ORIGINAL ARTICLE

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Preoperative Prediction of Stone Composition Using Hounsfield Units in Non-Contrast CT Imaging: A Single-Center Study from Turkey

Kontrastsız BT Görüntülemede Hounsfield Üniteleri Kullanılarak Taş Kompozisyonunun Preoperatif Tahmini: Türkiye'den Tek Merkezli Bir Çalışma

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ABSTRACT

Aim: Numerous studies have shown that urinary stone composition is directly associated with the effectiveness of extracorporeal shock wave lithotripsy and is significantly related to various factors, including stone-free rates and fragmentation time during endoscopic procedures. Therefore, this study aimed to predict stone composition using Hounsfield unit (HU) measurements obtained from non-contrast computed tomography (NCCT).

Materials and Methods: Urinary stones were classified according to their predominant composition. HU measurements were compared with spectrophotometric analysis results to assess the accuracy of predicting stone composition. Additionally, patient demographic data, clinical characteristics, and stone-related parameters—including HU values, HU density, stone size, volume, and composition were recorded and analyzed.

Results: A total of 571 patients' stone analysis data were retrospectively analyzed: mean core HU, peripheral HU, and average HU values. The calcium oxalate group had significantly higher values than those in the cystine, uric acid, and calcium oxalate + uric acid groups (all $p<0.001$). Furthermore, a statistically significant correlation was found between stone size and core HU values ($r=0.291$, $p<0.001$).

Conclusion: NCCT may aid in selecting the most appropriate treatment by identifying stone composition. HU measurements (core, peripheral, and density) can be utilized to differentiate calcium-based stones from cystine- and uric acid-based stones.

Keywords: Computed tomography, Hounsfield unit, stone, stone composition, stone type

ÖZ

Amaç: Üriner sistem taşlarının bileşiminin, ekstrakorporeal şok dalgası litotripsi etkinliği ile doğrudan ilişkili olduğu ve endoskopik prosedürlerde taşsızlık oranları ve taş fragmantasyon süresi gibi çeşitli faktörlerle önemli derecede ilişkili olduğu birçok çalışmada gösterilmiştir. Bu çalışmada kontrastsız bilgisayarlı tomografi (NCCT) ile elde edilen Hounsfield ünitesi (HU) ölçümlerinin taş bileşimini tahmin etmedeki rolünün araştırılması amaçlanmıştır.

Gereç ve Yöntem: Taşlar baskın kompozisyonlarına göre sınıflandırıldı. HU ölçümleri, taş bileşimini tahmin etmedeki doğruluğu değerlendirmek için spektrofotometrik analiz sonuçları ile karşılaştırıldı. Ayrıca, hasta demografik verileri, klinik özellikler ve taş ile ilişkili parametreler (HU değerleri, HU yoğunluğu, taş boyutu, hacmi ve kompozisyonu) kaydedilerek analiz edildi.

Bulgular: Toplam 571 hastanın taş analiz verileri retrospektif olarak incelendi. Kalsiyum oksalat grubunda ortalama kor HU, periferik HU ve ortalama HU değerleri; sistin, ürik asit ve kalsiyum oksalat + ürik asit gruplarına kıyasla anlamlı derecede daha yüksek bulundu (tüm $p<0{,}001$). Ayrıca, taş boyutu ile kor HU değerleri arasında istatistiksel olarak anlamlı bir korelasyon saptandı ($r=0{,}291$, $p<0{,}001$).

Sonuç: NCCT, taş kompozisyonunu belirleyerek en uygun tedavi seçiminin yapılmasına yardımcı olabilir. HU ölçümleri (kor, periferik ve yoğunluk) kullanılarak kalsiyum bazlı taşlar, sistin ve ürik asit bazlı taşlardan ayırt edilebilir.

Anahtar Kelimeler: Bilgisayarlı tomografi, Hounsfield ünitesi, taş, taş kompozisyonu, taş tipi

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INTRODUCTION

Urinary stone disease has seen significant advancements in diagnosis and management with the widespread use of non-contrast computed tomography (NCCT). NCCT enables the measurement of the stone's radiodensity through Hounsfield units (HU), which indirectly provides information about the stone composition. Preoperative prediction of stone composition is crucial, as it helps determine the most appropriate treatment approach, especially in predicting the success rates of extracorporeal shock wave lithotripsy (ESWL) and endoscopic procedures. Computed tomography (CT) additionally facilitates visualization of the stone within the surrounding tissues and allows HU measurements. Therefore, NCCT has replaced other conventional methods, including urinary system ultrasonography, plain radiography, and intravenous pyelography, due to these advantages[1,2].

