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The Role of Hounsfield Units in Predicting Urinary Stone Composition: A Systematic Review

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Abstract

Background: Urinary stone disease is a prevalent urological condition with significant morbidity worldwide. Computed tomography (CT) attenuation values, or Hounsfield Units (HU), have been proposed as a tool for estimating stone composition.

Objective: To evaluate the accuracy of HU in predicting urinary stone composition and its clinical utility in guiding treatment decisions.

Methods: A systematic search was conducted in online databases, including PubMed, Scopus, and Embase, for articles published from 2020 to 2024. Data extracted included study design, sample size, and HU values. The methodological quality of the included studies was assessed using the QUADAS-2 tool, which evaluated the risk of bias. Heterogeneity across studies was assessed using the I^2 statistic for stone subtypes and for variation in scanner protocols and patient populations.

Results: Uric acid stones consistently had the lowest HU values (258–679 HU), whereas calcium oxalate and hydroxyapatite had the highest. Cystine and struvite exhibited overlapping ranges, limiting diagnostic specificity. A combination of HU ≤500 and urine pH ≤5.5 predicted uric acid stones with 87% sensitivity and 83% specificity.

Conclusion: HU values correlate significantly with urinary stone composition and serve as a practical predictive tool, though standardization of imaging protocols is needed to improve diagnostic consistency.

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INTRODUCTION

The urinary system is one of the most vital systems in the human body. It is responsible for excretion, through which metabolic waste and substances that are no longer needed are eliminated primarily in urine.[1] Unfortunately, disorders of this system are also common; these are often referred to as urological disorders. Urological diseases encompass a wide spectrum of conditions affecting the urinary system. This group of diseases represents a significant global health challenge, with prevalence rates continuing to rise across various populations. The most common conditions encountered in daily clinical practice include urinary tract infections, benign prostatic hyperplasia, urological neoplasms, and urinary stone formation disorders. [2,3]

Among these conditions, urolithiasis (urinary tract stone disease) has a high prevalence and is a leading cause of visits to urology emergency departments. From an epidemiological perspective, urinary tract stones are a recurrent condition that significantly impacts patient morbidity and places a substantial economic burden on the healthcare system. Given that urolithiasis can be caused by many factors—such as age, lifestyle, gender, occupation, diet, genetics, obesity, metabolic syndrome, and other factors—its incidence is high; in 2021 alone, there were 106 million cases worldwide.[4,5] Meanwhile, in Indonesia, data indicate that the prevalence of BSK ranges from 1% to 20%. It is more common in men than in women, with a male-to-female ratio of 3:1, and the peak incidence occurs between the ages of 40 and 50. In children, the incidence of BSK is 5% to 10% of that seen in adults.[6]

The significance of addressing urinary tract stones lies in the inherent complexity of their clinical management. Stone treatment is by no means a one-size-fits-all approach; therapeutic success largely depends on a thorough understanding of the stone's chemical composition, anatomical location, and physical characteristics. Distinct stone types respond differently to available treatment modalities, spanning from Extracorporeal Shock Wave Lithotripsy (ESWL) and Retrograde Intrarenal Surgery (RIRS) to Percutaneous Nephrolithotomy (PCNL).[7,8] Consequently, the capacity to anticipate stone characteristics before any intervention is undertaken plays a pivotal role in selecting the most effective therapeutic strategy while reducing the likelihood of procedural complications. In the pursuit of predicting stone characteristics, Computed Tomography (CT) imaging — most notably Non-contrast Computed Tomography (NCCT) — has emerged as the gold standard for diagnosing urolithiasis. CT-based imaging offers considerable advantages over conventional radiological techniques such as plain radiographs or intravenous pyelography (IVP), owing to its superior spatial resolution, capacity for detailed anatomical visualization, and heightened sensitivity in stone detection. Through this modality, clinicians can obtain objective, quantitative measurements of stone density, expressed in Hounsfield Units (HU).[9–11] However, the use of HU as a predictor of stone composition remains a subject of debate and ongoing research in the medical field. The main challenge lies in the variability of threshold values found across studies.

