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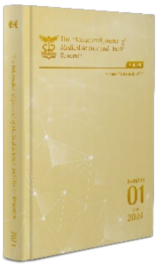

Analysis Study of Diagnostic Imaging Performance and Accuracy of Kidney Stone : A Comprehensive Systematic Review

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ABSTRACT

Background: Kidney stones (nephrolithiasis/urolithiasis) are a prevalent urological condition caused by crystallization of minerals in the urinary tract. Their formation can lead to pain, hematuria, infections, and renal dysfunction if untreated. The increasing incidence of nephrolithiasis is linked to dietary habits, metabolic disorders, dehydration, and obesity. Imaging is crucial for early diagnosis and management, guiding treatment options such as conservative management, medical expulsive therapy, or surgical interventions. **Objective**: This systematic review aims to evaluate the diagnostic accuracy of various imaging modalities—ultrasound (US), non-contrast computed tomography (NCCT), contrast-enhanced CT, dual-energy CT (DECT), magnetic resonance imaging (MRI), and KUB X-ray—in detecting and characterizing kidney stones. **Methods**: The study follows PRISMA 2020 guidelines. Peer-reviewed studies published from 2015–2025 were identified through searches in PubMed, Embase, Cochrane Library, Web of Science, and Scopus. Inclusion criteria encompass studies assessing imaging performance in nephrolithiasis, with sensitivity, specificity, and predictive values as primary outcomes. **Results**: After screening, eight relevant studies were included. Ultrasonography, while radiation-free and cost-effective, has lower sensitivity than NCCT, the gold standard for kidney stone diagnosis due to its high accuracy. Dual-energy CT improves stone composition characterization, while MRI offers a radiation-free alternative but is less sensitive in detecting calcified stones. **Conclusion**: Imaging techniques vary in sensitivity and specificity for nephrolithiasis diagnosis. NCCT remains the most accurate, while US is preferred for radiation-sensitive populations. MRI may serve as a secondary tool where radiation exposure is a concern. Future advancements in imaging technology may further refine nephrolithiasis detection and characterization.

Keywords: nephrolithiasis, urolithiasis, kidney stones, diagnostic imaging, ultrasound, computed tomography, magnetic resonance imaging

INTRODUCTION

Kidney stones, also referred to as nephrolithiasis or urolithiasis, are a common urological condition caused by the crystallization of minerals and other substances in the urinary tract. These stones, also known as renal or urinary calculi, form within the nephron—the functional unit of the kidney—and can vary in size, composition, and clinical impact. While small crystals may pass spontaneously in the urine without causing symptoms, larger stones can obstruct the urinary tract, leading to severe pain, hematuria, urinary tract infections, and even renal dysfunction if left untreated. Given the kidneys' critical role in filtering blood, regulating electrolyte balance, and maintaining fluid homeostasis, kidney stone formation presents a significant clinical challenge requiring prompt and accurate diagnosis.[1,2]

The prevalence of kidney stones has increased in recent decades, affecting approximately 1 in 10 individuals at some point in their lives. While improved diagnostic capabilities have contributed to the rising detection rates, other factors such as dietary habits, metabolic disorders, dehydration, and increasing obesity levels have also played a role in the growing incidence of nephrolithiasis. The burden of kidney stones extends beyond individual patient discomfort, as recurrent stone formation is associated with long-term renal complications and significant healthcare costs. [3,4]

Imaging plays a pivotal role in the diagnosis and management of nephrolithiasis. Early and accurate detection is essential for determining the most appropriate treatment strategy, whether through conservative management, medical expulsive therapy, extracorporeal shock wave lithotripsy (ESWL), ureteroscopy, or percutaneous nephrolithotomy (PCNL). Several imaging modalities are available for assessing renal stones, each with its own advantages and limitations. Ultrasound, being a non-invasive and radiation-free technique, is often the first-line imaging choice, particularly in pregnant women and children. However, its sensitivity in detecting smaller stones or ureteral calculi is lower compared to computed tomography (CT). Non-contrast-enhanced CT (NCCT) is currently considered the gold standard for kidney stone diagnosis due to its high sensitivity and specificity, allowing for precise stone localization and size measurement. Additionally, advanced imaging techniques, such as dual-energy CT and material decomposition imaging, offer the potential to characterize stone composition, which is crucial for determining appropriate management strategies. Magnetic resonance imaging

(MRI) is less commonly used for stone detection due to its limited ability to visualize calcified structures but may be beneficial in select cases where radiation exposure is a concern.[4,5]

Given the critical role of imaging in nephrolithiasis management, this systematic review aims to comprehensively analyze the diagnostic performance and accuracy of various imaging modalities in detecting and characterizing kidney stones. By evaluating the strengths and limitations of each technique, this review will provide insights into the most effective approaches for optimizing patient outcomes and guiding clinical decision-making in the diagnosis and treatment of kidney stones.

