A Prospective, Multicenter Evaluation of Point-of-care Ultrasound for Small-bowel Obstruction in the Emergency Department

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ABSTRACT

Objective: The main objective of this study was to evaluate the accuracy of emergency physician-performed point-of-care ultrasound (POCUS) for the diagnosis of small-bowel obstruction (SBO) compared to computed tomography (CT).

Methods: We performed a prospective, multicenter, observational study examining a convenience sample of adult patients with potential SBO presenting to the emergency department (ED) between July 2014 and May 2017. Each POCUS was interpreted at the bedside by the performing emergency physician and retrospectively by an expert reviewer. Test characteristics were calculated for POCUS, blinded expert interpretation, and specific POCUS parameters.

Results: A total of 217 subjects were included in the primary analysis with an overall SBO prevalence of 42.9%. For the diagnosis of SBO, POCUS demonstrated an overall sensitivity, specificity, positive likelihood ratio, and negative likelihood ratio of 0.88 (95% confidence interval [CI] = 0.80 to 0.94), 0.54 (95% CI = 0.45 to 0.63), 1.92 (95% CI = 1.56 to 2.35), and 0.22 (95% CI = 0.12 to 0.39), respectively. Expert review yielded a similar sensitivity (0.89 [95% CI = 0.81 to 0.95]) with a significantly higher specificity (0.82 [95% CI = 0.74 to 0.88]). The more sensitive sonographic parameters for both POC sonographers and expert reviewers were small-bowel dilation ≥ 25 mm (0.87 [95% CI = 0.79 to 0.93], 0.87 [95% CI = 0.79 to 0.93]) and abnormal peristalsis (0.82 [95% CI = 0.72 to 0.89], 0.85 [95% CI = 0.76 to 0.87]). The more specific parameters for both groups were transition point (0.82 [95% CI = 0.74 to 0.89], 0.98 [95% CI = 0.94 to 1.00]), intraperitoneal free fluid (0.82 [95% CI = 0.74 to 0.89], 0.93 [95% CI = 0.87 to 0.97]), and bowel wall edema (0.76 [95% CI = 0.67 to 0.83], 0.93 [95% CI = 0.87 to 0.97]).

Conclusion: POCUS is moderately sensitive for SBO, although less specific, when performed by a diverse group of emergency physicians across multiple EDs. Interpretation of acquired POCUS images is significantly more accurate when performed by physicians with prior emergency ultrasound fellowship training and familiarity with the sonographic appearance of SBO.

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Received November 11, 2018; revision received January 24, 2019; accepted February 11, 2019.
Presented at the American College of Emergency Physicians Scientific Assembly, Las Vegas, NV, October 2016; the American Institute of Ultrasound in Medicine Annual Convention, Orlando, FL, March 2017; and the Society for Academic Emergency Medicine Annual Meeting, Indianapolis, IN, May 2018.
The authors have no relevant financial information or potential conflicts to disclose.
ClinicalTrials.gov Identifier: NCT0219081.
Author contributions: BAB conceived and designed the study; BAB, MAG, BAS, TAK, SL, JCF, and JTN supervised the conduct of the trial and data collection; BAB, BAS, SL, TT, MB, and JTN managed the data, including quality control; BAB provided statistical advice on study design and analyzed the data; BAB drafted the manuscript and all authors contributed substantially to its revision; and BAB takes responsibility for the paper as a whole.
Supervising Editor: Timothy B. Jang, MD.
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ACADEMIC EMERGENCY MEDICINE 2019;26:921–930.

doi: 10.1111/acem.13713
ISSN 1553-2712

Background

Small-bowel obstruction (SBO) represents a clinical entity frequently encountered by emergency physicians. In the United States, published data suggest approximately 300,000 adults are hospitalized annually for SBO despite increasing use of laparoscopic surgery.[1,2] Imaging plays a significant role in making the diagnosis of SBO, as history and physical examination are unreliable.[3] Due to poor accuracy and frequently inconclusive results, traditional plain radiographs have been increasing eschewed in favor of computed tomography (CT).[4–7] CT is significantly more sensitive and specific for SBO, particularly with 64-slice scanners; however, its use confers significant expense, potential delays, and ionizing radiation.[3] Multiple studies have shown that ultrasound outperforms plain radiography for the detection of SBO.[4,6,8] The use of point-of-care ultrasound (POCUS) for the evaluation of SBO has grown in recent years and ultrasound is increasingly being touted as a first-line imaging modality for SBO.[9,10]

