Limitations to Ultrasound in the Detection and Measurement of Urinary Tract Calculi

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OBJECTIVES To evaluate differences in stone measurement using computed tomography (CT) and ultrasound (US). Axial unenhanced helical CT is the reference-standard imaging modality for the assessment of urinary tract calculi; however, US is also commonly used. Differences in stone measurement using these techniques are poorly described and contributors to measurement error remain unknown.

METHODS All patients at our institution undergoing both abdominal CT and renal US less than 1 month apart since June 2004 were reviewed. Solitary renal calculi were identified on both CT and US in all cases.

RESULTS We identified 71 calculi in 60 patients. Compared with CT, US overestimated stone size, an effect that was more pronounced with smaller calculi. The mean stone measurement on CT was 7.4 ± 4.4 mm and on US it was 9.2 ± 4.5 mm ($P = .018$). For stones ≤ 5 mm, US measurements were a mean of 1.9 ± 1.2 mm greater than CT ($P < .001$). US and CT measurements were discordant for 60% of stones ≤ 5 mm. Discordance was associated with US measurement of skin-to-stone distance ($P = .018$), but not body mass index ($P = .189$) or location within the urinary tract ($P = .161$). Review of the literature revealed that US has a pooled sensitivity and specificity of 45% and 94%, respectively, for the detection of ureteric calculi and 45% and 88%, respectively, for renal calculi.

CONCLUSIONS US overestimates stone size in urolithiasis, a finding that may have implications for stone management. Discordance in stone measurement varies with size and is greatest in stones ≤ 5 mm. US measurement of skin-stone-distance is an important determinant of error in US measurement of renal calculi. UROLOGY 76: 295–300, 2010.

Urinary tract stones are common, with a lifetime incidence of up to 12% and recurrence rates of up to 50%.[1] In diagnostic and treatment algorithms, stone burden is the most important factor to consider and forms the basis of all clinical decision-making. Thus, accurate measurement of all calculi is crucial. Since its introduction by Smith et al in 1995, unenhanced helical computed tomography (CT) has replaced intravenous urogram and is now regarded as the reference standard in the work-up of renal colic, owing to its high sensitivity and specificity.[2] Apart from being the diagnostic standard, CT has the advantage of providing detailed anatomical information, can identify secondary signs of stone passage, and is useful for ruling out alternate pathologies in cases of diagnostic uncertainty.

Despite the advantages of unenhanced CT, ultrasound (US) is also commonly used as a diagnostic tool in the management of urolithiasis. US is recognized to be both less sensitive and specific than CT; however, it is commonly available, inexpensive to operate and poses no risk of radiation exposure. In many cases, renal and ureteric calculi are incidentally diagnosed in the workup of other conditions. It has been reported that US may detect stones as small as 0.5 mm under optimal conditions.[3] For these reasons, some centers may still use US in the initial work-up of renal colic.[4]

To date, there has been little direct comparison of the accuracy and reliability of US compared with CT. The aim of the current study was to quantify the measurement error inherent to US compared with axial CT as well as to determine whether stone location or obesity contribute to measurement error.

MATERIAL AND METHODS

We performed a retrospective review of imaging for renal and ureteric calculi at a single institution. Enrolment was limited to the period between June 2004 and December 2008. Data were abstracted from patient records and an independent review of

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all imaging was conducted by a Urologist. Institutional ethics approval was obtained for this study.

Inclusion was limited to patients aged ≥18 years, with the finding of a solitary renal or ureteral calculus on both US and noncontrast CT. Both CT and US imaging were conducted at our institution ≤30 days apart. Patients were excluded if there was a finding of more than 1 stone per side or if the patient had received treatment or passed their stone in the interval between US and CT.

Unenhanced CT scans were conducted using either a General Electric LightSpeed VCT scanner at a pitch of 1.375:1, 120 kV, and CT-determined smart mA or a General Electric QXI helical CT at a pitch of 1.5:1, 120 kV, and 400 mA. Prior to January 2006, a slice collimation of 5.0 mm was used. This was progressively reduced to 3.8 mm and more recently, to 2.5 mm. Median slice collimation for this study was 2.5 mm. Stone measurement was conducted using calipers and both magnified soft-tissue and bony windows.

