

Diagnostic Value of Dual-Energy CT Attenuation Ratios for Urinary Stone Characterization in Patients Presenting with Acute Abdominal Pain

Akut Karın Başvurularında Üriner Taş Karakterizasyonunda Dual-Enerji BT Atenüasyon Oranlarının Tanısal Değeri

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ABSTRACT

Objective: To evaluate attenuation ratios derived from dual-energy computed tomography (DECT) in patients presenting with acute abdominal pain who were diagnosed with urinary stone disease, and to analyze their distribution among different stone categories in a real-world emergency setting.

Materials and Methods: This prospective single-center study was conducted in the emergency department of a tertiary referral hospital. A total of 210 consecutive adult patients presenting with acute abdominal pain underwent DECT examination. Among these, 56 patients diagnosed with urolithiasis on non-contrast DECT were included in the final analysis. Attenuation values were measured at 80 kVp and 140 kVp, and attenuation ratios were calculated. Stone size, localization, and number were recorded. Differences among stone types were analyzed using One-Way ANOVA or the Kruskal-Wallis test, depending on the normality of data distribution. Post-hoc comparisons were performed using Bonferroni or Games-Howell tests based on the homogeneity of variances.

Results: The mean attenuation ratio across all stones was 1.32 ± 0.20 . Uric acid stones demonstrated the lowest mean attenuation ratio (0.96 ± 0.09), whereas hydroxyapatite (1.54 ± 0.07) and calcium oxalate stones (1.40 ± 0.05) showed significantly higher values ($p < 0.001$). Statistically significant differences were observed among stone categories in terms of low-energy attenuation, high-energy attenuation, and attenuation ratios ($p < 0.001$). No significant differences were found regarding age or stone size. Distinct clustering patterns were observed, particularly between uric acid and calcium-containing stones.

Conclusion: DECT-derived attenuation ratios demonstrated significant differentiation among urinary stone types in patients presenting with acute abdominal pain. These findings support the clinical utility of DECT for non-invasive stone characterization in the emergency setting.

Keywords: tomography, x-ray computed, urinary calculi, urolithiasis, absorptiometry, photon, emergency service, hospital

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ÖZET

Amaç: Bu çalışmada, akut karın ağrısı ile başvuran ve üriner taş hastalığı tanısı alan hastalarda dual enerji bilgisayarlı tomografi (DEBT) ile elde edilen atenüasyon oranlarının değerlendirilmesi ve farklı taş tipleri arasındaki dağılımının gerçek yaşam acil servis pratiğinde analiz edilmesi amaçlandı.

Gereç ve Yöntemler: Bu prospektif, tek merkezli çalışmada üçüncü basamak bir hastanenin acil servisinde akut karın ağrısı nedeniyle dual-enerji bilgisayarlı tomografi (DEBT) uygulanan 210 ardışık erişkin hasta değerlendirildi. Non-kontrast DEBT’de ürolitiazis şüphesi olan 56 hasta analize dahil edildi. Taşların 80 kVp ve 140 kVp düzeylerindeki atenüasyon değerleri ölçülerek atenüasyon oranları hesaplandı. Taş boyutu, lokalizasyonu ve sayısı kaydedildi. Sürekli değişkenlerin normal dağılıma uygunluğu Shapiro-Wilk ve Kolmogorov-Smirnov testleri ile incelendi. Taş tipleri arasındaki farkların analizinde, parametrik varsayımların karşılandığı durumlarda Tek Yönlü Varyans Analizi (ANOVA), karşılanmadığı durumlarda ise Kruskal-Wallis testi kullanıldı. Gruplar arası ikili karşılaştırmalarda (post-hoc), varyansların homojenliğine göre Bonferroni veya Games-Howell testleri tercih edildi.

Bulgular: Tüm taşlarda ortalama atenüasyon oranı $1,32 \pm 0,20$ olarak bulundu. Ürik asit taşları en düşük ortalama atenüasyon oranını gösterirken ($0,96 \pm 0,09$), hidroksiapatit ($1,54 \pm 0,07$) ve kalsiyum oksalat taşlarında anlamlı derecede daha yüksek oranlar saptandı ($p < 0,001$). Taş tipleri arasında düşük enerji, yüksek enerji atenüasyon değerleri ve atenüasyon oranları açısından istatistiksel olarak anlamlı farklılık vardı ($p < 0,001$). Yaş ve taş boyutu açısından anlamlı fark izlenmedi. Özellikle ürik asit ve kalsiyum içeren taşlar arasında belirgin kümelenme gözlemlendi.

