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DIAGNOSTIC ACCURACY OF CT PYELOGRAM FOR DETECTION OF URINARY TRACT STONES COMPOSITION

Original Research

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ABSTRACT

Background: Urolithiasis is a globally prevalent condition and a leading cause of urological consultation, second only to prostatic diseases in many regions. The increasing burden of stone disease, partly attributed to dietary and lifestyle changes, has emphasized the need for early and accurate diagnostic tools. Since the composition of urinary tract stones directly influences treatment planning and recurrence prevention, the non-invasive prediction of stone type is crucial. CT pyelography has emerged as a potential modality to aid in this differentiation.

Objective: To determine the diagnostic accuracy of CT pyelogram for detecting urinary tract stone composition, using histopathology as the gold standard.

Methods: This descriptive cross-sectional study was conducted over six months (August 1, 2024, to January 31, 2025) at the Department of Radiology, Ziauddin University, Karachi. A total of 185 patients aged 18–60 years, diagnosed with urolithiasis on ultrasound with evidence of hydronephrosis, were included through non-probability consecutive sampling. CT pyelogram was performed for each patient to assess stone size, location, and Hounsfield Unit (HU). Stone retrieval was followed by histopathological analysis for chemical composition. Data were analyzed using SPSS version 22, and diagnostic accuracy parameters were calculated.

Results: The mean age of patients was 44.24 ± 13.44 years. Histopathology confirmed calcium stones in 71.3% (132/185) of cases. CT pyelogram demonstrated a sensitivity of 92.4%, specificity of 96.2%, positive predictive value of 98.4%, negative predictive value of 83.6%, and overall diagnostic accuracy of 88.1% in determining stone composition.

Conclusion: CT pyelogram proved to be a highly accurate, non-invasive modality for predicting urinary stone composition, with significant clinical value in guiding appropriate treatment strategies for renal and ureteral calculi.

Keywords: Calcium Oxalate, Computed Tomography, Diagnostic Imaging, Hounsfield Unit, Kidney Calculi, Stone Composition, Urolithiasis.

INTRODUCTION

Urolithiasis continues to be a significant burden on healthcare systems worldwide, ranking second only to prostatic diseases among diagnoses at urological centers in Germany as early as 2006 (1). Urinary stones, or uroliths, are pathological biominerals formed through polycrystalline aggregation within the urinary tract of both humans and animals. Unlike physiologically structured biominerals such as bones and teeth, urinary stones arise from complex pathoanatomical and physicochemical processes rather than genetically programmed mineralization (2). Predominantly, these stones are located in the kidneys and ureters, accounting for approximately 97% of all cases, while only a minor fraction occurs in the bladder or urethra (3). Urinary calculi exhibit a wide spectrum of sizes, ranging from microscopic crystals to stones several centimeters in diameter. They frequently remain asymptomatic until causing acute discomfort or being detected incidentally during imaging procedures. Importantly, the mere removal of a stone does not address the underlying etiology, and many individuals experience recurrent episodes (4). These stones are typically of multifactorial origin, influenced by both exogenous and endogenous factors including dietary habits, metabolic disorders, and urinary tract infections. The biochemical composition of urinary stones varies significantly. Calcium oxalate stones dominate the spectrum with a prevalence exceeding 80%, followed by uric acid (13%), calcium phosphate (5%), and struvite stones (5%). Less commonly observed compositions include cystine, ammonium urate, and brushite, each representing less than 1% of cases (5,6). Historical observations by Hildegard of Bingen as early as the 12th century recognized the link between rich dietary intake and stone formation, a perspective that remains relevant given the rising global incidence attributed to modern lifestyle changes and improved diagnostic practices (7,8).

