Emergency Physician Interpretation of Point-of-care Ultrasound for Identifying and Grading of Hydronephrosis in Renal Colic Compared With Consensus Interpretation by Emergency Radiologists

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ABSTRACT

Objective: The ability of emergency physicians (EPs) to identify hydronephrosis using point-of-care ultrasound (POCUS) has been assessed in the past using computed tomography (CT) scans as the reference standard. We aimed to determine the ability of EPs to identify and grade hydronephrosis on POCUS using the consensus interpretation of POCUS by emergency radiologists as the reference standard.

Methods: The study was conducted at an urban academic emergency department (ED) as a secondary analysis of previously collected ultrasound data from the EP-performed POCUS databank. Patients were eligible for inclusion if they had both POCUS and CT scanning performed during the index ED visit. Two board-certified emergency radiologists and six EPs interpreted each POCUS study independently. The interpretations were compared with the consensus interpretation by emergency radiologists. Additionally, the POCUS interpretations were also compared with the corresponding CT findings. Institutional approval was obtained for conducting this study. All the analyses were performed using Stata MP 14.0 (StataCorp).

Results: A total of 651 patient image-data sets were eligible for inclusion in this study. Hydronephrosis was reported in 69.6% of POCUS examinations by radiologists and 72.7% of CT scans ($p = 0.22$). Using the consensus radiology interpretation of POCUS as the reference standard, EPs had an overall sensitivity of 85.7% (95% confidence interval [CI] = 84.3%–87.0%), specificity of 65.9% (95% CI = 63.1%–68.7%), positive likelihood ratio of 2.5 (95% CI = 2.3–2.7), and negative likelihood ratio of 0.22 (95% CI = 0.19–0.24) for hydronephrosis. When using CT scan as the reference standard, the EPs had an overall sensitivity of 81.1% (95% CI = 79.6% to 82.5%), specificity of 59.4% (95% CI = 56.4%–62.5%), positive likelihood ratio of 2.0 (95% CI = 1.8–2.2), and

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negative likelihood ratio of 0.32 (95% CI = 0.29–0.35) for hydronephrosis. The specificity of EPs was improved to 94.6% (95% CI = 93.7%–95.4%) for categorizing the degree of hydronephrosis as "moderate or severe" versus "none or mild," with positive likelihood ratio of 6.33 (95% CI = 5.3–7.5) and negative likelihood ratio of 0.69 (95% CI = 0.66–0.73).

Conclusions: Emergency physicians were found to have moderate to high sensitivity for identifying hydronephrosis on POCUS when compared with the consensus interpretation of the same studies by emergency radiologists. These POCUS findings by EPs produced more definitive results when at least moderate degree of hydronephrosis was present.

Renal colic is a common emergency department (ED) presentation and results in more than a million ED visits every year in the United States alone.[1] Computed tomography (CT) scanning is considered the reference standard for nephrolithiasis and can also identify alternative diagnoses; however, most stones pass without the need for CT imaging.[2–4] Epidemiologic studies have suggested that the increasing use of CT scanning in renal colic evaluation have not changed the diagnostic rates or management plans in most patients.[5–7] Additionally, there is increasing concern about the health care costs and radiation risk that accompanies CT scans, especially when evaluating recurrent episodes.[8] Low-dose CT scans can dramatically reduce the radiation dose and are appropriate for patients who are likely to have kidney stone, including patients with hydronephrosis on ultrasound.[2,9]

Utilization of point-of-care ultrasound (POCUS) can be used in acute settings to rapidly rule in the diagnosis of renal colic and to avoid nonselective, standard-dose CT scan examination for all renal colic patients.[10–12] It has been suggested that ultrasound-first approach can avoid radiation exposure in about 70% of cases.[13–15] In a large multicenter, randomized trial, the initial ultrasound approach was found to be noninferior to the CT scan–first approach, when compared for the rates of complications, serious adverse events, or hospitalizations.[16,17] More recently, a large prospective, observational study found that POCUS used in conjunction with a clinical risk score may aid to identify patients more likely to require urologic intervention.[14]

