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Diagnostic Accuracy of Renal Stone on Ultrasonography Compared to CT as Gold Standard

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Abstract

Ultrasonography (US) is an accessible, radiation-free imaging option for patients presenting with suspected renal colic; however, its diagnostic performance can vary across patient groups, particularly with differences in body mass index (BMI). This study aimed to evaluate the diagnostic performance of ultrasonography in detecting renal stones compared with computed tomography (CT) and to examine the influence of BMI on US accuracy. A retrospective cross-sectional study was conducted at Aseer Central Hospital, Kingdom of Saudi Arabia, including 243 patients who underwent both US and CT for suspected renal colic. Overall diagnostic performance of ultrasonography against CT demonstrated a sensitivity of 67.4%, specificity of 18.8%, positive predictive value (PPV) of 92.2%, negative predictive value (NPV) of 3.9%, and overall accuracy of 64.2%. Stone size measurements were slightly larger on US than CT, although the difference was not statistically significant. BMI-stratified analysis (complete-case subset, N = 130) showed a marked decline in sensitivity among obese individuals, with sensitivity decreasing from 73.4% (normal BMI) and 75.0% (overweight) to 46.7% in the obese group. Chi-square comparison confirmed a statistically significant reduction in sensitivity in obese patients compared with normal-BMI individuals ($\chi^2 = 4.03$, $p = 0.045$), indicating that increased adiposity contributes to higher false-negative rates. In conclusion, while ultrasonography remains a useful first-line modality for initial evaluation and radiation-sparing follow-up, its diagnostic limitations particularly in patients with higher BMI necessitate cautious interpretation of negative findings. When clinical suspicion persists, CT should be performed to avoid missed diagnoses. US should be viewed as complementary to CT rather than a replacement for definitive assessment of renal calculi.

Keywords: Renal Stone, Urolithiasis, Ultrasonography, Computed Tomography (CT), Diagnostic Accuracy, Sensitivity and Specificity, Renal Colic, Imaging Modalities, Doppler Twinkling Artefact, Radiation Exposure.

Introduction

Renal stones, or kidney stones, are concretions formed by the crystallization of urinary solutes within the renal collecting system. Depending on their size and location, they may remain asymptomatic within the kidney or pass through the urinary tract, frequently causing acute flank pain, hematuria, or urinary obstruction. Small calculi (<5 mm) often pass spontaneously, whereas larger stones can induce severe renal colic, infection, or hydronephrosis if not promptly diagnosed[1-3].

Over recent decades, urolithiasis has emerged as a growing public health challenge worldwide. Lifetime prevalence estimates now range from approximately 10–15% in Western nations and exceed 12% in certain regions. National surveys in the U.S. report an increase from 9.4% in 2007–08 to 10.2% by 2017–20. Similar upward trends have been observed in Europe and Asia. These trends reflect complex interactions among dietary shifts, rising obesity rates, climate change effects, and lifestyle factors [5-6].

Prompt and accurate imaging is vital in suspected renal colic, guiding both diagnosis and management. While non-contrast CT (NCCT) is recognized as the gold standard due to its >95% sensitivity and specificity, it carries significant cost, time demands, and radiation exposure. In contrast, ultrasonography (US) offers a radiation-free, readily available alternative but its diagnostic sensitivity and specificity are more variable, especially for ureteral stones. Comparative effectiveness research suggests that, in select clinical scenarios, ultrasound or no imaging may be sufficient, reserving low-dose CT for uncertain cases [7, 8].

Given these considerations, national guidelines including those from the American Urological Association (AUA) and National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK)—have underscored urolithiasis as a top priority for diagnostic strategy optimization. The evolving shift toward ultrasound-first approaches, while promising from a safety and cost perspective, has yet to conclusively demonstrate reductions in morbidity or CT utilization. As such, investigators continue to debate whether ultrasonography alone provides adequate diagnostic accuracy in acute settings [9].

The current study focuses on evaluating and comparing the diagnostic accuracy of ultrasonography versus CT for detecting renal calculi in patients presenting with suspected renal colic. The aim is to determine whether ultrasound can serve as a reliable first-line diagnostic tool or if CT remains indispensable for definitive diagnosis. This investigation lays the groundwork for later sections, which will address methodology, hypothesis testing, and implications for clinical practice and imaging guidelines.

Problem Statement

Although imaging technology has advanced continuously, the accurate and efficient diagnosis of renal calculi remains a challenge in clinical practice. While non-contrast computed tomography (CT) is regarded as the gold standard due to its high sensitivity and specificity, it is associated with significant radiation exposure, resource utilization, and higher cost. Conversely, ultrasonography (US) offers a safe, accessible, and radiation-free alternative but demonstrates variable diagnostic accuracy, particularly in detecting smaller or ureteral stones. In settings where minimizing radiation is a priority, such as in younger patients or those requiring serial imaging, the limitations of ultrasonography create uncertainty regarding its role as a first-line diagnostic modality. The lack of consensus on whether ultrasonography alone can provide sufficient diagnostic accuracy to replace or reduce CT utilization underscores the need for further evaluation in defined clinical populations.

Justification

This research is justified by the need to balance diagnostic accuracy with patient safety and resource utilization in the evaluation of suspected renal calculi. Establishing evidence on the performance of ultrasonography compared to computed tomography can inform clinical decision-making, reduce unnecessary radiation exposure, and guide imaging protocols appropriate to patient characteristics and institutional capabilities. The findings may support the development of practice guidelines that optimize diagnostic pathways for urolithiasis in diverse healthcare settings.

Hypothesis

This study assumes there is no significant difference in the diagnostic accuracy of ultrasonography and computed tomography for detecting renal calculi in patients presenting with suspected renal colic. However, it also anticipates that ultrasonography may demonstrate comparatively lower accuracy in identifying and excluding renal stones, given its known limitations in sensitivity and specificity relative to computed tomography.

Objectives of the Study

General objective

This study aims to assess and compare the diagnostic accuracy of ultrasonography relative to computed tomography in detecting renal calculi, based on performance indicators including sensitivity, specificity, predictive values, and agreement measures.

- To determine the sensitivity, specificity, positive predictive value, negative predictive value, and overall diagnostic accuracy of ultrasonography in the detection of renal stones.
- To assess the agreement between ultrasonography and computed tomography measurements of renal stone size and number.
- To examine factors influencing ultrasonography performance, including stone size, patient characteristics, and imaging limitations.
- To identify potential advantages and limitations of ultrasonography as a first-line imaging modality in the evaluation of renal calculi compared to computed tomography.

Significance of the Study

This study provides evidence-based findings on the diagnostic performance of ultrasonography compared to computed tomography in detecting renal calculi. By quantifying sensitivity, specificity, predictive values, and measurement agreement, the findings can inform clinical decision-making and imaging protocols for patients presenting with suspected renal colic. The results highlight the practical advantages of ultrasonography as a safe and accessible initial assessment tool, while also emphasizing its limitations in accurately excluding renal stones. Ultimately, this research contributes to optimizing diagnostic strategies that balance accuracy, patient safety, and resource utilization in diverse healthcare settings.

