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Ultrasound versus computed tomography for the detection of ureteral calculi in the pediatric population: a clinical effectiveness study

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Abstract

Objective To determine the diagnostic performance of ultrasound for diagnosing ureteral calculi in children using a clinical effectiveness approach.

Methods Billing records and imaging reports were used to identify children (≤ 18 years old) evaluated for suspected urolithiasis using ultrasound between March 2012 and March 2017. Patients without unenhanced CT within 24 h (reference standard) were excluded. Imaging (ultrasound and CT) reports were reviewed for presence, number, size, and location of calculi. Diagnostic performance of ultrasound (versus CT) was calculated on an individual ureter basis both by direct calculus visualization as well as direct visualization combined with suspected presence of ureteral stone based on indirect ultrasound findings.

Results 41 ureteral calculi were present in 38 of 69 (55.1%) patients. Mean patient age was 14.7 ± 3.6 years, and 35 of 69 (51%) patients were boys. Based on direct calculus visualization, ultrasound had a sensitivity of 12.8% (95% CI 5.6–26.7%), specificity of 100% (95% CI 96.3–100%), positive predictive value (PPV) of 100% (95% CI 56.6–100%), and negative predictive value (NPV) of 74.4% (95% CI 66.4–81.1%). When ultrasound examinations reported as suspicious for ureteral calculi based on indirect findings also were considered positive, ultrasound had a sensitivity of 41.0% (95% CI 27.1–56.6%), specificity of 95.0% (95% CI 88.7–97.8%), PPV of 76.2% (95% CI 54.9–89.4%), and NPV of 80.3% (95% CI 72.2–86.5%).

Conclusions In clinical practice, ultrasound has low sensitivity for directly visualizing ureteral calculi subsequently identified by CT, although sensitivity improves when considering suspicious examinations as positive.

Keywords Children · Calculi · Ureter · Ultrasound · Computed tomography · Diagnostic performance

Introduction

The prevalence of pediatric urolithiasis in the United States is on the rise. In an analysis of the 42 pediatric hospitals in the Pediatric Health Information System database, Routh et al. demonstrated an increase from 13.9 cases of urolithiasis per hospital in 1999 to 32.6 cases per hospital in 2008 [1]. Similarly, in a 25-year population study, Dwyer et al. showed a 4% increase in incidence of pediatric kidney stone diagnoses per year over the study period [2]. What was once a predominantly adult disease is now becoming more common in children. Thus, there is a need to better understand the performance of diagnostic studies used to evaluate urolithiasis in the pediatric population.

Currently, unenhanced CT is the recommended imaging modality for the initial evaluation of adults presenting with acute flank pain and/or hematuria with suspicion for urolithiasis [3]. In contrast, for suspected urolithiasis in children, the American Urologic Association (AUA) and European Society of Pediatric Radiology (ESPR) recommend ultrasound as the initial imaging study [4, 5]. Ultrasound has advantages over CT including its lack of ionizing radiation, relatively lower cost, and widespread availability. Ultrasound is limited, however, by a smaller field of view and comparatively less image contrast than CT between calcifications and

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adjacent soft tissues, two limitations that are particularly important when it comes to detection of ureteral calculi. Mid-ureteral calculi are also relatively easily obscured by overlying bowel gas when using ultrasound.

Presently, there is a lack of studies evaluating the diagnostic performance of ultrasound for detecting ureteral calculi in the pediatric population. It is particularly important to understand the diagnostic performance of ultrasound for detecting ureteral calculi, as ureteral stones are more often symptomatic and clinically important than renal stones as they are associated with acute urinary obstruction, which can lead to significant morbidity if not treated expeditiously. This study sought to assess the diagnostic performance of ultrasound for suspected ureteral calculi in a pediatric population using a clinical effectiveness approach with unenhanced CT serving as the reference standard. The purpose of a clinical effectiveness study is to evaluate the diagnostic performance of a test in real clinical circumstances using actual patients, technologists of varying experience, clinical equipment and protocols, and clinically reported findings and interpretations (as opposed to clinical efficacy studies in which the diagnostic performance of a test is studied under ideal circumstances, such as a clinical trial) [6].

Materials and methods

This retrospective study was institutional review board-approved with a waiver of the requirement for informed consent. All study procedures were performed in a HIPAA-complaint manner.

