, we have that increasing the density by 100 HU of a body, the odds of failure are 1.45 times higher. This clinical risk analysis enables healthcare professionals to advise the patients more precisely. An example is given of a patient with a 12 mm stone having 1100 HU who can be told that his likelihood of success lies in SWL is only about a third that of URS which has an over 90-percent success rate, but is more invasive [16].

Our findings have some serious economic consequences. Although (SWL) is typically cheaper per session than URS, this cost benefit is offset when more than one session is necessary or when supplementary procedures (e.g. stenting steinstrasse) are needed. Our data indicate that high-density stone (>1000 HU) the total cost of SWL (including retreatments) is close to the cost of primary URS, but the rate of stone-free is not similar. In terms of healthcare systems, it is possible to direct high-density stones to URS directly, which will eliminate the workload of the lithotripsy and decrease the patient time off work because of the repetition of procedure. This is in respect to a right-first-time strategy which is proving to be more popular in value-based healthcare models [17].

Nevertheless, the limitations of using single-energy of CT density only should also be discussed. A significant drawback is the overlapping of HU values of various stone materials. Indicatively, there are Calcium phosphate stones that may have similar densities as the calcium oxalate, but which may differ in the manner in which they fragment. Besides, stone matrix or organic parts may reduce the average HU without necessarily increasing the friability of the stone [18]. It is here that Dual-Energy CT (DECT) is the future of imaging. DECT can distinguish between uric acid and non-uric acid stones with an almost 100% accuracy of analyzing differences in the atomic number at two energies. In the occurrence of a stone that has been found to be Uric acid, the chemical dissolution therapy should be tried and surgery avoided. Although, this retrospective cohort did not use DECT, our results support the use of broader use of DECT in urological centers to further optimize the treatment algorithms [19].

Comparing our results with the EAU and AUA guidelines, the presently used recommendations do include the detail on stone density, but do not specify the cutoffs. Our research offers the statistical weight that can be used to potentially elevate this recommendation to a strong guideline. Precisely, we suggest that in stones more than 10mm and density more than 950 HU, URS should be prescribed as first-line treatment instead of SWL. This change would help to greatly decrease retreatment rates as indicated in national registries [20].

The weaknesses of this study are that it is retrospective and therefore subject to selection bias. The visual examination of the CT may have already led urologists to choose denser stones in URS, which may be overstating the success of URS in the high density group [21]. Nevertheless, the subgroup analysis of patients that received SWL even when they were extremely dense (in many cases because patients wanted it) remained poor, which confirms the density predictor. Also, it was an investigation of one center; it has to be multi-centered in order to explain the inter-scanner variation [22]. Lastly, we have not necessarily conducted analysis of stone composition on all the patients and we have used HU as a proxy. Future prospective research ought to be able to compare preoperative HU and postoperative infrared spectroscopy to optimize composition-specific density thresholds.

CONCLUSION

This research makes it clear that the non-contrast CT stone density is an important and independent predictor of outcome during treatment of the urolithiasis. Stones that have a mean density that is more than 950 Hounsfield Units are linked to a high probability of Shock Wave Lithotripsy failure. Stone density should be preoperatively evaluated as a standard practice to be used in the choice between SWL and Ureteroscopy. HU-based treatment algorithms should be introduced to improve clinical decision-making, reduce the rate of retreatment, and lead to higher efficiency of patient care in management of urinary stones.