METHODS

Protocol

This systematic review follows the **Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines** to ensure transparency, consistency, and reproducibility. The objective is to systematically analyze and evaluate the diagnostic performance and accuracy of various imaging modalities for kidney stone detection and characterization. Specifically, this review will assess the sensitivity, specificity, and diagnostic reliability of different imaging techniques, including **ultrasound (US), non-contrast computed tomography (NCCT), contrast-enhanced CT, dual-energy CT (DECT), magnetic resonance imaging (MRI), and plain radiography (KUB X-ray)**. Additionally, we will explore the clinical utility of emerging imaging technologies in optimizing nephrolithiasis diagnosis and management.

Criteria for Eligibility

This review will include **peer-reviewed studies** published between **2015 and 2025** that investigate the diagnostic accuracy of imaging techniques for nephrolithiasis. Eligible studies must provide **quantitative assessments of imaging performance, including sensitivity, specificity, and predictive values** in detecting kidney stones.

Inclusion Criteria

- **Participants**: Patients diagnosed with or suspected of having kidney stones.
- **Imaging Modalities**:

  - Ultrasound (US)
  - Non-contrast computed tomography (NCCT)
  - Contrast-enhanced CT
  - Dual-energy CT (DECT)
  - Magnetic resonance imaging (MRI)
  - KUB X-ray (Kidneys, Ureters, Bladder radiography)
- **Outcomes**: Sensitivity, specificity, positive and negative predictive values, diagnostic accuracy, stone size detection limits, and ability to characterize stone composition.
- **Study Design**: Randomized controlled trials (RCTs), cohort studies, or case-control studies evaluating imaging performance in kidney stone detection.
- **Language**: Studies published in **English**.

Exclusion Criteria

- **Review articles, meta-analyses, conference abstracts, or expert opinions**.
- **Studies not directly assessing the diagnostic accuracy of imaging modalities for kidney stones**.
- **Animal studies or in vitro experiments**.

Search Strategy

A **systematic search** will be conducted using **electronic databases**, including **PubMed, Embase, Cochrane Library, Web of Science, and Scopus**. Search terms will focus on imaging techniques, their diagnostic accuracy, and their role in kidney stone detection. Boolean search strings will include:

- ("Nephrolithiasis" OR "Urolithiasis" OR "Kidney stones") AND ("Ultrasound" OR "CT" OR "MRI") AND ("Sensitivity" OR "Specificity")
- ("Computed tomography" OR "Dual-energy CT") AND ("Kidney stone detection" OR "Imaging accuracy")
- ("KUB X-ray" OR "MRI") AND ("Renal calculi" OR "Urinary stones")

Table 1. Search Strategy

Database	Search Strategy	Hits
PubMed	("Kidney stones" AND "Ultrasound" AND "Sensitivity") ("Nephrolithiasis" AND "CT" AND "Diagnostic accuracy") ("MRI" AND "Kidney stone detection") ("KUB X-ray" AND "Urolithiasis" AND "Specificity")	850
Embase	("Kidney stones" AND "Ultrasound" AND "Sensitivity") ("Nephrolithiasis" AND "CT" AND "Diagnostic accuracy") ("MRI" AND "Kidney stone detection") ("KUB X-ray" AND "Urolithiasis" AND "Specificity")	620
Cochrane Library	("Kidney stones" AND "Ultrasound" AND "Sensitivity") ("Nephrolithiasis" AND "CT" AND "Diagnostic accuracy") ("MRI" AND "Kidney stone detection") ("KUB X-ray" AND "Urolithiasis" AND "Specificity")	75
Web of Science	("Kidney stones" AND "Ultrasound" AND "Sensitivity") ("Nephrolithiasis" AND "CT" AND "Diagnostic accuracy") ("MRI" AND "Kidney stone detection") ("KUB X-ray" AND "Urolithiasis" AND "Specificity")	140

Data Retrieval

Titles and abstracts will be screened for relevance. Full-text articles meeting inclusion criteria will be **reviewed**, and the following **data will be extracted**:

- **Study Characteristics**: Year, location, sample size, study duration.
- **Imaging Modality**: Type of imaging used, scanning parameters, contrast use (if applicable).
- **Participant Demographics**: Age, gender, stone burden, comorbidities.
- **Diagnostic Performance**: Sensitivity, specificity, positive and negative predictive values, accuracy, stone composition characterization.

Quality Assessment and Data Synthesis

Two **independent reviewers** will assess study quality using the **QUADAS-2 (Quality Assessment of Diagnostic Accuracy Studies) tool**, evaluating **risk of bias, applicability, and methodological robustness**. Disagreements will be resolved through discussion or consultation with a third reviewer.

A **qualitative synthesis** will summarize findings by imaging modality, while, if data homogeneity allows, a **meta-analysis** will estimate pooled sensitivity, specificity, and diagnostic odds ratios for different imaging techniques. Subgroup analyses will be performed based on patient characteristics, stone location, and imaging parameters.