Using a search of diagnosis code records (BusinessObjects; SAP, San Jose, CA) and institutional Department of Radiology imaging reports (Illuminate InSight; Softek Illuminate, Overland Park, KS), pediatric patients (≤ 18 years-old) were identified who had been evaluated for known or suspected ureteral calculi (ureterolithiasis) by renal (or abdominal) ultrasound as well as by unenhanced CT within the same 24-h period between March 1, 2012 and March 31, 2017. Examples of ICD-9 and ICD-10 diagnosis codes used to identify pertinent imaging examinations included: calculus of kidney (592.0), calculus of ureter (592.1), urinary calculus unspecified (592.9), hydronephrosis with renal and ureteral calculous obstruction (N13.2), calculus of kidney (N20.0), calculus of ureter (N20.1), and calculus of kidney with calculus of ureter (N20.2). Examples of search terms used to query imaging reports included: nephrolithiasis, urolithiasis, stone, calculus, flank pain, and hematuria. If a patient had more than one instance where concurrent ultrasound and unenhanced CT examinations were performed within 24 h, only the initial pair of imaging examinations was included in our analysis.

The patient cohort examined in this study also was used in another recent investigation by our group which looked at the diagnostic performance of ultrasound for the evaluation of renal calculi (nephrolithiasis) [7]. Despite a shared patient population, all of the reported results and outcomes in the current study differed from our prior study with the notable exception of patient demographic information.

Our study population consisted of pediatric patients evaluated at Cincinnati Children's Hospital Medical Center which is a large children's hospital in the United States where, on average, 7500 ultrasound examinations of the retroperitoneum (kidneys, ureters, and bladder) are performed each year. All ultrasound examinations were performed by a group of ~ 35 dedicated pediatric sonographers (certified by the American Registry of Diagnostic Medical Sonography) utilizing Toshiba Aplio XG and Aplio 500 ultrasound systems (Toshiba America Medical Systems, Inc.; Tustin, CA). These examinations were performed according to a pre-defined clinical protocol that assessed the kidneys, ureters, and bladder utilizing a variety of transducers (depending on patient age and body habitus), with the patient both supine and prone (only the kidneys and proximal ureters were assessed in the prone position) and with the bladder filled with urine. Imaging of the kidneys and ureters included both grayscale and color Doppler assessments while documenting still images and cine clips. Color Doppler imaging was used to assess for ureteral jets in the bladder as well as sonographic twinkling artifact (the pulse repetition frequency was increased per protocol when assessing for twinkling artifact). Attempts were made to image the ureters starting proximally at the UPJ and distally at the UVJ. Dedicated transverse gray-scale and color Doppler imaging of the distal ureters and ureteral orifices were also obtained per protocol. All renal ultrasound examinations were reviewed by a Department of Radiology trainee (typically a fellow) or attending pediatric radiologist prior to study completion and patient discharge from the department.

CT examinations were performed using 64-row (Aquilion; Toshiba America Medical Systems, Inc.; Tustin, CA) and 320-row (Toshiba Aquilion One; Toshiba America Medical Systems, Inc.; Tustin, CA) scanners with 0.5 mm axial, 3 mm axial, and 3 mm coronal images provided to the interpreting radiologist for evaluation. No contrast material (neither intravenous nor oral) was administered. Imaging was performed from just above the kidneys to just below the urinary bladder.

Identified ultrasound and CT examinations previously had been clinically interpreted by a group (~ 20) of subspecialty-trained pediatric radiologists. For this investigation, a single investigator (N.P.R.) retrospectively reviewed relevant clinically generated ultrasound imaging reports and recorded the following findings, as available:

- Clinical indication for imaging;
- Presence and number of directly visualized ureteral stones;
- Location of ureteral stones (right vs. left; specific ureteral sector [proximal/ureteropelvic junction (UPJ), middle, distal/ureterovesical junction (UVJ)]);
- Ureteral stone size(s) (greatest dimension(s) recorded in image report);
- Ureteral stone sonographic features (echogenic focus, color Doppler twinkling artifact, and/or posterior acoustic shadowing artifact); and
- Suspicion for non-visualized ureteral stone based on indirect finding(s) (e.g., hydronephrosis [including reported "hydronephrosis, "pelvocaliectasis", and "renal collecting system dilation" or "renal collecting system dilatation"; a reported extra-renal pelvis was not considered to be hydronephrosis], hydroureter [including reported "hydroureter", "ureterectasis", and "ureter dilation" or "ureter dilatation"], absent color Doppler ureteral jet).

Correlative clinically generated CT reports were then retrospectively reviewed by the same investigator and the following findings were recorded, as available:

- Clinical indication for imaging;
- Presence and number of ureteral stones (calcific);
- Location of ureteral stones (right vs. left; specific ureteral sector [UPJ/proximal, middle, distal/UVJ]); and
- Ureteral stone size(s) (greatest dimension recorded in image report).