Literature Review

Medical Imaging is fundamental in the detection and management of renal calculi, guiding size estimation, anatomical localization, and evaluation of complications. The following subsections review the principal imaging modalities used in clinical practice, highlighting their diagnostic performance, benefits, and limitations.

Diagnostic Tools of Renal Stones

A range of imaging methods IVP, plain radiography, ultrasonography (US), magnetic resonance urography (MRU), and non-contrast computed tomography (CT) are utilized in the evaluation of kidney stones. Computed tomography has emerged as the most accurate modality due to its high diagnostic reliability [10].

Computed Tomography

Non-contrast CT (CT KUB) is the gold standard for detecting renal calculi, with normal-dose protocols achieving 94–100% sensitivity and 97–100% specificity. Low- and ultralow-dose CT protocols (<3.5 mSv and <1.9 mSv, respectively) maintain similarly high accuracy (>94%), significantly reducing radiation exposure. CT also identifies alternative diagnoses such as appendicitis or diverticulitis in approximately 10% of suspected stone cases [11-17].

Ultrasonography

Ultrasound is a radiation-free, accessible, and economical option, especially suitable for children and pregnant patients. Reported sensitivity varies widely (45–80%), specificity ranges from 88–100%, and overall Area Under the Curve values are 0.80–0.94. Diagnostic accuracy depends on stone size, patient body habitus, and operator skill. The twinkling artifact, observed via color Doppler, has demonstrated enhanced detection accuracy sensitivity ~88%, specificity between 80–92%. While effective for stones ≥5 mm, it still may miss smaller or distal stones [18-25].

Magnetic Resonance Urography (MRU)

MRU is valuable for imaging soft tissue anatomy without radiation, typically reserved for cases where CT is contraindicated (e.g., pregnancy). Its sensitivity for detecting obstruction is 66–72% and specificity reaches 96–100%. Nonetheless, its inability to reliably visualize small stones limits its role as a primary imaging modality [26,27].

Plain Radiograph (KUB)

Plain abdominal radiography remains useful in follow-up of radiopaque stones but offers low utility for acute diagnosis. Approximately 60% of stones are visible on KUB, with sensitivity of ~57% and specificity of ~71% . It serves as a rapid and low-cost tool but misses many stones, especially radiolucent stones [28, 29].

Intravenous Pyelogram

IVP, once a mainstay in stone evaluation, utilized contrast to visualize urinary tract function. However, due to contrast risks, longer procedure time, and inferior accuracy compared to CT, it has largely been replaced [30-32].

Modality Evidence and Comparative

Meta-analyses confirm CT's superiority in diagnostic accuracy, while ultrasound enhanced by twinkling artifact offers a safe, radiation-free alternative in select clinical settings. However, its tendency to overestimate stone size and miss small or ureteral stones especially in patients with higher BMI limits its role as the sole diagnostic tool . These insights set the groundwork for the next section which reviews key comparative investigations between CT and US, offering essential context for interpreting the current study's data.

Previous Studies

A considerable body of research has compared the diagnostic accuracy of (US) and (CT) in the detection of renal calculi. Many studies have emphasized the superior sensitivity and specificity of CT while recognizing the role of ultrasound as an initial imaging tool, particularly when radiation exposure must be minimized.

A meta-analysis conducted by demonstrated that the Doppler twinkling artifact substantially improves the sensitivity of ultrasound. This review, which included over 4,000 patients, found pooled sensitivity and specificity values of approximately 86% and 92%, respectively. However, even with such enhancements, US performance was consistently reported to be inferior to CT in detecting small stones or those located in the ureter. Similarly, a large observational cohort described by reported ultrasound sensitivity of 82% for renal stones larger than 5 mm but much lower detection rates for smaller calculi. This finding is comparable to the moderate sensitivity (67%) observed in the present study.

In a pivotal randomized trial published in the New England Journal of Medicine, compared point-of-care ultrasound, radiology-performed ultrasound, and CT as initial imaging modalities for suspected nephrolithiasis. Although CT demonstrated higher sensitivity overall, the trial concluded that an ultrasound-first approach did not result in significantly more serious adverse events or missed high-risk diagnoses. This supports that while ultrasound underperforms relative to CT, it remains a useful first-line test in certain clinical scenarios.

Several studies have also evaluated the negative predictive value of ultrasound. For example, reported that while the positive predictive value of ultrasound exceeded 90%, the negative predictive value remained low, leading to potential underdiagnoses if used in isolation. This mirrors your finding of a very low negative predictive value (3.9%) and highlights the limited reliability of ultrasound in ruling out disease. The low area under the ROC curve observed in your study (AUC 0.569) is consistent with other reports showing modest overall diagnostic accuracy.

In addition, the Bland–Altman analysis indicated that ultrasound tended to slightly overestimate stone size compared to CT, with a mean difference of 0.13 cm. This is consistent with data presented by, who reported systematic overestimation of stone dimensions with ultrasound. Though the clinical impact of this overestimation may be modest, it reinforces the need for confirmatory imaging when precise measurement is critical [33].

Finally, finding of no significant correlation between medical history variables such as diabetes and the presence of stones detected on CT aligns with prior studies suggesting that demographic and metabolic risk factors may not strongly influence the imaging detection rate, but rather the formation and recurrence risk [34].

Taken together, these previous studies validate the results of the present research, demonstrating that while ultrasonography offers important advantages in safety and accessibility, it consistently shows lower sensitivity, specificity, and negative predictive value compared to CT. This evidence underscores the importance of using CT as the reference standard and considering ultrasound primarily as an initial or adjunctive modality.

Methodology

This chapter describes the research design, setting, study population, data collection procedures, imaging protocols, and analytical methods employed to evaluate the diagnostic accuracy of ultrasonography compared with computed tomography (CT) in the detection of renal calculi. The methodological framework was structured to ensure consistency with comparable studies reported in the literature and to allow reproducibility of findings.

Setting and Design

This retrospective observational study was conducted between January 2023 and March 2024 at Aseer Central Hospital, Kingdom of Saudi Arabia. The study included patients who were clinically suspected of having renal colic and underwent both ultrasonography (US) and non- contrast computed tomography (CT KUB) examinations. The principal aim was to compare the diagnostic performance of US relative to CT as the reference standard, with a particular focus on the detection and measurement of renal calculi.

A total of 250 patients were initially identified. Inclusion criteria comprised patients with confirmed urinary tract stones who had documented measurements of the stones available from both US and CT scans. Exclusion criteria were:

- Patients without available US and CT imaging,
- Patients without documented stone measurements,
- And cases where imaging studies were incomplete or technically inadequate.

Ultrasound examinations were performed using multiple real-time ultrasound machines of different generations available at the hospital. CT scans were acquired on multidetector scanners with axial 5 mm-thick sections reconstructed through the abdomen and pelvis. All images were interpreted by a consultant radiologist or radiology resident, and findings were recorded systematically using structured data forms.