POCUS mostly relies on identifying indirect signs of obstruction such as hydronephrosis.[17] The degree of hydronephrosis is dependent on the degree of obstruction, hydration status of the patient, and the time elapsed since the obstruction.[2,18,19] Several studies have been published to assess the test characteristics of emergency physician (EP) performance and interpretation of POCUS to detect hydronephrosis using CT or intravenous pyelogram findings as the reference standard.[16,20–22] However, such comparisons may not be optimal because of the time difference between POCUS and the imaging test used as reference standard.[17,23–31]

In this study we aimed to determine the accuracy of EP interpreted POCUS for hydronephrosis using the consensus interpretation of POCUS by emergency radiologists as the reference standard. The secondary objective was to compare EP and radiologist performance using CT scan as the criterion standard.

METHODS

Study Design and Settings

The study was conducted at the Hamad General Hospital Emergency Department (HGH-ED), part of Hamad Medical Corporation, Doha, Qatar. HGH-ED is an urban academic tertiary care, major service provider ED, in the State of Qatar with an annual census of approximately 500,000.[22] The HGH-ED is staffed by emergency medicine (EM) board-certified attendings, postresidency (EM-boarded) specialists, and trainees under a residency training program accredited by the Accreditation Council of Graduate Medical Education-International (ACGME-I) and post residency EM-fellowship program. This study was conducted as a secondary analysis of previously collected ultrasound data from EP-performed renal POCUS examinations.

Selection of Patients

In 2014 to 2015, as part of a previous renal colic trial,[32] a renal POCUS databank was created. In consecutive patients presenting to the ED with moderate to severe renal colic, the EP investigating team performed and stored renal POCUS examinations. These data were later archived onto a computer hard disk drive (n = 982). In this study, we only included data from patients who had a complete renal POCUS video set and the CT examination within 24 hours of the POCUS recording (n = 651).[33] Patients with incomplete POCUS or without CT scan examination

were excluded from the study (Figure 1). All the patients for whom data are included in this study provided a written informed consent as part of the original study.

POCUS Image Generation

A typical complete renal POCUS video set would have four video clips of 6 seconds' duration each, including a longitudinal and a traverse axis view of both kidneys in swipe motion. Trained EPs or research assistants performed all the POCUS examinations, and each video set was coded with a unique identifier before storing them. Minimum training criteria included attending a 30-minute didactic teaching session and performance of 35 renal POCUS scans under supervision. The POCUS examinations were recorded on the SonoSite M-Turbo (using 5-4 MHz curved transducer, C60x) or Sonosite X-PORTE (using 8-3 MHz curved transducer, C35xp) machines (Sonosite Inc.), while the patient was lying in a supine position. Dynamic video images were stored in the Audio Video Interleave (AVI) or in the Digital Imaging and Communications in Medicine (DICOM) format. The interpretations of POCUS by the performing physicians or research assistant were recorded incompletely and hence not used to compare to the reference standard of consensus radiology interpretation of POCUS images.

POCUS Interpreters

The EP group consisted of two board-certified attending-grade EPs with ultrasound training and a minimum of 5 years' postboard experience, two EM fellow trainees who completed the 4-year EM residency program and were currently in the advanced EM fellowship program, and two EM resident trainees in 4-year EM residency programs at the time of study. The EM fellows and residents formed the training EPs group. All participants reviewed each of the 651 POCUS video sets independently. Findings were compared to