Patient demographic information (age, sex, height and weight) were obtained from the electronic medical record (EPIC Systems Corporation; Verona, WI). Subject body mass index (BMI) was calculated, and BMI percentile was established using the Centers for Disease Control and Prevention (CDC) Child and Teen BMI calculator [8]. In addition, clinical notes (any available urology, nephrology, and/or Emergency Department notes) were reviewed for any history of renal or ureteral calculi.

Statistical analysis

Continuous data were summarized as means, standard deviations, and ranges, while categorical data were summarized as counts and percentages. Using unenhanced CT as the reference standard, the diagnostic performance of ultrasound (including 95% confidence intervals) was calculated, including sensitivity, specificity, positive predictive value, and negative predictive value. Each ureter (or ureters in the setting of urinary tract duplication, although no instances of duplication were documented) was treated as an independent unit, with patients with two kidneys contributing two ureteral units to our analyses. Separate analyses were performed for (1) ureteral calculi directly visualized by ultrasound, and for (2) ureteral calculi directly visualized or suspected based on indirect findings (hydronephrosis, hydroureter, or absent ureteral color Doppler jet.). Furthermore, diagnostic performance statistics were calculated for individual indirect ultrasound features, again including hydronephrosis, hydroureter, and absent ureteral color Doppler jet.

All diagnostic performance statistics were calculated for the entire population and for the following sub-populations: (1) patients with normal versus abnormally increased (> 85th percentile for age) BMI, (2) female versus male patients, and (3) right versus left ureter.

A p value of < 0.05 was considered statistically significant for hypothesis testing. Analyses were performed using GraphPad Prism for Windows, version 7 (GraphPad Software; La Jolla, CA).

Results

Of the 69 patients in the study population, 35 (51%) were male. The study population had a mean age of 14.7 ± 3.6 years at the time the ultrasound examination was performed (range 4.7–18.8 years). BMIs were calculable for 57 of 69 (82.6%) patients with missing data most commonly due to the patient not having a recent height recorded in their electronic medical record. The average BMI of the study population was 23.7 ± 11.1 kg/m^2, equating to an average BMI percentile of 61.4 ± 32.7.

Of the 69 patients in our study population, 38 (55.1%) had at least one ureteral stone documented by unenhanced CT with a total of 41 discrete ureteral stones identified. Of the three patients with more than one ureteral stone, stones were identified in both ureters in one patient (Fig. 1). Eight stones (19.5%) were located at the UPJ or in the proximal ureter, four (9.7%) were located in the mid-ureter, and 29 (70.7%) were located in the distal ureter or at the UVJ.

Overall diagnostic performance of ultrasound

The diagnostic performance of ultrasound for detecting ureteral calculi in the entire study population is presented in Table 1. Based on direct calculus visualization, ultrasound had a sensitivity of 12.8%, specificity of 100%, positive predictive value of 100%, and negative predictive value of 74.4% for detecting ureteral calculi in any ureter. When sonographic suspicion based on the presence of secondary findings was also treated as a positive result, sensitivity and negative predictive value rose to 41.0% and 80.3%, respectively, while specificity remained high at 95.0% and positive predictive value decreased to 76.2%.