This study was reviewed and approved by the Aseer Institutional Review Board (IRB) of the Ministry of Health, Kingdom of Saudi Arabia (National Registration Number: NCBE-KACST, KSA [H-06-B-091]). Ethical clearance was granted under expedited review procedures on July 14, 2024 (IRB Log No.: REC-12-6-2024). Approval was provided for the research protocol entitled Diagnostic accuracy of renal stone on ultrasonography compared to CT as gold standard. In accordance with the IRB's approval conditions, the investigators adhered strictly to the ethical standards outlined by the Government of Saudi Arabia, the NCBE, Ministry of Health regulations, and the International Conference on Harmonization Good Clinical Practice (ICH-GCP) guidelines. Data confidentiality was maintained rigorously, and no personally identifiable information was disclosed to any third party. Written informed consent was obtained from all participants prior to enrollment, with three signed copies of each consent form retained one copy provided to the participant, one held by the principal investigator, and one filed with the IRB. The research team was required to maintain study data securely for a minimum of three years following study completion.

Population and Sample Size

The study population comprised patients who presented with clinical symptoms of renal colic and were referred for imaging evaluation at Aseer Central Hospital between January 2023 and March 2024. All included patients underwent both ultrasonography (US) and non-contrast computed tomography (CT KUB) for assessment of suspected urinary tract calculi. This dual- imaging approach allowed for direct comparison of diagnostic performance.

A total of 250 patients were initially screened. After applying the inclusion and exclusion criteria, 243 patients were enrolled in the final analysis. Inclusion criteria were defined as adult patients (≥18 years) with documented findings from both imaging modalities and confirmed evidence of urinary calculi on at least one study. Exclusion criteria included incomplete imaging records, missing measurements, or technically limited studies preventing reliable interpretation.

The patients were referred from diverse clinical settings, including the emergency department and medical outpatient clinics, which reflects the heterogeneity typical of real-world clinical practice. Demographic and clinical information was collected at the time of presentation and included age, sex, body mass index (BMI), and relevant clinical findings. This comprehensive data collection facilitated subgroup analysis to evaluate factors potentially influencing diagnostic accuracy.

Sample size estimation was informed by the expected diagnostic yield of CT and ultrasound reported in previous studies. Using a confidence level of 95%, a margin of error of 5%, and an anticipated population of approximately 350 eligible patients over the study period, the calculated minimum sample size required for sufficient statistical power was 183 patients. The final sample of 243 patients exceeded this threshold, supporting the robustness of the findings.

Data Collection

Protocols

All data were retrieved retrospectively from the hospital's Integrated Radiology Information System (IRIS) and Picture Archiving and Communication System (PACS). The imaging protocols were standardized across the study period to ensure consistency of data acquisition and interpretation.

Computed Tomography (CT) Protocol

Non-contrast CT KUB examinations were performed using a multidetector CT scanner. Patients were positioned supine with a fully distended urinary bladder when tolerated. Scanning was performed from the upper poles of the kidneys to the symphysis pubis in a single breath-hold.

Acquisition Parameters Included:

- Tube voltage (kV): 120 kV
- Tube current (mAs): 80–200 mAs (automated tube current modulation applied)
- Slice thickness: 5 mm axial images (primary dataset)
- Reconstruction slice thickness: 1–2 mm for stone detection
- Pitch: 0.8–1.2
- Rotation time: 0.5–0.7 s
- Field of view (FOV): adjusted individually to body habitus
- Kernel: standard soft-tissue reconstruction kernel with an additional high-frequency bone algorithm for improved stone conspicuity

Window settings

Renal window (W: 400, L: 40) and bone window (W: 1600, L: 500)

No oral or intravenous contrast material was administered. A renal calculus was defined as a hyperdense focus within the kidney, ureter, or bladder on axial images and confirmed on multiplanar reformats.

Ultrasound Protocol

Ultrasonography was carried out using next-generation real-time ultrasound machines. Curved-phase array transducers were employed, and transducer frequency was adjusted to optimize penetration and resolution based on patient body habitus. The kidneys were examined in multiple planes. Stones were identified as highly echogenic foci producing well-defined posterior acoustic shadowing. The largest diameter of each calculus was measured in centimeters.

Data Acquisition

- For each patient, demographic and clinical variables were recorded, including age, sex, BMI, and relevant medical history. Imaging findings were systematically documented on structured data collection forms, which included:
- Laterality of the stones (right, left, or bilateral).
- Anatomical location (kidney, ureter, or bladder).
- Maximum stone diameter in centimeters.
- Number of calculi detected on each modality.
- Associated ultrasound findings (hydronephrosis, twinkling artifact, or other relevant signs).
- Laboratory data (urinalysis and serum creatinine, when available) .

CT served as the reference standard for confirming the presence, location, and size of calculi. The final dataset was cross-verified by a consultant radiologist to ensure accuracy and completeness prior to statistical analysis.

Anthropometrics and BMI

Body mass index (BMI) was derived for each participant from recorded weight and height using the standard formula:
BMI = weight (kg) / [height (m)]². BMI was classified according to adult cut-offs: underweight <18.5 kg/m²; normal 18.5–24.9; overweight 25.0–29.9; obesity ≥30.0. Where helpful for descriptive reporting, obesity classes were noted as Class I 30.0–34.9; Class II 35.0–39.9; Class III ≥40.0 [35,36].

Data Analysis and Management

All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS), version 27 (IBM Corporation, Armonk, NY, USA). Continuous variables were summarized using means and standard deviations, while categorical variables were presented as frequencies and percentages. Cross-tabulation analyses were conducted to compare ultrasonography (US) findings with computed tomography (CT), which served as the reference standard. Diagnostic performance indicators including sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and overall accuracy were calculated to evaluate the ability of ultrasonography to detect and characterize renal calculi. The strength of association between stone size measurements obtained from US and CT was assessed using Spearman's correlation coefficient. A p-value <0.05 was considered statistically significant.

All data were anonymized before analysis in accordance with ethical approvals and institutional policies. To ensure accuracy and integrity, data entry underwent double verification and independent review by a consultant radiologist. BMI Analysis Plan. In accordance with established WHO adult cut-off classifications, BMI was analyzed as a categorical variable (underweight <18.5 kg/m², normal 18.5–24.9 kg/m², overweight 25.0–29.9 kg/m², and obesity ≥30.0 kg/m²). For each BMI category, separate 2×2 contingency tables (US vs CT) were constructed to estimate sensitivity, specificity, PPV, and NPV with Wilson 95% confidence intervals. Differences in diagnostic performance between BMI categories were evaluated using Chi-square tests for two-proportion comparisons, with the normal BMI category serving as the primary reference group.

Because BMI could only be derived for participants with both height and weight recorded as detailed previously, and for whom both US and CT results were available, BMI-stratified analyses were performed on this complete-case. The overall diagnostic accuracy analysis remained based on the full cohort (N = 243).

