Limitations of ultrasound compared with computed tomography for kidney stone surveillance

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ABSTRACT

INTRODUCTION: Renal ultrasound (US) offers less radiation exposure than computed tomography (CT) for kidney stone surveillance but has lower sensitivity and specificity for nephrolithiasis diagnosis. Additionally, US may overestimate stone size, leading to unnecessary surgical interventions. Evidence on US performance for kidney stone surveillance is variable, making its clinical utility unclear. We aimed to assess US accuracy against CT and identify factors influencing US performance.

METHODS: We performed a retrospective review of patients with known nephrolithiasis seen in urology clinic at Stanford who underwent both renal US and CT within 90 days for surveillance from January to December 2022. Patients with spontaneous stone passage or interventions were excluded. Stone characteristics were recorded, and statistical analysis compared the diagnostic accuracy of US and CT.

RESULTS: A total of 107 patients and 128 stones were included, with a mean time difference of 25.7 days between US and CT. US sensitivity was 77%, with a positive predictive value (PPV) of 75% for stone detection. The PPV was only 59% for stones >4 mm by CT. Mean stone size was 8.7 mm on US vs. 5.5 mm on CT ($p=0.02$), with more pronounced overestimation in smaller stones and higher body mass index (BMI) ($p<0.05$). No significant differences in US performance were found by stone location, laterality, or time between scans. Differences in stone detection ($p=0.01$) and size ($p=0.03$) were associated with the individual performing the ultrasound.

CONCLUSIONS: US performance is limited compared to CT and is influenced by stone size, BMI, and sonographer. Overestimation by US may lead to unnecessary interventions in up to 40% of patients with stones >4 mm.

INTRODUCTION

Accurate imaging is critical for the diagnosis and management of kidney stone disease. Computed tomography (CT) is the standard imaging modality due to its high sensitivity and specificity for stone diagnosis, and its ability to provide precise anatomic information;[1,2] however, increased use of CT scans has raised public health concerns over excessive exposure to ionizing radiation in patients.[3] Renal ultrasonography (US) has emerged in recent years as an alternative for kidney stone imaging because US does not use radiation, is easy to access, and costs less. US has been found to be effective in the emergency setting for the initial diagnosis of suspected renal colic, as it can be performed at the bedside, with no differences in complications, pain, return to emergency room, and hospitalization in 30 days as compared to CT.[4]

The widespread use of US for nephrolithiasis has been limited by concern over its lower sensitivity for stone detection compared to that of CT. This is largely because the quality of US imaging depends on operator experience, technique, and patient body habitus. US has varying sensitivity between 24-93%,[5-7] with a pooled sensitivity of 45%,[8] compared with CT, which exceeds 95%. Importantly, US may overestimate stone size, which can impact decision-making for stone management.[9] Since obstructing renal stones <5 mm have high spontaneous passage rates,[10-13] overestimation of stone size may result in unnecessary surgery for stones that would oth-

KEY MESSAGES

- US shows 77% sensitivity for kidney stones, contrasting with >95% with CT, but spares patients radiation exposure and is more accessible.
- US overestimates stone size, averaging 8.7 mm vs. 5.5 mm with CT, which may lead to unnecessary surgeries for stones that are likely to pass without intervention.
- US accuracy is affected by operator experience and patient BMI, with larger BMI values correlating to greater size overestimation.
- Reliance on US alone for treatment decisions may result in 40% of patients with stones >4 mm undergoing unnecessary interventions.

erwise pass. Thus, most urologists still rely on CT to confirm stone burden before offering patients surgical intervention, regardless of US findings.

Still, US remains an integral tool in the management of stone disease, particularly among patients who are younger, pregnant, or lack access to CT scanners. While existing studies have evaluated the inaccuracies of US compared with CT, few have identified factors associated with these inaccuracies. The purpose of this study was to assess the diagnostic accuracy of US using CT as reference, as well as to identify factors that affect US performance.

METHODS

Study design

This study was approved by Stanford University Institutional Review Board. We retrospectively reviewed all adult kidney stone patients seen in the urology clinic at Stanford Health Care between January 2022 and December 2022. We included patients who underwent both CT and US imaging within 90 days of each exam for kidney stone surveillance. To minimize variability of imaging qualities between different radiology departments, only patients who underwent both studies in the radiology department at Stanford were included. We excluded patients who underwent both CT and US for reasons other than stone burden confirmation, such as reassessment after stone surgery intervention, evaluation of stone passage, and change in clinical symptoms. We abstracted clinical data pertaining to patient demographics, body mass index (BMI), stone size, and stone location.