The literature indicates that the composition of urinary stones is directly correlated with the efficacy of ESWL and is also significantly associated with several factors, including stone-free rates and the duration of stone fragmentation during endoscopic procedures[3]. Several studies in the literature demonstrate a clear correlation between urinary stone composition and HU values[4-6]. Furthermore, HU is recognized as a crucial marker for predicting stone composition. This study aims to investigate the relationship between HU values obtained from NCCT and urinary stone composition in a Turkish patient population. Specifically, it seeks to evaluate whether HU values can distinguish different stone types, establish possible cut-off points to enhance preoperative prediction of stone composition, and assess the applicability of these findings to the Turkish population.

MATERIALS AND METHODS

The retrospective study received approval from the Tekirdağ Namık Kemal University Non-Interventional Clinical Research Ethical Committee (protocol number: 2023.73.04.09, date: 25.04.2023) and was carried out in accordance with the Declaration of Helsinki. Data were collected from patients who underwent surgical interventions for urolithiasis, including ureteroscopy, retrograde intrarenal surgery, percutaneous nephrolithotomy, and laparoscopic or open stone surgery, at our clinic, between August 2016 and January 2024. Patients who underwent surgical stone removal, had complete preoperative imaging with NCCT, and provided stone samples for infrared spectrophotometric analysis were included in the study.

The patient group was examined using a sixteen-channel, multi-slice BrightSpeed Series CT scanner (GE Healthcare, Milwaukee, WI, USA). The NCCT scans were obtained with a 16 × 1.25 mm collimation, an average slice width of 5 mm, and an instrument rotation speed of 27.50 rotations per 0.80 seconds (pitch 1.375), utilizing 120 kVp and 250 effective mAs. The field of view was calibrated to each individual's dimensions, extending from the upper abdomen to the pubis, and no intravenous contrast agent was used. The NCCT images were transmitted digitally to a computer (Sectra PACS Linköping, Sweden). The HU values of stones were measured at both the core and the periphery using region of interest techniques, with measurements performed at 25× magnification for enhanced accuracy (Figure 1). Two experienced endourologists (Ç.D. and M.F.Ş.) performed HU measurements with a specific focus on stone disease. The results demonstrated high agreement, with a correlation coefficient of 0.89. Stone size and volume were calculated according to the Sorokin formula (volume = π × length × width × height × 0.167)[7]. After obtaining HU values, the stone composition was analyzed for correlation with these radiodensity measurements.

Stone samples collected during surgical procedures were analyzed spectrophotometrically in the institutional laboratory. The stones were categorized by dominant composition as calcium oxalate (CaOx) (monohydrate or

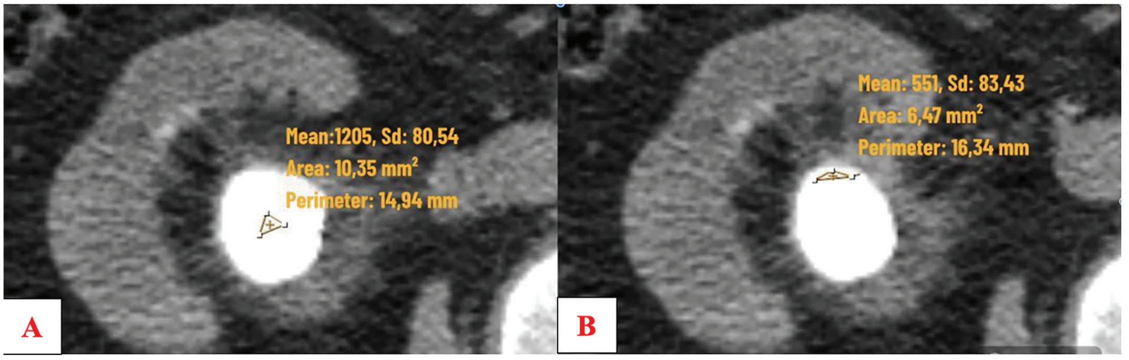

Figure 1. Demonstration of measuring HU value A) From the core and B) Periphery of the stone

HU: Hounsfield unit, SD: Standard deviation dihydrate), calcium phosphate, uric acid (UA), struvite, cystine, or mixed. HU measurements were subsequently compared with spectrophotometric results to evaluate predictive accuracy. Patient demographics, clinical characteristics, and stone parameters [(HU values, HU density (HUD) size, volume, and composition)] were recorded.

Statistical Procedure

Statistical analyses were performed using SPSS 23.0 for Macintosh (IBM, New York, U.S.A.). Numerical data were presented as means and standard deviations, whereas categorical data were reported as counts and percentages. Chi-square and Mann-Whitney U tests were employed to compare patient groups. The Spearman correlation test was used for non-parametric data.

