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Preferred radiological modalities in the diagnosis and management of kidney and urinary tract stones; a systematic review

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ABSTRACT

Introduction: Kidney and urinary tract stones are a common health concern, with a rising global incidence and significant impact on patient quality of life. Accurate diagnosis and effective management of these stones rely heavily on radiological imaging modalities. This systematic review aimed to synthesize the existing literature on preferred radiological modalities for diagnosing and managing kidney and urinary tract stones, focusing on their diagnostic accuracy, clinical efficacy, and impact on treatment outcomes.

Methods: This systematic review was conducted based on PRISMA guidelines to evaluate preferred radiological modalities for diagnosing and managing kidney and urinary tract stones. A comprehensive literature search across multiple databases, including PubMed, Embase, Cochrane Library, Scopus, and Google Scholar, was conducted up to July 2024, using a comprehensive set of MeSH keywords. Quality assessment was performed using the STROBE checklist, with medium and high-quality studies considered acceptable. Data extraction by two independent reviewers captured essential information, with discrepancies resolved through discussion or consultation with a third reviewer.

Results: The results of 12 included studies in this review indicated that, while CT scans are the most accurate imaging modality for diagnosing kidney and urinary tract stones, ultrasound presents a viable alternative due to its lower radiation exposure. Most studies reported ultrasound sensitivities above 55% and specificities over 95% compared to CT, although some studies noted significantly lower sensitivities. Additionally, X-ray imaging showed limitations, with sensitivities of only 46% to 57%, particularly for smaller stones.

Conclusion: This study highlights that while CT scans are the gold standard for diagnosing kidney and urinary tract stones due to their accuracy, ultrasound presents a valuable alternative as an initial diagnostic tool, primarily because of its lower radiation exposure, which enhances patient safety, especially for those needing repeated imaging. Furthermore, the limitations of X-ray imaging in detecting smaller stones caution against its exclusive use. The review also emphasizes the importance of balancing diagnostic accuracy with safety when considering high-dose versus low-dose CT scans.

Registration: This study has been compiled based on the PRISMA checklist, and its protocol was registered on the PROSPERO (ID: CRD42024579547) and Research Registry (UIN: reviewregistry1873) websites.

Systematic Review

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Implication for health policy/practice/research/medical education:
The findings from this systematic review have significant implications for clinical practice in diagnosing and managing kidney and urinary tract stones. While CT scans are the most accurate imaging modality, the results suggest that the ultrasound may serve as a suitable initial diagnostic tool, particularly given its lower radiation exposure, making it a safer option for patients, especially in cases requiring repeated imaging. The variability in sensitivity reported for the ultrasound highlights the importance of considering specific clinical contexts and patient characteristics when selecting imaging modalities. Furthermore, the limitations of X-ray imaging, particularly in detecting smaller stones, underscore the necessity for clinicians to be cautious when relying solely on this method for diagnosis. The comparison between high-dose and low-dose CT scans also emphasizes the need for a balanced approach that maximizes diagnostic accuracy while minimizing radiation exposure. Ultimately, these results advocate for a tailored imaging strategy that prioritizes patient safety without compromising diagnostic effectiveness..

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Introduction

Kidney and urinary tract stones, known as urolithiasis, represent a significant health concern affecting millions worldwide (1). These stones are hard mineral deposits that form in the kidneys and can travel down the urinary tract, leading to severe pain and various complications (1,2). The prevalence of kidney stones is notably high, with estimates indicating that 10% to 15% of individuals in the United States and Europe will experience this condition at some point in their lives (3), and this trend is on the rise due to various factors such as obesity, dietary habits, and environmental influences like living in warmer climates (2). These stones can vary in size and composition, ranging from small crystals to large masses (4), and their formation is influenced by a combination of genetic, metabolic, and lifestyle factors (5). Symptoms often include severe pain, hematuria, and urinary tract infections, which can complicate the clinical picture (2,6). Diagnosis typically involves imaging techniques and urine analysis to determine the stone's composition, guiding treatment strategies (2).