Imaging studies

In order to assess real-world clinical practice, all imaging studies were performed for assessment of kidney stone burden and reported at the discretion of the radiology department. CT studies were performed without contrast and scanned from the upper abdomen to the pelvis, acquired on a dual-source CT scanner (General Electric Revolution CT, Boston, MA, U.S.). US studies were performed using conventional grayscale with Doppler (General Electric LOGIQ, Boston, MA, U.S.) by certified technologists.

The presence of echogenic foci with or without twinkling artifact and acoustic shadowing were interpreted at the discretion of radiologists who specialize in body imaging. The findings of the formal radiology reports were recorded, including maximal stone size, stone location, and number of stones. Stones reported without associated details on size and location were omitted from data analysis. Stone detection on US was confirmed when CT detected the stone in the same location.

Outcomes

We defined the primary outcomes as the sensitivity and positive predictive value (PPV) of US to detect the presence of a kidney stone. We defined secondary outcomes as the percentage of times US overestimated the size of a stone to be >4 mm. A false-positive was defined as either a US-detected stone that was not identified on CT or an overestimated US-detected stone size that was ≤4 mm on CT. This cutoff was established given stones <5 mm are likely to pass spontaneously without intervention; hence, this represents a consequential false-positive if US alone were the determinant of intervention vs. conservative stone management.[10-13] Additionally, we performed subgroup analysis based on intrarenal and ureteral location, laterality, BMI, US technician performance, and interpreting radiologist.

Statistical analysis

We performed statistical analysis with SPSS Statistics 28.0 package (IBM, NY, U.S.). We compared continuous variables between groups with two-tailed Student's t-test and ANOVA. Categorical variables are described with proportions and compared using the Chi-squared or Fisher exact test. Multivariable logistic regression analyses were performed to evaluate potential associations with PPV of US-detected stones. A p-value of <0.05 was considered statistically significant.

RESULTS

A total of 107 patients underwent both US and CT exams for the evaluation of kidney stone burden. The study cohort had a mean age of 57.3±16.0 years and BMI of 27.4±5.8 kg/m^2 (Table 1). The mean time between US and CT was 25.7±23.7 days, and US was performed as the initial imaging modality in 86 (80.4%) patients for routine surveillance or incidental stone detection. Over a 12-month period, 39 certified US technologists and 28 radiologists participated in the renal US exam.

A total of 128 stones were identified on US. The sensitivity of US for stones seen by CT was 77% (95% confidence interval [CI] 68–84%). Of the 128 stones seen by US, 96 had corresponding stones on CT, with a PPV of 75%. Using a clinically relevant threshold of stone size >4 mm,[10-13] a total of 76 such stones were detected on US and only 45 (59%) corresponded to a >4 mm stone on CT. Examples of such occurrences are illustrated in Figure 1.

The sensitivity and PPV of US were further stratified by stone and patient factors. We found no correlation between US sensitivity and PPV with stone location, laterality, and patient BMI (Table 2). When stratified by stone size estimated by US, PPV ranged from 50% for 1–4 mm to 94% for >10 mm (Figure 2). When we examined stone size >4 mm by CT, the PPV by US was only 59%, with a range of 28–83%, as the US stone size increased from 3 mm to 40 mm.

US overestimated stone size compared with CT. Measurement of stone size by US was 8.7±6.2 mm, compared with 5.5±6.4 mm on CT (p=0.02), with a mean difference of 1.8±3.1 mm. When we categorized stone by location in the kidney or ureter, we found no significant difference in stone size measurements (p=0.64). Subgroup analysis showed that the discrepancy of stone size increased between US and CT in patients with greater BMI (p=0.037). In contrast, there was no significant difference in stone size between US and CT for patients who were not overweight (BMI <25) (p=0.25) (Figure 3), a group that accounted for 38% of this study cohort.

Since the quality of US is operator-dependent, we compared US stone detection from the top three technologists who conducted US exams (8%, 8%, and 7% of studies) and the top three radiologists who interpreted US exams (12%, 8%, and 8% of studies). We found a significant difference in PPV for stone detection by US when comparing technologists, ranging from 53–100% (p=0.01); in contrast, we found no difference in PPV for stone detection by US when comparing radiologists (Table 2). Similarly, there was a significant difference among technologists in the reporting of mean US stone size (p=0.03), but no difference among radiologists (p=0.30) (Table 3).

