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Prediction of Stone Composition by Non-Enhanced Computed Tomography in Urolithiasis Patients

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Abstract

Background and objectives: Understanding the composition of urolithiasis is crucial for effective stone management and prevention strategies. Our main objective was to determine stone composition through the analysis of Hounsfield Unit properties in pre-intervention tomography of non-contrast computed.

Methods: This prospective study was about urinary tract stones and involved fifty patients who visited Sulaimani Teaching Hospital between October 2021 to October 2022. Patients underwent imaging examination using Non-Enhanced Computed Tomography. The stones density was measured in the Hounsfield unites. The stones were physically analyzed for determining chemical compositions by Infrared Spectroscopy.

Results: In this research, the composition of the stone was determined using Hounsfield Units. The mean values for Calcium oxalate, Struvite, and Uric acid are 1001.85, 640.67, and 453.08, respectively. The outcomes demonstrated that there is a substantial difference among all urinary tract stone types with F statistics = 38.521, p value < 0.001 by using ANOVA. Furthermore, for validating achieved results, the Tukey honestly significant difference test was applied, and the test results indicate a significant disparity among various stone types, with a p value < 0.001.

Conclusions: The study provides evidence that non-contrast computed tomography is capable of accurately distinguishing between three common types of urolithiasis using Hounsfield Unit measurements.

Key words: Hounsfield Unit (HU), Infrared Spectroscopy, Non-Contrast Computed Tomography (NCCT), Stone Analysis, Urolithiasis

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Introduction

Urolithiasis, a common medical disease. There is evidence suggesting a substantial rise in the prevalence and incidence of kidney stones in recent years. About 10%–14% of the population have urolithiasis. The recurrence rates are estimated to be 50 % within five years. Renal stones cause morbidity, including urinary tract infections and increasing the risk of end-stage renal disease. urolithiasis disease imposes an enormous financial strain on individuals and healthcare systems. It's vital to accurately verify composition of the kidney stones. Understanding the stone's composition is crucial for identifying underlying causes, managing urolithiasis and preventing stone recurrence.[1-6] Two complementary analytical methods are commonly used for the detailed analysis of urinary tract stones: First, a microscopic study, second, compositional analysis via chemical titration or physical methods. Physical analytical approaches done by x-ray diffraction and Fourier-transform infrared spectroscopy (FTIR). Infrared spectroscopy involves measuring the absorption of infrared light by the stones. However, for analyzing the physical properties of stones in vitro, stones must be retrieved using endoscopic interventions such as ureteroscopy and percutaneous nephrolithotomy (PCNL) .[7,8] In recent years, non-contrast helical computed tomography (NCCT) has been a great standard for evaluating patients with urolithiasis. The American College of Radiology suggests that NCCT has a diagnostic specificity of approximately 98%. It provides information about characteristics of stone including size, location, stone density, and overall status of the kidney.[6,7] Computed tomography (CT) uses the Hounsfield unit (HU) as a quantitative measurement to evaluate the relative radiodensity of tissues. The observed attenuation coefficient of the X-ray beam is transformed linearly to produce HU. At a pressure and temperature of standard, the radiodensity values of distilled water, air, and bone are zero HU, -1000 HU, and 1000 HU, respectively. HU is used to determine the urinary stones composition. Predicting the chemical composition based on the HU is crucial for guiding treatment strategies. Such as, urinary alkalinization therapy may be used to treat uric acid stones and assessing the potential success of ESWL.[9-12] Our study aimed to assess the predictive capability of NCCT scan-based HU measurements for identifying stone composition, validated by in vitro infrared spectroscopy analysis of retrieved stones.

Patients and Methods

This work is prospective cross-sectional research; Fifty patients with urinary tract stones visited Sulaimani Teaching Hospital between October 2021 and October 2022. Our institutional ethics committee reviewed and approved the project. The individuals who met the inclusion criteria for our study were those who had only a single renal or ureteric stone and patients aged 19 years or older without restrictions based on stone size or body mass index (BMI). The most crucial factor was the availability of an NCCT scan. The radiological report by the radiologist provided valuable information about stone size, number, location, and stone density (measured in Hounsfield units) The exclusion criteria consisted of individuals who were unable to undergo NCCT due to specific circumstances, including the presence of stones in pregnancy and renal insufficiency. Additionally, we excluded individuals who declined to take part in the research. The stones were classified into two categories according to their chemical composition: pure stone and mixed stone. Pure stone is defined as a stone containing more than 80% minerals as one of its primary components. The entire stone sample was made up of just pure stone. We scanned the patients using an NCCT scanner according to our hospital