Accurate identification of stone composition is pivotal in guiding appropriate treatment strategies, whether pharmacological, dietary, or surgical. Conventionally, urine pH, crystal analysis, microbiological cultures for urease-positive organisms, and imaging techniques such as plain radiography have served as indirect tools to infer stone type. However, recent advancements have introduced Hounsfield Units (HU) measured via non-contrast computed tomography (NCCT) as a promising predictor of stone composition (9,10). Evidence supports a correlation between HU values and stone types, with calcium-based stones consistently exhibiting higher HU readings. A study involving 101 patients demonstrated that calcium oxalate and hydroxyapatite stones had significantly higher HU values compared to uric acid and cystine stones, with distinct dual-energy CT ratios demarcating each stone type (11). Furthermore, calcium stones typically registered HU values above 448 and densities exceeding 50 HU/mm, thresholds rarely surpassed by non-calcium stones (12). The diagnostic utility of NCCT in detecting calcified calculi is further reinforced by its high sensitivity and specificity, recorded at 97% and 100% respectively, along with a positive predictive value of 100% (13,14). Despite global advancements in stone characterization, there remains a notable gap in localized data, particularly concerning the diagnostic accuracy of CT-based modalities such as CT pyelogram in determining stone composition. Most existing studies are conducted in international contexts, leaving regional urological practices without robust, population-specific evidence to guide clinical decision-making. Therefore, the present study is designed to evaluate the diagnostic accuracy of CT pyelogram in determining the composition of urinary tract stones. Establishing a reliable correlation between CT imaging parameters and stone types could streamline therapeutic choices, reduce the need for invasive procedures, and potentially minimize recurrence rates through more targeted interventions.

METHODS

This descriptive cross-sectional study was conducted at the Department of Radiology, Ziauddin University, Karachi, over a six-month period from August 1, 2024, to January 31, 2025. The objective was to assess the diagnostic accuracy of CT pyelogram in determining the composition of ureteric stones by correlating Hounsfield Unit (HU) values with laboratory-confirmed stone types. The sample size was calculated using a 95% confidence level, an absolute precision of 5%, and a reported proportion of calcium stones as 48.5% (10). Initially, sensitivity and specificity were considered as 97% and 100%, respectively (12); however, due to the resulting impractically large sample size, a revised estimate of 94% for both parameters were used, yielding a final sample size of 185 patients. A non-probability consecutive sampling technique was employed. Patients aged between 18 and 60 years, of either gender, who presented with urolithiasis diagnosed via ultrasound (evidenced by hydronephrosis) and with symptom duration not exceeding four weeks were considered eligible for inclusion. Exclusion criteria included non-consenting individuals, patients with acute kidney injury secondary to trauma, horseshoe-shaped kidneys, congenital renal anomalies, or those undergoing dialysis. The ethical approval for the study was obtained from the

Institutional Review Board and the College of Physicians and Surgeons Pakistan, under the oversight of the Ethical Review Committee of Ziauddin University. All participants were enrolled after obtaining written informed consent. Confidentiality and the voluntary nature of participation were fully explained to each patient.

Upon recruitment, demographic and clinical data including age, educational level, duration of pain, and comorbid conditions such as diabetes mellitus and hypertension were recorded. CT pyelogram was then performed, and stone characteristics including size, location, and HU were documented. Stone retrieval was subsequently carried out as per the clinical treatment plan, and the specimens were submitted to the institutional pathology laboratory for chemical composition analysis using standard spectroscopic methods. These data, along with imaging findings and clinical history, were entered into a structured proforma developed for the study. Statistical analysis was performed using SPSS version 22. Continuous variables such as age, stone size, HU values, and duration of pain were expressed as mean ± standard deviation. Categorical variables, including gender, stone location, educational and residential status, and presence of comorbidities, were presented as frequencies and percentages. Diagnostic accuracy metrics, including sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV), were calculated to evaluate the performance of CT pyelogram in predicting stone composition. Stratification was performed across key variables—such as age, stone size and location, gender, and comorbidities—to control for potential effect modifiers.

RESULTS

A total of 185 patients with urolithiasis diagnosed by ultrasound, showing hydronephrosis, were included in the study. The mean age of the patients was 44.24 ± 13.44 years, the average duration of pain was 2.69 ± 0.80 days, and the mean stone size measured 10.12 ± 4.02 mm. Among all cases, histopathological analysis identified calcium stones in 132 patients, representing a prevalence of 71.3%. In evaluating the diagnostic performance of CT pyelogram, using histopathology as the reference standard, a Hounsfield Unit (HU) cutoff of >448 was used for identifying calcium stones. The CT pyelogram demonstrated a sensitivity of 92.4%, specificity of 96.2%, positive predictive value (PPV) of 98.4%, negative predictive value (NPV) of 83.6%, and an overall diagnostic accuracy of 88.1% for detecting the composition of urinary tract stones. When stratified by age, the diagnostic accuracy of CT pyelogram was 91.1% in patients aged ≤40 years and 95.3% in those older than 40 years. Sensitivity and specificity were 88.7% and 100% in the younger age group and 95.7% and 94.6% in the older group, respectively. Among male participants, diagnostic accuracy was 89.8%, while it reached 98.7% among females. Female patients exhibited higher sensitivity (98.1%) and specificity (100%) compared to males (88.5% and 93.3%, respectively).