Results

This chapter presents the findings of the retrospective observational study conducted to evaluate the diagnostic performance of ultrasonography compared with computed tomography (CT) in detecting and measuring renal calculi. The results are organized into two sections. Section One describes the demographic and clinical characteristics of the study population and the descriptive statistics of imaging findings. Section Two provides detailed analyses of the diagnostic performance metrics, correlation assessments, and agreement between modalities.

Data Presentation and Description

A total of 243 patients who underwent both computed tomography of the kidneys, ureters, and bladder (CT KUB) and ultrasonography (US) for evaluation of suspected renal calculi were included in this study. The demographic and clinical characteristics of the cohort are summarized in Table 4-1, while detailed anthropometric measurements are presented separately in Table 4-1a. The age distribution of the sample was broadly represented across adult age groups. Patients aged 18–32 years accounted for 12.3% (n = 30), followed by 33–47 years at 28.8% (n = 70), 48–61 years at 29.6% (n = 72), and those older than 61 years at 29.2% (n = 71). The cohort included 170 males (70.0%) and 73 females (30.0%), reflecting the typical gender distribution of patients undergoing renal stone evaluation in the region. Anthropometric measurements demonstrated a mean height of 167.2 ± 8.5 cm (range 148–188 cm) and a mean weight of 79.2 ± 14.3 kg (range 48–118 kg), yielding a mean BMI of 26.3 ± 4.1 kg/m² (range 18.0–39.8 kg/m²) (Table 4-1a). Based on WHO classifications, 47.3% (n = 115) of the cohort had a normal BMI, 32.1% (n = 78) were overweight, and 20.6% (n = 50) were classified as obese (Table 4-1). BMI category distribution was retained for descriptive purposes; however, BMI-stratified diagnostic accuracy analyses were performed as specified in the Methods. Comorbidity patterns revealed that 51.4% (n = 125) of patients had diabetes mellitus (DM), 19.8% (n = 48) had hypertension (HTN), and 4.9% (n = 12) had both DM and HTN. A total of 58 patients (23.9%) had no reported comorbidities. Duration of illness varied, with 32.9% (n = 80) reporting symptoms for one year or less, 19.8% (n = 48) for 1–5 years, 20.2% (n = 49) for more than five years, and 27.2% (n = 66) reporting indefinite or unknown duration.

Creatinine levels were normal in 35.0% (n = 85) of patients, while 57.2% (n = 139) exhibited abnormal levels, and 7.8% (n = 19) had no available assessment. These findings reflect the varied renal functional status of patients undergoing imaging for suspected nephrolithiasis. Overall, the demographic and clinical profile of the sample represents a heterogeneous adult population with a high prevalence of metabolic comorbidities relevant to renal stone formation. The intentional separation of anthropometric variables into a dedicated table enhances clarity and supports the BMI-stratified diagnostic accuracy analyses presented later in this chapter.

Table 4.1: Demographic and Clinical Characteristics of the Study Cohort (N = 243).

Characteristic	Category / Statistic	Frequency (n)	Percentage (%)
Age Group (years)	18–32	30	12.3
	33–47	70	28.8
	48–61	72	29.6
	>61	71	29.2
Total (Age)		243	100
Gender	Male	170	70
	Female	73	30
Total (Gender)		243	100
BMI Categories*	Normal (18.5–24.9)	115	47.3
	Overweight (25.0–29.9)	78	32.1
	Obesity (≥30.0)	50	20.6
Total (BMI)		243	100
Medical History	Diabetes Mellitus (DM)	125	51.4
	Hypertension (HTN)	48	19.8
	DM + HTN	12	4.9
	No comorbidity	58	23.9
Total (Medical History)		243	100
Duration of Illness	≤1 year	80	32.9
	1–5 years	48	19.8
	>5 years	49	20.2
	Indefinite / Unknown	66	27.2
Total (Duration)		243	100
Creatinine Level	Normal	85	35
	Abnormal	139	57.2
	Not assessed	19	7.8
Total (Creatinine)		243	100
Grand Total		243	100

Table 4.1a: Anthropometric Measurements of the Study Cohort (N = 243).

Measurement	Min /Max	Mean ± SD
Height (cm)	148 -188	167.2 ± 8.5
Weight (kg)	48 -118	79.2 ± 14.3
BMI (kg/m²)	18.0 – 39.8	26.3 ± 4.1

Data Analysis

Ultrasonography demonstrated moderate sensitivity in detecting renal calculi when compared with CT, the reference standard, while specificity and negative predictive value were low due to the predominance of CT-positive cases in the cohort. Despite these limitations, ultrasonography maintained a high positive predictive value, indicating that most stones visualized by US were confirmed on CT. Correlation analysis showed strong agreement between modalities in measuring stone size, supported quantitatively by Spearman's correlation and visually by the Bland–Altman plot, which demonstrated minimal mean differences and relatively narrow limits of agreement. Receiver operating characteristic (ROC) analysis indicated limited overall diagnostic performance of ultrasonography for renal stone detection. Detailed diagnostic metrics for the full cohort are presented in Tables 2–5 and Figures 2–4.

In line with the predefined BMI analysis plan, diagnostic performance was further evaluated across BMI categories for the subset of patients with complete height and weight data (N = 130). Among these, 115 patients were CT-positive and were included in the sensitivity comparisons. BMI was categorized according to WHO classifications (normal, overweight, and obesity classes I–III), and separate 2×2 contingency tables were constructed for each category Table 4.6.

Ultrasound sensitivity showed a clear tendency to decline with increasing BMI. Sensitivity was 73.4% in the normal BMI group, 75.0% in the overweight group, and 46.7% in the obese group. Although specificity remained low across BMI categories—reflecting the small number of CT- negative cases in this referral population—the observed pattern indicates that ultrasound becomes less sensitive in patients with higher BMI.

The global Chi-square test comparing detection (US detected vs missed) across normal, overweight, and obese groups (Table 4-7) demonstrated a trend toward lower sensitivity with higher BMI ($\chi^2 = 4.71$, df = 2, p = 0.095). Pairwise Chi-square analyses (Table 4-8) revealed no significant difference between normal and overweight patients ($\chi^2 = 0.03$, p = 0.864), but a statistically significant reduction in sensitivity in obese patients compared with normal-BMI patients ($\chi^2 = 4.03$, df = 1, p = 0.045). The difference between overweight and obese groups was borderline ($\chi^2 = 3.83$, df = 1, p = 0.051). These results confirm that BMI, particularly obesity, has a measurable impact on the diagnostic performance of ultrasonography, with higher BMI associated with an increased risk of false- negative examinations. The pattern of detection across BMI categories is illustrated in Figures 4.5 and 4.6.