Sonuçlar: DEBT ile elde edilen atenüasyon oranları, akut karın ağrısı ile başvuran hastalarda üriner taş tiplerinin ayırımında anlamlı farklılık göstermektedir. Bu bulgular, acil servis pratiğinde non-invaziv taş karakterizasyonunda DEBT’nin klinik değerini desteklemektedir.

Anahtar Kelimeler: tomografi, X-ışınli bilgisayarlı, üriner kalküller, ürolitiazis, absorpsiyometri, foton, acil servis, hastane

INTRODUCTION

Urinary stone disease is a common condition with increasing global prevalence and a substantial burden on healthcare systems. Lifetime prevalence has been reported between 6–15% in many populations and continues to rise worldwide (1). Acute flank pain caused by urinary calculi represents one of the most frequent causes of emergency department admissions, requiring rapid and accurate diagnostic imaging for timely management (2).

Non-contrast helical computed tomography (CT) is currently considered the imaging modality of choice for detecting urinary calculi due to its high sensitivity and specificity (2). In addition to accurate detection, CT provides valuable information regarding stone size and localization. However, conventional single-energy CT has limited capability in determining stone composition. Although Hounsfield unit (HU) measurements may offer indirect information, significant overlap exists among different stone chemistries, reducing the reliability of single-energy attenuation values for definitive compositional assessment (3).

Dual-energy CT (DECT) has emerged as a valuable imaging modality that utilizes attenuation differences at two distinct energy spectra to improve material differentiation. Early clinical and experimental studies demonstrated that DECT enables reliable discrimination between uric acid and non-uric acid stones (4,5). Subsequent investigations confirmed that energy-dependent attenuation characteristics allow improved stone characterization compared to conventional CT (6,7). Quantitative approaches based on attenuation ratios derived from paired low- and high-energy datasets have been proposed as practical and reproducible tools for urinary stone classification (7,8). Advanced post-processing techniques further enhance compositional analysis and diagnostic confidence (8,9).

From a clinical standpoint, non-invasive identification of stone composition is particularly relevant in acute abdominal

presentations. Uric acid stones may respond to medical dissolution therapy, whereas calcium-containing stones more frequently require interventional procedures (8,10). Several studies have emphasized the potential role of DECT in guiding management decisions and optimizing therapeutic planning in urolithiasis (4,10).

Despite growing evidence supporting the role of DECT in urinary stone characterization, many published investigations have been conducted in controlled or experimental settings, including in vitro or ex vivo analyses (4,5). Data reflecting routine emergency department practice and real-world attenuation ratio distributions remain comparatively limited.

Therefore, in this single-center study, we aimed to assess DECT-derived attenuation ratios in patients presenting with urinary stone disease among acute abdominal presentations and to analyze their distribution across different stone categories in a real-world emergency setting.

MATERIALS AND METHODS

Study Design and Patient Population

This prospective single-center study was approved by the institutional ethics committee (Approval Number: B.30.2.ATA.0.01.00/277, Date: October 4, 2018). Written informed consent was obtained from all participants prior to enrollment, and the study was conducted in accordance with the principles of the Declaration of Helsinki.

The study was carried out in the emergency department of a tertiary referral hospital. A total of 210 consecutive adult patients presenting with acute abdominal pain underwent dual-energy CT (DECT) examination. Among these patients, individuals presenting with acute flank pain and diagnosed with urinary stone disease on non-contrast DECT were considered eligible. The present study represents a predefined subgroup analysis of a broader prospective emergency department cohort undergoing DECT evaluation for acute abdominal presentations. In the present study, the term “acute abdominal pain” refers to the overall emergency department cohort, whereas “acute flank pain” specifically describes the subgroup of patients with suspected urolithiasis included in the final analysis.

Patients aged 18 years or older with at least one urinary stone detected on DECT were included in the study. Patients with incomplete imaging data, insufficient image quality preventing reliable attenuation measurements, prior intervention affecting stone morphology, or significant motion artifacts were excluded. Ultimately, 56 patients met the eligibility criteria and were included in the final analysis.