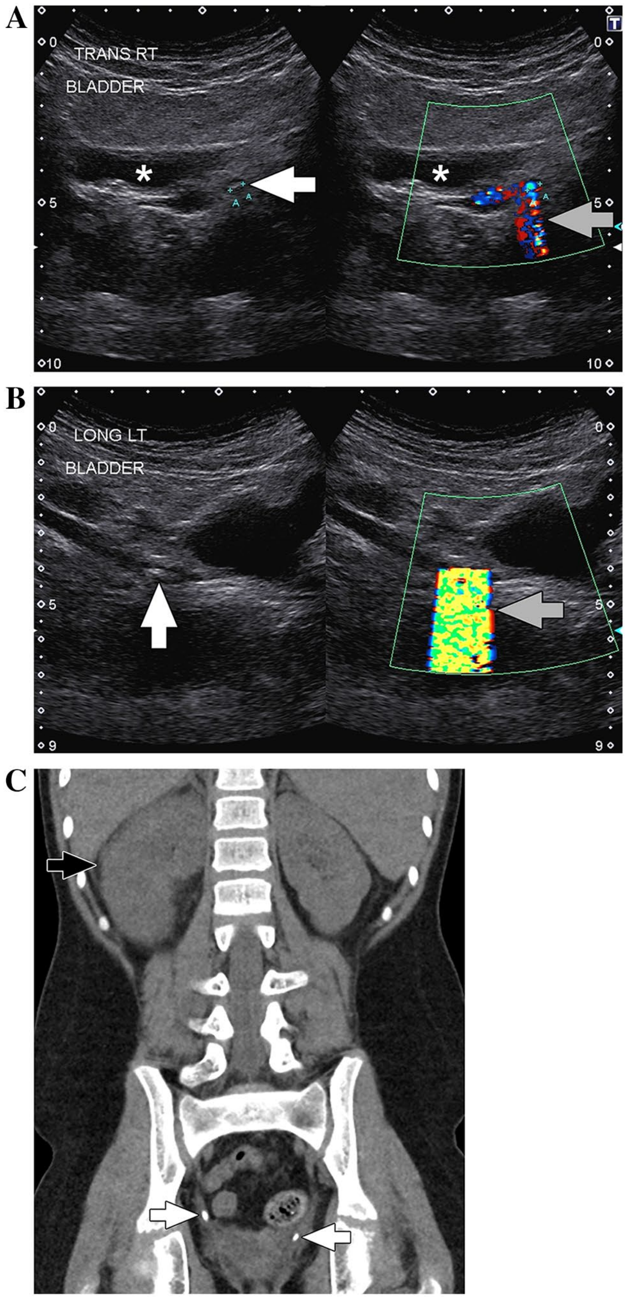

Fig. 1 10-year-old girl presenting with right lower quadrant pain with multiple bilateral renal (not shown) and ureteral calculi identified on ultrasound (**a** and **b**) and subsequently confirmed on CT (**c**). **a** Transverse split-screen ultrasound image at the level of the decompressed bladder (asterisk) shows an echogenic focus in the distal right ureter (white arrow) with associated twinkling artifact on color Doppler (grey arrow). **b** Longitudinal split-screen ultrasound image at the level of the pelvis shows an echogenic focus in the distal left ureter (white arrow) with associated twinkling artifact on color Doppler (grey arrow). **c** Coronal reformatted image from non-contrast CT performed later the same day shows bilateral distal ureteral calculi (white arrows). The partially visualized right kidney (black arrow) is edematous with perinephric stranding reflecting obstruction

Diagnostic performance of ultrasound based on sex

The diagnostic performance of ultrasound for detecting ureteral calculi based on sex is presented in Table 2. Based on direct calculus visualization, ultrasound had a low sensitivity in both boys and girls (11.5% to 15.4%) and a very high specificity (100%) in both groups. There was suggestion of some separation in the NPV of ultrasound between boys and girls with suggestion of higher NPV in girls (83.3% vs. 65.7%) though the 95% confidence intervals overlapped. When sonographic suspicion for ureteral calculi was also treated as a positive result, both sensitivity (84.6% vs. 38.5%) and NPV (96.1% vs. 73.3%) were higher in girls than in boys.

Diagnostic performance of ultrasound based on patient BMI

The diagnostic performance of ultrasound for detecting ureteral calculi based on patient BMI (normal versus abnormally increased [>85th percentile]) is presented in Table 3. Diagnostic performance statistics were mostly similar between groups with a trend toward lower sensitivity in patients with BMI above the 85th percentile (20% [95% CI 8.1–41.6%] vs. 0% [95% CI 0–21.5%] for directly visualized stones and 70.0% [95% CI 48.1–85.5%] vs. 35.7% [95% CI 16.3–61.2%] when also treating suspicion for ureteral calculi as a positive result).

Diagnostic performance of ultrasound based on side (right vs. left)

The diagnostic performance of ultrasound for detecting ureteral calculi analyzed by side is presented in Table 1. Diagnostic performance statistics were similar for both the right and left ureters.

Diagnostic performance of specific indirect ultrasound features

The diagnostic performance of isolated hydronephrosis, hydroureter, and absent color Doppler ureteral jet for detection of ureteral calculi is presented in Table 4. Of these individual ultrasound findings, hydronephrosis (Fig. 2) had the highest sensitivity (71.8%), while hydroureter (Fig. 3) had the highest specificity (92.9%).