RESULTS

A total of 571 patients' stone analysis data were retrospectively included in the study. The average age of the patients was 50±13.9 years (range, 13 to 85 years), and the mean stone volume was 1662.85 mm^3. A total of 388 patients had a single stone, while 183 patients had multiple stones. Based on stone analysis, the urinary stones were classified into seven groups[8]. There was no significant difference between the groups in terms of gender distribution. The demographic data and stone-related properties are presented in Tables 1 and 2. The average values of core HU, peripheral HU, and average HU in the CaOx group were significantly elevated compared to those in the cystine, UA, and CaOx + uric acid (UA) groups (p<**0.001**, p<**0.001**, and p<**0.001**, respectively). However, there was no statistical difference among the CaOx and carbonate apatite, brushite, or carbonate apatite + CaOx + struvite groups in terms of peripheral, mean, and core HU values (p>0.05). In addition, HUD values were consistent with the results of peripheral HU, mean HU, and core HU measurements. A statistically significant relationship existed between stone size and core HU values (r=+0.291, p<**0.001**); however, no correlation was observed between HUD and stone volume (p>0.05). The classification of stone types and their HU values is detailed in Table 3. We were unable to identify a statistically significant HU-related cut-off value to predict stone type in our ROC analyses.

DISCUSSION

Urinary system stones may consist of a pure single component or multiple components. The most observed subtype is the CaOx group, which is resistant to ESWL. Similarly, cystine stones,

Table 1. Demographic properties of patients grouped by stone compositions

	Ca oxalate (n=379)	Uric acid (n=45)	Carbonate apatite (n=38)	Cystine (n=7)	Ca oxalate + Struvite + Carbonate apatite (n=70)	Ca oxalate + Uric acid (n=26)	Brushite (n=6)	p-value
Age (mean ± SD) W	49.3±14.6	57.6±15.2	47.7±15.5	26.7±11.3	50.5±15.0	57.7±15.8	45.8±16.3	**0.0011**
BMI (kg/m^2)$^{\Omega}$	27.4±3.9	29.4±3.7	25.2±5.8	23.1±2.2	27.4±3.7	28.6±3.8	23.5±4.4	**0.0042**
Positive preoperative urine culture$^{\Omega}$ (%)	9 (2.4%)	0 (2.2%)	3 (7.9%)	0 (0%)	6 (8.6%)	2 (7.7%)	1 (16.7%)	**0.0013**
Male$^{\Psi}$	247 (65.2%)	26 (57.8%)	12 (31.6%)	4 (57.1%)	38 (54.3%)	14 (53.8%)	3 (50%)	**0.235**
Female	132 (34.8%)	19 (42.2%)	26 (68.4%)	3 (42.9%)	32 (45.7%)	12 (46.2%)	3 (50%)	

$^{\Psi}$: The Chi-square test, $^{\Omega}$: The Mann-Whitney U test, SD: Standard deviation, BMI: Body mass index

Table 2. Stone related properties

	Ca oxalate (n=379)	Uric acid (n=45)	Carbonate apatite (n=38)	Cystine (n=7)	Ca oxalate + Struvite + Carbonate apatite (n=70)	Ca oxalate + Uric acid (n=26)	Brushite (n=6)	p-value
Stone volume$^{\Omega}$ mm^3	1324.8±315.7	3715.4±521.4	1320.7±979.8	4689.7±746.3	933.7±480.5	4300.3±898.8	3336.5±498.3	**0.0274**
Stone side$^{\Psi}$ right left bilateral	 146 (38.5%) 186 (49.1%) 47 (12.4%)	 20 (44.4%) 23 (51.1%) 2 (4.5%)	 19 (50%) 16 (42.1%) 3 (7.9%)	 3 (42.8%) 2 (28.6%) 2 (28.6%)	 32 (45.7%) 30 (42.9%) 8 (11.4%)	 15 (57.7%) 9 (34.6%) 2 (7.7%)	 3 (50%) 3 (50%) 0	**0.0016**

$^{\Psi}$: The Chi-square, $^{\Omega}$: The Mann-Whitney U test was used

Table 3. The presentation of measured HU and HU density based on stone compositions