For each patient, demographic data including age and sex were recorded, along with stone localization, number of stones, and maximum long-axis diameter (mm). When multiple stones were present, attenuation measurements were performed separately for each stone. Attenuation values at 80 kVp and 140 kVp were measured, and attenuation ratios were subsequently calculated.

CT Acquisition Protocol

All examinations were performed using a 256-slice dual-source multidetector CT scanner (Somatom Definition Flash; Siemens Healthineers, Forchheim, Germany). The system is equipped with two X-ray tubes and corresponding detectors positioned at approximately 95° angular offset within the gantry, enabling simultaneous dual-energy acquisition. Dual-energy imaging was performed using tube voltage settings of 80 kVp and 140 kVp. Automatic tube current modulation (CARE Dose 4D; Siemens Healthineers) was applied to optimize radiation exposure. The detector configuration was 32 × 0.6 mm with a gantry rotation time of 500 ms and a pitch of 0.6. The field of view was 50 cm for Tube A and 33 cm for Tube B. Non-contrast acquisition was performed for urinary stone evaluation. Images were reconstructed with a slice thickness of 1 mm and transferred to a dedicated workstation (Syngo Via, version 2.0; Siemens Healthineers) for post-processing and analysis. Circular regions of interest (ROIs) were manually placed on axial images over the largest cross-sectional area of each stone, carefully avoiding adjacent soft tissue and minimizing

partial-volume effects. Attenuation values were recorded separately for 80 kVp and 140 kVp datasets, and attenuation ratios were calculated using matched dual-energy datasets.

Image Analysis

For each urinary stone, circular regions of interest (ROIs) were manually placed on axial images over the largest cross-sectional area of the stone on both low-energy (80 kVp) and high-energy (140 kVp) datasets. ROIs were positioned centrally within the stone to minimize partial-volume effects and to avoid inclusion of adjacent soft tissue. When multiple stones were identified in the same patient, measurements were performed for each stone individually.

The following parameters were recorded for each stone: low-energy attenuation value (HU), high-energy attenuation value (HU), and attenuation ratio calculated as the quotient of low-energy HU divided by high-energy HU. Attenuation ratios were used to evaluate differences among stone categories.

Stone size was measured as the maximum long-axis diameter on axial images. All measurements were performed using the institutional PACS workstation under standardized viewing conditions. Image analysis was performed independently by two radiologists with 8 and 5 years of experience in abdominal radiology, respectively. Both readers were blinded to the clinical and laboratory data during attenuation measurements and stone characterization. Interobserver agreement for attenuation measurements was assessed using the intraclass correlation coefficient (ICC).

Stone classification was based on dual-energy attenuation characteristics consistent with previously reported ranges in the literature (4,5,7). Stones were categorized as calcium oxalate, hydroxyapatite, uric acid, or cystine according to their dual-energy attenuation characteristics and attenuation ratio profiles.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics software (version 20.0; IBM Corp., Armonk, NY, USA). Continuous variables were presented as mean $\pm$ standard deviation, median, minimum, and maximum values, while categorical variables were expressed as frequencies and percentages.

Normality of continuous variables was assessed using the Shapiro–Wilk test for sample sizes <50 and the Kolmogorov–Smirnov test for sample sizes ≥ 50 . For comparisons between two independent groups, the Independent Samples t-test was used when normal distribution was satisfied, and the Mann–Whitney U test was applied otherwise. For comparisons among more than two independent groups, one-way analysis of variance (ANOVA) was performed when parametric assumptions were met, and the Kruskal–Wallis test was used when they were not. Following ANOVA, post hoc analyses were conducted using the Bonferroni correction when variances were homogeneous and the Games–Howell test when homogeneity assumptions were violated.

Effect sizes for ANOVA analyses were evaluated using eta squared (η^2). According to conventional criteria, η^2 values of 0.01, 0.06, and 0.14 were interpreted as small, medium, and large effect sizes, respectively. A 2-sided p -value < 0.05 was considered statistically significant.

Interobserver agreement for attenuation measurements was evaluated using the intraclass correlation coefficient (ICC). ICC values greater than 0.90 were considered indicative of excellent agreement.