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Differences in scanning protocols, variations in CT scanners, and even biological factors inherent to the stones themselves have led to a lack of consensus on specific HU values for accurately distinguishing stone types. It is this uncertainty about the optimal cutoff value that underscores the importance of this study in re-evaluating HU's relevance for predicting the composition of urinary tract stones.[12–14] Therefore, by synthesizing existing data, this study aims to clarify current discrepancies in HU thresholds and establish a more standardized approach to the clinical assessment of urinary stone composition.

METHODS

This study was conducted as a systematic review to assess the diagnostic accuracy of Hounsfield Units (HU) for determining urinary tract stone composition. An extensive literature search was performed across three major databases — PubMed, Scopus, and Embase — to retrieve original research articles published from January 1, 2020, through December 31, 2024, employing a combination of search terms including "Hounsfield Units," "urinary stone composition," "computed tomography," and other relevant keywords. The review was carried out in accordance with PRISMA 2020 guidelines, in which two reviewers, working independently, screened titles, abstracts, and full-text articles against predefined inclusion criteria encompassing adult patient populations, HU measurements derived from Non-contrast Computed Tomography (NCCT), and stone composition verified through laboratory testing or infrared spectroscopy. Information extracted from each eligible study included the study design, sample size, and HU values for each stone type. To uphold methodological rigor and reduce the risk of bias, all included studies underwent quality appraisal using the QUADAS-2 tool, which evaluates the domains of patient selection, index test, reference standard, and flow and timing.

Studies were excluded if they were published before January 2020 or after December 2024, failed to report HU values, lacked laboratory or spectroscopic confirmation of stone composition, or included pediatric populations. Given the considerable heterogeneity in study designs, CT scan acquisition parameters, and outcome measures across the included studies — as reflected by an I^2 value exceeding 75% — a formal meta-analysis was not feasible; data were therefore synthesized narratively. Diagnostic performance metrics were extracted and compiled into tables for descriptive comparison.

RESULTS

Following a literature screening process guided by PRISMA methodology, 10 studies satisfied the inclusion criteria and were incorporated into the final synthesis. The included studies represented a range of research designs and sample sizes, with urinary stone composition confirmed through either laboratory analysis or infrared spectroscopy. Hounsfield Unit (HU) values obtained via Non-contrast Computed Tomography (NCCT) showed considerable variability with stone composition. Uric acid stones consistently yielded lower HU values relative to calcium

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oxalate and hydroxyapatite stones, whereas the latter two stone types tended to exhibit notably higher HU values. Furthermore, several studies investigated supplementary parameters, including the stone heterogeneity index, the coefficient of variation in stone density, and optimal HU cut-off values, as potential predictors of diagnostic accuracy and treatment outcomes. Table 1 summarizes the characteristics and key findings of all studies included in this systematic review.

These findings align with the well-established physicochemical properties of each stone type. Uric acid stones, being composed of organic compounds with lower atomic numbers, inherently attenuate X-rays less than calcium-based stones, which contain heavier elements such as calcium and phosphate. This physical basis explains why HU values reliably differentiate uric acid from calcium oxalate and hydroxyapatite stones across multiple study populations and CT acquisition settings, and underlies the clinical relevance of early compositional identification as a direct determinant of treatment strategy.