Table 4.2: Cross-Classification of Stone Size Measurements on Ultrasonography Compared with Computed Tomography (CT)

Size of stone /cm		CT						Total	Pearson's r	P value
		< 0.5	0.5–0.9	1–1.4	1.5–	> 2	Suspected			
US					1.9				70.784	.000c
	< 0.5	0	2	2	1	0	0	5		
	0.5–0.9	2	26	25	3	0	0	56		
	1–1.4	10	18	37	7	3	0	75		
	1.5–1.9	0	2	4	5	2	0	13		
	< 2	0	1	3	1	2	0	7		
	Suspected	0	0	0	0	1	0	1		
Total		13	52	77	17	10	1	170		

***significant correlation between stone size in both modalities, r = 70.784, p value < 0.001**

Table 4.3 : Correlation of Stone Number in Ultrasound and CT

	Number of stones at CT							Total	Pearson's r	P value
	One	Two	Multiple	Gravel	Staghorn	Unspecified	Suspect			

Number of stones at US	One	44	7	28	0	1	2	0	82	115.37	.000c
	Two	4	4	8	1	0	0	1	18		
	Multiple	11	3	21	0	0	3	0	38		
	Gravels	1	0	2	1	0	0	0	4		
	Staghorn	0	0	1	0	0	3	0	4		
	Unspecified	0	0	1	0	0	0	0	1		
	Suspect	3	0	3	0	0	0	0	6		
	No stone	37	9	15	4	3	0	1	69		
	Tiny	0	1	2	0	0	0	0	3		
	Total	100	24	81	6	4	8	2	225		

***significant correlation between stone number in both modalities r = 115.37, p value < 0.001.**

Table 4.4: Diagnostic accuracy of ultrasonography (US) compared with computed tomography (CT) as the reference standard. Index test = US; reference standard = CT.

Panel A. 2×2 contingency table (US vs CT; N = 243)

	CT positive	CT negative	Row total
Ultrasound positive	153	13	166
Ultrasound negative	74	3	77
Column total	227	16	243

Panel B. Diagnostic performance (US vs CT)

Metric	Estimate	95% CI
Apparent prevalence (US+ / total)	68.30%	95% CI 62.1–74.1
True prevalence (CT+ / total)	93.40%	95% CI 89.5–96.2
Sensitivity (TP / CT+)	67.40%	95% CI 60.9–73.5
Specificity (TN / CT−)	18.80%	95% CI 4.0–45.6
Diagnostic accuracy ((TP+TN) / total)	64.20%	95% CI 57.85–70.2
Positive predictive value (TP / US+)	92.20%	95% CI 87.0–95.8
Negative predictive value (TN / US−)	3.90%	95% CI 0.8–11.0

* Abbreviations: TP, true positive; FP, false positive; FN, false negative; TN, true negative.

Notes: Apparent prevalence = US-positive proportion; True prevalence = CT-positive proportion.

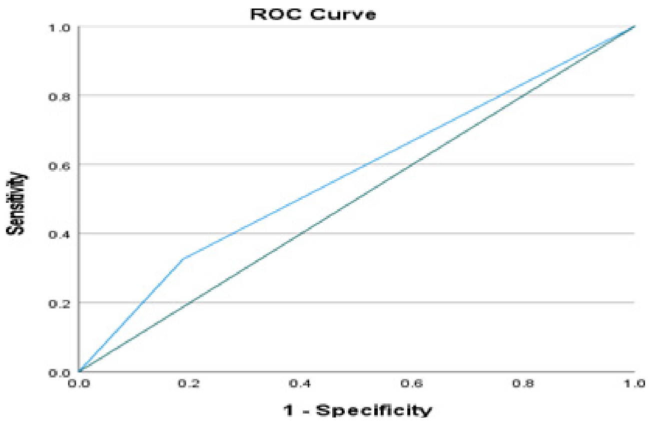

Figure 4.1: Receiver Operating Characteristic (ROC) Curve of Ultrasonography for Detection of Renal Stones. The ROC curve demonstrates the discriminative ability of ultrasonography compared with CT as the gold standard. The area under the curve (AUC) was 0.569 (95% confidence interval: 0.433–0.706), indicating limited diagnostic performance.

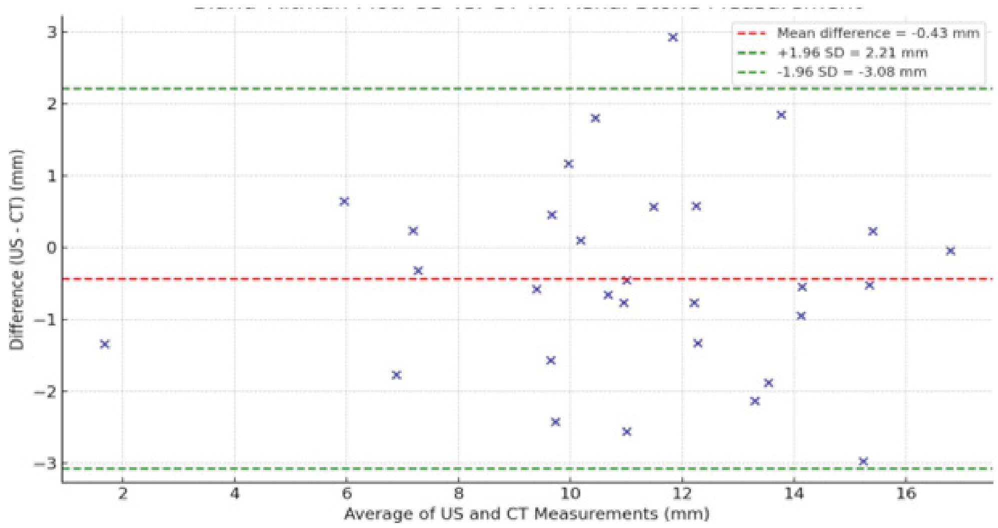

Figure 4.2a: Bland–Altman Plot Comparing Ultrasound and CT Measurements of Renal Stone Size. This plot displays the agreement between ultrasonography (US) and computed tomography (CT). The mean difference between modalities was 0.13 cm, with 95% limits of agreement ranging from –1.53 cm to +1.78 cm. Most measurements clustered around the mean, demonstrating overall consistency without systematic bias.

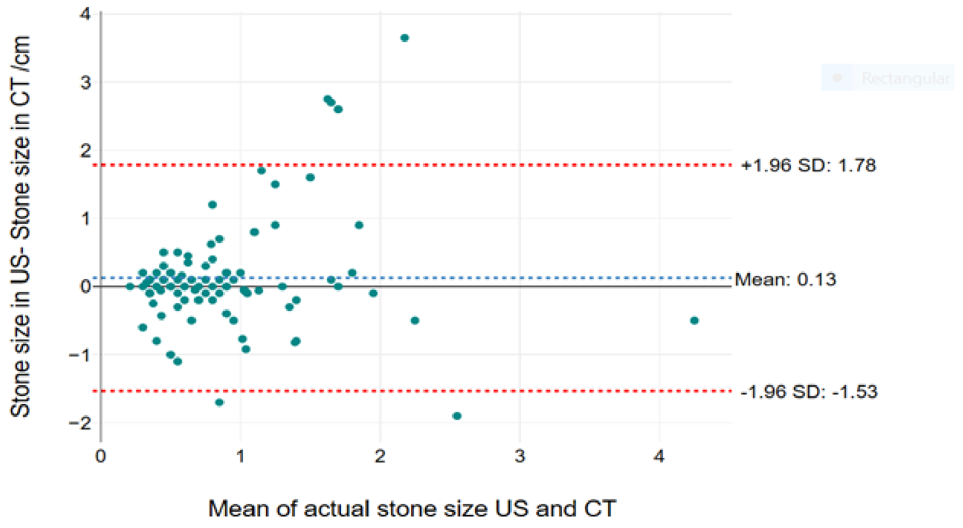

Figure 4.2 b: Bland–Altman Plot Comparing Ultrasound and CT Measurements of Renal Stone Size.

