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ORIGINAL PAPER

Exploring the potential of combined B-mode features and color Doppler ultrasound in the diagnosis of ureteric stone as an alternative to ionizing radiation exposure by computed tomography

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Summary

***Objective:** To assess the diagnostic efficacy of integrating B-mode and color Doppler capabilities of ultrasound (US) to establish a robust standalone diagnostic tool for the diagnosis of ureteric stones as an alternative to non-contrast-enhanced computed tomography (NCCT).*
***Methods:** A total of 140 consecutive patients diagnosed with ureteric stones using NCCT were enrolled. On the same day, US in both B-mode and Color Doppler was performed by an experienced radiologist who was blinded to the NCCT scan results. The diagnostic rate of US for stone detection was recorded. Additionally, baseline patient and stone characteristics were analyzed for their association with the accuracy of stone detection using US.*
***Results:** US exhibited a high sensitivity of 91.43%, detecting 128 out of 140 stone foci. Notably, ureteric stones in the proximal and uretero-vesical junction (UVJ) segments were readily identifiable compared to those in the pelvic region ($p = 0.0003$). Additionally, hydronephrosis enhanced the US's ability to detect stones ($p < 0.0001$). Conversely, abdominal gases and obesity adversely affected US capabilities ($p < 0.0001$ and $p = 0.009$, respectively). Stone side, size, and density showed no statistically significant impact ($p > 0.05$).*
***Conclusions:** US with its color Doppler capabilities could serve as a reliable and safe alternative imaging modality in the diagnostic work up of patients with ureterolithiasis. Factors including stone location, Hydronephrosis, weight and abdominal gases significantly influenced its accuracy.*

KEY WORDS: *Renal colic; Urolithiasis; Ultrasonography; Twinkling artifact.*

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INTRODUCTION

Urolithiasis is a common health issue, with prevalence rates varying worldwide, ranging from 1% to 20% (1, 2). Patients with ureteral stones typically present repeatedly to the *emergency room* (ER) with acute abdominal pain, necessitating prompt evaluation. *Non-contrast-enhanced computed tomography* (NCCT) is the standard for diagnosing urinary stones. However, utilizing NCCT for all patients may pose challenges since it has the inherent property of releasing ionizing radiation even with the usage of low-dose CT protocols with possible undesirable effects on the human body. This directed research efforts towards the utilization of other safe diagnostic tools, such as *ultrasonography* (US) (1-3). US is now established as the primary diagnostic imaging modality in patients with ureteric colic. It is safe (no radiation risk), reproducible, inexpensive, and widely available. It can identify urinary stones, *upper urinary tract* (UUT) dilatation, as well as other causes of acute abdomen like ovarian problems and appendicitis (4). However, B-mode US is deemed lesser than CT in diagnosing ureteral stones. US has a sensitivity of 45% and a specificity of 94%, compared to 93.1% and 96.6% for low-dose CT (1, 5). Changes in gain and depth, along with other modes such as angling, S (stone-specific) mode, and color Doppler capabilities like *twinkling artifact* (TA), are key variables enhancing US accuracy for stone detection (6, 7). In this study, we aimed to assess the diagnostic efficacy of integrating B-mode and color Doppler capabilities of US to establish a robust standalone diagnostic tool for the diagnosis of ureteric stones as an alternative to NCCT.

PATIENTS AND METHODS

This is an interventional prospective study carried out between March 2022 and June 2023, including 140 consecutive patients diagnosed with ureteric stones by NCCT. We excluded pregnant women, patient with sonographically detected issues responsible of the pain other than ureteric calculi like appendicitis, oophoritis, ovarian cyst and diverticulitis, and patients with double-J ureteric stents.

Procedures

All studied patients initially underwent systematic examination by NCCT then US in B-mode and color Doppler.

The examination occurred at *Al-Azhar University Hospital, New Damietta*.