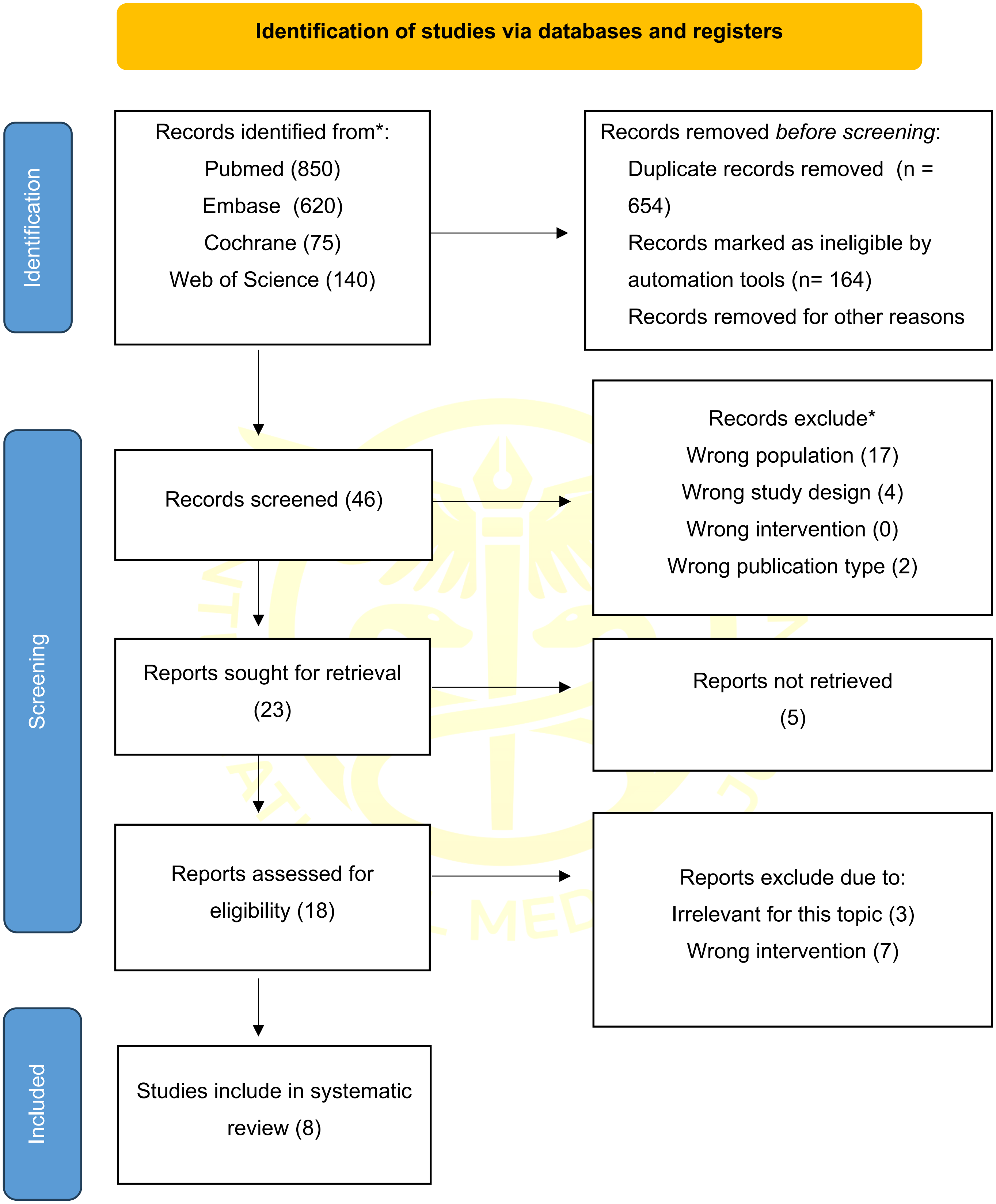

Figure 1. PRISMA Flowchart

RESULT

Our research team first gathered publications from reputable sources such as Embase, PubMed, and Web of Science. After a thorough three-level screening procedure, only eight papers were determined to be directly relevant to our ongoing systematic evaluation. Following that, these sections were picked for additional research and a close reading of the entire manuscript. The material that was evaluated for this analysis is compiled in Table 2 for ease of viewing.

Table 2. The literature included in this study

Author	Origin	Method	Sample Size	Result
Wang et al. (2022).[7]	US	A randomized trial.	64 ED Providers and 254 patients with suspected nephrolithiasis were enrolled from January 2019 through Dec 2020.	The US-First CDS tool was deployed for 128 patients and was not deployed for 126 patients 86.7% of patients in the CDS arm received a CT vs. 94.4% in the usual care arm, resulting in an absolute risk difference of -7.7% (-14.8 to -0.6%). Mean radiation dose in the CDS arm was 6.8 mSv (95% CI 5.7-7.9 mSv) vs. 6.1 mSv (95% CI 5.1-7.1 mSv) in the usual care arm. The CDS arm did not result in increased ED revisits CT scans, or hospitalizations at 7 or 30 days.
Shen et al. (2023).[8]	China	A randomized trial, in vitro and in vivo.	A total of 45 pig models were established, including 23 in the	The ultrasound screening time in the CT-ultrasound group was significantly shorter than that in the ultrasound group (P < .001). In addition, the success rate of puncture in the CT-ultrasound group was significantly higher than that in the ultrasound group (P =.015) Furthermore, in the simulated PCNL puncture