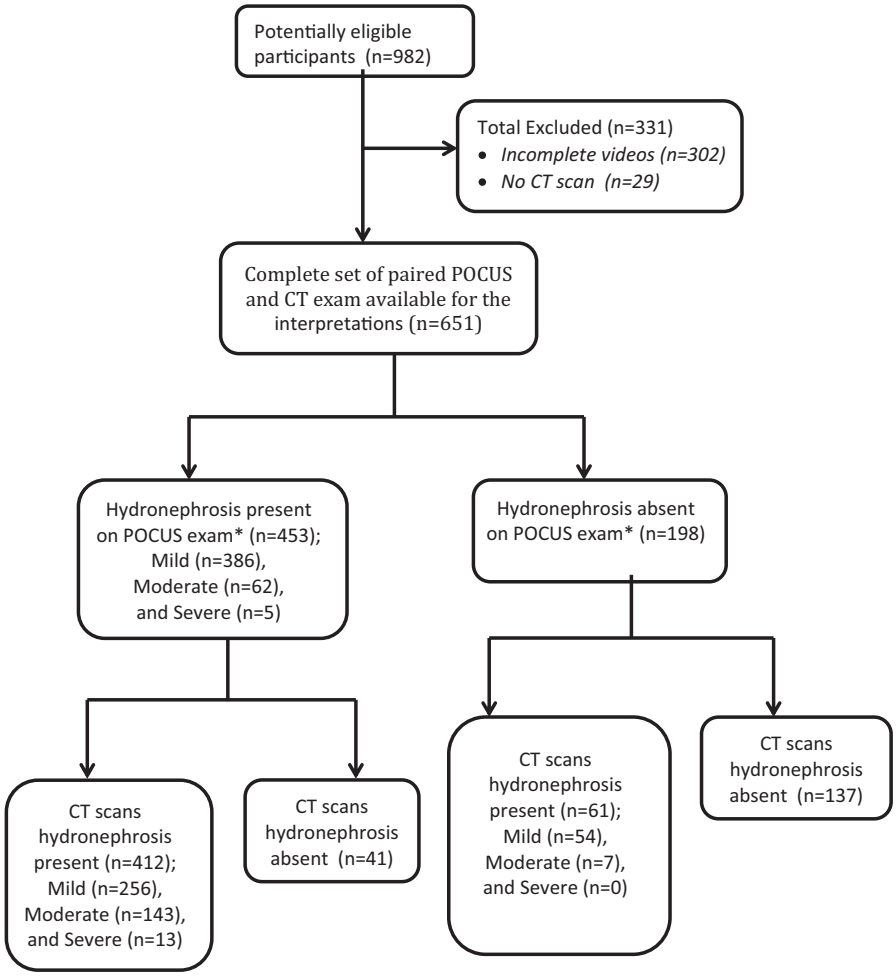

Figure 1. Standards for Reporting of Diagnostic Accuracy (STARD) flow diagram for study flow.

the consensus interpretation by the emergency radiologists with a minimum of five-year post-board experience. Initially, POCUS interpretations by the two emergency radiologists were assessed for congruency, and a third senior radiologist served as the arbiter to settle any disagreement.[26] The final outcome of this process formulated the consensus interpretation result for each POCUS examination and served as the criterion standard to assess EP performance.[34]

Furthermore, the POCUS findings recorded by EPs and emergency radiologists were compared to the CT scan findings of hydronephrosis. All the CT scans were prospectively reported by a senior radiologist using a common grading system. While reporting the CT scan findings, the senior radiologist was blinded to the POCUS examination findings. The data collected were patient demographics, CT scan findings of hydronephrosis (presence, side, and grade), stone information (presence, location, and size), and the POCUS interpretation results for each of the participating radiologists and the EPs. The data were collected using a Google form onto an Excel sheet (Microsoft Corp.). All the interpreting EM physicians completed a 45-minute training session including 15-minute didactic followed by supervised 25 to 30 practice scan interpretations with active correction feedback as necessary.[35] Interpreting clinicians were blinded to patient clinical data including CT scan results. The interpreting EM clinicians were asked to identify the presence or absence of hydronephrosis, determine the side of hydronephrosis, and grade the hydronephrosis if assumed to be present. In case of bilateral hydronephrosis, the interpreters were also asked to record the side assumed to have greater grade of hydronephrosis.