Importance

Ultrasound for SBO was first described in case series during the 1970s and has been shown to be both sensitive and specific in subsequent studies.[6,11–15] The ability of POCUS to accurately diagnose SBO could potentially improve patient care by decreasing time to diagnosis and expediting consultation, as seen with other POCUS applications.[16,17] A recent meta-analysis reflects a strong performance of ultrasound for SBO in the emergency department (ED) setting; however, only two trials examined POCUS performed by emergency physicians and analysis on this specific subgroup was not possible.[18] Moreover, the available published research on POCUS for SBO largely consists of small, single-center studies with variable reference standards.[6,8,10,13,14]

Goals of This Investigation

The main objective of this study was to conduct a multicenter evaluation of the accuracy of emergency physician–performed POCUS for the diagnosis of SBO compared to CT. We also aimed to compare POCUS interpretation to that of emergency ultrasound fellowship–trained experts and assess the role of specific sonographic parameters in confirming the diagnosis of SBO by POCUS.

METHODS

Study Design and Setting

We performed a prospective, multicenter, observational study examining the diagnostic accuracy of POCUS for SBO. A convenience sample of adult ED patients presenting between July 2014 and May 2017 with suspicion for SBO underwent goal-directed POCUS of the abdomen for the evaluation of SBO. POCUS findings were interpreted at bedside by a physician sonographer blinded to laboratory and imaging results, including CT, and retrospectively by an expert reviewer after deidentification of the images. Each POCUS interpretation was compared to abdominal CT as the reference standard.

Subjects were enrolled at three separate facilities, including two suburban, academic community hospitals and an urban, university-based tertiary referral center. The combined annual ED census of the three centers is approximately 250,000 visits. All three facilities support independent three-year (PGY-1 to -3) emergency medicine (EM) residency training programs and emergency ultrasound fellowships. The institutional review boards at each site provided approval, and written informed consent was obtained from all subjects. The study was preregistered with ClinicalTrials.gov (NCT0219081) and conducted in accordance with Standards for Reporting of Diagnostic Accuracy Studies (STARD) guidelines.[19,20]

Selection of Participants

Potential subjects were identified either by direct clinical contact by a member of the study team or referral by other ED providers not directly participating in the study. Patients were eligible for enrollment only when a physician participating in the study was available. The study team member obtained patient consent prior to performing POCUS for SBO. Patients were eligible for enrollment if they were at least 18 years of age, able to provide consent in English, not pregnant, had not yet undergone radiology imaging, and presented with symptoms concerning for possible SBO. The latter criterion was not explicitly defined, but was based on the clinical assessment by the treating physician. Patients were excluded if they did not receive CT imaging.

Data Collection and Measurements

Data were collected using universal standardized data collection forms common to all participating sites. Sonographic data and bedside interpretations were recorded at the time of POCUS. Clinical features were also recorded at the time of POCUS, including diarrhea within 24 hours, vomiting, duration of symptoms, timing of last bowel movement, and presence of diffuse abdominal pain or tenderness. Follow-up data were collected by review of the electronic medical record and included patient demographics, discharge diagnosis, operative reports, abdominal x-ray imaging, and CT results. CT scanners used included: Phillips Ingenuity 128 slice (hospital 1), Phillips Brilliance iCT 256 slice (hospital 1 and 2), and Siemens SOMATOM Definition AS 64 slice (hospital 3). Board-certified attending radiologists rendered all final CT interpretations.