			CT-ultrasound group and 22 in the ultrasound group.	study, baseline data including age, BMI, and S.T.O.N.E score between the two groups showed no statistical difference. The ultrasound screening time of the two groups was (2.60 ± 0.33) min and (3.37 ± 0.51) min respectively and the difference was statistically significant (P < .001).
Pakmanesh et al. (2024).[9]	India	a randomized clinical trial.	100 patients.	The primary outcome was successful access. In 90% of cases in the XRAY and 95% in the SONO group access dilatation process was performed uneventfully at the first attempt (p = 0.5). In 45% of cases in the SONO group, bi-prong forceps were used as salvage for short-advancement. In one case in the X-ray group over-advancement occurred. One month after surgery, the stone-free rate on the CT-scan was 75% for the X-ray group and 85% for the SONO group (p = 0.4). There were no significan differences in operation time, hospitalization duration, transfusion, or complication rates between the two groups.
Zhu et al. (2023).[10]	China	Prospective study.	A total of 140 patients with complicated kidney stones requiring PCNL were prospectively enrolled,	Compared to the control group, the research group had higher stone clearance rate in stage I PCNL, success rate of one-time puncture, less percutaneous channels, less reduction o hemoglobin and shorter procedure time Complications in stage I PCNL were comparable in the two groups, and there was no significant change in the final stone clearance rates between the two groups.

			from January 2020 to December 2022.	
Zhang et al. (2022).[11]	South Korea	Prospective study.	Sixty patients with suspected renal calculi were prospectively enrolled.	A total of 130 calculi were observed on LD-HIR images. Stone detection rates of ULD-HIR and ULD-DLR images were 93.1% (121/130) and 95.4% (124/130). A total of 129 lesions were detected on the LD-HIR images. The lesion detection rate on ULD-DLR images was 92.2% with 10 cysts < 5 mm in diameter missed. The CT values of organs on ULD-DLR were similar to those on LD-HIR and lower than those on ULD-HIR. Signal-to-noise ratio was highest and noise lowest on ULD-DLR. The subjective image quality of ULD-DLR was similar to that of LD-HIR and better than that of ULD-HIR. The effective radiation dose of ULDCT (0.64 ± 0.17 mSv) was 77% lower than that of LDCT (2.75 ± 0.50 mSv).
Alqahtani et al. (2024).[12]	Saudi Arabia.	Retrospective study.	243 patients with CT and US for suspected renal stones.	From the 243 data sets, 153 stones were detected in US and CT. The US exhibited sensitivity (67.4%), specificity (18.8%), diagnostic accuracy (64.2%), positive (92.2%), and negative predictive values (3.9%) in renal stones detection. The mean size of the renal stone detected in the US was 0.95 ± 0.08 mm, while the mean size detected by CT was 0.83 ± 0.07 mm. Furthermore, Bland-Altman's analysis comparing US and CT for measuring rena

				stones indicated perfect agreement between the two modalities.
El-Sheikh et al. (2022).[13]	Egypt	Retrospective study	There were 36 patients in our study, and each one signed an informed consent form after learning about the details of our research. CT and MRI scans were performed on each of them.	Stone density ranged from 815.63 to 340.99 with a low of 159 and a maximum of 1500 while the stone size ranged from 14.91 to 8.67 with a minimum of 6 and a maximum of 55. In contrast, the distribution of stone size and density by MRI was 15.648.16 with a minimum of 10 and a maximum of 50, respectively. We found that MRI was only able to identify 25 of the 36 instances discovered by the gold technique (CT). This indicates that MRI has a low sensitivity when it comes to stone identification (69.4 percent). The difference in stone size and density found by CT and MRI when compared just those instances sharing positive, was extremely significant. Although CT is the gold standard for the diagnosis of renal stones because of its high sensitivity for their direct detection, MRI also plays an important role in their identification. More sequences are needed to inhibit fat in this function, which is dependent on stone size (more than 1 cm), stone position (upper or lower pole).
Ibrahim et al. (2016).[14]	US	Diagnostic performance study with a retrospective, blinded comparative approach.	total of 160 patients were identified with an interval between the	The study found that MRI had a low detection rate for kidney stones compared to CT, with an overall sensitivity of **19%**. In the initial MRI review, **32 stones (23%)** were identified, with an average size of **8 ± 4 mm**, primarily located in the lower pole, upper pole, interpolar region, renal pelvis, and bladder. However, **106 stones**

			CT and MR examinations of 11 ± 9 days.	**(77%)** remained undetected, and these wer significantly smaller (**5 ± 3 mm**, P < 0.0001). A second MRI review, conducted with knowledg of CT findings, led to the identification of **1 additional stones (11%)**, bringing the tota number of detected stones to **44**. Despite thi improvement, **94 stones (89%)** still wen undetected, and stone size continued to be a ke determinant of visibility (P = 0.001). Furthe evaluation revealed that **9 of the initiall identified stones (28%)** were artifacts reducing the confirmed MRI-detected stones t **23**. In the final retrospective review, **26 of th 35 MRI-confirmed stones (74%)** wer reaffirmed, with an average size of **9 ± 4 mm** primarily located in the lower pole, upper pole interpolar region, and renal pelvis. However, **stones (26%)** were determined to b unidentifiable in a real-world setting highlighting MRI's limited reliability for kidne stone detection. Reviewer performance wa consistent, with both radiologists identifying similar percentage of stones, and retrospectiv review modestly improved detection rates Overall, these findings underscore MRI's poo sensitivity for kidney stone detection, with ston size being a crucial factor influencing visibility