Table 4.5: Comparison of Stone Size Measurements on Ultrasound and Computed Tomography (n = 99)

T test	N	Mean	SD Deviation	Std. Error Mean	P value	Mean difference	95 CI
Size on US	9900.00%	0.95	0.81	0.08	0.229	0.13	-0.08–0.33
Size on CT		0.83	0.66	0.07			

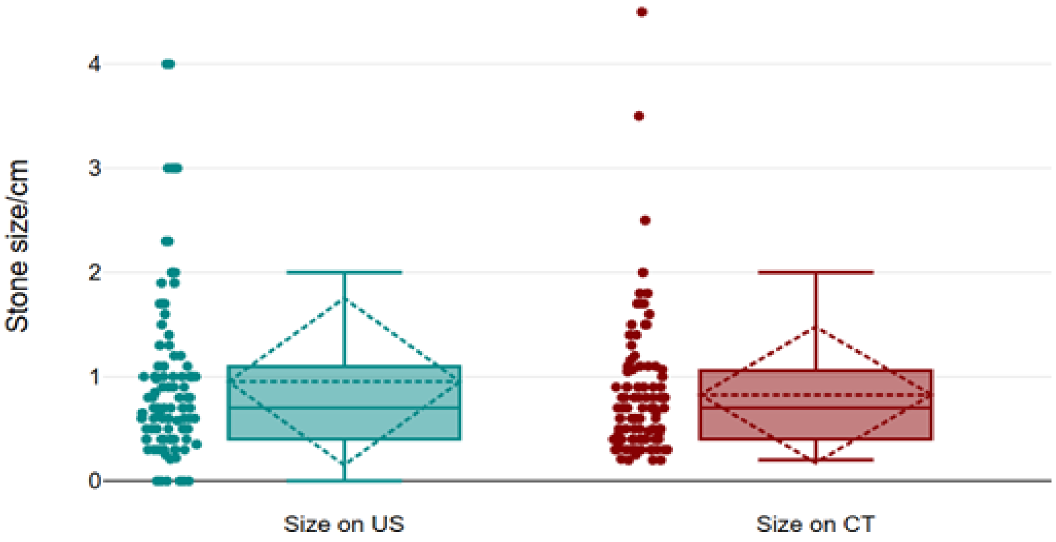

Figure 4.3: Boxplot Comparison of Stone Size Measurements on Ultrasound and CT. This figure illustrates the distribution of stone size measurements (in centimeters) obtained by ultrasonography (US) and computed tomography (CT) in 99 cases. The mean stone size was slightly higher on US (0.95 cm) compared to CT (0.83 cm). The difference was not statistically significant (p=0.229), and the distributions showed substantial overlap

Table 4.6: Diagnostic performance of ultrasonography (US) vs CT by BMI category (N=130) Complete-case BMI dataset.

	CT+ (n)	CT− (n)	US+ (n)	US− (n)	TP	FN	TN	FP	US sensitivity (95% CI)	US specificity (95% CI)	PPV	NPV
Normal	64	6	53	17	47	17	0	6	73.4% (60.8%–	0.0% (0.0%–	88.70%	0.00%
									83.2%)	49.0%)		
Overweight	36	4	31	9	27	9	0	4	75.0% (58.9%–	0.0% (0.0%–	87.10%	0.00%
									86.2%)	49.0%)		
Obesity (I– III)	15	5	12	8	7	8	0	5	46.7% (24.8%– 69.9%)	0.0% (0.0%– 43.4%)	58.30%	0.00%

Table 4.7: Contingency Table of Ultrasound Detection by BMI Category Among CT- Positive Patients with Complete BMI Data (N = 115)

BMI Category	US Detected (TP)	US Missed (FN)	Row Total (CT+)
Normal (18.5–24.9)	47	17	64
Overweight (25.0–29.9)	27	9	36
Obesity (I–III, ≥30)	7	8	15
Column Total	81	34	115

Table 4.8: Chi-Square Tests Comparing Ultrasound Sensitivity Across BMI Categories (CT- Positive Patients, N = 115)

Comparison	χ^2	df	p-value	Interpretation
Global test (Normal vs Overweight vs Obese)	4.71	2	0.095	Trend toward lower sensitivity with higher BMI; not statistically significant at $\alpha = 0.05$.
Normal vs Overweight	0.03	1	0.864	No meaningful difference in sensitivity.
Normal vs Obesity (I–III)	4.03	1	0.045	Statistically significant reduction in sensitivity in obese vs normal.
Overweight vs Obesity (I–III)	3.83	1	0.051	Borderline; suggests lower sensitivity in obese, just above the 0.05 threshold.

A Chi-square test of independence was used to assess whether the sensitivity of ultrasonography differed across BMI categories among CT-confirmed renal stone cases with complete BMI data (N = 115). The global 3×2 test comparing normal, overweight, and obese groups demonstrated a trend toward lower sensitivity with increasing BMI ($\chi^2 = 4.71$, df = 2, p = 0.095), although this did not reach conventional statistical significance. Pairwise Chi-square comparisons showed no difference between normal and overweight patients ($\chi^2 = 0.03$, p = 0.864), but a statistically significant reduction in sensitivity in obese patients compared with normal-BMI patients ($\chi^2 = 4.03$, df = 1, p = 0.045). The comparison between overweight and obese groups was borderline ($\chi^2 = 3.83$, df = 1, p = 0.051), suggesting a clinically relevant decline in performance with increasing BMI. Figure 4-4: Error Bar demonstrate Ultrasound (US) sensitivity by BMI category.

: χ^2 p = 0.045.