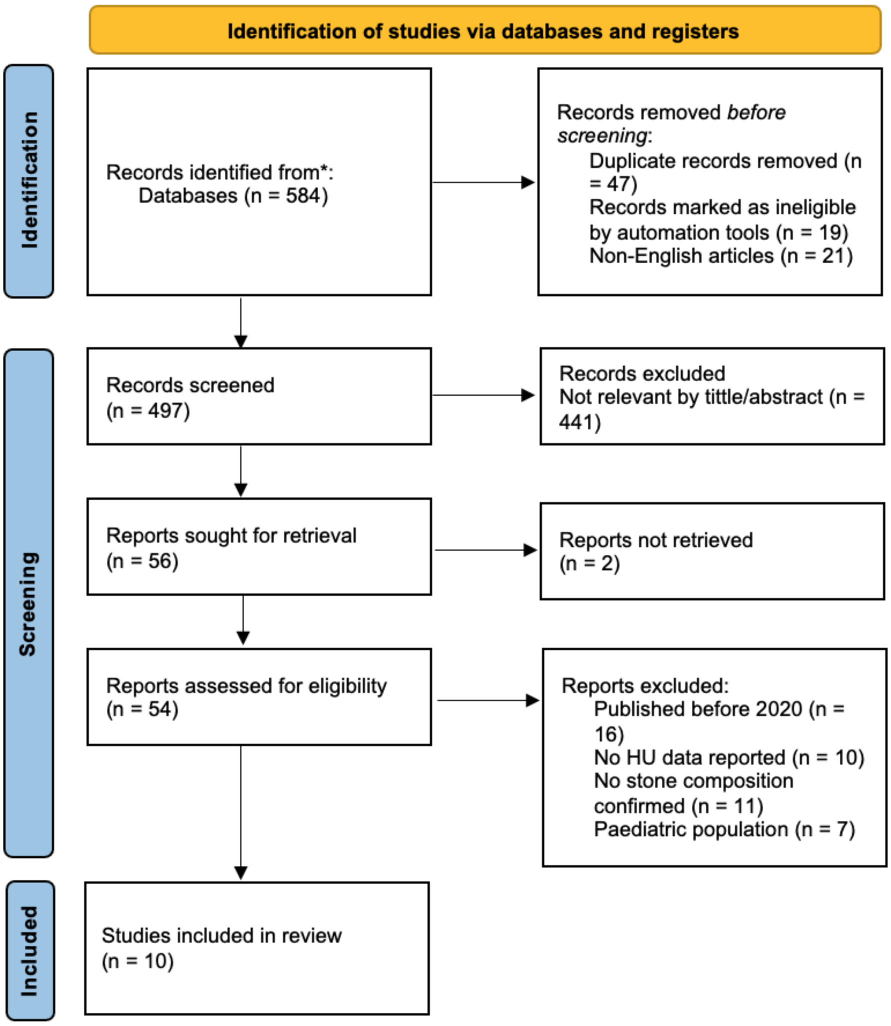

Figure 1. PRISMA Chart

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Table 1. Study Characteristics and Summary of Findings on Hounsfield Units (HU) Based on the Composition of Urinary Tract Stones

Author	Country	Study Design	Sample	Urinary Stone Composition	HU Score
Hussain et al. (2025)[15]	UK	Retrospective cohort	110	Uric acid and Struvite	432±98 694±182
Alharbi et al. (2024)[16]	UAE	Retrospective single-center	67	Calcium & uric acid	841.95 (completely fragmented); 978.79 (partially fragmented)
Kalyenci et al. (2025)[17]	Turkey	Observational and retrospective review	383	Stone culture (+)	HUcore: 919 (694–1250) HUprox: 733 (437–950) HUdist: 502 (302–850)
Oktay et al. (2022)[18]	Turkey	Retrospective study	850	Stone culture (+)	669 ± 226 – 930 ± 195
Kaviani et al. (2022)[19]	USA	Retrospective study	218	Calcium oxalate and uric acid	Threshold ≥ 130 HU
Qin et al. (2022)[20]	China	Retrospective study	440	Uric acid Calcium oxalate Struvite Carbonate apatite Calcium oxalate + carbonate apatite Calcium oxalate + uric acid	679±240 1168 ± 238 845 ± 319 1152 ± 269 1192 ± 240 969 ± 221
Merticariu et al. (2022)[13]	Rumania	Literature review	N/A	Uric acid Calcium oxalate Calcium oxalate monohydrate Calcium oxalate dihydrate Struvite Cystine Hydroxyapatite	367–556 400–600 783–1010 873–1218 540–693 367–556 835–1034
Iqbal et al. (2025)[21]	Pakistan	Prospective observational study	360	ESWL <900 HU ESWL ≥900 HU	< 900 ≥900
Shehata et al. (2021)[22]	Egypt	Retrospective study	N/A	Uric acid Calcium oxalate Struvite Cystine Mixed CaOx + calcium phosphate Mixed CaOx + uric acid	428 ± 81 1158 ± 83 714 ± 38 997 ± 14 1427 ± 152 886 ± 139
Ahmed et al. (2021)[23]	Iraq	Cross-sectional	80	Uric acid Calcium oxalate Struvite Cystine Mixed CaOx + uric acid	258,57 ± 65,50 824,23 ± 211,15 550,00 ± 17,68 487,50 500,00 ± 0,00