Table 3. Critical appraisal of Study

Parameters	Wang et al. (2022)	Shen et al. (2023)	Pakmanesh et al. (2024)	Zhu et al. (2023)	Zhang et al. (2022)	Alqahtani et al. (2024)	El-Sheikh et al. (2022)	Ibrahim et al. (2016)
1. Bias related to temporal precedence								
Is it clear in the study what is the "cause" and what is the "effect" (ie, there is no confusion about which variable comes first)?	Yes, CDS intervention was applied before outcome measurement.	Yes, CT-ultrasound was used before outcome assessment.	Yes, nephrostomy access methods were compared before outcome measurement.	Yes, overlapping technique was applied before observing the outcome.	Yes, deep learning reconstruction was applied before outcome evaluation.	Yes, evaluation was conducted after the diagnostic procedure.	Yes, MRI was performed after CT for comparison.	Yes, MRI was compared to CT after the procedure.
2. Bias related to selection and allocation								
Was there a control group?	A control group (without CDS) was present.	A control group (US only) was present.	A control group (fluoroscopy) was present.	A control group (without overlapping technique) was present.	A control group (LD-HIR vs ULD-HIR vs ULD-DLR) was present.	No clear control group, only diagnostic comparison between US and CT.	No explicit control group, only imaging method comparison.	No explicit control group, only imaging method comparison.
3. Bias related to confounding factors								

Were participants included in any comparisons similar?	Patient characteristics were comparable between groups.	Animal model characteristics were comparable between groups.	Patient characteristics were comparable between groups.	Not explicitly stated.	Patient characteristics appeared to be comparable.	Unclear if patient characteristics were comparable.	Not explicitly stated.	Not explicitly stated.
4. Bias related to administration of intervention/exposure								
Were the participants included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No (Retrospective)
5. Bias related to assessment, detection, and measurement of the outcome								
Were there multiple measurements of the	Yes	Yes	Yes	Yes	Yes	Not relevant (diagnostic study).	Not relevant (diagnostic study).	Not relevant (diagnostic study).

outcome, both pre and post the intervention/ exposure?								
Were the outcomes of participants included in any comparisons measured in the same way?	Yes	Yes	Yes	Yes	Yes	Not relevant (diagnostic study).	Not relevant (diagnostic study).	Not relevant (diagnostic study).
Were outcomes measured in a reliable way?	Other treatments were similar in both groups.	Other treatments were similar in both groups.	Other treatments were similar in both groups.	Not clear.	Unclear whether differences existed beyond reconstruction technique.	Not relevant (diagnostic study).	Not relevant (diagnostic study).	Not relevant (diagnostic study).
6. Bias related to participant retention								
Was follow-up complete and, if not, were differences between	Measurement was standardized with clear	Measurement was performed using	Measurement was performed using	Measurement was performed using the	Measurement was performed using the same method.	Outcome measurement was performed using the same	Outcome measurement was performed using the	Outcome measurement was performed using the same method (CT vs MRI).

groups in terms of their follow-up adequately described and analyzed?	methodology.	the same method.	the same method.	same method.		method (CT vs US).	same method (CT vs MRI).	
7. Statistical conclusion validity								
Was appropriate statistical analysis used?	Statistical analysis was appropriate and significance was tested.	Statistical analysis was appropriate and significance was tested.	Statistical analysis was appropriate and significance was tested.	Unclear whether statistical analysis was robust.	Statistical analysis was performed with intergroup comparisons.	Unclear whether statistical methods were robust.	No in-depth statistical analysis.	No in-depth statistical analysis.

DISCUSSION

Ultrasonography (US) is a cost-effective imaging modality without ionizing radiation, increasingly used as an alternative to CT, especially outside the U.S. Its adoption is also growing in the U.S. US works by transmitting sound waves that reflect when encountering tissues with different acoustic impedances, generating images based on travel time and amplitude.[16-19]

B-mode (brightness mode) ultrasound visualizes stones as bright structures with a dark distal shadow. Harmonic mode enhances resolution and reduces noise, while Doppler ultrasound displays urine flow (ureteral jets) but may introduce artifacts around stones.