Imaging techniques are essential for the accurate diagnosis and management of kidney and urinary tract stones, as they provide crucial information about the size, location, and composition of stones, which directly influences treatment decisions. Ultrasound is often the first-line imaging modality due to its safety profile and lack of ionizing radiation, making it particularly suitable for vulnerable populations such as children and pregnant women; it effectively identifies stones and assesses renal anatomy, although its sensitivity can be limited for smaller stones or those located in certain anatomical regions (7). Computed tomography (CT) scan has emerged as the gold standard for diagnosing urolithiasis, offering high sensitivity and specificity, with studies indicating that non-contrast CT can detect stones in up to 95% of cases, making it invaluable in acute settings where rapid diagnosis is critical (7,8). X-ray imaging, while less sensitive than CT, can still play a role in specific scenarios, such as monitoring the passage of radiopaque stones or assessing complications associated with stone disease (2). Additionally, advanced imaging techniques, such as dual-energy CT scan with different dosage, are gaining traction for their ability to provide detailed insights into stone composition and associated renal pathology, further enhancing the diagnostic toolkit available for clinicians (9).

Review of the previous studies showed that the choice of imaging modality is influenced by various factors, including the patient's clinical presentation, the need for rapid diagnosis, and considerations regarding radiation exposure, underscoring the importance of an individualized approach to managing kidney stones effectively. This study aimed to systematically evaluate and compare the effectiveness, sensitivity, and specificity of various radiological imaging and identify the most reliable imaging modalities that enhance diagnostic accuracy and guide treatment decisions, ultimately improving patient outcomes in urolithiasis management.

Objectives

The objective of this systematic review is to evaluate and synthesize the existing literature on preferred radiological modalities for diagnosing and managing kidney and urinary tract stones. Specifically, it aims to compare the diagnostic accuracy, clinical efficacy, and impact on treatment outcomes of various imaging techniques, including ultrasound, X-ray, and CT scan.

Materials and Methods

Study design

This systematic review will adhere to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (10) to evaluate the preferred radiological modalities for diagnosing and managing kidney and urinary tract stones. The objective of this study is to assess and synthesize the existing literature on the preferred radiological modalities for the diagnosis and management of kidney and urinary tract stones, with a focus on comparing the diagnostic accuracy, clinical efficacy, and impact on treatment outcomes of various imaging techniques, including ultrasound, X-ray, and CT scan.

Search strategy

A comprehensive literature search was conducted across multiple databases, including PubMed, Embase, Cochrane Library, Scopus and Google Scholar with the most recent search performed in July 2024. Google Scholar search engine was also used to complete the search. The search strategy employed a comprehensive set of Medical Subject Headings (MeSH) keywords terms to identify relevant studies, including "Kidney calculi," "Kidney Stone," "Renal Calculi," "Nephrolith," "Urinary calculi," "Urinary stones," "Urinary tract stone," "Urolithiasis," "Imaging Techniques," "Radiological Techniques," "Radiological modalities," "Ultrasonography," "Ultrasound," "Ultrasonic Imaging," "Computed tomography," "CT scan," "Tomodensitometry," "X-ray," and "MicroCT." These terms were strategically combined to capture studies investigating various imaging techniques used in the diagnosis and management of kidney and urinary tract stones. The search strategy for this systematic review did not impose any restrictions on the time, language, or location of the included studies. Two independent reviewers screened the titles and abstracts of the retrieved articles and full-text articles were assessed for eligibility.

The following shows an example of a search strategy in the PubMed database: ((((((((((((((((((Kidney calculi[Title/Abstract]) OR (Kidney Stone[Title/Abstract])) OR (Renal Calculi[Title/Abstract])) OR (Nephrolith[Title/Abstract])) AND (Urinary calculi[Title/Abstract])) OR (Urinary stones[Title/Abstract])) OR (Urinary tract stone[Title/Abstract])) OR (Urolithiasis[Title/Abstract])) AND (Imaging Techniques[Title/Abstract])) OR (Radiological Techniques[Title/Abstract])) OR (Radiological modalities[Title/Abstract])) AND (Ultrasonography[Title/Abstract])) OR (Ultrasound[Title/Abstract])) OR (Ultrasonic Imaging[Title/Abstract])) AND (Computed tomography[Title/Abstract])) OR (CT scan[Title/Abstract])) OR (Tomodensitometry[Title/Abstract])) AND (X-ray[Title/Abstract])) OR (MicroCT[Title/Abstract])

PICO components

- Population (P): Patients with kidney and urinary tract stones or those suspected of having these conditions.
- Intervention (I): Various radiological modalities used for diagnosis and management, specifically CT scans, ultrasound, and X-ray imaging.
- Comparator (C): Comparison of the effectiveness and accuracy of these imaging modalities against each other, particularly focusing on CT scans as the gold standard.
- Outcome (O): Diagnostic accuracy (sensitivity and specificity) of each imaging modality in identifying kidney and urinary tract stones, as well as considerations regarding radiation exposure and patient safety.