We also analyzed clinical factors that were associated with stones estimated to be >4 mm by US that were smaller or undetectable by CT (i.e., a false-positive). Patient demographics, including age, gender, eth-

Table 1. Baseline characteristics of study cohort

	Total (N=107)
Age	
Mean, years ± SD	57.3±16.0
18-30	7 (7)
31-40	9 (8)
41-50	17 (16)
51-60	24 (23)
61-70	24 (23)
71-80	20 (19)
>80	6 (6)
Gender	
Male	50 (47)
Female	57 (53)
BMI	
Mean ± SD	27.4 ± 5.8
<25	40 (38)
25-30	38 (36)
30-35	24 (23)
>35	4 (4)
Race	
White	57 (53)
Black	4 (4)
Asian	15 (14)
Hispanic	25 (23)
Other	6 (6)

BMI: body mass index; SD: standard deviation.

nicity, and BMI, were not associated with higher odds of a false-positive US reading (Table 4). The timing of US and CT, including chronological order of the scans and time interval between scans, also did not associate with higher odds of a false-positive US reading. The volume of participating technologists or radiologists, ranging from 1–12% of the total US studies, did not correlate with false-positive US findings. A small stone size on US (5–7 mm) was the only factor that associated with overcalling the size of a stone by US relative to CT (odds ratio 2.06, 95% CI 1.29–3.33, p=0.02).

DISCUSSION

CT is regarded as the gold-standard modality for the diagnosis of kidney stones due to its superior sensitivity, specificity, size determination, and ureteral calculi detection; however, it is limited by associated increased costs and radiation exposure. The oncogenic effects of accumulated ionizing radiation have been well-established and are particularly concerning in kidney stone patients, who tend to be relatively young at disease onset, with a mean age of 43 years, and have multiple recurrences over their lifetime.[14,15] US lacks radiation and is relatively accessible, but its role in the first-line setting for the evaluation of nephrolithiasis has been controversial due to limitations of reduced sensitivity, specificity, and overestimation of stone sizes.[5–8]

Several studies have examined the sensitivity of US compared to CT, which has a pooled sensitivity of 45%,[8] but few have investigated potential factors associated with these tendencies. As US continues to be an important imaging modality for kidney stone patients, we sought to investigate the diagnostic accuracy of US in our institution and identify potential factors that could affect the accuracy of kidney stone characterization on US.

In this study, the overall sensitivity of US for stones seen on CT was 77%, which was in the range of those reported in the literature but on the higher end, particularly compared to recent studies. Ganesan et al reported a sensitivity of 54% in a large cohort of 552 CT/US pairs,[9] and Sternberg et al reported a sensitivity of 63% in a multicenter analysis of 155 patients.[16] This is likely explained by the homogeneity of our single-institution design, as well as minimal inclusion of ureteral calculi in our analysis due to the exclusion of acute renal colic patients in the present study cohort.