RESULTS

A total of 56 patients with urolithiasis were included in the analysis. Excellent interobserver agreement was achieved between the two readers for attenuation measurements, with an intraclass correlation coefficient (ICC) of 0.92.

Among these patients, 19 (33.9%) were female and 37 (66.1%) were male. The mean age was 51.3 ± 13.16 years. Demographic characteristics, stone localization, stone type distribution, and number of stones are summarized in Table 1. Stone localization was most commonly observed in the ureter (44.6%) and calyceal system (35.7%), followed by the bladder (16.1%) and renal pelvis (3.6%).

Regarding stone size distribution, 16 patients (28.6%) had stones measuring ≤ 5 mm, 32 patients (57.1%) had stones between 6–15 mm, 6 patients (10.7%) had stones between 16–20 mm, and 2 patients (3.6%) had stones ≥ 20 mm (Table 2). The mean stone long-axis diameter was 8.53 ± 4.92 mm.

Overall descriptive statistics for age, stone size, attenuation values, and attenuation ratios are presented in Table 3. Across the entire cohort, the mean attenuation value at low energy (80 kVp) was $1,182.14 \pm 351.02$ HU, and at high energy (140 kVp) was 887.55 ± 177.81 HU. The mean attenuation ratio (80 kVp / 140 kVp) was 1.32 ± 0.20 .

Based on dual-energy CT analysis, stones were categorized as calcium oxalate in 30 patients (53.6%), hydroxyapatite in 8 patients (14.3%), uric acid in 10 patients (17.9%), and cystine in 8 patients (14.3%) (Table 1).

Comparative analysis of stone types is summarized in Table 4. When evaluated according to stone composition, calcium oxalate stones demonstrated a mean attenuation ratio of 1.40 ± 0.05 , hydroxyapatite stones 1.54 ± 0.07 , uric acid stones 0.96 ± 0.09 , and cystine stones 1.26 ± 0.15 . Statistically significant differences were observed among stone types in terms of low-energy attenuation values, high-energy attenuation values, and attenuation ratios ($p < 0.001$ for all comparisons).

Table 1. Demographic and stone-related characteristics of patients with urolithiasis (n = 56)

Variable	Category	n	%
Sex	Female	19	33.9
	Male	37	66.1
Localization	Calyx	20	35.7
	Renal pelvis	2	3.6
	Ureter	25	44.6
	Bladder	9	16.1
Stone Type	Calcium oxalate	30	53.6
	Hydroxyapatite	8	14.3
	Uric acid	10	17.9
	Cystine	8	14.3
Number of Stones	Single	40	71.4
	Multiple	16	28.6

Table 2. Distribution of stone size according to maximum long-axis diameter (n = 56)

Stone size (mm)	n	%
≤ 5	16	28.6
6–15	32	57.1
16–20	6	10.7
≥ 20	2	3.6

Post hoc comparisons demonstrated significant differences in attenuation ratios among several stone categories, particularly between uric acid stones and calcium-containing stones, as detailed in Table 4. No statistically significant differences were found among stone types with respect to patient age or stone size.

The distribution of attenuation ratios according to stone type is illustrated in Figure 1, demonstrating clear clustering patterns, particularly between uric acid stones and calcium-containing stones.

A representative dual-energy CT case demonstrating attenuation measurements and material characterization is shown in Figure 2.

DISCUSSION

In the present study, we evaluated dual-energy CT (DECT)-derived attenuation ratios in patients presenting with acute abdominal pain who were diagnosed with urinary stone disease. Our findings demonstrated statistically significant differences in both attenuation values and attenuation ratios among stone categories. Most notably, uric acid stones demonstrated distinctly lower attenuation ratios compared with calcium-containing stones, supporting the clinical utility of DECT-based compositional analysis in the emergency setting.