Outcomes Measures

The primary outcome of interest was presence or absence of any hydronephrosis. Hydronephrosis, when present, was graded as mild, moderate or severe (Data Supplement S1, available as supporting information in the online version of this paper, which is available at http://onlinelibrary.wiley.com/doi/10.1111/acem.13432/full).[36,37] *Mild hydronephrosis* was defined as the separation of the renal sinus and enlargement of calices by interconnected areas filled with sonolucent urine, with the preservation of renal papillae. *Moderate hydronephrosis* was defined as the blunting or rounding of the calices or the obliteration of renal papillae without affecting the cortical thickness. *Severe hydronephrosis* was considered to be present if caliceal ballooning and cortical thinning were found. No attempts were made to measure the dimensions of the kidney or calyx.

Data Analysis

Sensitivity, specificity, and positive and negative likelihood ratios of EP interpretations were assessed using consensus interpretation by emergency radiologists as the reference standard. We also compared POCUS interpretations for hydronephrosis against CT interpretations. The presence or absence of hydronephrosis was treated as a dichotomous outcome, and the grade of hydronephrosis was dealt with as ordinal data. Nonparametric continuous data were reported as median (interquartile range), and the categorical data were reported as proportions with 95% confidence interval (CI). Statistical significance of differences between proportions were assessed using the chi-square test. Interobserver reliability between the two radiologists reporting POCUS was assessed using kappa (κ) for dichotomous outcomes, and a weighted kappa was used for ordinal data. Each pair of the participants (radiologists, attending EPs, senior trainees, and the junior trainees) was assessed for inter-rater agreement at the same experience level. All the analyses were performed using Stata 14.0 MP (StataCorp). A post hoc analysis was performed by collapsing the grades of hydronephrosis, into two categories—"moderate or severe" versus "none or mild" categories, to compare the POCUS interpretation using broader categories. This study was approved by the HMC-IRB and registered with Monash University Human Research and Ethics Committee (number [SCH-Joint-111] IRB-00009413 and CF15/3781–2015001648).

RESULTS

Data from 651 patients who had a complete set of paired imaging tests (POCUS and CT scan) performed during the index visit were included for this study. Hydronephrosis were described as present in 69.6% (453/651) of the studies on consensus interpretation by radiologists and in 72.7% (473/651) of the CT scan interpretations ($p = 0.22$) by radiologists (Table 1). The interobserver agreement between the radiologist POCUS interpretations to determine presence or absence of hydronephrosis (κ) was 0.77 (0.72 to 0.82) and for grading hydronephrosis the weighted κ was 0.82 (0.72 to 0.90), interpreted as good and very good,

Table 1
Patient Demographics and Prevalence of POCUS and CT Scan Findings

Total examinations (video sets)	651	
Age (years), median (IQR)	34 (28–42)	
Male, *n* (%)	545 (83.7)	
Weight (kg), median (IQR)	72.5 (65–83)	
Height (cm), median (IQR)	167 (162–172)	
Body mass index (kg/m^2), median (IQR)	26.6 (23.9–29.9)	
Nationality, *n* (%)		
Indian	163 (25.0)	
Egyptian	121 (18.6)	
Nepalese	93 (14.3)	
Pakistani	56 (8.6)	
Bangladeshi	51 (7.8)	
Sri Lankan	45 (6.9)	
Filipino	29 (4.5)	
Syrian	24 (3.7)	
Others	62 (9.5)	
Missing	7 (1.1)	
Pain complain side, *n* (%)		
Bilateral	16 (2.5)	
Left	302 (46.4)	
Right	333 (51.1)	
Imaging, *n* (%)	Consensus grade	CT report
Hydronephrosis		
Yes	453 (69.6)	473 (72.7)
No	198 (30.4)	178 (27.3)
HNP grade		
None	198 (30.4)	178 (27.4)
Mild	386 (59.3)	310 (47.6)
Moderate	62 (9.5)	150 (23.0)
Severe	5 (0.8)	13 (2.0)
Stone on CT scan, *n* (%)		
Stone present	546 (83.9)	
Significant stone	238 (36.6)	
Stone size on CT scan, by location, median (IQR)		
PCS (*n* = 50)	5 (3–7)	
PUJ (*n* = 7)	7 (4–12)	
Upper ureter (*n* = 92)	6 (4–9)	
Mid ureter (*n* = 39)	7 (4–9)	
Lower ureter (*n* = 152)	4 (3–6)	
VUJ (*n* = 163)	4 (3–5)	
Bladder (*n* = 21)	3 (2.5–3)	
Urethra (*n* = 1)	4	
Overall (*n* = 525)	4 (3–7)	