The sensitivity of ultrasound for kidney stones varies due to technique and patient characteristics. A meta-analysis reported a sensitivity of 45% and specificity of 88% for renal stones, and 45% sensitivity with 94% specificity for ureteral stones. Combining ultrasound with KUB radiography improves sensitivity to 58–100%.[16-19]

The STONE trial compared CT, bedside ultrasound, and radiology-performed ultrasound in 2,759 patients with obstructive nephrolithiasis. No significant differences were found in sensitivity (~85%) or specificity (~50%), but 41% of patients initially evaluated with bedside ultrasound later required additional CT. Ultrasound excels in portability, lower cost, and absence of radiation, making it the preferred first-line imaging for children and pregnant women. The AUA, EAU, and ACR recommend ultrasound for these populations. However, CT remains the standard for preoperative evaluation and complex cases. [16-19]

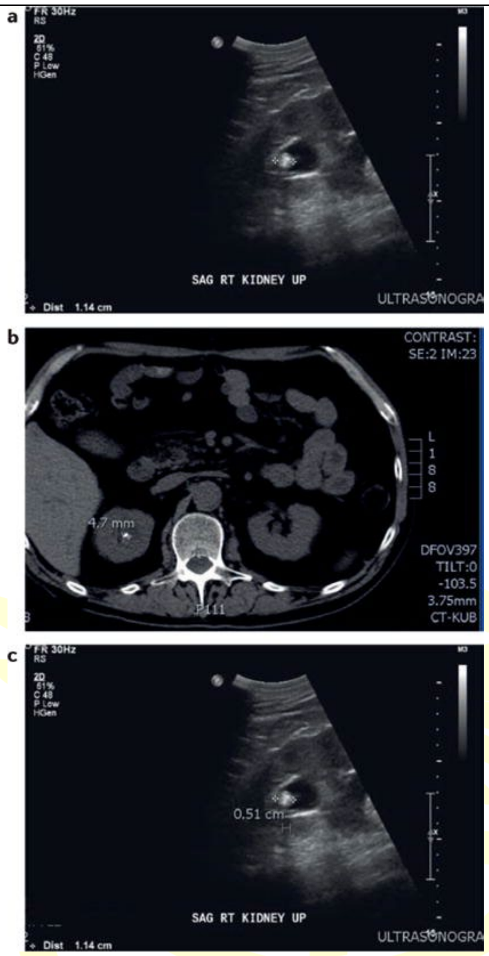

Figure 2. Comparison of stone size estimates by B-mode ultrasonography and CT.
a | B-mode ultrasonographic stone sizing on a longitudinal view of the kidney. b | CT scan image with an estimate of stone size, which is about half of the estimated size according to ultrasonography. c | Measurement of the stone shadow using B-mode ultrasonography provides a much closer estimate to that estimated using CT imaging.

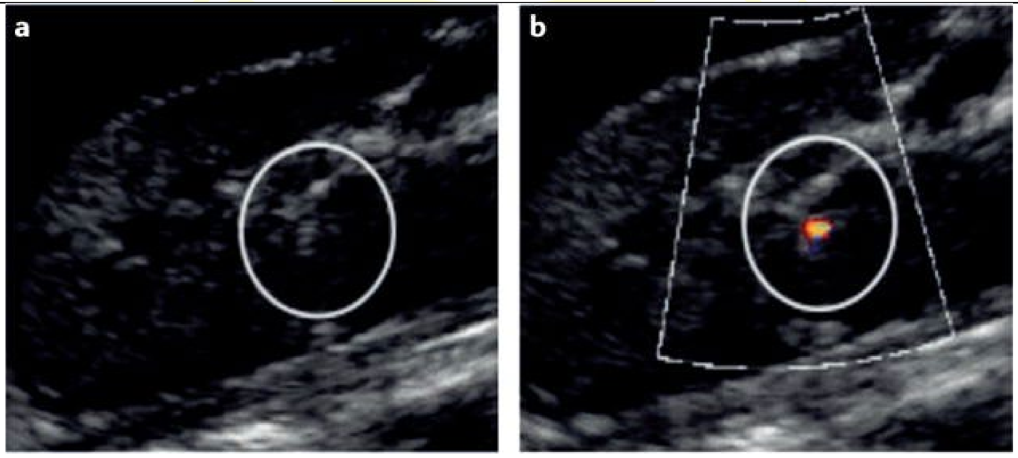

Figure 3. Comparison of ultrasonography in B-mode or the novel 'S-mode' in humans.

a | Conventional B-mode and b | novel S-mode. S-Mode combines enhanced B-mode and enhanced Doppler detection based on the twinkling artefact to make the stone particularly evident in the image. The bright opaque green on the bright white stone increases the contrast:background ratio, enabling easy of identification of the stone41.

CT imaging includes various scan types, with or without contrast, tailored to the clinical question. In nephrolithiasis, noncontrast CT or CT-KUB is preferred due to its ability to differentiate stones from renal tissue based on radiation absorption. CT provides high sensitivity (~95%) and specificity (98%) for kidney stones, though small stones (<3 mm) may be missed. Most stones are visible except for those from protease-inhibitor precipitation. Additionally, CT helps evaluate other causes of flank pain, including infections, tumors, and vascular disorders. [16-19]

CT can also assess stone composition using Hounsfield units (HU), which correlate with density and predict response to shockwave lithotripsy. Dual-energy CT improves accuracy by imaging at different voltages. CT remains more reliable than ultrasonography in obese patients, with guidelines favoring CT for BMI >30. [16-19]

Limitations include cost and radiation exposure (~10 mSv per scan). Low-dose CT (<3 mSv) reduces radiation while maintaining high sensitivity (99%) and specificity (94%). However, image quality declines at lower doses, particularly for stones <3 mm. Guidelines suggest standard CT for obese patients but recommend dose modulation based on clinical need. [16-19]

Overall, CT is the preferred modality for diagnosing renal colic and planning surgical interventions. Despite cost and radiation concerns, low-dose protocols offer a compromise. ACR, AUA, and EAU recommend CT as the first-line test for obstructive nephrolithiasis, reserving it for cases where ultrasonography is inconclusive.