False-negative calculi by ultrasound

In total, there were 34 calculi (85.4% of 41) missed by ultrasound (false negatives) based on direct visualization (ultrasound missed 18 calculi [44% of 41] when treating sonographic suspicion for ureteral calculi also as a positive

Table 1 Diagnostic performance of ultrasound for detecting ureteral calculi using unenhanced CT as the reference standard for the entire study population

Analysis	Sensitivity (%) (95% CI) [N/D]	Specificity (%) (95% CI) [N/D]	Positive predictive value (%) (95% CI) [N/D]	Negative predictive value (%) (95% CI) [N/D]
True positive = Direct visualization				
Any ureter (*n* = 138)	12.8 (5.6–26.7) [5/39]	100.0 (96.3–100.0) [99/99]	100.0 (56.6–100.0) [5/5]	74.4 (66.4–81.1) [99/133]
Right ureter (*n* = 69)	11.1 (2.0–32.8) [2/18]	100.0 (93.0–100.0) [51/51]	100.0 (17.8–100.0) [2/2]	76.1 (64.7–84.7) [51/67]
Left ureter (*n* = 69)	14.3 (5.0–34.6) [3/21]	100.0 (92.6–100.0) [48/48]	100.0 (43.9–100.0) [3/3]	72.7 (61.0–82.0) [48/66]
True positive = Direct visualization or suspicion raised based on secondary finding(s)				
Any ureter (*n* = 138)	41.0 (27.1–56.6) [16/39]	95.0 (88.7–97.8) [94/99]	76.2 (54.9–89.4) [16/21]	80.3 (72.2–86.5) [94/117]
Right ureter (*n* = 69)	50.0 (29.0–71.0) [9/18]	94.1 (84.1–98.4) [48/51]	75.0 (46.8–91.1) [9/12]	84.2 (72.6–91.5) [48/57]
Left ureter (*n* = 69)	57.1 (36.6–75.5) [12/21]	93.8 (83.2–97.9) [45/48]	80.0 (54.8–93.0) [12/15]	83.3 (71.3–91.0) [45/54]

CI Confidence interval, *N/D* numerator/denominator

Table 2 Diagnostic performance of ultrasound for detecting ureteral calculi using unenhanced CT as the reference standard in boys vs. girls

Analysis	Sensitivity (%) (95% CI) [N/D]	Specificity (%) (95% CI) [N/D]	Positive predictive value (%) (95% CI) [N/D]	Negative predictive value (%) (95% CI) [N/D]
True positive = Direct visualization				
Female (*n* = 34)	15.4 (2.7–42.2) [2/13]	100.0 (93.5–100.0) [55/55]	100.0 (17.8–100.0) [2/2]	83.3 (72.6–90.4) [55/66]
Male (*n* = 35)	11.5 (4.0–29.0) [3/26]	100.0 (92.0–100.0) [44/44]	100.0 (43.9–100.0) [3/3]	65.7 (53.7–75.9) [44/67]
True positive = Direct visualization or suspicion raised based on secondary finding(s)				
Female (*n* = 34)	84.6 (57.8–97.3) [11/13]	89.1 (78.2–95.0) [49/55]	64.7 (41.3–82.7) [11/17]	96.1 (86.8–99.3) [49/51]
Male (*n* = 35)	38.5 (22.4–57.5) [10/26]	100.0 (92.0–100.0) [44/44]	100.0 (72.3–100.0) [10/10]	73.3 (61.0–82.9) [44/60]

CI confidence interval, *N/D* numerator/denominator

result). Six (17.6%) of the missed calculi were located at the UPJ or in the proximal ureter, three (8.8%) were located in the mid-ureter, and 25 (73.5%) were located in the distal ureter or at the ureterovesical junction (UVJ).

The average age of patients who had a calculus missed on ultrasound but detected by unenhanced CT was 14.2 years, and 24 (75%) were male. The average BMI of this sub-population of patients was 23.7 kg/m^2 with an average percentile of 68, as compared to the subpopulation of patients with true-positive calculi who had an average BMI of 22.4 kg/m^2 with an average percentile of 49 and the subpopulation of patients with true-negative calculi who had an average BMI of 23.8 kg/m^2 with an average percentile of 69.

Table 3 Diagnostic performance of ultrasound for detecting ureteral calculi using unenhanced CT as the reference standard in children with normal vs. abnormal body mass index (BMI)