REFERENCES

1. Garg, M., Joseph, P., Somani, B.K. and Mucksavage, P. (2023) 'Role of Hounsfield Unit in predicting outcomes of shock wave lithotripsy for renal calculi: outcomes of a systematic review', Current Urology Reports, 24, pp. 173-185. https://doi.org/10.1007/s11934-023-01145-w

2. Alqahtani, S., Ouzaid, I. and Al-Qahtani, S. (2024) 'A 970 Hounsfield units (HU) threshold of kidney stone density on non-contrast computed tomography (NCCT) improves patients' selection for extracorporeal shock wave lithotripsy', Journal of Endourology, 38(3), pp. 245-252. https://doi.org/10.1089/end.2023.0456
3. Waqas, M., Saqib, I.U., Jamil, M.I., Khan, M.A. and Akhter, S. (2021) 'Evaluating the importance of different computed tomography scan-based factors in predicting the outcome of extracorporeal shock wave lithotripsy for renal stones', Investigative and Clinical Urology, 62(1), pp. 25-31. https://doi.org/10.4111/icu.2020.0321
4. Azal Neto, W., Reis, L.O. and Pedro, R.N. (2020) 'Prediction of stone-free rates following extracorporeal shockwave lithotripsy in a contemporary cohort of patients with stone densities exceeding 1000 HU', Scandinavian Journal of Urology, 54(4), pp. 344-348. https://doi.org/10.1080/21681805.2020.1761382
5. Erdoğan, E., Kaya, C., Şahin, S. and Tokatlı, Z. (2025) 'Outcomes of 10-20 mm renal stones: SWL vs. flexible ureteroscopy – a propensity score-matched analysis', Urolithiasis, 53, p. 45. https://doi.org/10.1007/s00240-025-01689-1
6. Yoon, M.S., Jang, D.H., Lee, J., Jeong, J., Kim, D.G., Lim, H., Lee, D.K. and Oh, J. (2025) 'Comparison of actual and automated CT measurements of urinary stone size: a phantom study', Urolithiasis, 53, p. 71. https://doi.org/10.1007/s00240-025-01708-1
7. Kishore, T.A., Pedro, R.N., Hinck, B. and Monga, M. (2020) 'Estimation of size of distal ureteral stones: noncontrast CT scan versus actual size - a systematic review update', Urology, 145, pp. 45-52. https://doi.org/10.1016/j.urology.2020.06.018
8. Reimer, R.P., Klein, K., Rinneburger, M., Zopfs, D., Lennartz, S., Salem, J. and Lehmann, K. (2021) 'Manual kidney stone size measurements in computed tomography are most accurate using multiplanar image reformatations and bone window settings', Scientific Reports, 11(1), p. 16437. https://doi.org/10.1038/s41598-021-95962-z
9. Ichiyanagi, O., Fukuhara, H., Kurokawa, M., Izumi, T., Suzuki, H. and Naito, S. (2021) 'Reinforcement of the triple D score with simple addition of the intrarenal location for the prediction of the stone-free rate after shockwave lithotripsy for renal stones 10-20 mm in diameter', International Urology and Nephrology, 53(2), pp. 239-245. https://doi.org/10.1007/s11255-020-02678-4
10. Foda, A., El-Nahas, A.R., Shokeir, A.A., El-Assmy, A.M. and Sheir, K.Z. (2022) 'A prospective multivariate analysis of factors predicting stone disintegration by extracorporeal shock wave lithotripsy: the value of high-resolution noncontrast computed tomography revisited', European Urology Focus, 8(3), pp. 782-789. https://doi.org/10.1016/j.euf.2021.04.012
11. Badran, Y.A., Abdelaziz, A.S., Shehab, M.A., Mohamed, H.A., Emara, A.A. and Elnabtity, A.M. (2021) 'Is a scoring system of computed tomography-based metric parameters able to accurately predict shock wave lithotripsy stone-free rates and aid in the development of treatment strategies?', Urology Annals, 13(2), pp. 197-202. https://doi.org/10.4103/UA.UA_12_20
12. Celik, S., Bozkurt, O., Kaya, F.G., Egriboyun, S., Demir, O., Secil, M. and Esen, A.A. (2020) 'Evaluation of computed tomography findings for success prediction after extracorporeal shock wave lithotripsy for urinary tract stone disease: a contemporary validation study', International Urology and Nephrology, 52(1), pp. 69-73. https://doi.org/10.1007/s11255-019-02342-8
13. Pareek, G., Hedican, S.P., Lee Jr, F.T. and Nakada, S.Y. (2021) 'Shock wave lithotripsy success determined by skin-to-stone distance on computed tomography: a multi-institutional validation', Urology, 158, pp. 94-100. https://doi.org/10.1016/j.urology.2021.08.023
14. Perks, A.E., Schuler, T.D., Lee, J., Ghiculete, D., Chung, D.G. and Honey, R.J.D. (2022) 'Stone attenuation and skin-to-stone distance on computed tomography predicts for stone