Several new-generation US scanners were used (Philips iU22, ATL HDI 5000, ATL HDI 3000, Antares and GE Logic9). Abdominal US were conducted through multiple planes, and maximal stone length was reported. Curved phased-array transducers were used and transducer frequency varied depending on body habitus, using the highest frequency to optimize both patient penetration and resolution. All US were conducted by experienced technologists using conventional grayscale and verified by radiologists who specialize in body imaging. All US images were independently reviewed by a Urologist. The maximal length measurement made by the sonographer was recorded for comparison.

Unenhanced CT was considered as the reference standard when determining stone size. Calculi were classified according to 3 size categories, often used clinically: stones ≤5 mm, 5.1-10 mm, and >10 mm. Stone size was considered concordant if CT and US measurement of the stone were within the same size group. Skin-stone-distance was measured from the midpoint of the interface between the US probe and the skin to the midpoint of the stone.

Systematic Review

We performed a systematic review of all reports investigating US for the detection of urinary tract calculi using unenhanced CT or unenhanced CT plus follow-up as the reference standard. The MEDLINE database was searched using a comprehensive search strategy that included specific medical subject headings and text words including urolithiasis, calculi, US, CT, sensitivity, and specificity and systematic review. References of cited articles were also reviewed. In total, 17 articles were identified for inclusion. We excluded articles involving pediatric patients (2), articles using only the combination of US and KUB (kidney, ureter, and bladder) for diagnosis (3), and articles with insufficient data to allow calculation of sensitivity and specificity (2). Two articles contained data on both renal and ureteric calculi. Where possible, data were analyzed separately. All relevant articles and abstracts identified by the literature search were reviewed independently by 2 of the authors.

Statistical Analysis

Data were analyzed using chi-square analysis for nonparametric data and paired *t* tests and analysis of variance to compare parametric data. Agreement between US and CT measurements was calculated using the Kappa (κ) statistic. Differences were considered statistically significant when the 2-sided $P < .05$. Analyses were performed using the SPSS 16.0 statistical package.

Table 1. Patient demographics (N = 60)

Age	51.8 ± 12.7
Sex	
Male	39 (66.1%)
Female	20 (33.9%)
BMI (kg/m^2)	26.6 ± 4.5
Interval between US and CT (d)	9.6 ± 9.5
Skin-Stone-Distance by US (mm)	67.9 ± 17.5
Side	
Right	31 (43.7%)
Left	40 (56.3%)
Stone location	
Kidney	56 (78.9%)
Ureter	15 (21.1%)
Indication for imaging	
Follow-up of known stone	34 (56.7%)
Acute flank pain	17 (28.3%)
Incidental diagnosis	8 (13.3%)
Prior nondiagnostic CT	1 (1.7%)
Pregnancy	0 (0.0%)
Pediatric patient	0 (0.0%)

RESULTS

Data were analyzed for 60 patients with 71 renal or ureteric calculi (Table 1). In total, 56 renal and 15 ureteric stones were included. The mean interval between CT and US examinations was 9.6 ± 9.5 days. US was conducted as the initial examination in 68.3% of cases. Indications for US were follow-up of a known stone in 34 (56.7%) and as the initial imaging modality for the investigation of acute flank pain following presentation to the emergency department in 17 (28.3%). Additionally, in 8 cases (13.3%), there was an incidental finding of a urinary tract stone on US. Finally, in 1 patient (1.7%), US was conducted for a suspected stone following a nondiagnostic CT scan. In this case, there was diagnostic uncertainty between renal colic, appendicitis, and ovarian pathology. Although CT revealed a middle calyceal stone of size 3.4 mm, US examination of this patient revealed a stone of size 4.7 mm in the same location.