NCCT technique

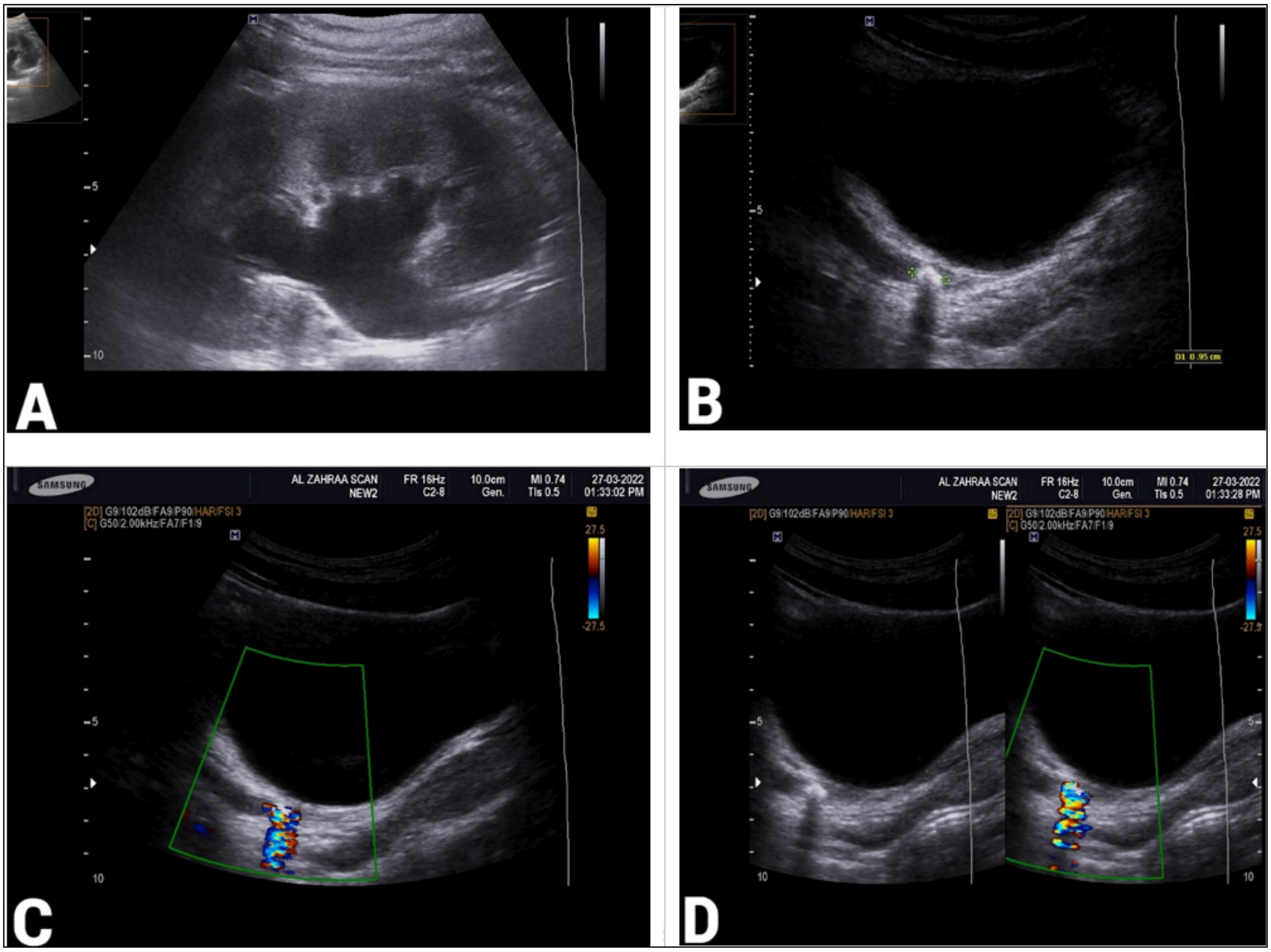
CT imaging was performed using Toshiba aquilion 160 slices scanner, Japan, 2015. Patients were examined with full urinary bladder in supine position. The coverage area extended from the upper pole of both kidneys to the base of the urinary bladder. Tube potential of 100-120 kVp and automatic tube current modulation with mA range of 80-500 was frequently used; however, the scan acquisition protocols were tailored to the patient body weight and CT scanner technology. Axial sections of 5mm thickness were taken, complimented with 3 mm coronal/sagittal reformatted images. Stone size was estimated by measuring largest dimension. Measurements were made on the soft tissue window (window width - 400 HU and window level - 30 HU).