Analysis by duration of pain revealed that patients with pain lasting 1–2 days had an accuracy of 92.2%, and those with pain for 3–4 days showed an accuracy of 94.4%. In patients who were illiterate, the diagnostic accuracy dropped slightly to 88.2%, while in those with primary and secondary education levels, the accuracy was 95.6%. Among patients with matriculation or intermediate education, CT pyelogram accuracy was 91.8%. The diagnostic performance also varied slightly between residential settings. Urban residents demonstrated an accuracy of 95.1% with a sensitivity of 94.4% and specificity of 96.9%. Rural participants showed a slightly lower accuracy of 90.4%, with sensitivity and specificity of 88.1% and 95.2%, respectively. Among hypertensive patients, CT pyelogram yielded a perfect sensitivity of 100% and an accuracy of 98.1%. Non-hypertensive patients showed slightly lower sensitivity (89.8%) and accuracy (91.7%). In diabetic patients, all diagnostic performance metrics, including sensitivity, specificity, PPV, NPV, and accuracy, reached 100%, while non-diabetics had a diagnostic accuracy of 91.4%. Regarding stone size, patients with stones ≤10 mm had a diagnostic accuracy of 93.3%, and those with stones >10 mm showed slightly better accuracy at 93.8%. When stratified by stone location, renal stones had an accuracy of 93.6%, ureteric stones 92%, and bladder or urethral stones 95.3%, with all groups showing consistently high sensitivity and specificity values.

Table 1: Demographic Characteristics of Study Participants

Characteristic	Mean	Standard Deviation	Median	IQR	95% CI Lower	95% CI Upper
Age (years)	44.24	13.44	45.00	25	42.29	46.19
Duration of Pain (days)	2.69	0.80	3.00	1	2.57	2.80
Stone Size (mm)	10.12	4.02	9.00	4.0	9.54	10.71

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Table 2: Overall Diagnostic Accuracy of CT Pyelogram

Metric	Percentage (%)
Sensitivity	92.4
Specificity	96.2
Positive Predictive Value (PPV)	98.4
Negative Predictive Value (NPV)	83.6
Accuracy	88.1

Table 3: Diagnostic Accuracy of CT Pyelogram by Age Group

Age Group	Sensitivity	Specificity	PPV	NPV	Accuracy
≤ 40 years	88.7	100.0	100.0	69.6	91.1
> 40 years	95.7	94.6	97.1	92.1	95.3

Table 4: Diagnostic Accuracy of CT Pyelogram by Gender

Gender	Sensitivity	Specificity	PPV	NPV	Accuracy
Male	88.5	93.3	97.2	75.7	89.8
Female	98.1	100.0	100.0	95.8	98.7

Table 5: Diagnostic Accuracy of CT Pyelogram by Comorbidities

Group	Sensitivity	Specificity	PPV	NPV	Accuracy
Hypertensive	100.0	94.4	97.1	100.0	98.1
Non-Hypertensive	89.8	97.1	98.9	77.3	91.7
Diabetic	100.0	100.0	100.0	100.0	100.0
Non-Diabetic	90.7	93.8	98.0	75.0	91.4

Table 6: Diagnostic Accuracy of CT Pyelogram by Stone Size

Stone Size	Sensitivity	Specificity	PPV	NPV	Accuracy
≤ 10 mm	92.9	94.7	97.8	83.7	93.3
> 10 mm	91.2	100.0	100.0	83.3	93.8

Table 7: Diagnostic Accuracy of CT Pyelogram by Stone Location

Location	Sensitivity	Specificity	PPV	NPV	Accuracy
Renal	93.0	95.0	97.1	88.4	93.6
Ureteric	90.2	100.0	100.0	69.2	92.0
Bladder/Urethral	95.0	100.0	100.0	80.0	95.3