Using axial CT and magnified soft-tissue windows, stones were categorized according to 3 size groupings (Table 2). US measurement of maximal stone length was greater for stones of all sizes compared with CT. Mean stone length on CT was 7.4 ± 4.4 mm compared with 9.2 ± 4.6 mm on US (P = .018). For stones ≤5 mm, mean length on CT was 3.8 ± 0.9 mm compared with 5.7 ± 1.3 mm on US (P <.001). For stones of size 5.1-10 mm, mean length on CT was 6.8 ± 1.3 compared with 8.4 ± 1.7 mm on US (P <.001). Finally, for stones >10 mm, mean stone size was 14.2 ± 3.8 on CT compared with 16.4 ± 3.6 mm on US (P = .051). The correlation between US and axial CT was 0.759 when using con-

Table 2. CT and ultrasound measurements of stone size

Stone Size	CT (mm)	US (mm)	Difference (mm)	*P*
All stones (N = 71)	7.4 ± 4.4	9.2 ± 4.5	1.8 ± 2.3	.018
≤5 mm (N = 25)	3.8 ± 0.9	5.7 ± 1.3	1.9 ± 1.2	<.001
5.1-10 mm (N = 30)	6.8 ± 1.3	8.4 ± 1.7	1.6 ± 1.7	<.001
>10 mm (N = 16)	14.2 ± 3.8	16.4 ± 3.6	2.2 ± 4.0	.051

Stone size was initially stratified by axial CT measurement using magnified soft-tissue windows.
Data are presented as mean ± SD.

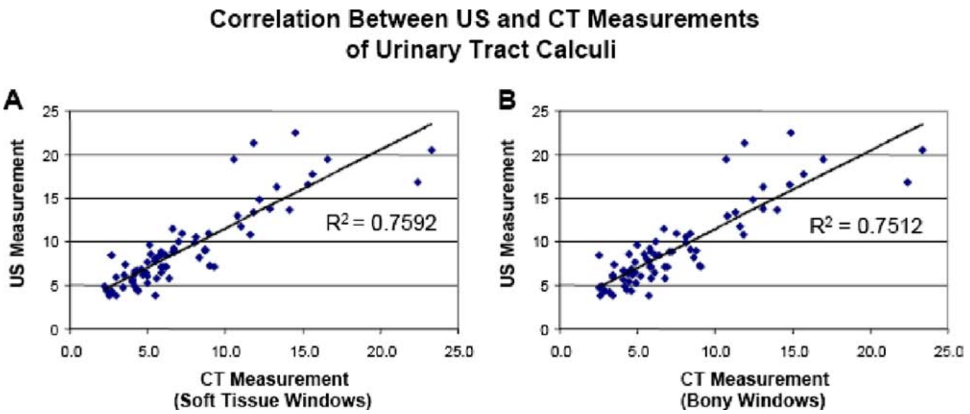

Figure 1. Correlation between maximal measurements using US and axial CT. **(A)** CT measurements conducted with magnification and soft-tissue windows. **(B)** CT measurements conducted with magnification and bony windows.

Table 3. Size concordance

	CT		
	≤5 mm	5.1-10 mm	>10 mm
US			
≤5 mm	10 (40.0%)	1	0
5.1-10 mm	15	25 (83.3%)	0
>10 mm	0	4	16 (100%)

κ (agreement) = 0.563 (*P* <.001).

ventional soft-tissue windows and 0.751 when using bony windows (Fig. 1).

Measurement agreement between US and CT is reported in Table 3. Overall, 51 of 71 stones (71.8%) were within the same size category on both US and CT. Thus, stone size was discordant for 28.2% of all stones. However, when analysis was limited to stones ≤5 mm on axial CT, size discordance increased to 60.0%. The agreement between the 2 tests (κ) was 0.563 (*P* <.001).

There was good agreement for axial CT stone measurements using both soft-tissue and standard bony windows. Overall, mean stone length using soft-tissue windows was 7.4 ± 4.4 mm compared with 7.5 ± 4.3 mm using bony windows (*P* = .19). Similarly, no significant size differences were found for stones ≤5 mm, 5-10 mm, or >10 mm in size. The Pearson correlation between both methods of measurement was calculated to be 0.997, while the agreement (κ) was 0.935 (*P* <.001).