HNP = hydronephrosis; IQR = interquartile range; PCS = pelvicalyceal system; POCUS = point-of-care ultrasound; PUJ = pelviureteric junction; VUJ = vesicoureteral junction.

respectively. However, the concordance rate between the POCUS consensus results and the corresponding CT scan results was 67.3% (438/651) for detecting presence or absence of hydronephrosis with a κ value of 0.47 (0.45–0.51), and weighted κ for grading of hydronephrosis as mild, moderate, or severe was 0.64 (0.56–0.72), interpreted as fair and moderate, respectively (Data Supplement S2, Appendix B-1, available as supporting information in the online version of this paper, which is available at http://onlinelibrary.wiley.com/doi/10.1111/acem.13432/full).

Of the 651 POCUS examinations, in 10.1% (7.9%–12.7%) of cases, radiologists were in disagreement on the absence of hydronephrosis, and when rated positive by either radiologist (66 examinations) it was of mild grade only in all cases. POCUS examinations for hydronephrosis were categorized as none in 30.4%, mild in 59.3%, moderate in 9.5%, and severe in 0.8% based on the consensus interpretations (Table 1). Figure 1 displays test characteristics of hydronephrosis on the POCUS exam versus the CT scan in the Standards for Reporting of Diagnostic Accuracy (STARD) format.[23,37]

Overall, hydronephrosis identification on POCUS by EPs was 85.7% sensitive, 65.9% specific, with a positive likelihood ratio of 2.5 (95% CI = 2.3–2.7) and a negative likelihood ratio of 0.22 (95% CI = 0.19–0.24), when compared with consensus interpretations by the radiologists (Table 2). Among the EP-reported false-negative POCUS interpretations, 11 had moderate hydronephrosis and the 365 had mild hydronephrosis, when compared to the consensus interpretation.

Using CT scan findings as the reference standard, the EPs compared to emergency radiologists had comparable sensitivity, 81.1% (79.6%–82.5%) versus 85.0% (82.5%–87.2%), and lower specificity, 59.4% (56.4%–62.5%) versus 79.7% (75.1%–83.7%). However, when moderate and severe hydronephrosis grades were considered together as a positive POCUS finding, the specificity of EPs improved significantly to 94.6% (98.4% specificity for attending EPs and 92.7% specificity for training EPs), comparable to 97.3% specificity for the emergency radiologists (Table 2). The improvement in specificity on categorization of moderate or severe grade together was also associated with a significant drop in sensitivity for all examinations, and it was not significantly different between the emergency radiologists and attending or training EPs. Of the false-negative interpretations for POCUS, 14 of 148 cases reported by radiologists and 86 of 506 cases reported by EPs had moderate hydronephrosis on a corresponding CT scan. The EP group reported two cases of false-negative examinations on