US (B-mode & color Doppler) technique

US imaging was performed using a real-time US machine (*Accuvix XG, Samsung Medison co., Korea 2018*) which was equipped with an abdominal curved probe (*C2-8 convex probe 2-8 MHz*) and linear probe (*11L-D High Frequency 2D Probe 4-10 MHz*). Patients were examined with full urinary bladder. After applying US gel on the abdomen, US imaging series were acquired aiming to scan the urinary tract as well as other abdominopelvic organs that may be responsible for the complaint. The size and echogenicity of the renal parenchyma (normal, increased, or decreased) and the presence of any detectable parenchymal calcifications or abnormality were noted. Starting with the identification of fluid-filled (an-echoic) calyces and renal pelvis, we went ahead to the ureter tracking it in its anatomical site which is also a fluid-filled tubular structure with absent flow signal in color mapping study. The degree of dilatation of the pelvicalyceal system was graded (mild, moderate, and severe), and the ureters were visualized for dilatation. The gases in the intestine that handicapped the visualization of the ureter were fought by gentle pressure by the probe as well as making the patient lie on the contralateral side. Identification of calculi in the ureter was by

Figure 1.

US images from a 45-year-old female patient with Distal Ureteric Stone. (A) B-mode US scan of the right kidney in the longitudinal plane showing moderately dilated Pelvi-Caliceal System (PCS). (B) B-mode US scan of the urinary bladder and distal ureter (which is an-echoic tubular structure) in the longitudinal oblique plane, showing an echogenic stone with posterior acoustic shadowing inside the distal ureter. (C) Color Doppler scan on the previous plane exhibiting absent flow signal in the tubular structure (ensuring being ureter) & TA caused by the distal ureteric stone. (D) Dual (B & Color) modes of the same plane.