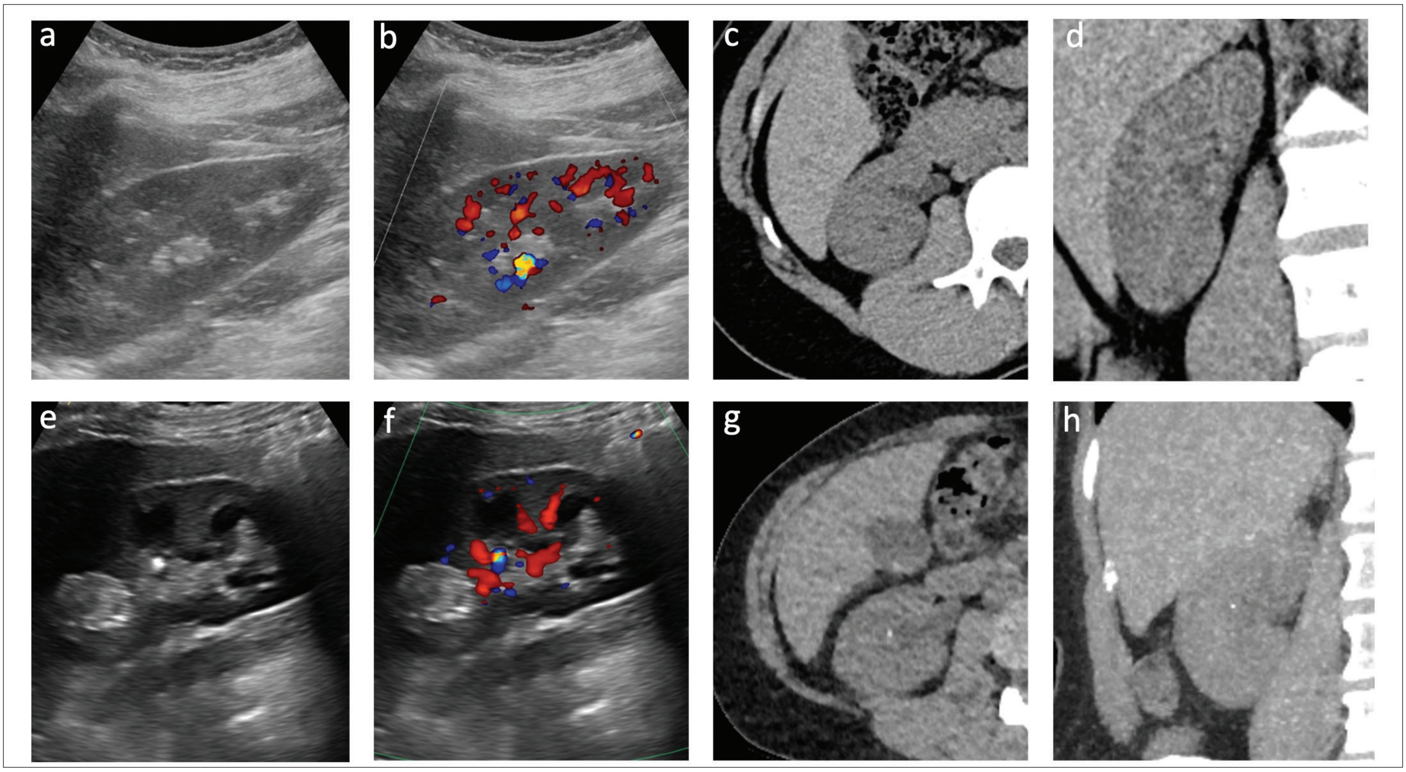

Figure 1. Examples of ultrasound (US) stone detection and subsequent discordant computed tomography (CT) finding. US was initially performed for a 28 F with known history of nephrolithiasis due to right flank pain. Initial US image (a) and twinkling (b) suggested presence of a 5 mm right renal stone. CT performed on the same day revealed no evidence of stone (c, d). A 51 F who underwent routine stone surveillance with US initially showed a 6 mm right interpolar stone (e) with twinkling (f), and subsequent CT after 12 days revealed only a punctate 2 mm right renal stone (g, h). Based on history, neither patient passed any stones spontaneously between the imaging studies.

Accurate size measurement of stone burden is paramount in the counseling and management of kidney stone disease. Small stones <5 mm are often observed and treated medically, as spontaneous passage rates are favorable,[10-13] while larger stones may require surgical intervention, in which different options also exist depending on stone size. For example, current American Urological Association guidelines suggests that ureteroscopy and shockwave lithotripsy could be offered to patients with ≤10 mm lower pole renal stones, while ureteroscopy and percutaneous surgery should be considered for >10 mm lower pole stones due to higher stone-free rate.[17]

Our data supports the well-established notion that US overestimates stone size by 58%, with a mean difference of 1.8±3.1mm. Similarly, a small study found that US overestimates stone size in 87% of cases by a mean of 1.8 mm, and another study found that US reports most kidney stones <5 mm in size to be >5 mm.[8] More recently, Sternberg et al found US overestimates stone size by 2.2 mm, and even more for stones <5 mm.[16]

Indeed, while our study showed an overall PPV of 75% for stone detection by US, similar to the PPV of 78% reported in a meta-analysis,[8] when we limited our analysis to larger stone sizes (i.e., stones >4 mm) seen on US, the PPV was only 59% relative to the same stone size by CT. This size discrepancy between US and CT was even greater for smaller stones; of all the stones measured between 5–7 mm by US, only 28% corresponded to a stone at least 5 mm on CT. In other words, if only US was used for decision-making, up to 72% of patients with 5–7 mm stones on US would undergo unnecessary surgical intervention.

Many factors affect US diagnostic accuracy for renal stones. Stones in the left kidney were hypothesized to be more difficult to detect by US because the higher anatomic location of the left kidney may require intercostal scanning. The evidence for this hypothesis is mixed; some studies have found worse sensitivity for left-sided stones,[7,18] particularly left upper pole, while others have found no difference.[5,9] In our study, no statistically significant difference was found between sensitivity of US detection of left-sided (72%) vs. right-sided (84%) stones (p=0.07).

Patient BMI may also affect US accuracy, as tissue thickness may limit US image quality due to sound beam attenuation.[19] Our data suggests that sensitivity for stones is not affected by BMI, which is consistent with the findings from other groups;[7,18,20] however, we found that patient BMI does impact stone size estimation by US: greater BMI was associated with increased