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urinary stone protocol (0.5 s rotation time, 1-2 mm collimation, 120 240 quality reference MAs, kV with a tin filter, sixty-four slides, and stone density recorded). Every pixel within this region of interest (ROI) representing the kidney stone was assessed to evaluate its Hounsfield attenuation level. We determined the highest HU value within each CT image slice by focusing on the ROI located at the center of the slice. These slices were chosen to intersect with the widest diameter of the kidney stone. Only, the high attenuation value of the stones was recorded, and statistical analyses were performed to assess potential correlations between the composition of the stone obtained through physical stone analysis and the HU value of the CT scan. The stones were collected from patients who underwent operations such as ureteroscopy or PCNL at the Sulaimani teaching hospital. All the retrieved stones were transferred to the Lal Pathlab Laboratory, Lal Pathlab is specialized in FTIR and is in New Delhi, India. FTIR analysis is a method studying material-radiation interaction. Initially, the stones were thoroughly washed with distilled water to eliminate any contaminants. Then grind the stone into a fine powder. Potassium bromide was added, to create a transparent pellet. Using a spectrometer with a range of 4000 to 400 cm^{-1}. Spectrometer employs infrared light radiation to create atomic vibrations, which results in energy absorption and the development of absorption bands at various wavelengths in the infrared spectroscopy. The instrument records the absorption of infrared light as a spectral pattern, and every mineral has a unique infrared absorption pattern. Then the obtained spectral pattern was compared to reference spectra to identify the specific mineral components of the stone. Prior to conducting this research, ethical clearance was obtained, and participants provided informed consent. Detailed information regarding the research purpose, usage of medical examination results, data confidentiality measures, and the right to withdraw was provided in a consent form signed by each participant. The consent form was approved by the Kurdistan Higher Council of Medical Specialties (KHCMS) before starting data collection. Microsoft excel and statistical analysis in IBM SPSS was used to organize and analyze the input data. We used the Anderson-Darling test for data normality and homogeneity, mean and standard deviation for continuous variables, Tukey HSD test and ANOVA for comparison of continuous data, chi-square tests for categorical variables, calculating the Area under the Curve (AUC), and constructing Receiver Operating Characteristic (ROC) curves.

Results

A total of fifty patients were included as participants in the study as presented in Table (1). The patients' mean age was 39 years, the mean BMI among the patients was calculated to be 28 kg/m². Forty-one individuals underwent PCNL and nine underwent ureteroscopy. Kidney stones have been identified in 82%. Most of these stones were located on the right side, and the diameters of the kidney stones ranged from 11 to 26 mm. Furthermore, 18% of the patients had ureteral stones. The ureter stones’ sizes ranged from 6 to 12 mm.

Table (1): Biographic Variation

Variables		Frequency n=50	Percentage (%)
Sex	Female	30	60
	Male	20	40
Age year (Range and Mean)		19-67, and 39	
Body Mass Index (BMI) (Mean ± SD)		23.85 (4.128)	
Location	Kidney	41	82
	Ureter	9	18
Side	Right	28	56
	Left	22	44
Stone size	Kidney	11-26 mm	
	Ureter	6-12 mm	

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For various type of stones, mean HU values were calculated and presented in the Table (2). The stones were arranged in increasing order of density order from the densest to the least dense, depending on their stone density as below: calcium phosphate, calcium oxalate monohydrate (COM), struvite, and uric acid. The mean HU was found to be 1416.50 for Carbonate apatite, which had the highest value; COM was 1001.85; struvite was 640.67; and uric acid was 453.08. The possibility that COM will be a major component of a stone increases with its HU density. As HU density decreases, the probability of urate and/or struvite being the key components increases.

Table (2): Mean and standard deviation of Hounsfield Unit

Types of Stone	N	Mean	Std. Deviation	Ninety-five percent Confidence Interval for Mean	
				Lower Bound	Upper Bound
Carbonate apatite	2	1416.5	51.619	952.72	1880.28
Calcium oxalate	26	1001.85	163.19	935.93	1067.76
Struvite	9	640.67	167.824	511.67	769.67
Uric acid	13	453.08	212.508	324.66	581.49

To compare the mean value of independent groups, a one-way ANOVA was utilized by calculating the F-statistic, which is the ratio of the Mean Square among groups to the Mean Square within groups. The F-statistic was calculated for the HU value on the NCCT, as illustrated in Table (3). Among the four types of kidney stones, a statistically substantial distinction was observed based on the HU measurement, indicated by a high F-statistic value of 38.521 and a low P value of $\leq$0.001.