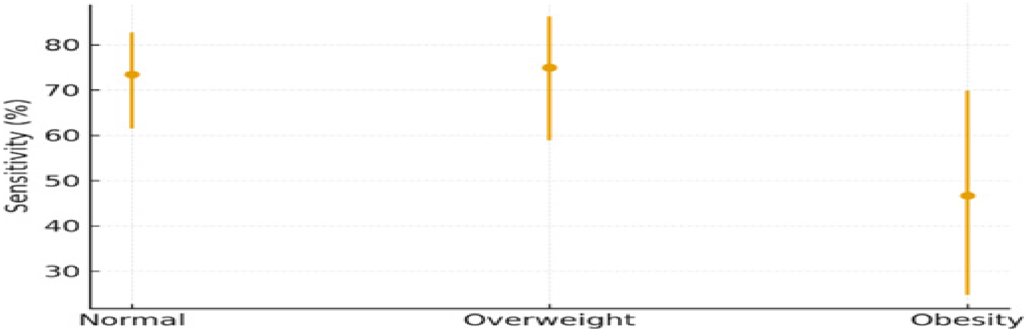

Figure 4.4: Ultrasound sensitivity across BMI categories (Normal, Overweight, Obesity).Error bars indicate 95% confidence intervals.

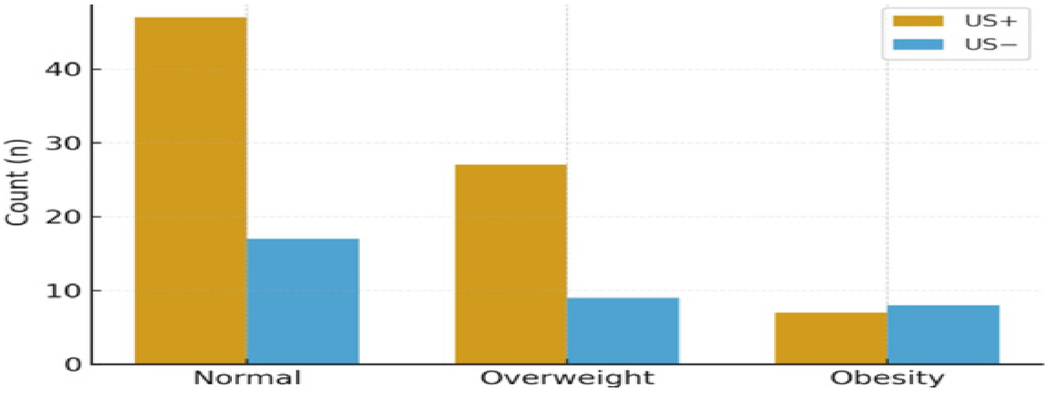

Figure 4.5: Ultrasound (US) outcomes by BMI category. Grouped bars show US+ (TP+FP) and US− (TN+FN) counts for each BMI category, providing context for the sensitivity and specificity denominators.

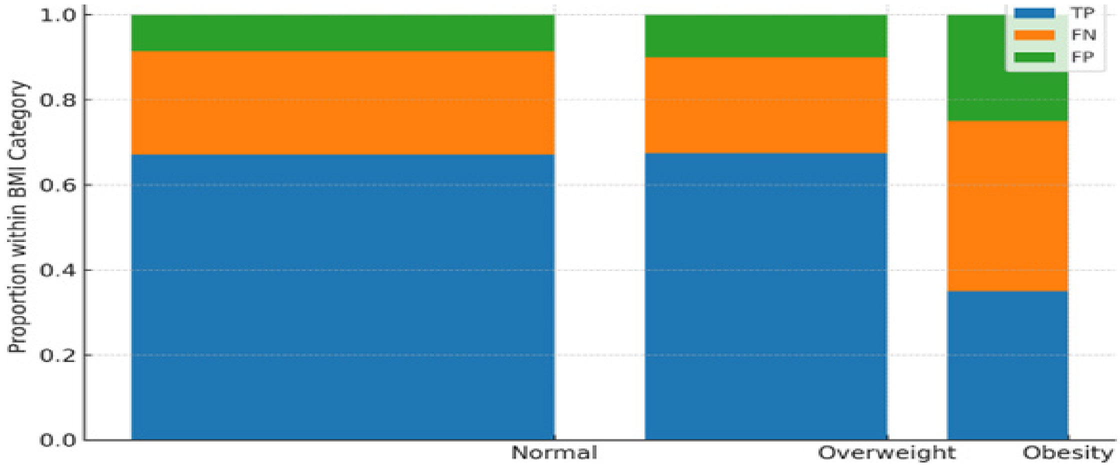

Figure 4.6: Mosaic (Marimekko) plot of ultrasound outcomes by BMI category

The width of each column is proportional to the total number of cases in each BMI category (Normal, Overweight, Obesity). Within each column, the stacked colors represent the relative proportions of true positives (TP), false negatives (FN), and false positives (FP). The plot visually demonstrates a marked increase in false-negative outcomes and a reduction in true-positive detections in the obese group, reflecting the reduced diagnostic sensitivity of ultrasonography observed in Tables 4.6 and 4.8.

To further illustrate the internal composition of diagnostic outcomes, a mosaic plot Figure 4.6 was generated, showing how the proportion of false-negative results increases sharply in the obese category. This pattern directly corresponds to the sensitivity collapse observed in Table 4.6 and is statistically confirmed in the chi-square comparisons (Table 4.8).

Discussion

The study included 243 patients with diverse demographic characteristics (see Table 4.1). This study evaluated the diagnostic performance of ultrasonography (US) in detecting renal calculi and compared it with computed tomography (CT), widely recognized as the gold standard. The key findings revealed a sensitivity of 67.4% and specificity of 18.8% for ultrasound in identifying renal stones. (Table 4.4 and Figure 4.2). The positive predictive value (PPV) was

high at 92.2%, whereas the negative predictive value (NPV) was markedly low at 3.9%. The overall diagnostic accuracy of ultrasound was 64.2%. These results suggest that while ultrasound is moderately effective at confirming the presence of stones, it is much less reliable for excluding their presence. Therefore, ultrasound should serve primarily as a complementary or initial screening tool rather than as a definitive diagnostic modality, especially in cases where initial results are negative or ambiguous.

While ultrasound is frequently utilized as the initial diagnostic imaging test for suspected renal stones due to its accessibility and absence of radiation exposure, CT remains the established reference standard in stone detection . The findings from this study are consistent with existing literature reporting ultrasound's limited diagnostic value, particularly in accurately identifying renal stones. The observed reduced sensitivity of ultrasound relative to CT in the current study aligns with previous research findings and can be partly attributed to technical limitations, such as obscuration by bowel gas [37-39].

Our results closely correspond to findings from previous studies. For example, an Iranian study documented similar sensitivity (75.4%) and specificity (16.75%) for ultrasonography, thereby mirroring our results closely. Furthermore, despite the generally accepted pooled sensitivity and specificity of ultrasound in renal stone detection reported as approximately 45% and 88% respectively, our study exhibited a comparatively higher sensitivity yet markedly lower specificity. (Table 4.4) This discrepancy indicates a trade-off where enhanced stone detection capability simultaneously increases false-positive rates. Notably, earlier studies reported superior diagnostic performances with sensitivities and specificities ranging from 81% to 100%, possibly reflecting the advantages of highly controlled study conditions, advanced ultrasound technologies, or greater operator expertise. In contrast, the sensitivity achieved in this study notably exceeded that reported by, who documented a remarkably low sensitivity of only 19% for ureteric stones, albeit with very high specificity (97%) [40-43].