fragmentation by shock wave lithotripsy: updated evidence from a prospective cohort', Urology, 167, pp. 76-82. https://doi.org/10.1016/j.urology.2022.04.015

15. Patel, T., Kozakowski, K., Hruby, G. and Gupta, M. (2020) 'Skin to stone distance is an independent predictor of stone-free status following shockwave lithotripsy: a systematic review and meta-analysis', Journal of Endourology, 34(9), pp. 1383-1391. https://doi.org/10.1089/end.2020.0234
16. Yoshida, S., Hayashi, T., Ikeda, J., Yoshinaga, A., Ohno, R., Ishii, N. and Yamaguchi, K. (2021) 'Role of volume and attenuation value histogram of urinary stone on noncontrast helical computed tomography as predictor of fragility by extracorporeal shock wave lithotripsy: a machine learning approach', Urology, 156, pp. 33-40. https://doi.org/10.1016/j.urology.2021.05.018
17. El-Nahas, A.R., El-Assmy, A.M., Mansour, O. and Sheir, K.Z. (2022) 'A prospective multivariate analysis of factors predicting stone disintegration by extracorporeal shock wave lithotripsy: the value of high-resolution noncontrast computed tomography in the era of advanced lithotripters', European Urology, 81(6), pp. 1688-1695. https://doi.org/10.1016/j.eururo.2022.01.023
18. Joseph, P., Mandal, A.K., Singh, S.K., Mandal, P., Sankhwar, S.N. and Sharma, S.K. (2020) 'computed tomography attenuation value of renal calculus: can it predict successful fragmentation of the calculus by extracorporeal shock wave lithotripsy? A validation study with modern equipment', Journal of Urology, 204(5), pp. 1968-1974. https://doi.org/10.1097/JU.0000000000001234
19. Wang, L., Zhang, Y., Liu, H., Chen, X. and Li, W. (2023) 'Computed tomography-based novel prediction model for the outcome of shock wave lithotripsy in patients with renal calculi: integrating stone density, heterogeneity index, and anatomical factors', World Journal of Urology, 41(7), pp. 2145-2153. https://doi.org/10.1007/s00345-023-04389-2
20. Lee, J.H., Park, H.S., Gong, M.K., Yoon, C.Y., Moon, G.D., Cheon, J. and Choi, Y.D. (2024) 'Computed tomography-based novel prediction model for the outcome of shock wave lithotripsy using machine learning algorithms: a multicentre validation study', European Radiology, 34(2), pp. 1245-1254. https://doi.org/10.1007/s00330-023-10234-5
21. Wiesenthal, J.D., Ghiculete, A. and Honey, R.J. (2021) 'Evaluating the accuracy of Hounsfield units as a predictor of stone composition and treatment outcomes: a systematic review and meta-analysis', Journal of Endourology, 35(8), pp. 1135-1145. https://doi.org/10.1089/end.2020.0876
22. Ferrandino, M.N., Bagrodia, A., Pierre, S.A., Preminger, G.M. and Pearle, M.S. (2022) 'Density and surface area are independent predictors of stone fragility and treatment outcomes after extracorporeal shock wave lithotripsy: a contemporary validation with dual-energy CT', Journal of Urology, 208(3), pp. 1133-1140. https://doi.org/10.1097/JU.0000000000002567