Analysis	Sensitivity (%) (95% CI) [N/D]	Specificity (%) (95% CI) [N/D]	Positive predictive value (%) (95% CI) [N/D]	Negative predictive value (%) (95% CI) [N/D]
True positive = Direct visualization				
Normal BMI ($n=35$)	20.0 (8.1–41.6) [4/20]	100.0 (92.9–100.0) [50/50]	100.0 (51.0–100.0) [4/4]	75.8 (64.2–84.5) [50/66]
Abnormal BMI ($n=22$)	0.0 (0.0–21.5) [0/14]	100.0 (88.7–100.0) [30/30]	–	68.2 (53.4–80.0) [30/44]
True positive = Direct visualization or suspicion raised based on secondary finding(s)				
Normal BMI ($n=35$)	70.0 (48.1–85.5) [14/20]	92.0 (81.2–96.9) [46/50]	77.8 (54.8–91.0) [14/18]	88.5 (77.0–94.6) [46/52]
Abnormal BMI ($n=22$)	35.7 (16.3–61.2) [5/14]	96.7 (83.3–99.8) [29/30]	83.3 (43.7–99.2) [5/6]	76.3 (60.8–87.0) [29/38]

CI Confidence interval, *N/D* numerator/denominator

Table 4 Diagnostic performance of selected ultrasound features for detecting ureterolithiasis using unenhanced CT as the reference standard for the entire population ($n=138$)

Analysis	Sensitivity (%) (95% CI) [N/D]	Specificity (%) (95% CI) [N/D]	Positive predictive value (%) (95% CI) [N/D]	Negative predictive value (%) (95% CI) [N/D]
Hydronephrosis	71.8 (56.2–83.5) [28/39]	83.8 (75.4–89.8) [83/99]	63.6 (48.9–76.2) [28/44]	88.3 (80.3–93.3) [83/94]
Hydroureter	30.8 (18.6–46.4) [12/39]	92.9 (86.1–96.5) [92/99]	63.2 (41.0–80.9) [12/19]	77.3 (69.0–83.9) [92/119]
Absence of ureteral jets	53.9 (35.5–71.2) [14/26]	82.8 (71.1–90.4) [48/58]	58.3 (38.8–75.5) [14/24]	80.0 (68.2–88.2) [48/60]

CI confidence interval, *N/D* numerator/denominator

Discussion

Based on a 2008 meta-analysis, unenhanced CT has a very high sensitivity and specificity for the detection of urolithiasis and is thus the recommended imaging modality for adults presenting with flank pain suspicious for urinary tract calculi [9]. In children, however, ultrasound is commonly the recommended modality for initial assessment of ureteral calculi despite little supporting evidence, including at the authors' institution. Our study sought to address this lack of evidence by examining the clinical effectiveness (diagnostic performance in real clinical circumstances) of ultrasound for detecting ureteral calculi in a pediatric population.

In our study, we observed a sensitivity of ultrasound for ureteral calculi of just 12.8% when only direct visualization of a ureteral calculus was considered positive. Sensitivity was 41.0%, however, when sonographic suspicion, without direct visualization of a ureteral calculus, was also considered a positive result. These are much lower sensitivities than what has been previously reported for adult populations. In a study of 296 adults, Park et al. observed a sensitivity of 98.3% and a specificity of 100% for the detection of ureteral calculi by ultrasound [10]. Similarly, Ripolles et al. found ultrasound to have a sensitivity of 90% and specificity of 100% for the detection of ureteral calculi in a population of 100 adult patients [11]. Not all adult studies have shown such good diagnostic performance, however. Mos et al. and Kanno et al. both reported sensitivities of ultrasound for detecting ureteral calculi at 55.8% and 57.3%, respectively, closer to that seen in our pediatric population [12, 13]. For all four of

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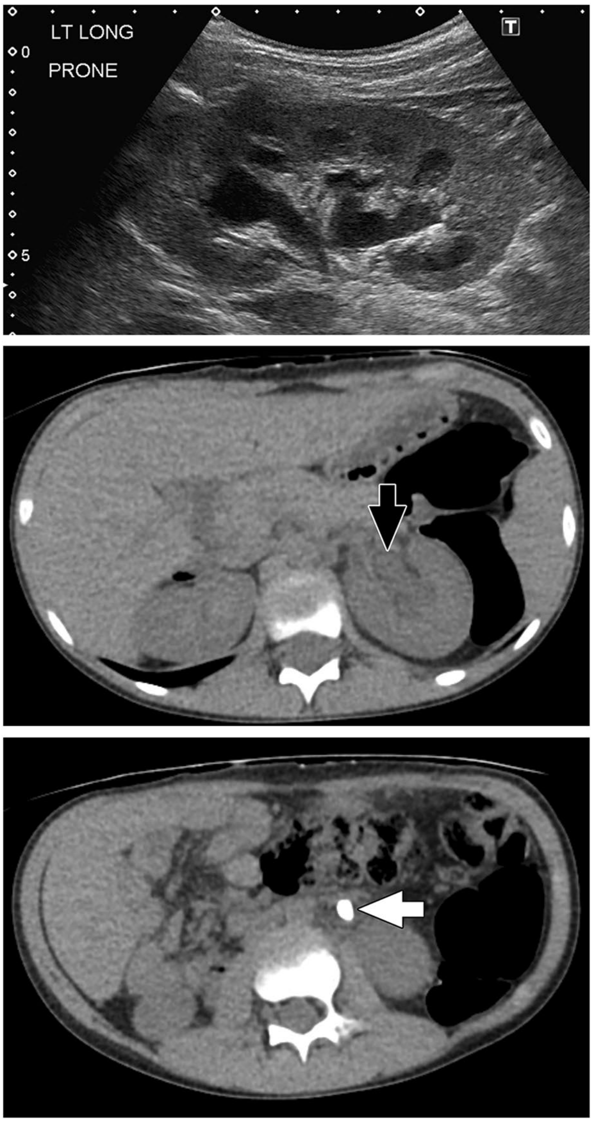