Table 3. Descriptive statistics of demographic and dual-energy CT parameters (n = 56)

Variable	Mean	SD	Median	Minimum	Maximum
Age (years)	51.30	13.16	49.00	28.00	79.00
Stone size (mm)	8.53	4.92	7.45	2.30	25.00
Low-energy attenuation (80 kVp, HU)	1182.14	351.02	1227.00	466.00	1976.00
High-energy attenuation (140 kVp, HU)	887.55	177.81	894.50	535.00	1240.00
Attenuation ratio (80/140 kVp)	1.32	0.20	1.39	0.81	1.65

Table 4. Comparison of dual-energy CT parameters according to stone type

Variable	Calcium Oxalate (n = 30)	Hydroxyapatite (n = 8)	Uric Acid (n = 10)	Cystine (n = 8)	Test statistic	p	Effect Size (η^2)
Age (years), mean $\pm$ SD	51.37 $\pm$ 11.98	52.88 $\pm$ 10.01	57.00 $\pm$ 17.66	42.38 $\pm$ 11.19	5.143	0.162	-
Stone size (mm), mean $\pm$ SD	8.48 $\pm$ 5.59	8.05 $\pm$ 3.48	8.69 $\pm$ 3.94	9.03 $\pm$ 5.33	0.517	0.915	-
Low-energy attenuation (80 kVp, HU), mean $\pm$ SD	1334.67 $\pm$ 194.67 ^c	1413.38 $\pm$ 367.20 ^c	661.70 $\pm$ 145.85 ^{a,b,d}	1029.50 $\pm$ 273.02 ^c	43.163	<0.001	0.72
High-energy attenuation (140 kVp, HU), mean $\pm$ SD	959.87 $\pm$ 135.28 ^c	922.38 $\pm$ 211.26 ^c	719.90 $\pm$ 120.77 ^{a,b}	791.13 $\pm$ 186.09 ^a	7.436	<0.001	0.36
Attenuation ratio (80/140 kVp), mean $\pm$ SD	1.40 $\pm$ 0.05 ^{b,c}	1.54 $\pm$ 0.07 ^{a,c,d}	0.96 $\pm$ 0.09 ^{a,b,d}	1.26 $\pm$ 0.15 ^{b,c}	8.560	<0.001	0.81

Note: Data are presented as mean $\pm$ SD. Groups with different superscript letters differ significantly from each other based on Bonferroni or Games-Howell post-hoc analyses ($p < 0.05$). Effect size was calculated using eta squared (η^2).

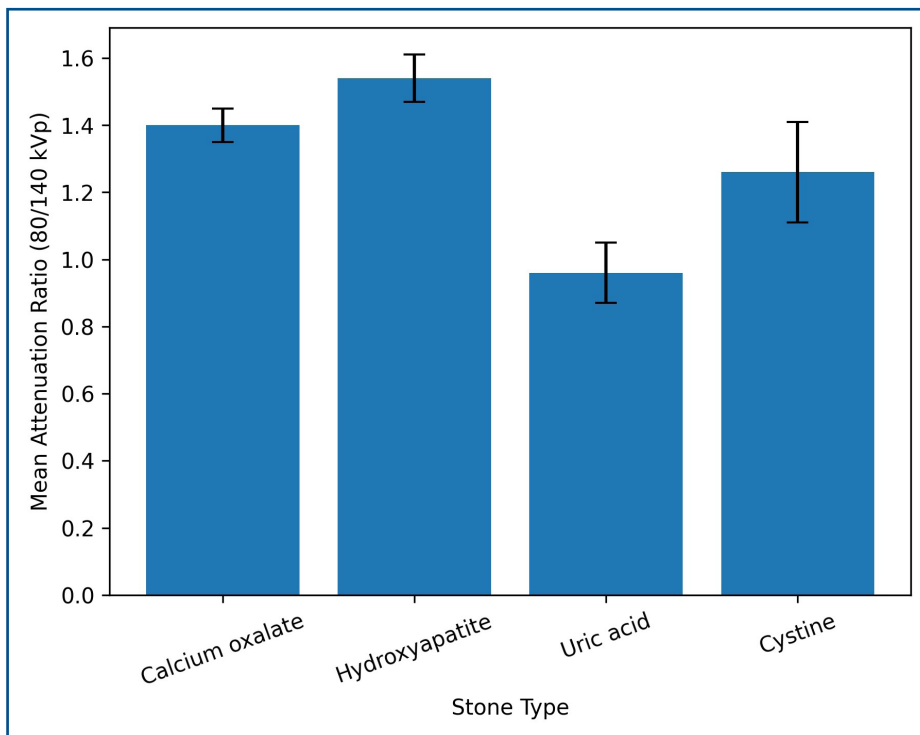


Figure 1. Distribution of mean attenuation ratios according to urinary stone type. Uric acid stones demonstrate significantly lower attenuation ratios compared with calcium-containing stones.