HU variable	Ca oxalate (n=379)	Uric acid (n=45)	Carbonate apatite (n=38)	Cystine (n=7)	Ca oxalate + Struvite + Carbonate apatite (n=70)	Ca oxalate + Uric acid (n=26)	Brushite (n=6)	p-value
Core HU$^{\Omega}$	1073.9±342.3	789.6±318.8	1047.4±335.2	901.3±338.0	1090.3±371.7	846.5±213.3	1103.1±311.2	**0.001**
Periphery HUW	852.4±219.1	615.3±183.1	758.9±218.9	735.3±282.0	978.7±165.5	698.4±193.6	892.7±254.4	**0.001**
Mean HU$^{\Omega}$	1006.8±308.6	722.9±279.5	996.5±312.8	812.3±321.0	1023.1±337.2	767.9±252.9	1036.7±259.6	**0.001**
HU density$^{\Omega}$	96 (47-379)	51 (29-187)	81 (36-332)	69 (31-277)	99 (41-401)	63 (34-366)	87 (51-356)	**0.001**

$^{\Omega}$: The Mann-Whitney U test, HU: Hounsfield unit

frequently observed in the pediatric population, are naturally resistant to ESWL due to their intrinsic characteristics. On the other hand, UA stones can be chemolysed. Furthermore, in cases of infection stones, antibiotic treatment plays a vital role in preventing recurrences. Predicting kidney stone types is crucial for personalizing treatment strategies and implementing preventive measures, especially for specific compositions such as UA, cystine, and infection-related stones.

Recent papers on predicting stone composition from HU values report conflicting results. Numerous studies have demonstrated that stone composition can be predicted from NCCT measurements[9-12]. However, some studies report contradictory outcomes, including one that found NCCT is ineffective for accurately determining stone composition[13]. Two recent studies have focused on the use of HU values in distinguishing UA stones from CaOx stones[14,15]. These studies reported that the density of UA stones is lower than that of CaOx stones. In line with these two studies, our findings also demonstrated consistent results. However, in our research, HU measurements (peripheral, core, and density) failed to distinguish CaOx stones from carbonate apatite or cystine stones from UA stones, with no statistically significant difference observed.

Advancements in NCCT measurements have led to the definition of additional HU values, including the stone core HU, peripheral HU, and HUD were used to predict stone composition. A recent study reported that CaOx stones are typically associated with an HUD >80[15]. Similarly, Torricelli et al.[16] observed significant variations in core HU, HUD, and peripheral HU values among CaOx, UA, and cystine stones. Furthermore, the study demonstrated that CaOx stones can be effectively distinguished from UA and cystine stones; however, no significant distinction was observed between cystine and UA stones[4]. In our study, the outcomes were consistent with those reported by Torricelli et al.[16]. Significant differences were observed in peripheral HU, core HU, and HUD values among different calcium-based stone compositions; however, these parameters were insufficient to differentiate between UA and cystine stones. In contrast to the literature, we were unable to identify a statistically significant HU-related cut-off value in our ROC analyses. This may be due to the inclusion of mixed-type stones alongside pure stones in our study.

While our study primarily focuses on the role of HU values in predicting urinary stone composition, it is important to consider the clinical implications of these findings, particularly in the context of fluoroscopy usage and surgical complications. The HU value not only provides insights into stone composition but also has potential implications for intraoperative management. Higher HU values are often associated with harder stones, which may necessitate longer laser lithotripsy times and higher energy settings, potentially leading to longer operative durations and a higher risk of thermal injury to the urothelium. Additionally, stone density can influence the need for fluoroscopy during endourological procedures, as denser stones may require more frequent imaging for localization and assessment of fragmentation. Future studies should investigate the relationships between HU values, radiation exposure, and perioperative complications to optimize surgical planning and patient safety[17].

Study Limitations

Our study has some limitations, primarily its retrospective design. While the number of stone analyses may appear limited when only pure stone compositions are considered, we observed that including mixed-type stones significantly increases the sample size. Nevertheless, our study includes a sufficient number of patients to provide valuable insights and guide national data and future publications.

CONCLUSION

NCCT may help select the most effective treatment by identifying stone composition. Calcium-based stones can be differentiated from cystine and struvite stones using HU measurements (peripheral, core, and density). However, additional technical assessments and predictive markers should be explored to more accurately distinguish CaOx from carbonate apatite stones and cystine from UA stones.

Ethics

Ethics Committee Approval: The retrospective study received approval from the Tekirdağ Namık Kemal University Non-Interventional Clinical Research (protocol number: 2023.73.04.09, date: 25.04.2023) and was carried out in accordance with the Declaration of Helsinki.

Informed Consent: This is a retrospective study.

Footnotes

Authorship Contributions

Surgical and Medical Practices: Ç.D., C.M.Y., Concept: Ç.D., M.F.Ş., M.S.K., Design: Ç.D., M.F.Ş., Data Collection or Processing: Ç.D., M.S.K., Analysis or Interpretation: Ç.D., M.F.Ş., C.M.Y., Literature Search: Ç.D., O.O., Writing: Ç.D., M.F.Ş., M.S.K., O.O., C.M.Y.

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