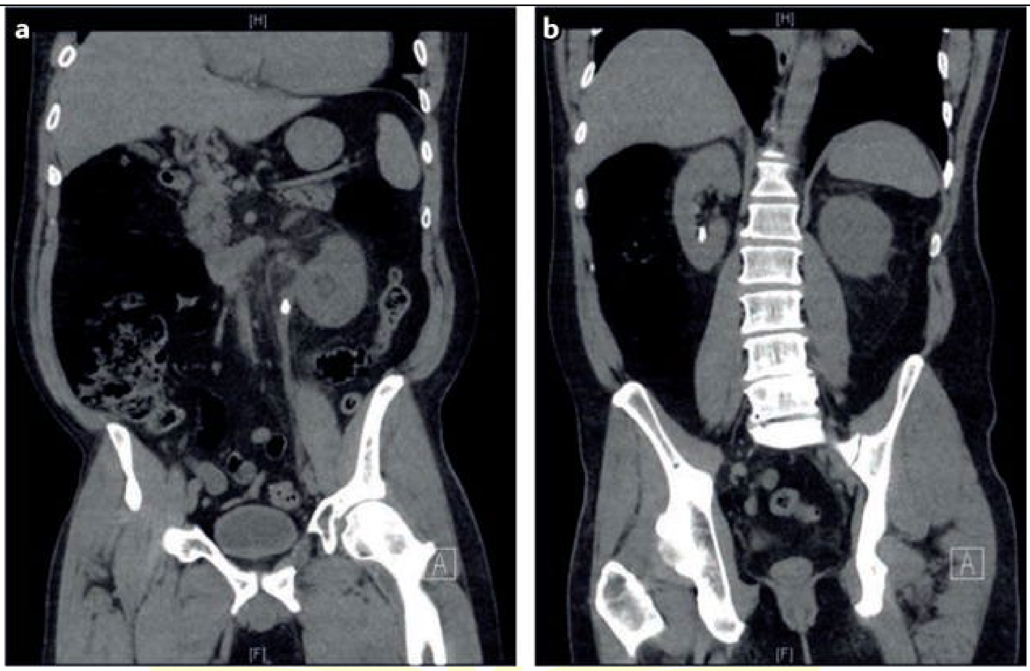

Figure 4. A coronal demonstration of bilateral 8 mm nephrolithiasis on noncontrast CT. Open in a new tab These stones are clearly visible using this imaging modality. Additional anatomical detail can be obtained by reconstructing the images in an axial plane. a | This coronal CT image clearly demonstrates a left-sided obstructing stone. b | Posterior coronal CT view of panel ademonstrating a lower-pole nonobstructing stone. An excellent level of anatomical detail can be seen here and can be further increased by reconstructing the image in an axial plane.

MRI utilizes a magnetic field to align free water protons along a specific axis. A radiofrequency coil placed over the targeted area emits pulses that temporarily disrupt this alignment. As the protons realign with the magnetic field, they release energy, which is captured to generate an image. MRI's sensitivity for detecting stones varies but can be improved by the presence of hydronephrosis. Standard MRI sequences show stones as nonspecific signal voids, but adjustments in imaging protocols can enhance detection. While MRI has a sensitivity of 82%, higher than ultrasonography and KUB radiography, it remains less sensitive than CT, as stones are more difficult to visualize. Hydronephrosis is clearly visible, but MRI may not always determine the underlying cause, requiring CT for definitive diagnosis in cases of suspected ureteral obstruction. However, when stones are identified, MRI has a high specificity of 98.3%.[16-19]

A key advantage of MRI is its ability to provide 3D imaging without radiation exposure. However, its high cost—approximately three times that of CT—along with lower accuracy and longer acquisition times, limits its widespread use in stone imaging. MRI is most suitable as a supplementary tool for ultrasonography, particularly in pregnant patients, where physiological renal dilation reduces the reliability of hydronephrosis as an obstruction marker. In such cases, MRI can be used when ultrasound fails to detect suspected obstructing stones. [16-19]

The ACR, AUA, and EAU recommend MRI as a second-line imaging modality in pregnant patients when ultrasound is inconclusive. Low-dose CT is also an option but requires discussion of radiation risks with the patient. Future advancements, such as ultrashort-echo-time MRI sequences, may improve sensitivity, specificity, and stone size estimation. [16-19]

Figure 5. Image sequence demonstrating coronal cuts on MRI.
a,b | Images obtained using T2 and c,d | images obtained using T1 sequences, clearly demonstrating hydronephrosis but distal pathology is not clear. Scan performed for cancer

surveillance — differential included metastasis, extrinsic ureteral compression and stones. e-g | CT images showing the hydronephrosis and hydroureter; a distal right ureteral stone is now easily visualized enabling diagnosis and considerably altering this patient’s treatment course.