Table 2. Comparison of stone detection on ultrasound compared to CT

Stone detection	CT	Ultrasound		
	N (%)	Sensitivity (%)	PPV (%)	PPV of stones >4 mm (%)
All	125 (100)	96/125 (77)	96/128 (75)	45/76 (57)
Renal location				
Upper pole	9 (11)	8/9 (89)	12/16 (75)	8/15 (53)
Mid pole	16 (20)	10/16 (63)	17/25 (68)	11/20 (55)
Lower pole	28 (35)	23/28 (82)	23/31 (74)	14/24 (58)
Renal pelvis	11 (14)	6/11 (55)	4/5 (80)	2/4 (50)
p		0.77	0.23	0.61
Ureteral location				
Proximal ureter	5 (6)	2/5 (40)	1/1 (100)	0/1 (0)
Mid ureter	2 (3)	0/2 (0)	0/0 (0)	0/0 (0)
Distal ureter	9 (11)	2/9 (22)	2/2 (100)	1/1 (100)
p		0.37	0.08	0.38
Laterality				
Left	64 (51)	46/64 (72)	45/56 (80)	21/35 (60)
Right	61 (49)	51/61 (84)	51/62 (82)	24/41 (59)
p		0.07	0.90	0.27
BMI				
<25	40 (38)	33/40 (83)	25/34 (74)	12/24 (50)
25-30	38 (35)	26/38 (68)	26/33 (79)	20/28 (71)
31-35	24 (23)	21/24 (87)	14/19 (74)	6/19 (32)
>35	4 (4)	4/4 (100)	2/2 (100)	1/2 (50)
p		0.61	0.81	0.20
Technician				
#1 (n=8)	21	12/21 (57)	12/12 (100)	4/6 (67)
#2 (n=9)	16	10/16 (63)	8/15 (53)	1/4 (25)
#3 (n=7)	17	14/17 (82)	9/11 (82)	2/6 (33)
p		0.18	0.01	0.40
Radiologist				
#1 (n=9)	16	11/16 (69)	12/16 (75)	4/6 (66)
#2 (n=9)	14	12/14 (86)	10/13 (77)	2/7 (29)
#3 (n=13)	17	16/17 (94)	13/16 (81)	3/6 (50)
p		0.68	0.76	0.19

BMI: body mass index; CT: computed tomography; PPV: positive predictive ratio.

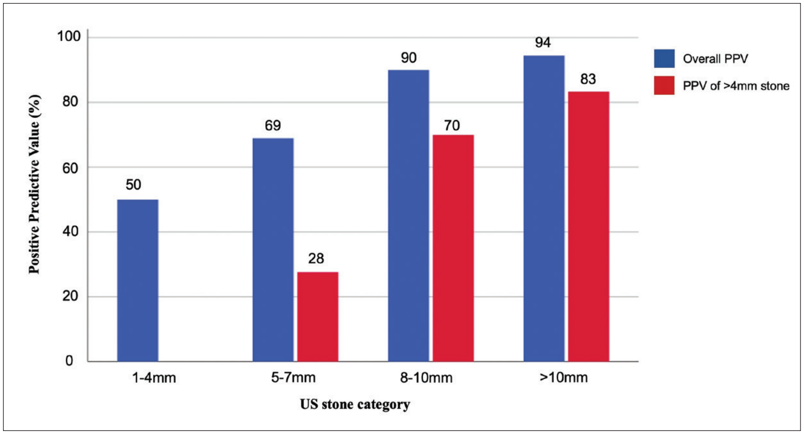

Figure 2. Positive predictive value (PPV) of corresponding computed tomography (CT) stone according to reported ultrasound (US) stone size. As a whole, the PPV was 75% and ranged from 50–94%, increasing as US stone size increased. When analysis was limited to clinically relevant threshold of >4 mm stones, the PPV for the presence of a corresponding >4 mm stone on CT was only 59% and ranged from 28–83%, increasing as US stone size increased.

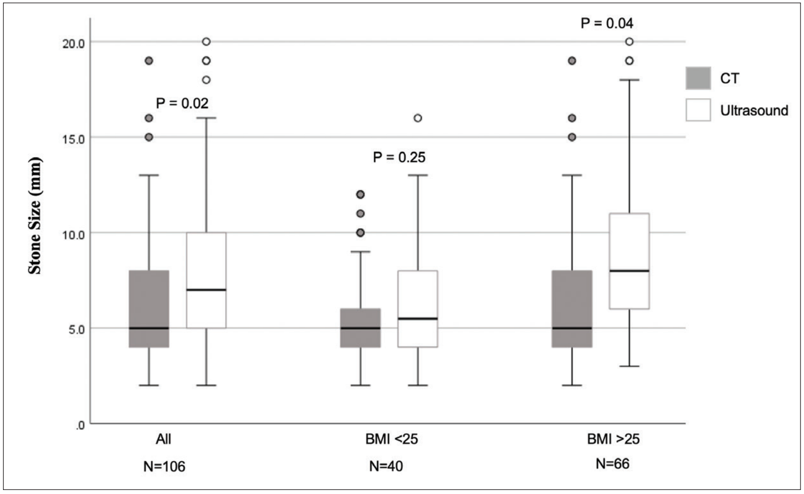

Figure 3. Comparison of renal stone size measurements between ultrasound (US) and computed tomography (CT) among those with normal or increased body mass index (BMI). As a whole, US overestimated stone size with a mean difference of 1.8±3.1mm (p=0.02). The mean difference was 0.7±1.7 mm (p=0.25) in patients with a normal BMI of <25, compared with a difference of 3.0±3.5 mm (p=0.04) in those with increased BMI of >25.

stone size estimation by US (p=0.037). Despite this, no significant difference was determined in PPV of US for detecting stones >4 mm among patients with BMI of 30–35 and those patients with a BMI of <30 (p=0.19).