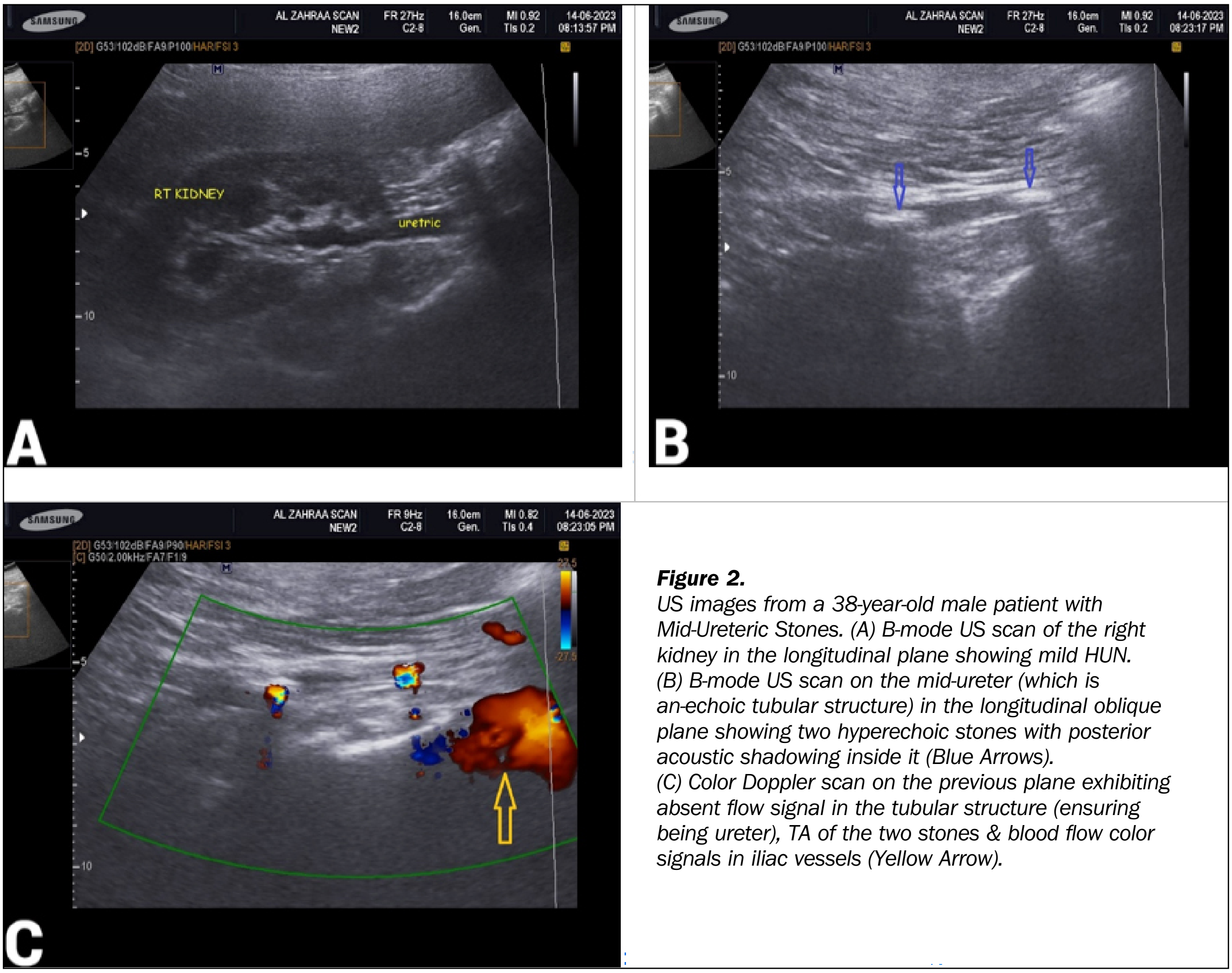


Figure 2.
US images from a 38-year-old male patient with Mid-Ureteric Stones. (A) B-mode US scan of the right kidney in the longitudinal plane showing mild HUN.
(B) B-mode US scan on the mid-ureter (which is an-echoic tubular structure) in the longitudinal oblique plane showing two hyperechoic stones with posterior acoustic shadowing inside it (Blue Arrows).
(C) Color Doppler scan on the previous plane exhibiting absent flow signal in the tubular structure (ensuring being ureter), TA of the two stones & blood flow color signals in iliac vessels (Yellow Arrow).

detection of abnormal objects with increased echoes on grayscale US that casts posterior acoustic shadowing. Color Doppler US came after to detect TA presence utilizing a red-blue color map (Figures 1, 2).

Outcome measures

Data about patients' age, sex, BMI and stone characteristics (side, size, location, density and hydroureteronephrosis) were collected. In addition, the diagnostic rate of US (B-mode in combination with color Doppler) for stone detection was recorded.

Sample size and statistical analyses

An online statistical calculator "*https://statulator.com/SampleSize/ss1P.html*" was used to estimate the sample size considering the following factors: assuming that 10% of the subjects in the population suffer from urolithiasis (1, 2), 5% absolute precision, and 95% confidence. Allowing for a 10% dropout rate, a total sample size of 139 patients was estimated. Data were tabulated and analyzed using the SPSS package 25 (*IBM Corp, Armonk, NY, USA*). Univariate analyses of continuous and categorical variables were done using the independent sample t-test and chi-square test, respectively. The sensitivity of US (B-mode in combination with color Doppler) for stone detection was calculated with 95% CI (confidence interval), with statistical significance considered at $p < 0.05$.

Informed consent was obtained from all participants in the study, and the protocol for this research project was approved by our ethical committee under the Institutional Review Board (IRB/ 00012367-24-03-007).

RESULTS

This study included 140 consecutive patients diagnosed with ureteric stones using NCCT. The patients' age ranged from 14 years to 77 years with a mean of 41 years. The pre-procedural patients' demographics (age, sex and BMI) and stone characteristics (side, size, location, density and hydroureteronephrosis) are detailed in Table 1. When B-mode and color Doppler US were employed, the US demonstrated a high sensitivity of 91.43% (95% CI: 85.51% to 95.49%), detecting 128 out of 140 stone foci, which indicates its effectiveness in accurately identifying true positive cases. For further analysis, we assessed all factors potentially influencing US accuracy for stone detection, including baseline patients' and stone characteristics (Table 2). Interestingly, stone-related variables (side, size, and density) showed no statistically significant impact ($p > 0.05$). Conversely, patient-related variables

Table 1.
Baseline (patient and stone) characteristics.

Patient, n	140
Age, mean ± SD (range), year	41.75 ± 5.34 (14-77)
Sex, n (%)	
Male	99 (70.71)
Female	41 (29.29)
BMI, mean ± SD (range), Kg/m^2	27.03 ± 2.01 (22.85-31.35)
Laterality, n (%)	
Rt.	69 (49.29)
Lt.	71(50.71)
HUN, n (%)	
No	17 (12.14)
Mild (Gr.1)	78 (55.72)
Mod. (Gr. 2)	38 (27.14)
Sever (Gr. 3)	7 (5)
Stone Size, mean ± SD (range), mm	8.5 ± 1.19 (3.74-21.2)
Stone Density, mean ± SD (range), HU	693.17 ± 590.35 (110-1440)
Location, n (%)	
Lumber	42 (30)
Pelvic	81 (57.86)
UVJ	17 (12.14)

BMI: Body Mass Index; HU: Hounsfield Units; HUN: Hydro-Uretero-Nephrosis; n: Number; SD: Standard Deviation; UVJ: Uretero-Vesical Junction.