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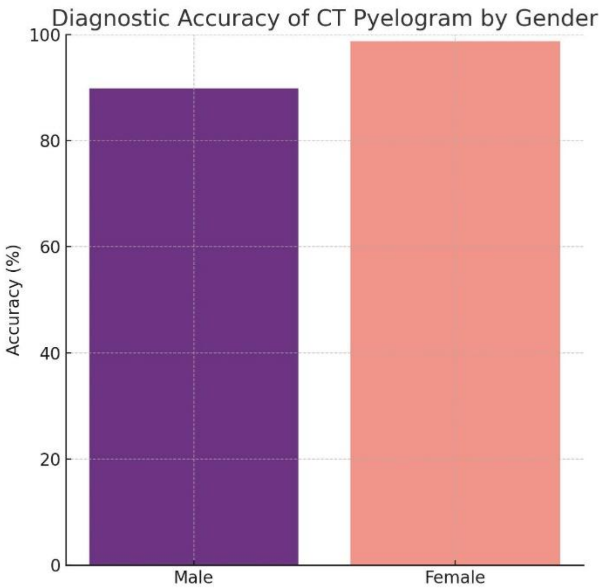

Figure 2 Diagnostic Accuracy of CT Pyelogram by Gender

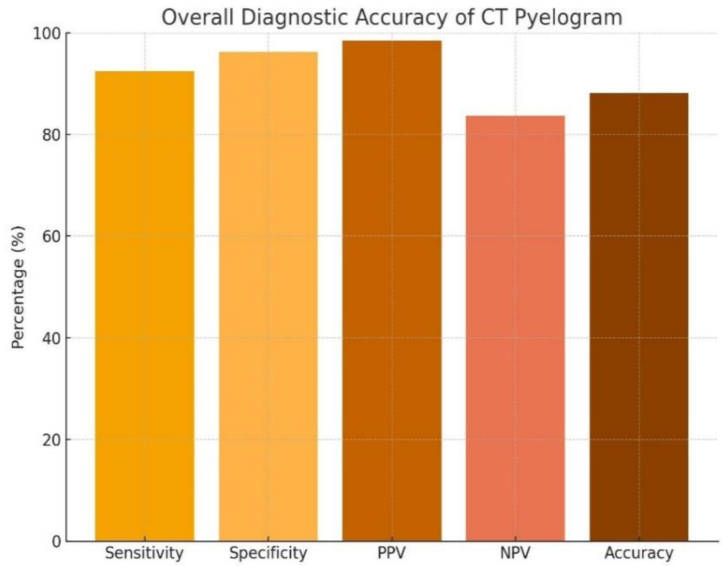

Figure 2 Overall Diagnostic Accuracy of CT Pyelogram

DISCUSSION

Urolithiasis remains a pervasive health issue globally, affecting individuals regardless of race, culture, or geography. In recent decades, its incidence has markedly increased, driven in part by modern lifestyle factors and the growing prevalence of obesity (13,14). The clinical management of urinary tract calculi is influenced by various factors, including stone size, anatomical location, number, and most critically, chemical composition. Accurate pre-treatment identification of stone composition holds significant clinical value, as it directly informs the selection of appropriate therapeutic strategies (15,16). For example, uric acid stones respond favorably to pharmacological dissolution, while calcium oxalate monohydrate and cystine stones exhibit resistance to shock wave lithotripsy (SWL) (17,18). Moreover, determining stone composition aids in guiding long-term preventive strategies, thereby minimizing the risk of recurrence. Historically, prediction of stone composition relied on clinical history, urinary pH, microscopic crystal analysis, identification of urease-positive organisms, and plain radiographic imaging (9,19). With the advent of advanced imaging modalities, non-contrast computed tomography (CT) has emerged as the preferred tool for in vivo assessment of urinary calculi. The evolution of dual-energy CT (DECT) has further enhanced the precision of composition determination (20,21). In this study, the diagnostic accuracy of CT pyelogram in predicting urinary tract stone composition was evaluated against histopathological confirmation, serving as the gold standard. A total of 185 patients, aged 18–60 years and diagnosed with urolithiasis via ultrasound, were assessed. The mean age was 44.24 ± 13.44 years, consistent with prior observations that urinary stones commonly manifest between the third and fourth decades of life (22,23). The study population demonstrated a male predominance (58.38%), aligning with literature that reports a higher prevalence of urolithiasis among men, likely due to gender-based metabolic and anatomical differences, such as lower urinary citrate excretion in males (24).