CT slice collimation decreased over time, from 5.0 to 3.8 mm and, finally, 2.5 mm. Slice collimation was not found to be a significant determinant of error when comparing maximal measurement on CT and US (*P* = .478).

Measurement error was associated with US measurement of skin-to-stone distance (*P* = .018), but not body mass index (*P* = .189). Location within the urinary tract (kidney vs ureter) was not found to be a significant contributor to measurement error (*P* = .161).

We reviewed all published studies investigating US for the diagnosis of urinary tract lithiasis using CT or CT plus clinical follow-up as a reference standard (Table 4). Our review identified 8 studies encompassing data from 618 patients with ureteral stones and 4 studies encompassing data from 460 patients with renal stones. In this context, the cumulative sensitivity, specificity, positive predictive value, and negative predictive value for US detection of ureteral stones was 45%, 94%, 93%, and 50%, respectively (Table 5). The cumulative sensitivity, specificity, positive predictive value, and negative predictive value for the detection of renal calculi were 45%, 88%, 78%, and 62%, respectively.

COMMENT

Unenhanced axial CT has the benefit of providing rapid diagnosis with high sensitivity and specificities and is considered the gold standard imaging modality for the diagnosis of kidney stones.[1] As knowledge of stone burden forms the basis of management decisions and guides clinical decision-making, accurate measurement of urinary tract calculi is essential. Now routinely performed with slice collimations of less than 3 mm, published sensitivity and specificities approach 98%-100%.[14] At this degree of resolution, stones smaller than 3 mm are easily detected. Although highly accurate, measurement

Table 4. Ultrasound detection of urinary tract calculi (Summary of studies evaluating US for the detection of urolithiasis using CT or CT and follow-up as a reference)

Reference	N	US	Comments
Ureteric Stones			
Yilmaz et al, 1998[5]	97	Sensitivity = 19 Specificity = 97	Prospective - Acute flank pain - Comparison with CT and FUP data
Sheafor et al, 2000[6]	45	Sensitivity = 61 Specificity = 100	Prospective - Acute flank pain - Comparison with CT and FUP data
Patlas et al, 2001[7]	62	Sensitivity = 93 Specificity = 95	Prospective - Acute flank pain - Comparison with CT and FUP data
Hamm et al, 2001[8]	125	Sensitivity = 11 Specificity = 97	Prospective - Acute flank pain - Comparison with CT and FUP data
Unal et al, 2003[9]	137	Sensitivity = 69 Specificity = 87	Prospective - Acute flank pain - Comparison with CT and FUP data
Ather, Jafri, and Sulaiman, 2004[10]	34	Sensitivity = 46 Specificity = 100	Retrospective - Comparison with CT only - Patients with CRF (creatinine ≥1.8 mg/dl)
Ripollés et al, 2004[11]	66	Sensitivity = 79 Specificity = 100	Prospective - Acute flank pain - Comparison with CT and FUP data
De Souza et al, 2007[12]	52	Sensitivity = 23 Specificity = 100	Prospective - Acute flank pain - Comparison with CT only
Overall	618	Sensitivity = 45 Specificity = 94	
Renal Stones			
Fowler et al, 2002[16]	188	Sensitivity = 24 Specificity = 90	Retrospective - Comparison with CT only
Unal et al, 2003[9]	137	Sensitivity = 69 Specificity = 87	Prospective - Acute flank pain - Comparison with CT and FUP data
Ather, Jafri, and Sulaiman, 2004[10]	34	Sensitivity = 81 Specificity = 100	Retrospective - Comparison with CT only - Patients with CRF (creatinine ≥1.8 mg/dl)
Ulusan, Koc, and Tokmak, 2007[13]	101	Sensitivity = 44 Specificity = 82	Prospective - Acute Flank Pain - Comparison with CT
Overall	460	Sensitivity = 45 Specificity = 88	

FUP, follow-up; CRF, chronic renal failure.
N, number of cases per study (stone present or absent).