Inclusion and exclusion criteria

The inclusion criteria for this systematic review encompass randomized controlled trials, cohort studies, and case-control studies that compare the diagnostic accuracy and clinical outcomes of various imaging techniques used for the diagnosis and management of kidney and urinary tract stones, with a focus on studies published up to July 2024. Conversely, the exclusion criteria consist of case reports, case series, letters, editorials, and review articles, as well as studies that contain incomplete or unavailable data.

Quality assessment

The quality assessment of the included studies in this systematic review was conducted using the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) checklist. This checklist comprises 22 items that address various components of observational studies. Each item is assigned a score of two points, and the overall quality score is determined by aggregating the points from these items. In this scoring system, a total score ranging from 1 to 15 indicates poor quality, scores between 16 and 30 reflect medium quality, and scores from 31 to 44 signify high quality (11). In the present study, the established points for acceptable quality were studies with medium and high quality. Two independent reviewers assessed the risk of bias, and any discrepancies were resolved through discussion or consultation with a third reviewer.

Data extraction

Data extraction was conducted by two independent reviewers utilizing a standardized form that captured essential information, including the authors' names, year of publication, study design, country of origin, sample size, study objectives, and key findings. In instances where discrepancies arose between the reviewers, a third investigator was enlisted to re-evaluate the data to ensure accuracy and consistency.

Results

Figure 1 outlines the systematic review process, detailing record identification, screening, and eligibility assessment. Initially, a total of 1,141 records were identified from databases. Following this, 714 duplicate records were removed, leaving 427 records for screening. Out of these, 323 records were excluded based on predefined criteria. Subsequently, 104 reports were sought for retrieval, but 61 of these reports could not be retrieved. A total of 43 reports were assessed for eligibility, resulting in the exclusion of 31 reports due to reasons such as insufficient data, the nature of the study (including case reports, meta-analyses, systematic reviews, and letters to editors), unavailability of full texts, and poor quality. Ultimately, 12 studies were included in the review.

The characteristics of the extracted studies are comprehensively summarized in Table 1. This systematic

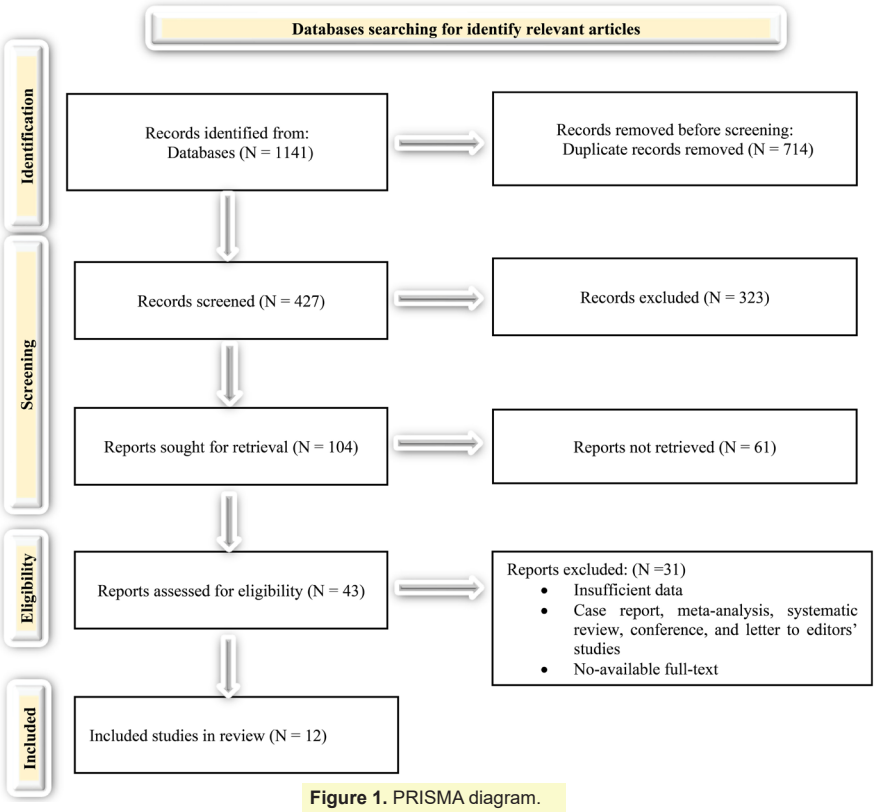

Figure 1. PRISMA diagram.