Table 2.
Categorical variables tested against US accuracy for stone detection.

Variable	US		Total, n	P
	Yes	No		
Laterality:				
Right	63	6	69	0.96
Left	65	6	71	
Stone Size:				
< 5 mm	25	4	29	0.52
5-10 mm	65	5	70	
> 10 mm	38	3	41	
Stone Location:				
Lumber	54	2	56	0.0003
Pelvic	35	10	45	
UVJ	39	0	39	
Stone Density:				
< 400	43	4	47	0.98
400-1000	56	5	61	
> 1000	29	3	32	
HUN:				
No	8	9	17	< 0.0001
Mild (Gr. 1)	77	1	78	
Mod. (Gr. 2)	37	1	38	
Severe (Gr. 3)	6	1	7	
BMI:				
< 25	39	2	41	0.009
25-30	64	3	67	
> 30	25	7	32	
Gaseous abdomen:				
Yes	7	8	15	< 0.0001
No	121	4	125	

BMI: Body Mass Index; HUN: Hydro-Uretero-Nephrosis; n: Number; UVJ: Uretero-Vesical Junction.

(BMI and gaseous abdomen), stone location, and the degree of *hydroureteronephrosis* (HUN) demonstrated a statistically significant association. Ureteral stones in the proximal and *uretero-vesical junction* (UVJ) segments were readily identifiable compared to those in the pelvic region ($p = 0.0003$). Additionally, the presence of HUN enhanced the US's ability to detect stones ($p < 0.0001$). Conversely, the presence of gases in the abdomen and obesity negatively impacted on US capabilities ($p < 0.0001$ and $p = 0.009$, respectively).

DISCUSSION

It is now a common practice to conduct imaging studies in all patients with suspected renal colic admitted to the emergency room. This trend may stem from concerns about overlooking potentially life-threatening conditions that resemble renal colic, such as a ruptured aortic aneurysm, ovarian torsion, or appendicitis. Additionally, there is a necessity for imaging confirmation to determine the underlying cause of symptoms before considering discharge (8, 9). NCCT is the official method for diagnosing urinary stones due to its benefits, being unaffected by intestinal gas and posing excellent accuracy in detecting ureteral stones. However, concerns about the over-utilization of CT are growing because of increasing health care costs and, more importantly, exposure to ionizing radiation. A study published in the *Journal of the American Medical Association* estimated that 1 in 1400 people over the age of 60 who receive NCCT may develop cancer or leukemia (10). It is noteworthy that radiation exposure has cumulative effects, raising the risk of future cancers. This cumulative impact builds up over time.

Consequently, young individuals and pregnant women should minimize exposure to radiation whenever possible (11). Currently, there is a growing emphasis on radiation protection when imaging patients with suspected renal colic. This focus has extended beyond the radiological community (12, 13) and emergency physicians (14, 15) to include urologists. In the 2023 guidelines on urolithiasis of the European Association of Urology, it is stated that US should be the primary diagnostic imaging tool in patients with renal colic, and NCCT should be reserved for cases where the diagnosis is doubtful (1). US is a safe, cost-effective, non-invasive, and readily available technique for assessing patients with renal colic. Importantly, prioritizing US usage can prevent radiation exposure in approximately 70% of cases and possesses the ability to identify alternative diagnoses mimicking renal colic (9, 16). Nevertheless, its application remains a subject of debate as it effectively detects dilatation of the excretory system even in inexperienced hands (14). However, challenges arise in directly visualizing stones, particularly in the pelvic ureters, making it operator-dependent for stone detection and relying on "*indirect findings*" for diagnosis.