Table 5. Meta-analysis of results (sensitivity and specificity for US detection of urinary tract calculi)

	Sensitivity N (%)	Specificity N (%)	PPV N (%)	NPV N (%)	Accuracy N (%)
Ureteric calculi	174/391 (44.5%)	213/227 (93.8%)	174/188 (92.6%)	213/430 (49.5%)	387/618 (62.6%)
Renal calculi	102/228 (44.7%)	203/232 (87.5%)	102/131 (77.9%)	203/329 (61.7%)	305/460 (66.3%)

of calculi on CT is often performed less than rigorously. A recent study by Kampa et al[15] revealed the surprising finding that to save time, radiologists frequently rely on visual estimates, rather than electronic measurements when reporting stone size. The authors concluded that this may be due in part to a lack of understanding as to the implications measurement accuracy may have on stone management.

Despite the advantages of CT, abdominal US is often used both in the follow-up of patients with known urolithiasis and as an investigative tool. Although it is recognized that sensitivity and specificity are lower than CT, the ability of US to accurately determine stone size has recently come into question. Fowler et al[16] compared CT and US measurements of 24 calculi and found that stone size differed by an average of 1.5 ± 0.7 mm. This group also noted that the sensitivity of US for detecting renal calculi increased with stone size, from a low value of 13% for stones ≤3.0 mm to 71% for stones >7.0 mm. Stone size was concordant in 79% of cases. However, this study was limited by its small size and by the large 5.0-mm slice collimation used.

Our data confirm these results and demonstrate that maximal stone length is overestimated for stones of all sizes using conventional grayscale US. Specifically, US measurement was greater than CT measurement in 87% of cases in our series and for stones ≤5 mm, the degree of overestimate was almost 2 mm. In this category, size discordance was 60.0%. This is an important finding as small stones often pass spontaneously and may warrant a period of observation before more aggressive interventions are attempted.[17] Thus, workup of acute flank pain using US may lead to overtreatment in some patients.

Furthermore, our data reveal that this finding holds true whether soft-tissue or bony windows are used. Recently, Eisner et al[18] examined both the influence of CT settings and stone composition on measurement error. It was found that compared with caliper measurements of collected calculi, the maximal measurements of stones on CT were most accurate when magnified bony windows were used. Additionally, it was found that stone composition may also affect measurement error. Maximal length for both calcium oxalate and uric acid calculi were significantly different from collected calculi for all CT settings, except magnified bony windows. In contrast, our data indicate that there is no significant difference in maximal stone length using either magnified soft-tissue or bony window measurements. Additionally, the margins of stones with a low Hounsfield unit density may be difficult to visualize using bony windows despite the use of magnification, thereby complicating measurements. Stone analysis was not available for comparison in our study.

There have been several studies comparing US to CT for the diagnosis of urinary calculi (Tables 4,5). Most data currently exist for ureteric stones, with reported sensitivities of 11%-93% and specificities of 95%-100%.[5-12] In contrast, for renal calculi, sensitivity and specificity are in the range 24%-81% and 83%-100%, respectively.[9,10,13,16] To ensure as accurate a dataset as possible, we included only those studies where the sensitivity and specificity of US were compared with axial CT with or without clinical follow-up. Analysis of pooled data yielded an overall sensitivity of 45% and specificity of 94% for the detection of ureteral calculi compared with 45% and 88% for renal calculi.

The diagnosis of a urinary tract stone requires the presence of a hyperechoic focus with an acoustic shadow. On occasion, calculi may be missed due to impaired acoustic shadowing. This may be caused by the acoustic impedence of intervening tissue or inappropriate balance of transducer power and focal length.[19] Thus, it is not surprising that specificity is greater in the ureter than the kidney. In this location, there may be fewer causes for these findings and the diagnosis is greatly aided by the presence of hydroureter.[6,10-12] In contrast, in the kidney, vascular calcifications and other artifacts may be mistaken for calculi and may partially account for the reduction in specificity.