US measurements depend on operator experience and technique, leading to inter-observer variation. The single-institution design of this study allowed for evaluation of this potential effect. We found that the individual technologist who performed the US exam, but not radiologist who interprets the US exam, was associated with differences in stone detection (p=0.01) and stone size measurement (p=0.03). We conclude that these differences reflect the technologist's performance in

Table 3. Comparison of stone size measurements on ultrasound compared to CT

Stone size	CT	Ultrasound	
	Size (mm ± SD)	Size (mm ± SD)	Δ from CT (mm ± SD)
All	5.5±6.4	8.7±6.2	1.8±3.1
Renal location			
Upper pole	11.8±15.5	12.4±10.1	1.6±2.2
Mid pole	5.7±2.6	7.2±3.3	1.6±1.7
Lower pole	7.3±5.7	8.7±5.3	2.5±4.4
Renal pelvis	9.2±5.3	11.7±5.2	2.2±2.5
p	0.22	0.25	0.85
Ureteral location			
Proximal ureter	4.2±1.1	7.0±1.4	2.5±2.1
Mid ureter	4.5±2.1	–	–
Distal ureter	4.6±1.7	5.0±2.6	0.25±2.1
p	0.63	0.16	0.14
Laterality			
Left	6.7±5.4	9.0±5.0	2.8±4.3
Right	5.3±4.4	7.5±3.9	1.2±1.9
p	0.35	0.32	0.17
BMI			
<25	5.0±6.7	7.3±6.5	0.7±1.7
25-30	5.7±5.9	10.3±6.3	2.7±3.7
31-35	5.8±7.0	8.6±5.0	2.8±3.2
>35	7.5±6.8	9.5±6.4	5.4±3.2
p	0.15	0.61	0.037
Technician			
#1 (n=8)	6.9±4.2	11.0±5.5	2.7±3.7
#2 (n=9)	3.0±2.5	5.1±1.8	1.2±2.5
#3 (n=7)	3.9±3.3	8.0±4.4	2.1±2.8
p	0.07	0.03	0.65
Radiologist			
#1 (n=9)	4.3±5.4	9.0±4.5	3.0±2.8
#2 (n=9)	3.1±3.0	6.0±3.0	1.1±1.8
#3 (n=13)	3.7±4.0	8.0±4.2	1.4±0.9
p	0.77	0.30	0.29

BMI: body mass index; CT: computed tomography; SD: standard deviation.

Table 4. Association between clinical factors and false-positive US detection of a >4 mm stone

Clinical factor	OR (95% CI)	p
Age >65	0.86 (0.33–2.23)	0.86
Male gender	1.31 (0.84–2.02)	0.22
Non-White ethnicity	1.05 (0.61–1.80)	0.87
BMI >25	1.15 (0.81–1.65)	0.43
US stone size 5-7 mm	2.06 (1.29–3.33)	0.02
US technician participation <5%	2.10 (0.79–5.50)	0.15
US radiologist participation <5%	1.05 (0.40–2.76)	0.93
US performed before CT	0.35 (0.10–1.21)	0.15
> 2 weeks between scans	2.05 (0.71–5.95)	0.20

BMI: body mass index; CI: confidence interval; CT: computed tomography; OR: odds ratio; US: ultrasound.

acquiring a high-quality US exam. While the analysis was limited by the retrospective nature of this study, these findings in the real-world setting support that inter-observer variation exists for stone characterization on US. These findings should prompt efforts to achieve consistency in knowledge and skills in all personnel to improve US performance, even as more technologists are used in the clinical setting.

Several strategies have been used to attenuate some of the inaccuracies associated with US. Current standard adjunctive signs to improve stone detection include the "twinkle artifact" (Figure 1B), a phenomenon created by ultrasound echoes reflecting off a stone and appearing as alternating colors behind the stone. This has led to increased sensitivity for stones, but with a risk of false-positives, particularly among children.[21,22]

Additionally, the presence of an acoustic shadow, created by the inability of ultrasound waves to penetrate through stones, has been used to improve diagnostic accuracy. It is more commonly present in larger stones >8 mm, reflected by a high specificity.[23] The measurement of the acoustic shadow width has been found to limit US overestimation of stone size, and was more recently validated in human patients.[24,25]

Another strategy is the addition of an abdominal plain film (Kidney-Ureter-Bladder [KUB]) to US, which has been found to markedly improve sensitivity and specificity to >90%.[26,27] KUB is particularly useful for identifying radiopaque stones, and can provide quick imaging in the acute care setting; however, its effectiveness may be limited for non-radiopaque stones or those located in areas obscured by bony structures, as well as smaller stones <5 mm, all of which are less likely to be detected.[28] Despite these limitations, KUB remains a valuable modality for long-term followup of known stones, as it can enable monitoring stone status and progression over time with minimal radiation exposure, making it especially beneficial for patients with recurrent nephrolithiasis.