Fig. 2 10-year-old boy with 1 week of back pain and emesis with hydronephrosis detected by ultrasound (**a**), shown to be due to a proximal ureteral calculus on a subsequent CT (**b** and **c**). **a** Longitudinal grayscale ultrasound image shows left pelvocaliectasis without identification of an obstructing calculus. Given collecting system dilation, suspicion for a non-visualized obstructing calculus was raised. **b** and **c** Axial images from a non-contrast CT performed later the same day confirms left renal hydronephrosis (black arrow in **b**) and an obstructing left proximal ureteral calculus (white arrow in **c**)

A
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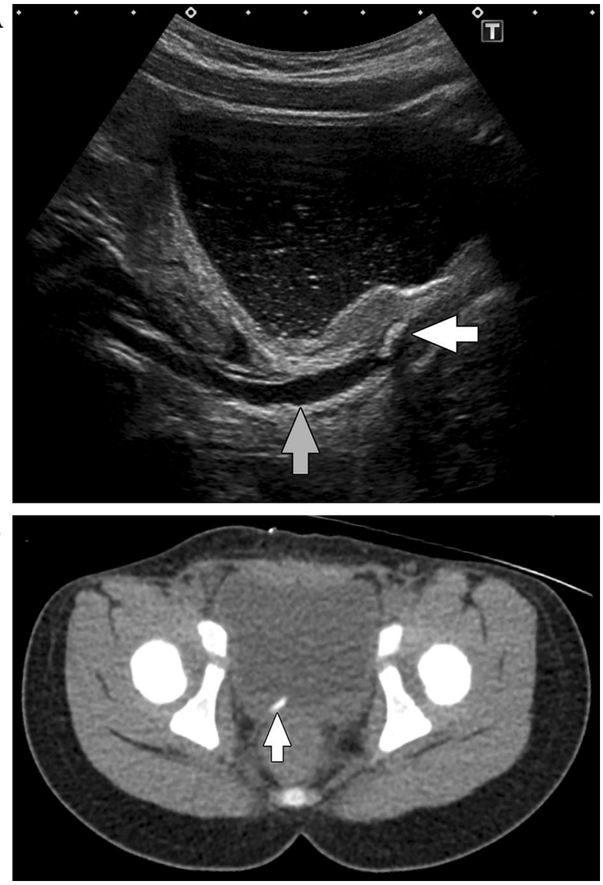

Fig. 3 4-year-old boy with abdominal pain and hematuria with right distal ureteral calculus. Ultrasound (**a**) showed right pelvocaliectasis (not shown) and ureterectasis (grey arrow) to the level of an obstructing calculus at the ureterovesical junction (white arrow). Mobile echogenic debris is present in the urinary bladder. Axial image from a subsequently performed CT to fully assess stone burden (**b**) confirms the presence of an obstructing calculus at the ureterovesical junction on the right (white arrow)

the above studies, a positive diagnosis for ureteral calculi was made with direct visualization of a calculus inside the ureter lumen.

False-negative ultrasound examinations were more common than false-positive examinations in our study. Of the 34 stones that were missed on ultrasound but detected by unenhanced CT, the majority (73.5%) were located in the distal ureter or at the UVJ. This was despite acquiring dedicated transverse grayscale and color Doppler imaging of the distal ureters and ureteral orifices per protocol. This is concordant with the study by Ripolles et al. who reported that 50% of stones missed by ultrasound were located at the UVJ [11]. Lack of visualization of stones at the UVJ may be due to inadequate distention of the bladder at the time of imaging. It has been reported that a bladder volume of 110 mL is required for adequate visualization of the distal ureters in adults [14]. Other possible causes include obscuration by overlying bowel and poor visualization at depth due to patient size. Whatever the explanation, it is clear that specific attention needs to be paid to the region of the UVJ in patients with suspected ureteral calculi.