(Tables 4.2, 4.3, 4.5 and Figures 4.3a, 4-3b, 4.4) An unexpected observation in our study was the notably high false-positive rate (approximately 81%) for ultrasound-diagnosed renal calculi, despite the relatively high PPV. This substantial false-positive rate could result from misinterpretation of renal vascular calcifications or other nonspecific echogenic foci as stones. Moreover, it was particularly surprising to observe that ultrasound occasionally failed to detect larger stones, which typically present clear posterior acoustic shadowing. Such discrepancies might be attributable to patient-related factors (e.g., high BMI or excessive bowel gas), as well as technical limitations such as suboptimal transducer frequency selection or incorrect adjustment of the focal zone during ultrasound imaging.

In our cohort, US sensitivity decreased with increasing BMI, consistent with the physical reality that greater adiposity attenuates ultrasound beam energy and narrows acoustic windows, degrading stone conspicuity on sonography. By contrast, CT performance is minimally affected by body habitus and remains the most accurate test for suspected nephrolithiasis, while US accuracy varies with patient factors and stone characteristics . Clinically, a negative US in patients with elevated BMI should therefore be interpreted cautiously, with a lower threshold for CT when suspicion persists. (Table 4-6) [44-46].

The BMI-stratified analyses in this study demonstrated that body habitus has a meaningful influence on the diagnostic performance of ultrasonography for renal stone detection. While ultrasound sensitivity was comparable between normal and overweight patients, there was a clear decline in sensitivity among obese patients. The global Chi-square test across BMI categories showed a trend toward reduced sensitivity with increasing BMI, and pairwise comparisons confirmed a statistically significant reduction in sensitivity in obese patients compared with those of normal BMI ($\chi^2 = 4.03$, $p = 0.045$), with a borderline difference between overweight and obese groups ($p \approx 0.051$). These findings suggest that obesity represents a critical threshold beyond which ultrasound becomes substantially less reliable for detecting renal calculi. This pattern is reflected in the increasing number of ultrasound-negative (US−) cases in the overweight and obese categories (Figure 4-4), which directly contributes to the observed decline in sensitivity observed with rising BMI Clinically, this implies that negative ultrasound examinations in obese patients should be interpreted with caution and, where appropriate, supplemented by CT to avoid missed diagnoses [47].

Despite these limitations, ultrasound continues to hold significant clinical value as an initial screening method, especially in scenarios demanding rapid patient assessment or where radiation exposure needs to be minimized, such as in pediatric, pregnant, or radiation-sensitive patients. Current clinical guidelines endorse ultrasound as the first-line imaging modality in these patient groups, while also emphasizing the need for clinical vigilance when ultrasound results are negative in symptomatic patients, advocating early escalation to CT to mitigate diagnostic uncertainty. Future research should Focus evaluating advanced ultrasound techniques, notably the Doppler twinkling artifact, for their potential to improve renal stone detection. Emerging evidence indicates that the use of Doppler twinkling artifact may enhance diagnostic accuracy, particularly for smaller calculi, which often elude detection with standard ultrasonography approaches. Additionally, prospective multicenter trials involving varying levels of operator experience and standardized ultrasound protocols are warranted to provide deeper insights into ultrasonography's diagnostic capabilities and enhance the generalizability of these findings [48-50].

In summary, this study illustrates the moderate sensitivity and high PPV of ultrasound, tempered by significantly limited specificity when compared to CT as the reference standard. These findings reiterate the role of ultrasound as primarily complementary rather than definitive in diagnosing renal stones. Acknowledging and clearly communicating the diagnostic limitations of ultrasound is essential to ensure accurate clinical decision-making and optimal patient management [51-54].

Conclusion

Ultrasonography demonstrated moderate sensitivity and lower specificity compared with computed tomography in detecting renal calculi, with reduced diagnostic accuracy in patients with higher body mass index. Although ultrasound remains a useful, radiation-free modality for initial assessment and follow-up, computed tomography shows superior sensitivity and specificity and remains the gold standard for definitive diagnosis. A negative ultrasound finding, particularly in high-BMI patients, should therefore be interpreted with caution, and CT should be performed when clinical suspicion persists.

Recommendations

Study Limitations

Several limitations should be considered when interpreting the findings of this study:

Timing of Imaging

There was often an extended interval between ultrasound and the follow-up CT imaging. In some cases, stones might have passed spontaneously or changed in size during this period, potentially leading to discrepancies between the ultrasound and CT results.

Operator Dependency

The performance of ultrasound was operator-dependent, and factors related to patient anatomy (such as obesity or overlying bowel gas) could have hindered stone detection. Additionally, newer ultrasound techniques, such as Doppler "twinkling artifact," were not utilized in this study; the absence of these methods may have contributed to missed stones.

Single-Center and Sample Size

The study was conducted at a single center in a specific region with a relatively small sample size. These factors may limit the generalizability of the findings to broader populations or different clinical settings.

Cross-Sectional Design

The cross-sectional design of the study limits the ability to establish temporal or causal relationships between the variables observed. For example, it is not possible to determine changes over time or to infer causality from the associations identified.

Study Population

Because the research was carried out in a hospital setting, the study population may not be fully representative of the general population. Patients who seek hospital care may differ in risk profiles and disease prevalence from individuals who do not, which may affect the applicability of the results to the wider community.

Clinical Implications

The findings have important implications for clinical practice. Ultrasonography remains a valuable, radiation-free first-line imaging modality in suspected renal colic, particularly in settings where radiation minimization is essential, such as pregnancy, pediatrics, and serial follow-up. However, clinicians must be mindful of its limited specificity and very low negative predictive value, especially in patients with higher BMI. A negative US result should therefore be interpreted with caution. When clinical suspicion persists, confirmatory CT imaging is recommended to avoid missed diagnoses. Implementing standardized US scanning protocols, improving operator training, and integrating advanced sonographic techniques may enhance diagnostic confidence and reduce false-negative outcomes.

Future Directions and Research Plans

Future research should include prospective, multi-center studies to validate the diagnostic accuracy of ultrasound across varied clinical environments. Assessing the impact of structured operator training and standardized protocols on diagnostic performance would be valuable. Incorporating Doppler-based techniques, such as the twinkling artifact may improve detection of small stones and should be evaluated in further studies. Additionally, randomized controlled trials comparing ultrasound-first versus CT-first diagnostic pathways could inform clinical guidelines and optimize resource utilization.

Recommendations

- Utilize ultrasonography as the initial imaging tool for suspected renal stones, reserving CT for cases with negative, equivocal, or clinically discordant findings.
- Provide targeted operator training and implement standardized scanning protocols to improve diagnostic accuracy.
- Integrate advanced ultrasound techniques (e.g., Doppler twinkling artifact) where available to enhance detection of small cal-

culi.

• Conduct larger prospective and randomized trials to strengthen evidence-based clinical guidelines and support broader generalizability.

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