Of concern is that almost 30% of renal US in our study were conducted in the emergency department as the initial investigation for acute flank pain. Given the low sensitivity of US in this setting, the true stone burden may not be appreciated by the treating physician. We believe that use of US should be limited to routine follow-up of radiolucent calculi as well as a first-line investigative tool for pediatric and pregnant patients with suspected urolithiasis in whom radiation exposure is undesirable. However, US may also be of benefit in the evaluation of hydronephrosis and should be considered in patients at risk of repetitive CT scans.[20]

There are several factors that may affect US diagnosis and interpretation of stone size including the presence of hydronephrosis, stones abutting renal sinus fat, the presence of vascular calcifications, and the presence of bowel gas, which may obscure ureteral calculi. Additionally, the measurement of stones in multiple orthogonal planes affects reproducibility. Ultrasonographers use numerous techniques to improve detection of renal calculi and diagnostic accuracy. The presence of hydronephrosis or hydroureter allows the ultrasonographer to follow fluid levels to the point of obstruction.[11] Resistive Index >0.70 has also been shown to improve both sensitivity and specificity; however, it may be less valid in the setting of acute obstruction <6 hours, patients with "partial obstruction" and patients taking nonsteroidal anti-inflammatory drugs.[21] Experience is essential and knowledge of upper tract anatomy and the so-called "twinkle" artifact on Doppler settings may also improve diagnostic accuracy.[22] This artifact is seen deep to a granular reflecting surface and may be caused by renal and bladder calcifications as well as cholesterol crystals in the gallbladder.[22] Ureteral jets are often documented by ultrasonographers and can be helpful. However, it must be recognized that they are only useful in high-grade obstruction and may be absent in poorly hydrated patients.[23] Finally, KUB with US can markedly improve the clinical accuracy of imaging studies. In 2 studies, the sensitivity improved to 77%-96% and specificity to 91%-93% with the addition of KUB alone.[4,24]

Our study included stones in patients presenting over a 4-year period. This reflects our desire to both limit analysis to patients with a single stone per kidney and minimize the interval between CT and US. There are several limitations to our data. First, this retrospective study was not designed to evaluate US measurement of renal and ureteric calculi under optimal conditions. Instead, we have demonstrated the error inherent to US performed in a clinical setting, upon which treatment decisions were made. Second, US measurements were conducted by multiple experienced technologists. At our institution, sonographers routinely measure stones in both longitudinal and transverse planes. Unfortunately, no standard exists for the number of measurements to be conducted per stone. As such, intra- and interobserver variability exists and may partially account for measurement inaccuracy. However, as the maximal length of the stone is recorded, multiple measurements in additional orthogonal planes would only magnify this effect and lead to increased discrepancy between US and axial CT. Consequently, the discordance between US and CT measurement for urinary tract stones may be even greater than we report here. Ulusan et al[13] performed a prospective evaluation of renal US in the Emergency Department followed by CT examination for the detection of renal calculi. Their finding that US performed poorly, with an accuracy of 67%-77% demonstrates the limitation of the technique in clinical practice. Third, the use of axial CT as the reference standard is problematic. Because stones are often largest in the coronal plane, accurate measurement in this plane would be likely to decrease measurement error compared with US. Unfortunately, the error inherent to reformatted coronal sections on CT is approximately one-half of the slice collimation,[15] in our case 2.5-5.0 mm. Although this effect would likely be mitigated in small stones ≤5 mm, we performed measurements from axial CT images only. Finally, maximal stone length may not be the optimal method for determining management. Total cross-sectional area is more representative of stone burden, and therefore we continue to advocate the use of this term.

CONCLUSIONS

Overestimation of stone size may have important implications for patient counselling and may affect the choice of intervention. Our data indicate that US overestimates renal stone size, an effect that is particularly pronounced for stones ≤5 mm. Furthermore, compared with unenhanced CT, US has poor sensitivity for detecting stones in both the ureter and kidney. For these reasons, US should be considered of limited value in the work-up of urolithiasis. Management decisions should incorporate information from other imaging modalities such as KUB and axial CT.

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