Table 2
Test Characteristics for EP POCUS Interpretations

Test (Interpreters) and the Reference Standard→ Interpreters ↓	Sensitivity % (95% CI)	Specificity, % (95% CI)	Positive Likelihood Ratio (95% CI)	Negative Likelihood Ratio (95% CI)
Presence or absence of hydronephrosis				
EP POCUS interpretations vs. radiologist POCUS interpretations				
Overall EPs performance	85.7 (84.3–87.0)*	65.9 (63.1–68.7)*	2.5 (2.3–2.7)*	0.22 (0.19–0.24)*
Attending EPs	96.9 (95.6–97.9)	57.2 (52.1–62.2)	2.3 (2.0–2.5)	0.05 (0.03–0.07)
Training EPs	80.1 (78.2–81.9)	70.3 (66.9–73.5)	2.7 (2.4–3.0)	0.28 (0.25–0.31)
EP POCUS interpretations vs. radiologist CT interpretations				
Overall EPs performance	81.1 (79.6–82.5)	59.4 (56.4–62.5)	2.0 (1.8–2.2)*	0.32 (0.29–0.35)*
Attending EPs	92.4 (90.5–94.0)	51.6 (46.2–57.0)	1.9 (1.7–2.1)	0.15 (0.12–0.18)
Training EPs	75.4 (73.3–77.3)	63.3 (59.6–66.9)	2.1 (1.8–2.3)	0.39 (0.35–0.43)
Moderate or severe vs. none or mild hydronephrosis (EP POCUS interpretations vs. radiologist CT interpretations)				
Overall EPs performance	34.2 (31.2–37.3)	94.6 (93.7–95.4)	6.33 (5.3–7.5)*	0.69 (0.66–0.73)*
Attending EPs	24.4 (19.7–29.5)	98.4 (97.4–99.1)	15.4 (8.9–26.4)	0.77 (0.72–0.82)
Training EPs	39.1 (35.3–43.0)	92.7 (91.4–93.8)	5.3 (4.4–6.4)	0.66 (0.62–0.70)

POCUS = point-of-care ultrasound.
*Primary results.

POCUS that had severe hydronephrosis on corresponding CT scans.

DISCUSSION

Using consensus interpretation by radiologists as reference standard, we found that the EPs had a high sensitivity (85.7%) and moderate specificity (65.9%) for detecting hydronephrosis. The attending EPs with ultrasound training background had a higher sensitivity for detecting hydronephrosis than the EPs in training. Using CT scan as the reference standard, EPs had specificity of 94.6% to identify moderate or severe hydronephrosis though sensitivity was poor (34.2%).

Our results were comparable to those of the largest study conducted on provider experience of POCUS use in a pragmatic study design, using CT scan as a reference standard.[38] This study adds to the previous knowledge by validating EP test characteristics for detection of hydronephrosis in comparison with consensus interpretation of the same POCUS data by radiologists. The test characteristics were different between the EP attending and trainee group for determining presence or absence of hydronephrosis (Data Supplement S2, Appendix B-2). However, the results were more consistent across the EPs for determining moderate or severe hydronephrosis and were found to provide a more definitive answer for stone disease. Therefore, when using POCUS for assessment of patients with renal colic, attempts should be made to determine the presence of severe or moderate hydronephrosis to rule in the disease at the bedside.[31]

More recent work on POCUS published in 2016 assessed the utility of POCUS in conjunction with a clinical risk score and proposed an algorithm based on the degree of hydronephrosis.[17,31,37] Using a Bayesian approach, we applied EP test results to the pretest probabilities obtained from a previous study clinical risk score[17,39] and estimated posttest probabilities (Table 3). Our findings add to the previous work[17] by validating that the presence of moderate to severe hydronephrosis on POCUS examination, in patients with moderate or high risk of ureteric calculi, provides a more definitive answer regarding the presence of a stone without the need for high-dose CT scanning. In such patients, a low-dose CT scan is advised if the size and location of the stone is desired to plan surgical management.