Additionally, the absence of these "*indirect findings*" does not rule out ureteral stones (17). The performance of US studies by radiologists and modifications in gain and depth settings, along with the utilization of various modes such as angling, S (stone-specific) mode, and color Doppler features like TA, have been reported to enhance the precision of US for stone detection (6-8 & 18-20). The color Doppler TA manifests as a rapidly alternating signal in color Doppler imaging, resembling turbulent flow. It is often observed when scanning a stationary object with an irregular surface, such as urinary stones, which reflects the Doppler signal. In Doppler imaging, this phenomenon presents as a jumbled pattern. The spectral analysis of twinkling may reveal aliasing (7). It is very useful to confirm findings of grey-scale, especially in doubtful cases due to the small size of the stone or when its location is in difficult-to-visualize ureteral portions. However, careful interpretation is essential since the jumbled pattern of twinkling may mimic turbulent flow, which could be confusing and may lead to errors in diagnosis. Additionally, the presence of aliasing in the twinkling spectrum could further complicate the interpretation, potentially making it challenging to distinguish between true flow abnormalities and artifacts. Therefore, it should be interpreted along with other clinical information and imaging modalities to ensure an accurate diagnosis (17). Several studies have highlighted the usefulness of US compared to NCCT in the initial diagnosis and management of renal colic patients, without a notable increase in complications, serious adverse events, return emergency department visits, or hospitalizations (18-20). In our study, the sensitivity of US for detection of ureteric stones was about 91.43%, detecting 128 out of 140 stone foci (95% CI: 85.51% to 95.49%) which is in accordance with previous reports (21-23). The role of patient's and stone-related variables in the US detection of ureteric stones has been extensively evaluated in previous reports. Factors such as the presence of HUN, vascular calcifications and other artifacts that may also be mistaken for stones, experience and knowledge of the urinary tract anatomy and the presence of bowel gas, which may obscure the ureteral calculi, as well as stone size, location, and density, can affect the detection of ureteric stones. For instance, *Ahmed et al.* reported an overall sensitivity of US of 75.4%. The detection rate of mid and distal ureteral stone was lower than that at proximal locations, and the detection rate increased with stone size and the degree of HUN. Conversely, US is of limited value, particularly when used by an inexperienced radiologist, and in the case of smaller stone size, increased weight, and low grade of HUN (22). Another study by *Sen et al.* reported a sensitivity of US of 86.8 %, with better success noted in proximal ureteral stones (95.6 %) (21). Goertz and Lotterman also found that the increasing degree of HUN was associated with an increased likelihood of diagnosing ureteric stones using US (24). In a more recent report on the diagnostic value of US in ureteric stones ≤ 10 mm by *Krakhotkin et al.*, while the US demonstrated a sensitivity rate exceeding 90% for stones ≥ 5 mm located in the proximal and distal ends of the ureter, its accuracy was notably restricted, not exceeding 53%, for stones sizing 1-3 mm and those situated in the middle ureter possibly due to bowel interposition (25). Our results closely align with previous reports, indicating that the stone location and increasing degree of HUN were associated with increasing detection rate of ureteric stone in US ($p = 0.0003$ and < 0.0001, respectively). On the other hand, the presence of bowel gases negatively impacted US capabilities ($p < 0.0001$). Of note all US assessments in our study were conducted solely by an experienced radiologist. Regarding the impact of BMI on the sensitivity of US and color Doppler capabilities, some studies have reported that higher BMI values decrease the sensitivity of both modalities (22, 26, 27), consistent with our findings ($p = 0.009$). However, others have not found any correlation (18, 21, 28), possibly due to the small number of patients with BMI > 30 kg/m². As for the role of stone size, it was evaluated in several studies. *Winkel et al.* (16) and Mitterberger et al. (19) found no correlation. However, *Sen et al.* (21), *Ahmed et al.* (22), *Krakhotkin et al.* (25), and *Sorensen et al.* (29) reported that as the stone size increased, the sensitivity of US also increased. In our study, the ureteral stone side, size, and density exhibited no statistically significant impact ($p > 0.05$).

Limitations

Our study possesses certain limitations. Firstly, color Doppler US relies heavily on the examiner's skill; specific training of healthcare professionals may be required to develop sufficient skills and be aware of its strengths and limitations. Also, our study was single-blinded; future double-blinded research investigations may shed more light on the preference of US over NCCT. Furthermore, future studies examining US outcomes in relation to different operators rather than a single expert, as well as investigating the role of stone composition and surface roughness are warranted.

CONCLUSIONS

US with its color Doppler capabilities could serve as a promising and safe alternative imaging modality in the diagnostic work up of patients with ureterolithiasis. However, factors such as stone location, HUN, weight, and the presence of abdominal gases, along with the examiner's competence significantly influence its accuracy.

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