Direct visualization of ureteral calculi can be difficult due to incomplete visualization of the ureter and suboptimal contrast between the stone and surrounding soft tissue. Indirect ultrasound findings associated with ureteral calculi, such as absent color Doppler ureteral jet, hydronephrosis, and hydroureter, can be important findings of ureteral stones and improve diagnostic performance even in the absence of direct visualization. Kanno et al. previously reported ultrasound was 57.3% sensitive when a ureteral stone was directly visualized but was 81.3% sensitive when hydronephrosis was considered indicative of the presence of a stone [12]. While overall sensitivities were lower in our study, we observed a similar improvement in sensitivity (12.8% vs. 41.0%) when treating suspicion for a ureteral calculus as a positive result.

With regard to the diagnostic performance of specific sonographic secondary (indirect) findings, hydronephrosis was the most sensitive (71.8%) and hydroureter was the most specific (92.9%) finding for ureteral calculi. The positive predictive value of hydroureter was 63.2%, however, indicating that false positive instances of hydroureter occurred in some patients, perhaps due to a recently passed calculus with persistent ureteral dilation. The absence of a color Doppler ureteral jet had a sensitivity of 53.9% and a specificity of 82.8%. It has been noted that ureteral jet abnormalities are more common when high-grade obstruction is present versus low-grade obstruction [15]. This may be important because calculi that cause high-grade obstruction are more likely to require urologic intervention.

When only direct visualization of a stone was considered a positive result, performance of ultrasound for diagnosis of ureteral calculi was essentially equivalent between boys and girls in our population. We did, however, observe differences between boys and girls when sonographic suspicion was also considered a positive result. Specifically, the sensitivity for detection of ureteral calculi was higher in girls (84.6%) than boys (38.5%) while other statistics were relatively similar. To our knowledge, the effect of patient sex on the diagnostic performance of ultrasound for ureterolithiasis has not been previously explored. The observed difference in sensitivity between boys and girls is of uncertain etiology.

It has been posited that body mass index affects diagnostic performance of ultrasound for detecting urinary tract calculi, especially in the ureters due to their location within the retroperitoneum. Pichler et al. observed that BMI independently affected detection rates of ureteral calculi by ultrasound [16]. In our sub-analysis separating the study population by BMI percentile ($\leq$ 85th percentile vs. $>$ 85th percentile) when treating both direct visualization and sonographic suspicion as a positive result, ultrasound had a sensitivity of 70.0% in patients with a normal BMI compared to a sensitivity of 35.7% in patients with BMI $\geq$ 85th percentile. Thus, BMI may be an important patient factor to consider when choosing a diagnostic imaging method for assessing children with suspected urolithiasis.

Our study has limitations. While the retrospective design is common for clinical effectiveness research which assesses existing clinical data to attain a better understanding of what happens in the real-world circumstances, this research design has the potential for introducing selection bias. Specifically, in our study, the patients who underwent CT and ultrasound within 24 h may be clinically different than patients who underwent only CT or ultrasound. The implications of this potential bias are uncertain. Even so, it is highly concerning that ultrasound only directly visualized seven of 41 ureteral calculi. This raises the possibility that a not insignificant percentage of children with suspected ureteral calculi and negative ultrasound imaging that do not undergo CT imaging may actually have ureteral calculi. Another potential limitation of our study was that it was based on a patient population treated at a large, tertiary, pediatric hospital. This potentially limits the generalizability of our results. It is possible that, given pediatric expertise, our diagnostic performance statistics actually overestimate ultrasound's abilities at other institutions.

In conclusion, based on a clinical effectiveness assessment, ultrasound has suboptimal diagnostic performance for detection of ureteral calculi in a pediatric population due to very low sensitivity. This low sensitivity largely reflects missed calculi at the ureterovesical junction. Such a low sensitivity brings into question the role of ultrasound as a screening test, and suggests the need for further research into improving the performance of ultrasound and possibly into other modalities such as low dose CT. Considering secondary indirect findings as indicative of a ureteral calculus improves diagnostic performance of ultrasound, although a considerable percentage of ureteral calculi will still go undetected. Patient BMI seems to substantially impact the diagnostic performance of ultrasound for ureteral calculi and should be a consideration when selecting a diagnostic imaging method for evaluating suspected ureteral calculi in children.

Compliance with ethical standards

Conflicts of interest All authors declare that they have no conflict of interest.

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