review incorporated a total of 12 studies conducted across three continents, reflecting a diverse range of geographical contexts. The overall sample size consisted of 6262 patients from eight different countries, representing regions in Asia, Europe, and the Americas during the period from 2007 to 2023. Notably, the majority of the studies included in this review were conducted in the United States, highlighting a significant concentration of research activity in this country. The majority of the studies included in this systematic review employed a cross-sectional (C-S) design, which is commonly utilized to assess the prevalence of conditions within a population at a specific point in time. Among the studies, the minimum sample size was reported in a study by Bilal et al (12), which included 21 patients, while the maximum sample size was found in the study by Smith-Bindman et al (13), which encompassed 2759 patients. The majority of the studies included in this systematic review aimed to evaluate the comparative diagnostic value of three commonly used imaging modalities: X-ray, ultrasound, and CT scans, with or without contrast, in the diagnosis of kidney and ureteral stones. Among these studies, the most frequent comparison was between CT scans and ultrasound, followed by comparisons between CT scans and X-rays. Notably, no studies were identified that compared ultrasound directly with X-rays.

The results of the studies included in this systematic review indicate that CT scans are the more accurate imaging modality for diagnosing kidney and urinary tract stones compared to both ultrasound and X-ray. In terms of quantitative comparative analysis, the majority of studies reported sensitivities greater than 55% and specificities exceeding 95% for ultrasound compared to CT scans. However, two studies by Roberson et al (14) and de Souza et al (15) reported notably lower ultrasound sensitivities of 12.8% and 22%, respectively. Notably, Smith-Bindman et al (13) found no significant differences in outcomes between CT scans and ultrasound, suggesting that ultrasound may be preferred as the initial diagnostic test due to the lower radiation exposure associated with this modality. Overall, the results showed that while CT scans demonstrate superior accuracy, ultrasound may be a viable alternative for initial evaluation, particularly in light of the potential risks of repeated radiation exposure from CT scans.

In the comparison between X-ray and CT scans, the results indicated sensitivities of 57% in one study (12), and 46% and 52% for stones smaller and larger than 5 millimeters (mm) in another study (16), indicating the limitations of X-ray imaging in the accurately detection of urinary stones, particularly for those with smaller sizes. Additionally, when comparing different types of CT scans, high-dose CT scans demonstrated superior diagnostic outcomes relative to their low-dose counterparts.

Discussion

The results of this systematic review highlight that ultrasound—often the first-line imaging choice due to