Table (3): ANOVA Hounsfield

	Sum of Squares	DF	Mean Square	F statistic	p value
Within Groups	1435672.808	46	31210.278	38.521	0.001
Between Groups	3606772.812	3	1202257.604		
Total	5042445.62	49			

The test of Tukey's Honestly Significant Difference (HSD) is a substantial parameter used to identify the differences between the four types of kidney stones based on the mean HU values from CT scans. Table (4) shows the Tukey HSD measurements for the four types of stones. The Tukey HSD test showed that all four types of stones significantly differed from each other in their HU values, with a large effect size and a P value < 0.001, except for the comparison between struvite and uric acid, where the P value was 0.082.

Table (4): Multiple comparisons among mean Hounsfield of urolithiasis

Tukey's Honestly Significant Difference (HSD)				
Physical Analysis (I)	Physical analysis (J)	Mean Difference (I-J)	Std. Error	p value
Calcium Oxalate	Carbonate Apatite	-414.654*	129.636	0.013
	Struvite	361.179*	68.324	0
	Uric Acid	548.769*	60.01	0
Carbonate Apatite	Calcium Oxalate	414.654*	129.636	0.013
	Struvite	775.833*	138.105	0
	Uric Acid	963.423*	134.186	0
Struvite	Calcium Oxalate	-361.179*	68.324	0
	Carbonate Apatite	-775.833*	138.105	0
	Uric Acid	187.59	76.607	0.082
Uric Acid	Calcium Oxalate	-548.769*	60.01	0
	Carbonate Apatite	-963.423*	134.186	0
	Struvite	-187.59	76.607	0.082

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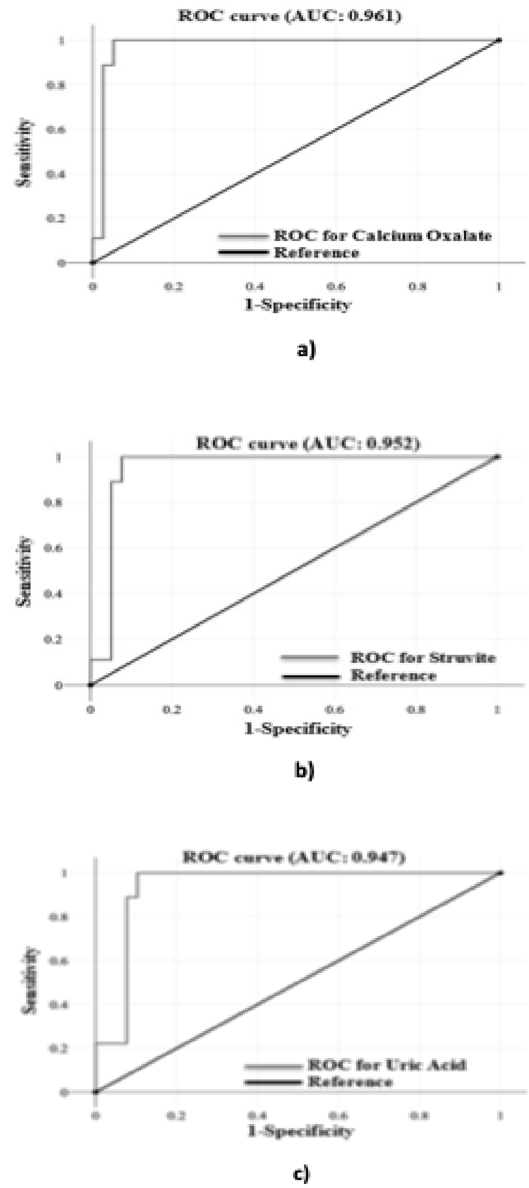
The measurements obtained from both HU on CT scans and physical stone analysis for several types of stones showed consistent finding. The diagnostic accuracy rate reached a high level of 93.7%. The correct identification was twenty-five out of twenty-six for calcium oxalate monohydrate stones, eight out of nine for struvite stones and eleven out of thirteen for uric acid stones, as display on the Table (5). There was a high level of agreement was observed between the HU measured on NCCT scans and the results of physical stone analysis.