We also recommend continued assessment of patients with low pretest probability of stone diagnosis in the absence of hydronephrosis or with only a mild degree of hydronephrosis. Furthermore, immediate imaging modalities are necessary in patients without clinical improvement after treatment and in patients at higher risk of complications such as those with fever or leukocytosis[17,39] or patients with single kidney, transplant, immune compromise, or congenital urinary abnormalities, and/or at risk of renal failure. The results of this study were consistent with the previous studies showing that EPs can detect and grade hydronephrosis on POCUS with a sensitivity between 72% and 97% and specificity between 69% and

Table 3
Influence of POCUS Results by EP on Posttest Probability of Stone Diagnosis, Given That the Pretest Probabilities Is Determined by Prevalidated STONE Risk Scores

Overall EPs Performance						
Posttest probability, % → Pretest Probability of Urolithiasis Based on STONE Score,* % ↓	Test Positive (Posttest Probability Based on +LR)			Test Negative (Posttest Probability Based on –LR)		
	HNP Present or Absent (+LR 2)	Moderate or Severe vs. None or Mild (+LR 6.3)	Severe vs. Nonsevere (+LR 54.4)	HNP Present or Absent (–LR 0.32)	Moderate or Severe vs. None or Mild (–LR 0.69)	Severe vs. Nonsevere (–LR 0.57)
10 (low risk)	18.2	41.2	85.8†	3.4†	7.2†	5.9†
50 (moderate risk)	66.7	86.3†	98.2†	24.2	40.8	36.3
90 (high risk)	94.7†	98.3†	99.8†	74.2	86.1	83.7

*STONE score: sex, timing, origin (race), nausea, and erythrocytes in urine.
†Clinically meaningful impact on posttest probability.
HNP = hydronephrosis; +LR = positive likelihood ratio; –LR = negative likelihood ratio.

88%,[15] and affirms the recommendation of using POCUS information in conjunction with clinical information.[17,23–30]

LIMITATIONS

Some limitations should be considered before applying the results to any other population. The POCUS examinations and the CT scans were not performed contemporaneously. The CT scan was performed after POCUS with a median of 104 (31–190) minutes and with range of 1,356 minutes before POCUS to 666 minutes after. However, most scans were completed within 5 hours of POCUS examination. Renal or ureteric stone was not detected in 21 CT scans but "the signs of recently passed stone" were mentioned in the reports. This may contribute to variation of hydronephrosis grade detected over time. Radiologists and EM physicians were not provided with clinical data while interpreting the results, which may be a possible reason for the lower specificity recorded in reporting hydronephrosis. We believed that it was important to avoid bias of overinterpreting mild hydronephrosis. The use of color Doppler to differentiate renal vessels was not employed while recording the video clips. The above-mentioned factors may partly explain the discordant results observed between the POCUS and CT images and also the false-negative rates for mild-grade hydronephrosis when compared with CT scan. The study was conducted at a single large academic center with POCUS training in the initial phases, and only eight interpreters with similar training background were used to represent EP performance. Therefore, results may not be generalizable to centers where POCUS training is not available, or the EPs are from different training backgrounds. However, inclusion of EM trainees with minimal prior renal ultrasound exposure showed promising results with just 30 minutes of training in this study. Finally, we did not assess the skills required to obtain a quality image, rather the study focused on assessing the accuracy of EP interpretations of POCUS findings.

CONCLUSION

Emergency physicians were found to have moderate to high sensitivity for identifying hydronephrosis on point-of-care ultrasound when compared with the consensus interpretation of the same studies by emergency radiologists. These findings on point-of-care ultrasound by emergency physicians produced more definitive results when at least a moderate degree of hydronephrosis was present. Point-of-care ultrasound findings are best utilized in conjunction with the pretest clinical probability as a part of a diagnostic algorithm.

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Supporting Information

The following supporting information is available in the online version of this paper available at http://onlinelibrary.wiley.com/doi/10.1111/acem.13432/full

Data Supplement S1. Hydronephrosis grading.

Data Supplement S2. Appendixes.