Table 1. The characteristics of included studies in this systematic review

First author	Publication year	Place	Study design	Objective	Sample size	Results
Bilal M, (12)	2023	Ireland	C-S	Sensitivity evaluation of X-rays compared to low-dose CT without contrast for diagnosis of nephrolithiasis	21	The sensitivity of X-rays in comparison to CT scans was 57% (12 of 21 patients)
Riddell J, (17)	2014	USA	C-S	Sensitivity evaluation of ED bedside US in hydronephrosis diagnosis compared to CT-proven stones	125	The bedside US demonstrated an overall sensitivity of 78.4% for detecting hydronephrosis, with higher sensitivity in patients with stones ≥6 mm (90%) compared to those with stones <6 mm (75%), and 100% sensitivity in patients with three or more stones.
Bozdar H-u-R (18)	2016	Pakistan	C-S	Comparison of US, IVU, and CT-KUB in the detection of ureteral stone	60	US and IVU have less accuracy compared to CT-KUB
Passerotti C (19)	2009	USA	C-S	Comparison of US vs CT in urethral stone diagnosis	50	The US missed 8 patients with CT-proven urethra stones and showed sensitivity and specificity of 76% and 100% respectively compared to the CT scan
Aggarwal G (20)	2023	India	C-S	Sensitivity evaluation of low-dose CT scan without contrast compared to non-contract standard CT scan for urolithiasis diagnosis	222	All stones were detected on standard CT; the sensitivity was 99.61% for CT-100 mA and 98.82% for CT-50 mA compared to standard CT.
Metzler IS (21)	2017	USA	Clinical effectiveness study	Evaluation the effect of initial diagnosis by the ultrasound on the management of nephrolithiasis	1666	Patients who were diagnosed with kidney stones via the initial US did not experience a significant delay in receiving surgical intervention for nephrolithiasis.
Winkel RR (22)	2012	Denmark	C-S	Assessment the effectiveness of Color-Doppler US in the urethra stone diagnosing	105	Color-Doppler US indicated 55% sensitivity, 99% specificity 67% PPV, and 98% NPV in the diagnosis of urothelial stones compared to CT scan; which made it a valuable tool in this field
Çakıroğlu B (23)	2013	Turkey	C-S	Efficacy comparison of NECT with ultrasound in the detection of urolithiasis	138	The sensitivity of NECT in the diagnosis of both small and large urethral stones was significantly greater than US.
Roberson NP (14)	2019	USA	Clinical effectiveness study	Assessment the diagnostic value of US compared to CT scan for urolithiasis diagnosis in pediatric	38	In comparison to CT scan, the US showed a sensitivity of 12.8%, specificity of 100%, PPV of 100%, and NPV of 74.4%, which indicating its low diagnostic value.
Innes GD (16)	2021	Canada	C-S	Evaluate the diagnostic value of x-ray vs CT scan in urolithiasis diagnosis	1026	X-ray alone demonstrated a sensitivity of 46% for stones larger than 5 mm and 52% for interventional calculi, defined as ureteral calculi greater than 7 mm and proximal or middle calculi greater than 5 mm. In contrast, the combination of X-ray and hydronephrosis evaluation indicated a sensitivity of 68% for diagnosing calculi larger than 5 mm and 82% for interventional calculi.
de Souza LR, (15)	2007	Brazil	C-S	Diagnostic accuracy comparison of US and NCCT in acute ureteral stone diagnosis	52	The US indicated a sensitivity of 22% and a specificity of 100% compared to NCCT
Smith-Bindman R, (13)	2014	USA	Effectiveness trial	The diagnostic value comparison of US vs CT scan for patients suspected with kidney stones	2759	The US is associated with lower radiation exposure than CT scan, without significant differences in high-risk diagnoses and other complications

C-S; Cross-sectional, US; Ultrasound, IVU; Intravenous urography, CT-KUB; Computed Tomography of Kidneys, Ureters, and Bladder, NECT; Non-enhanced CT, NCCT; Non-contrast CT, vs; Versus, ED; Emergency departments, USA; United States of America, PPV; Positive predictive value, NPV; Negative predictive value.

its safety and lack of ionizing radiation—demonstrates variable sensitivity, particularly in detecting smaller stones. For instance, studies indicate that ultrasound can achieve higher sensitivity rates in cases of hydronephrosis and larger stones, but its overall effectiveness may be compromised compared to more advanced imaging techniques. In contrast, CT scan is frequently regarded as the gold standard for urolithiasis diagnosis, with numerous studies confirming its superior sensitivity and specificity. The review shows that non-contrast CT can detect nearly all stones, making it invaluable in acute clinical settings where rapid diagnosis is essential. However, the trade-off includes higher radiation exposure, which raises concerns, especially in vulnerable populations. Additionally, the review points out that while X-ray imaging is less sensitive than CT, it can still play a role in specific scenarios, such as monitoring the passage of radiopaque stones.

The study by Bilal et al (12) in Ireland evaluated X-rays against low-dose CT for diagnosing nephrolithiasis, and found that X-ray imaging exhibited a sensitivity of 57% when compared to CT scans. Innes et al (16) in Canada compared X-ray and CT for urolithiasis, noting varying sensitivity based on stone size from 46% to 52%. This low sensitivity underscores the limitations of X-ray imaging in accurately identifying kidney stones, particularly in cases where high sensitivity is critical for effective diagnosis and management.