Limitations

There are several limitations to our study.

First, the single-center, retrospective design limits the generalizability of the findings.

Second, there was a mean difference of 26 days between US and CT scans, during which stones could have moved or passed. We tried to address this issue by excluding patients with stone passage events, change in symptoms, or stone interventions in the interval period. The resulting US/CT pairs were likely obtained without significant change in true stone burden, as supported by the lack of an association between length of time between US/CT exams and US performance.

Third, some patients underwent CT prior to US and it is possible that results of the CT could have introduced some bias during the subsequent US studies.

Finally, there may be selection bias in this study cohort because we excluded patients with acutely changing symptoms and patients with negative studies on both US and CT, as no comparison of stone characterization could be made. Patients with unambiguous US were also unlikely to undergo CT, and therefore, an unbiased comparison with CT was not possible. Nevertheless, the present study provides valuable insights into the application of US for kidney stone disease and identifies factors predictive of US inaccuracy for stone characterization.

CONCLUSIONS

Although US is a convenient imaging modality that does not expose patients to ionizing radiation, it may miss stones and overestimate stone size compared with CT scanning. The shortcomings of US are more pronounced for smaller stone sizes and for patients with greater BMI, and appropriate patient counseling should consider these factors. If US is used alone to guide management, two in five patients with stones measuring >4 mm may undergo unnecessary surgery for stones that would otherwise pass without intervention due to overestimation of stone size. Future efforts should aim to improve consistency in knowledge and skills for technologists to improve US performance for stone detection and stone size estimation.

COMPETING INTERESTS: Dr. Conti is an advisor for Dornier MedTech's Worst Pain Ever website. The remaining authors do not report any competing personal or financial interests related to this work.