The studies included in this review highlight the diverse imaging modalities employed in the detection and management of nephrolithiasis. Wang et al. (2022) assessed the effectiveness of an ultrasound-first clinical decision tool (CDS) in an emergency department setting. The study found a slight reduction in CT utilization in the CDS group without increasing revisit rates, hospitalization, or additional imaging.[7] Meanwhile, Shen et al. (2023) introduced a novel CT-ultrasound fusion technique for percutaneous kidney access in an experimental model. Their findings demonstrated a significantly shorter ultrasound screening time and higher puncture success rates, emphasizing the potential benefit of combining imaging techniques to improve procedural efficiency.[8] Similarly, Pakmanesh et al. (2024) compared ultrasound-guided and fluoroscopy-guided percutaneous nephrolithotomy (PCNL) for non-opaque stones. Their results revealed comparable success rates in renal access and stone clearance, with no significant differences in complication rates or hospital stays, suggesting that ultrasound may serve as a viable alternative to fluoroscopy in certain cases.[9]

Further exploration into imaging innovations was conducted by Zhu et al. (2023), who evaluated the application of image overlapping in PCNL. Their study showed improved stone clearance rates in the first-stage procedure, a higher rate of successful first-time punctures, and reduced procedure time, indicating that enhanced imaging techniques may optimize surgical outcomes.[10] In contrast, Zhang et al. (2022) investigated deep learning reconstruction applied to ultra-low-dose CT (ULD-CT) for detecting renal calculi. The study found that ULD-CT significantly reduced radiation exposure while maintaining high diagnostic accuracy, making it a promising approach for minimizing radiation risks in patients requiring recurrent imaging.[11]

Comparing different imaging modalities, Alqahtani et al. (2024) evaluated the diagnostic accuracy of ultrasonography versus CT in detecting renal stones. While ultrasonography demonstrated moderate sensitivity, CT remained superior in terms of specificity and diagnostic accuracy.[12] Similarly, El-Sheikh et al. (2022) assessed MRI’s capability in detecting kidney stones compared to CT. Their results indicated MRI’s limited sensitivity (69.4%) in identifying calculi, reinforcing CT’s role as the gold standard.[13] Ibrahim et al. (2016) further supported this conclusion, reporting that MRI had a poor detection rate (19%) and was particularly unreliable for smaller stones. However, their findings also suggested that MRI could still play a role in stone detection, particularly in patients for whom radiation exposure is a concern. [14]

Overall, the included studies underscore the ongoing advancements in nephrolithiasis imaging, highlighting the strengths and limitations of each modality. While CT remains the most reliable tool for stone detection, newer approaches, such as CT-ultrasound fusion, deep learning-enhanced CT, and improved ultrasound techniques, show promise in enhancing diagnostic accuracy while reducing radiation exposure. This systematic review has several limitations. The heterogeneity in study designs, populations, and imaging protocols complicates direct comparisons and limits generalizability. Variability in operator expertise, machine settings, and interpretation criteria may introduce bias. Many studies, especially those on novel imaging techniques, were conducted in controlled settings or had small sample sizes, reducing real-world applicability. Retrospective studies are prone to selection and information bias, and the lack of long-term follow-up limits the assessment of clinical outcomes. Additionally, potential publication bias and differences in healthcare systems across countries may impact findings. Future research should focus on standardizing imaging protocols and conducting larger, multicenter trials.

CONCLUSION

Kidney stones, or nephrolithiasis, represent a significant clinical challenge due to their potential to cause severe pain, urinary tract obstruction, and renal dysfunction. The increasing prevalence of this condition, driven by factors such as dietary habits, metabolic disorders, and obesity, underscores the importance of accurate and timely diagnosis. Imaging plays a pivotal role in the detection, characterization, and management of kidney stones, with various modalities offering distinct advantages and limitations.

This systematic review evaluated the diagnostic performance of imaging techniques, including ultrasound (US), non-contrast computed tomography (NCCT), dual-energy CT (DECT), magnetic resonance imaging (MRI), and plain radiography (KUB X-ray). The findings highlight that **NCCT remains the gold standard** for kidney stone diagnosis due to its high sensitivity and specificity, particularly for precise stone localization and size measurement. However, **ultrasound** is a valuable first-line imaging tool, especially in specific populations such as pregnant women and children, owing to its non-invasive nature and lack of radiation exposure. Emerging techniques, such as **CT-ultrasound fusion** and **deep learning-enhanced CT**, show promise in improving procedural efficiency and reducing radiation exposure while maintaining diagnostic accuracy. Despite its advantages, **MRI** has limited sensitivity for detecting kidney stones, particularly smaller ones, and is generally reserved for cases where radiation exposure is a concern, such as in pregnant patients. **KUB X-ray**, while less sensitive, can be useful in conjunction with ultrasound to improve diagnostic accuracy in certain scenarios.

In conclusion, the choice of imaging modality for kidney stone diagnosis should be guided by clinical context, patient characteristics, and the need to balance diagnostic accuracy with safety. Continued innovation in imaging technology holds the potential to improve the management of nephrolithiasis, ultimately enhancing patient care and reducing the burden of this common urological condition.

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