Table (5): Hounsfield in NCCT and physical analysis tests

Stones	HU in NCCT	Physical analysis Agreement	
		Yes	No
Calcium oxalate	26	25	1
Struvite	9	8	1
Uric acid	13	11	2
Total	48	45	3
Diagnosis accuracy	93.70%		

The ROC curve depicted in Figure (1) presents the specificity and sensitivity HU values for every type of urinary tract stone were as follows: 92% and 95% for COM stones, 88% and 95% for struvite stones and 84.6% and 97.1% for uric acid stones, respectively. AUC values were calculated for the COM 0.961, Struvite 0.953, and Uric acid 0.947. It is obvious that the sensitivity is high. In addition, the value of AUC is close to one, which indicates excellent discrimination between the different types of renal stones.



Calcium Oxalate: 92.5 Sensitivity, 95.2 Specificity
Struvite: 88.9 Sensitivity, 97.4 Specificity
Uric Acid: 84.6 Sensitivity, 97.1 Specificity

Figure (1): Sensitivity, specificity, and ROC curve for a) Calcium Oxalate, b) Struvite, and c) Uric acid

Discussion

Precise preoperative prediction of composition and stone density is critical as it directly influences treatment options and preventive measures. The results we achieved are compatible with those reported by

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previous researchers such as Shawky et al, Bellin et al and Motley et al.[13,14] suggesting that CT scans appropriately predict the chemical constituents of urolithiasis in vivo context. This conclusion was reached through a comprehensive analysis, where the mean and standard variation of the HU of the stone were identified as the best CT parameters for successfully distinguishing between the three most prevalent renal stones types: struvite, calcium oxalate, and uric acid. The mean HU value on CT scans for carbonate apatite was 1416 HU, calcium oxalate stone were 1001.8 HU, struvite was 640 HU, and uric acid was 453 HU. However, when compared to the previous research, the mean Hounsfield value differed marginally and was not significant. This small discrepancy in CT scan HU values among various research reports was explained by Levi et al., who revealed substantial discrepancies in their values acquired by scanning the exact phantom with varied equipment. This variation was seen in scanners made by different businesses as well as among several scanners with an identical model and brand.[15-17] A statistically significant correlation was observed between HU value on the CT scans and physical stone examination utilizing infrared spectroscopy, indicating a reasonable level of agreement between the two procedures. Taking into consideration the standard deviation and mean variance of each stone, the likelihood of misdiagnosis was found to be extremely minimal. In fact, a high accuracy rate of 93.7% was achieved in diagnosing the stones, including eleven out of thirteen uric acid stones, eight out of nine struvite stones, 25 out of 26 COM stones, and both brushite stones, which were all correctly classified. Mussmann et al and Chaytor et al, who also discovered substantial concordance between infrared spectroscopy and CT scans for determining the types of kidney stones.[9,17] The sensitivity and specificity of three different types of urinary stones were determined as follows: For calcium oxalate stones, the sensitivity was 92%, and the specificity was 95%. Struvite stones showed a specificity of 95% and a sensitivity of 88%. Lastly, uric acid stones exhibited a sensitivity of 84.6% and a specificity of 97%. These values were obtained at a single energy level of 120 kV in the region of interest. When these findings were compared to those of Sheikhi et al, Bellin et al, and Naeem et al, we noticed that our research achieved identical results with just minor differences in sensitivity and specificity. These variations, however, were not statistically significant, suggesting that our findings are consistent with previous research.[2,16,18] We successfully distinguished uric acid stones from all other urolithiasis. This outcome is also consistent with Ahmed et al who found the HU parameter to accurately differentiate between uric acid stones and calcium oxalate stones.[10] For each of the three urinary stones (calcium oxalate, uric acid, and struvite), we computed the AUC. The AUC is a valuable metric that assesses the overall performance of a diagnostic test. An AUC value greater than 0.97 signifies a substantial level of distinction between the true positive and false positive rates, indicating that the CT scan was a dependable and efficient diagnostic tool. At the point When we compared our outcomes with those by Sheikhi et al and Padma et al. We observed that the AUC generated identical outcomes, which were close to one. The high AUC value suggests that the CT scan is well-suited for accurately identifying and distinguishing between the three commonly occurring urinary stones: calcium oxalate, struvite, and uric acid.[2,19] Our study has certain limitations that need to be considered. After lithotripsy some segments of the stone may be missing, potentially impacting the accuracy of stone analysis. This aspect requires thoughtful examination and further research is necessary to examine the relationship between HU of stone density and stone clearance following percutaneous nephrolithotomy.

Conclusion

Non-contrast computed tomography scans are helpful in providing accurate and detailed information about the type of stones. The results of the study demonstrate that HU values obtained from NCCT scans efficiently discriminate between various stone types. Furthermore, HU values have revealed high sensitivity and specificity in identifying the compositions of urinary tract stones.

Conflict of Interest

The authors declare no conflict of interest.

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