REFERENCES

1. Brisbane W, Bailey MR, Sorensen MD. An overview of kidney stone imaging techniques. *Nat Rev Urol* 2016;13:654. https://doi.org/10.1038/nrurol.2016.154
2. Heidenreich A, Desgrandschamps F, Terrier F. Modern approach of diagnosis and management of acute flank pain: Review of all imaging modalities. *Eur Urol* 2002;41:351-62. https://doi.org/10.1016/S0302-2838(02)00064-7
3. Brenner DJ, Hall EJ. Computed tomography--an increasing source of radiation exposure. *N Engl J Med* 2007;357:2277-84. https://doi.org/10.1056/NEJMra072149
4. Smith-Bindman R, Aubin C, Bailitz J, et al. Ultrasonography versus computed tomography for suspected nephrolithiasis. *N Engl J Med* 2014;371:1100-10. https://doi.org/10.1056/NEJMoa1404446
5. Fowler KAB, Locken JA, Duchesne JH, et al. US for detecting renal calculi with nonenhanced CT as a reference standard. *Radiology* 2002;222:109-13. https://doi.org/10.1148/radiol.2221010453
6. Ather MH, Jafri AH, Sulaiman MN. Diagnostic accuracy of ultrasonography compared to unenhanced CT for stone and obstruction in patients with renal failure. *BMC Med Imaging* 2004;4:2. https://doi.org/10.1186/1471-2342-4-2
7. Kanno T, Kubota M, Sakamoto H, et al. The efficacy of ultrasonography for the detection of renal stone. *Urology* 2014;84:285-88. https://doi.org/10.1016/j.urology.2014.04.010
8. Ray AA, Ghiculete D, Pace KT, et al. Limitations to ultrasound in the detection and measurement of urinary tract calculi. *Urology* 2010;76:295-300. https://doi.org/10.1016/j.urology.2009.12.015
9. Ganesan V, De S, Greene D, et al. Accuracy of ultrasonography for renal stone detection and size determination: Is it good enough for management decisions? *BJU Int* 2017;119:464-69. https://doi.org/10.1111/bju.13605
10. Jendeberg J, Geijer H, Alshamari M, et al. Size matters: The width and location of a ureteral stone accurately predict the chance of spontaneous passage. *Eur Radiol* 2017;27:4775-85. https://doi.org/10.1007/s00330-017-4852-6
11. Ordon M, Andonian S, Blew B, et al. CUA Guideline: Management of ureteral calculi. *Can Urol Assoc J* 201;9:E837-51. https://doi.org/10.5489/cuaj.3483
12. Shah TT, Gao C, Peters M, et al; British Urology Researchers in Surgical Training (BURST) Collaborative MIMIC Study Group. Factors associated with spontaneous stone passage in a contemporary cohort of patients presenting with acute ureteric colic: Results from the MIMIC study. *BJU Int* 2019;124:504-13. https://doi.org/10.1111/bju.14777
13. Tzelves L, Geraghty R, Lombardo R, et al. Duration of follow-up and timing of discharge from imaging follow-up in adult patients with urolithiasis after surgical or medical intervention: A systematic review and meta-analysis from the European Association of Urology Guideline Panel on Urolithiasis. *Eur Urol Focus* 2023;9:188-98. https://doi.org/10.1016/j.euf.2022.06.016
14. Council NR. Health effects of exposure to low levels of ionizing radiation. *Natl Acadamies Press* Published online January 1, 1990.
15. Li Y, Bayne D, Wiener S, et al. Stone formation in patients less than 20 years of age is associated with higher rates of stone recurrence: Results from the Registry for Stones of the Kidney and Ureter (ReSKU). *J Pediatr Urol* 2020;16:373.e1-373.e6. https://doi.org/10.1016/j.jpurol.2020.03.014
16. Sternberg KM, Eisner B, Larson T, et al. Ultrasonography significantly overestimates stone size when compared to low-dose, noncontrast computed tomography. *Urology* 2016;95:67-71. https://doi.org/10.1016/j.urology.2016.06.002
17. Assimos D, Krambeck A, Miller NL, et al. Kidney stones: Surgical management guideline - American Urological Association. *J Urol* 2016;196:1161. https://doi.org/10.1016/j.juro.2016.05.091
18. Viprakasit DP, Sawyer MD, Herrell SD, et al. Limitations of ultrasonography in the evaluation of urolithiasis: a correlation with computed tomography. *J Endourol* 2012;26:209-13. https://doi.org/10.1089/end.2011.0177
19. Rezaei-Dalouei H, Seilanian-Toosi F, Nekooei S, et al. Comparing the image quality of tissue harmonic and conventional B-mode ultrasound of kidney in over-obese individuals. *Electron Physician* 2018;10:7095. https://doi.org/10.19082/7095
20. Ulusan S, Koc Z, Tokmak N. Accuracy of sonography for detecting renal stone: Comparison with CT. *J Clin Ultrasound* 2007;35:256-61. https://doi.org/10.1002/jcu.20347
21. Mitterberger M, Aigner F, Pallwein L, et al. Sonographic detection of renal and ureteral stones. Value of the twinkling sign. *Int Braz J Urol* 2009;35:532-39. https://doi.org/10.1590/S1677-55382009000500004
22. Alsaiady M, Alqatie A, Almushayqih M. Twinkle artifact in renal ultrasound, is it a solid point for the diagnosis of renal stone in children? *J Ultrason* 2021;21:282-85. https://doi.org/10.15557/JoU.2021.0048
23. Verhagen MV, Watson TA, Hickson M, et al. Acoustic shadowing in pediatric kidney stone ultrasound: A retrospective study with non-enhanced computed tomography as reference standard. *Pediatr Radiol* 2019;49:777-83. https://doi.org/10.1007/s00247-019-04372-x
24. Dunmire B, Harper JD, Cunitz BW, et al. Use of the acoustic shadow width to determine kidney stone size with ultrasound. *J Urol* 2016;195:171-77. https://doi.org/10.1016/j.juro.2015.05.111
25. Dai JC, Dunmire B, Sternberg KM, et al. Retrospective comparison of measured stone size and posterior acoustic shadow width in clinical ultrasound images. *World J Urol* 2018;36:727. https://doi.org/10.1007/s00345-017-2156-8
26. Fulgham PF, Assimos DG, Pearle MS, et al. Clinical effectiveness protocols for imaging in the management of ureteral calculous disease: AUA technology assessment. *J Urol* 2013;189:1203-13. https://doi.org/10.1016/j.juro.2012.10.031
27. Mitterberger M, Pinggera GM, Pallwein L, et al. Plain abdominal radiography with transabdominal native tissue harmonic imaging ultrasonography vs unenhanced computed tomography in renal colic. *BJU Int* 2007;100:887-90. https://doi.org/10.1111/j.1464-410X.2007.07048.x
28. Ege G, Akman H, Kuzucu K, et al. Can computed tomography scout radiography replace plain film in the evaluation of patients with acute urinary tract colic? *Acta Radiol* 2004;45:469-73. https://doi.org/10.1080/02841850410005264

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