Riddell et al (17) in the United States focused on the sensitivity of bedside ultrasound for hydronephrosis compared to CT and reported the acceptable diagnostic value, especially in cases with more number and larger stones. Bozdar et al (18) from Pakistan compared ultrasound, intravenous urography, and CT-KUB (kidneys, ureters, and bladder) in detecting ureteral stones, and found that the ultrasound and intravenous urography have less accuracy compared to CT-KUB. Passerotti and colleagues' (19) research in the United States examined ultrasound versus CT for urethral stone diagnosis, revealing that ultrasound missed several cases, nevertheless revealed an acceptable diagnostic value. Metzler and colleagues' (21) clinical effectiveness study in the USA explored how initial ultrasound diagnoses affected the management of nephrolithiasis, indicating timely surgical interventions. Winkel et al (22) from Denmark assessed the effectiveness of Color-Doppler ultrasound in diagnosing urethral stones, reporting notable sensitivity and specificity. Çakıroğlu et al (23) from Turkey compared non-enhanced CT with ultrasound for detecting urolithiasis, finding superior sensitivity for CT scan. Roberson et al (14) conducted a study in the United States to assess the diagnostic value of ultrasound compared to CT scans for the diagnosis of urolithiasis in pediatric patients. The findings revealed that ultrasound demonstrated a sensitivity of only 12.8% but a specificity of 100% relative to CT scans, which served as the reference standard. Lastly, de Souza et al (15) in Brazil compared ultrasound and non-contrast CT for acute ureteral stone diagnosis, while Smith-Bindman and colleagues' (13) effectiveness trial in the United States highlighted the lower radiation exposure associated with ultrasound compared to CT without compromising diagnostic accuracy. Overall, while bedside ultrasound demonstrates acceptable diagnostic value, particularly in cases with larger stones, its sensitivity is often lower compared to CT scans, which remain the gold standard due to their high accuracy. Studies indicate that ultrasound and intravenous urography generally exhibit less diagnostic accuracy than CT-KUB, highlighting the need for careful selection of imaging techniques based on clinical scenarios. Additionally, while ultrasound offers the advantage of lower radiation exposure, its limitations in sensitivity necessitate the use of CT scans in certain cases to ensure timely and effective patient management.

Aggarwal and Adhikary (20) conducted a comparative study in India to assess the efficacy of low-dose CT scans without contrast against standard CT scans for the diagnosis of urolithiasis. The findings revealed that standard CT scans exhibited significantly high sensitivity rates, effectively detecting all stones present in the study cohort. Specifically, the sensitivity of standard CT was reported to be notably high, while the low-dose CT scans demonstrated slightly lower sensitivity, albeit still maintaining a high diagnostic capability. This study highlights the trade-off between radiation exposure and diagnostic accuracy, as standard CT scans, while highly sensitive, expose patients to higher levels of radiation compared to low-dose alternatives. The implications of these findings are critical for clinical practice, as they underscore the importance of selecting appropriate imaging modalities that balance diagnostic effectiveness with patient safety.

Overall, despite the acceptable diagnostic value of this imaging modalities in diagnosis of kidney and urinary stones, the emerging use of advanced imaging modalities, such as dual-energy CT with different dosage, also warrants discussion, as these techniques may provide further insights into stone composition and associated renal pathology considering their radiation risks. Ultimately, the choice of imaging modality should be individualized based on the patient's clinical presentation, the urgency of diagnosis, and the need to minimize radiation exposure, emphasizing the importance of a tailored approach in the management of kidney stones. This comprehensive evaluation of existing literature underscores the need for ongoing research to refine imaging strategies and optimize patient outcomes in urolithiasis management.

Conclusion

In conclusion, the findings of this systematic review indicated that while CT scan remained a gold standard for accuracy, the potential of ultrasound as an initial diagnostic tool offers a compelling alternative, particularly due to its

reduced radiation exposure, making it a safer choice for patients requiring frequent imaging. The variability in ultrasound sensitivity necessitates careful consideration of individual clinical scenarios and patient characteristics, highlighting the importance of personalized imaging strategies. Additionally, the limitations of X-ray imaging in detecting smaller stones serve as a reminder for clinicians to avoid sole reliance on this method. The insights gained from comparing high-dose and low-dose CT scans further reinforce the necessity of balancing diagnostic precision with patient safety. Ultimately, this review advocates for a tailored imaging approach that enhances patient care while ensuring effective diagnosis and management of urinary tract conditions.

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Authors' contribution

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Supervision: Ramin Haghighi.
Validation: Jalal Rezaei.
Visualization: Zahra Askari.
Writing–original draft: All authors.
Writing–reviewing and editing: All authors.

Conflicts of interest

There are no competing interests.

Ethical issues

This investigation has been compiled based on the PRISMA checklist, and its protocol was registered on the PROSPERO (International Prospective Register of Systematic Reviews) website with (ID: CRD42024579547) () and Research Registry website with (Unique Identifying Number (UIN) reviewregistry1873). Besides, the authors have observed ethical issues (including plagiarism, data fabrication, and double publication).

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