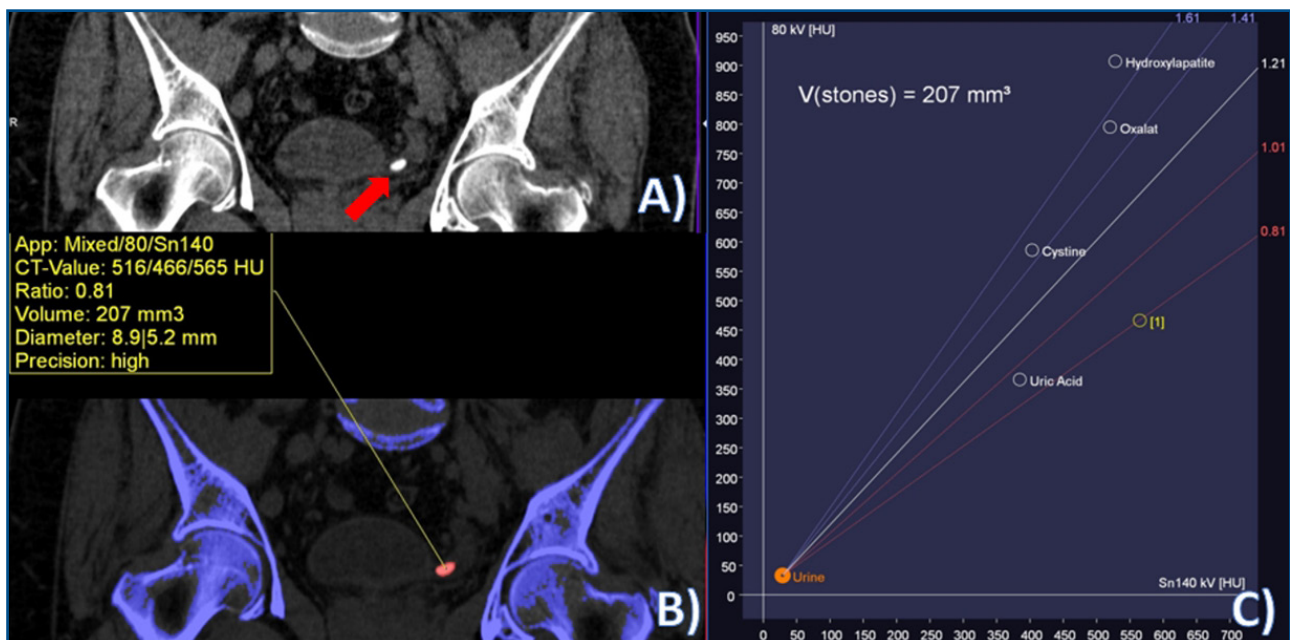


Figure 2. Representative dual-energy CT images of a urinary stone demonstrating attenuation measurements and material characterization. (A) Axial non-contrast image showing a distal ureteral stone (arrow). (B) Dual-energy material decomposition image with region-of-interest (ROI) placement. Attenuation values measured at 80 kVp and 140 kVp are displayed, and the calculated attenuation ratio is provided. (C) Dual-energy attenuation distribution plot illustrating the energy-dependent separation of the stone, supporting material classification based on attenuation characteristics. The calculated attenuation ratio is consistent with uric acid composition.

Non-contrast CT has long been established as the imaging modality of choice for the evaluation of suspected urolithiasis due to its high sensitivity and specificity (2,11). However, conventional single-energy CT provides limited information regarding stone composition, as attenuation values measured in Hounsfield units often overlap among different stone types (3). Previous investigations have demonstrated that attenuation-based differentiation using single-energy CT is unreliable for definitive compositional analysis, particularly among calcium-containing subtypes (3). Our findings further support the utility of energy-dependent techniques to improve material discrimination.