However, the diagnostic utility of single-HU measurements is limited by the overlap in attenuation ranges among stone subtypes. Cystine stones recorded HU values of 367–556 and 487.50, closely mirroring those of uric acid stones. Similarly, struvite stones demonstrated wide HU variability, reflecting their heterogeneous mineral composition. These overlapping ranges are particularly problematic in mixed-composition stones, where HU

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values represent an average of multiple mineral densities.

Data show a significant correlation between Hounsfield Units (HU) and the chemical composition of urinary tract stones. Lower density is identified as uric acid, while higher density is associated with calcium stones. Among the included studies, Hussain et al. reported that a combination of HU ≤500 and urine pH ≤5.5 predicted uric acid stones with a sensitivity of 87% and a specificity of 83%. Findings confirm the crucial role of NCCT not only as a diagnostic tool for stone localization but also as a predictive instrument in determining the most effective therapeutic strategy for patients.

DISCUSSION

Across the included studies, uric acid stones consistently exhibited the lowest HU values, ranging from 258 to 679 HU, while calcium oxalate and hydroxyapatite stones had the highest values. Hussain et al. reported an average HU value of 432 ± 98 for uric acid stones, while Ahmed et al. found a lower value of 258.57 ± 65.50. Significant differences may be due to variations in CT protocols; however, the compositional density where uric acid is consistently lower than calcium remains consistent. Consistency in this pattern reinforces HU's reliability as a clinically valid marker of stone composition, although absolute values have not yet been universally standardized.

However, there are significant limitations when using a single HU due to overlapping values. Cystine and struvite are reported to have a wide HU range, and both overlap with the ranges of uric acid and calcium oxalate. A study by Merticariu et al. reported that calcium oxalate, ranging from 400–600 HU, directly overlaps with uric acid. These findings can lead to a lack of clarity, especially in mixed stones or stones with low-to-moderate density, making HU alone insufficient to determine stone composition. To address these limitations, several studies have explored the combination of HU with other clinical and laboratory parameters. Hussain et al. demonstrated that a combination of HU ≤500 and urine pH ≤5.5 predicted uric acid stones with 87% sensitivity and 83% specificity. In another approach, Kalyenci et al. compared HU values at three distinct locations and found that a significant HU difference between the core and periphery was associated with a positive stone culture, suggesting bacterial colonization on the stone surface.

In addition, the therapeutic implications of HU are further supported by Alharbi et al. and Iqbal et al., who demonstrated that stones with a HU below 900 have a higher probability of fragmentation during extracorporeal shock wave lithotripsy (ESWL), while stones with a HU ≥900 tend to be resistant and more frequently require more invasive procedures. This information allows clinicians to select the most appropriate treatment modality before the intervention, thereby minimizing unnecessary procedures.

CONCLUSION

Hounsfield Unit measurements show a significant correlation with the composition of urinary stones and can be used as a predictive

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tool in clinical practice. Uric acid stones consistently show the lowest HU values, while calcium oxalate and hydroxyapatite stones fall within the highest density range. However, single-energy CT carries inherent limitations due to overlapping HU values among stone subtypes, particularly between uric acid and cystine stones, and between struvite and calcium-based stones, which reduce its specificity as a standalone diagnostic tool. Therefore, a combination of HU with other clinical parameters, such as urine pH and infection markers, is required to compensate for the limitations of single-energy CT. In contrast, dual-source CT offers superior stone characterization by analyzing material attenuation at two distinct energy levels, enabling more accurate differentiation of stone compositions that overlap on conventional single-energy imaging. Despite this diagnostic advantage, dual-source CT remains less accessible in routine clinical settings due to higher cost and limited availability. HU measurement protocols need to be standardized so that established threshold values can be applied more universally and consistently in the management of urinary tract stones.

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