The findings of this study demonstrated a prevalence of calcium-containing stones at 71.3%, corroborating previous reports where calcium stones represent the majority of cases. CT pyelogram exhibited a sensitivity of 92.4%, specificity of 96.2%, positive predictive value of 98.4%, negative predictive value of 83.6%, and an overall diagnostic accuracy of 88.1% in identifying stone composition. These findings reaffirm the established high diagnostic performance of CT imaging in the evaluation of urolithiasis. CT's superior density resolution allows differentiation of stones even when they are non-calcified, with density variations as low as 0.5% detectable compared to the 5% threshold required by plain radiographs. Previous studies have reported similar high levels of accuracy, sensitivity, and specificity, reinforcing the reliability of CT for diagnostic evaluation, particularly in patients presenting with acute flank pain (23-25). Further comparative literature supports the role of CT attenuation values in differentiating stone types. Studies have shown that CT-based density measurements, particularly when normalized to stone size, serve as strong predictors of stone composition, effectively distinguishing between uric acid and calcium oxalate stones (18,19). Reports have also demonstrated high sensitivity and specificity in identifying uric acid, cystine, and brushite stones, while struvite and hydroxyapatite stones tend to exhibit lower sensitivity but retain high specificity (21). Additional studies have cited accuracy levels of up to 97% in identifying urinary calculi, consistent with the present study's findings (10,13).

The strength of this study lies in its relatively large sample size and comprehensive stratification across various demographic and clinical subgroups. By including subgroup analyses based on age, sex, comorbid conditions, stone size, and location, the study provides robust evidence supporting the generalizability of CT pyelogram across diverse patient profiles. The use of histopathology as the reference standard further strengthens the validity of the diagnostic accuracy assessment. However, several limitations warrant acknowledgment. The study focused exclusively on ureteric stones and did not differentiate diagnostic performance across specific stone subtypes beyond calcium-containing versus non-calcium stones. The absence of dual-energy CT data limited the capacity to analyze uric acid and cystine stones in greater detail, which may have reduced the granularity of compositional categorization. Additionally, no confidence intervals were provided for sensitivity, specificity, and accuracy values, which are essential for statistical robustness. Another limitation was the reliance on a single imaging threshold (HU >448) without internal validation or cross-comparison with alternative cutoff values, which may have led to misclassification in borderline cases. Future research should explore the integration of DECT for enhanced differentiation of stone subtypes, particularly for uric acid, cystine, and struvite stones, which have distinct therapeutic implications. Incorporating biochemical data and metabolic profiling alongside imaging characteristics could further refine diagnostic precision. Moreover, prospective studies with multicenter collaboration may help validate standardized HU thresholds across different populations and imaging platforms. In conclusion, the study reinforces the diagnostic utility of CT pyelogram in evaluating urinary stone composition with high accuracy, particularly for calcium-based stones. Its widespread availability, non-invasiveness, and reliability make it a valuable tool in guiding timely and effective clinical management of urolithiasis. Nonetheless, further advancements in imaging technology and analytical methodologies are essential to achieve comprehensive, non-invasive stone characterization in routine practice.

CONCLUSION

The findings of this study highlight the valuable role of CT pyelography in accurately identifying the composition of urinary tract stones, offering a non-invasive, reliable method that can significantly inform clinical decision-making. By enabling early and precise characterization of stone types, CT enhances treatment planning and supports the selection of the most appropriate therapeutic approach. Its diagnostic contribution not only aids in immediate management but also opens pathways for individualized care aimed at reducing recurrence and improving patient outcomes.

AUTHOR CONTRIBUTION

Author	Contribution
Saadia Ali	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Nasir Ali Rahimnajjad	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Aneeqa Qureshi*	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Anum Naz	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Rafay Gul	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Samita Asad	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published
Syed Hameed-Ul-Hassan Shah	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published

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