Dual-energy CT enables material characterization by exploiting differences in X-ray attenuation at two distinct energy spectra. Early in vitro and clinical studies by Graser et al. (4) and Stolzmann et al. (5) demonstrated that DECT can reliably differentiate uric acid stones from non-uric acid stones. Similarly, Primak et al. (7) showed that attenuation ratios derived from paired dual-energy datasets provide reproducible discrimination between uric acid and non-uric acid stones. In agreement with these reports, our study demonstrated a clear separation of uric acid stones, which exhibited the lowest mean attenuation ratio (0.96 ± 0.09), while hydroxyapatite and calcium oxalate stones demonstrated significantly higher ratios.

Our results also revealed statistically significant differences among calcium oxalate, hydroxyapatite, cystine, and uric acid stones in terms of attenuation ratios. Hydroxyapatite stones demonstrated the highest attenuation ratios, whereas cystine stones showed intermediate values with partial overlap. Similar observations have been reported in previous clinical studies, which noted that while DECT performs excellently in binary differentiation (uric acid vs. non-uric acid), overlap may occur among certain non-uric acid subtypes (8,9,12). Therefore, although attenuation ratios provide valuable classification information, absolute cut-off thresholds may vary depending on scanner platform, acquisition parameters, and post-processing algorithms.

From a clinical perspective, accurate non-invasive identification of stone composition may have potential therapeutic implications. Uric acid stones may be treated with urinary alkalinization and medical dissolution therapy, potentially avoiding invasive procedures (10). Therefore, early identification of uric acid stones using DECT-derived attenuation ratios may help support more individualized treatment planning, particularly in emergency department settings where rapid therapeutic decision-making is required. In contrast, calcium-containing stones frequently require interventional management such as ureteroscopy or extracorporeal shock wave lithotripsy. Previous studies have emphasized the possible role of DECT in supporting treatment planning and management strategies (8,10). However, the present study did not include direct analyses of treatment decisions, patient management changes, or clinical outcomes. Therefore, the clinical impact of DECT-derived attenuation ratios should be interpreted cautiously.

Another relevant aspect is radiation exposure. Low-dose CT protocols have been widely adopted in the evaluation of renal colic (13), and advances in multidetector CT technology have enabled optimized acquisition protocols while maintaining diagnostic accuracy (11,14). Modern dual-source DECT systems allow simultaneous acquisition without substantially increasing radiation dose compared with conventional single-energy CT (15). Therefore, incorporation of dual-energy protocols into routine emergency imaging may be feasible without compromising patient safety.

Despite these promising findings, several limitations should be acknowledged. First, stone composition was not confirmed by reference standard methods such as chemical analysis or infrared spectroscopy in any of the cases. Instead, stone classification was based on dual-energy attenuation characteristics consistent with previously reported literature ranges (4,5,7). Although this approach reflects real-world clinical practice, the absence of reference standard compositional confirmation limits definitive validation. Second, the study was conducted at a single center, and certain stone subgroups, particularly hydroxyapatite and cystine stones—had relatively small sample sizes. These limited subgroup sizes may have reduced the statistical power of subgroup comparisons and may restrict the generalizability of the findings. Third, attenuation ratio thresholds may be scanner-specific, and results may not be

directly transferable across different DECT platforms. In addition, formal diagnostic performance analyses including ROC-derived cutoff values, sensitivity, and specificity were not performed due to the relatively small subgroup sizes and the absence of chemical reference standard analysis.

Nevertheless, the present study reflects routine emergency department practice and provides real-world attenuation ratio distribution data among different urinary stone types. The statistically significant separation observed between uric acid and calcium-containing stones reinforces the potential role of DECT as a clinically meaningful adjunct tool in the evaluation of acute urolithiasis.

CONCLUSION

In conclusion, dual-energy CT–derived attenuation ratios demonstrated significant differences among urinary stone categories in patients presenting with acute abdominal pain. Clear clustering patterns were observed, particularly between uric acid and calcium-containing stones. These findings support the integration of DECT-based attenuation analysis into emergency imaging protocols for non-invasive urinary stone characterization.

Conflict of Interest: The authors declare no conflict of interest.

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Ethics Approval: This study was approved by the Ethics Committee of Atatürk University (Approval No: B.30.2.ATA.0.01.00/277, Date: October 4, 2018). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Informed Consent: Written informed consent was obtained from all participants included in this study.

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Manuscript writing: Mustafa Yeşilyurt

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