Ultrasound Technique and Interpretation

Point-of-care ultrasound for SBO was performed in supine patients using a standardized protocol: a curvilinear probe between 1 and 5 MHz was placed on the patient's anterior abdomen. Sonographers conducted a systematic evaluation of the entire abdomen, including dedicated views of the right upper quadrant, left upper quadrant, right lower quadrant, and left lower quadrant. Sonographers were instructed to adjust the probe orientation with respect to the body (transverse, sagittal, or coronal) to optimize longitudinal images of the small bowel. All POCUS examinations required at least one video clip of the small bowel in each quadrant. Maximum bowel diameter was measured and recorded as a still image. Any suspected transition point, defined as the region between the proximal segment of dilated small bowel and the distal segment of decompressed small bowel, was recorded via a video clip. Each patient was also specifically assessed for four other sonographic parameters previously associated with SBO: small-bowel dilation, abnormal peristalsis, small-bowel wall edema, and intraperitoneal free fluid (Table 1).[9] Small-bowel dilation was defined as bowel diameter ≥ 25 mm measured outer wall to outer wall. Abnormal peristalsis was defined as "to-and-fro," shuttling or swirling movements of intraluminal bowel contents. Bowel wall edema was present if the plicae circulares projected into the bowel lumen, resulting in a "keyboard sign."[21] Given a lack of clear consensus on the maximum wall thickness in normal bowel, no specific cutoff for bowel wall thickness was used.

Table 1
Specific Ultrasound Parameters Assessed During POCUS for SBO

1. Small bowel dilation ≥ 25 mm
2. Abnormal peristalsis
3. Intraperitoneal free fluid
4. Small-bowel wall edema
5. Transition point

POCUS = point-of-care ultrasound; SBO = small-bowel obstruction.

Intraperitoneal free fluid was considered present if anechoic, extraluminal collections were visualized between bowel loops. Sonographers utilized a checklist on the bedside data collection form to ensure all aforementioned views and measurements were obtained. Still images and video clips were saved, exported, and deidentified for independent interpretation by a blinded expert reviewer.

Each POCUS was performed by an attending ED physician, emergency ultrasound fellow, or upper-level EM resident (PGY-2 or PGY-3). The attending group included physicians both with and without emergency ultrasound fellowship training. All participating fellows and residents received a 30-minute lecture on the POCUS technique for SBO, followed by brief hands-on scanning practice on normal individuals without SBO. Residents had completed at least one emergency ultrasound rotation and performed at least 50 POCUS examinations; however, they had no prior exposure to or training in POCUS for SBO prior to joining the study. Standardized didactic materials were distributed among the three enrolling centers to ensure consistency of POCUS training, but there was no prerequisite number of POCUS for SBO before participants were cleared to enroll. Sonographers were blinded to the results of other diagnostic tests, including laboratory values and subsequent imaging results. The treating physicians and radiologists were similarly blinded to the results of the POCUS. POCUS findings were not used in clinical decision making, and each patient otherwise received normal ED standard of care.

The specific ultrasound devices used depended on the site and included Mindray TE7 (Mindray North America), Sonosite M-Turbo (FUJIFILM Sonosite), Sonosite X-porte (FUJIFILM Sonosite), Ultrasonix SonixTOUCH (BK Ultrasound), and Zonare ZS3 (Mindray North America). All images were acquired using a low-frequency, convex array transducer (1–5 MHz) and archived using site-specific software, namely, SonixHUB (Analogic Corporation), AGFA Healthcare

Enterprise Imaging (AGFA-Gevaert Group), and QPath (Telexy Healthcare).

The performing sonographer completed a closed-response data collection form at the time of the examination. Each POCUS was classified as positive, negative, or indeterminate for SBO, based on the presence of small bowel dilation ≥ 25 mm or abnormal peristalsis. The additional three ultrasound parameters (small-bowel wall edema, intraperitoneal free fluid, and transition point) served to augment the sonographers' overall impression based on small-bowel diameter and peristalsis.

Blinded interpretations of the deidentified POCUS images were conducted in an analogous fashion, utilizing the same standardized closed-response form as the POC sonographer. Expert reviews were conducted by the primary author (BB) or the emergency ultrasound director at two of the sites (TK, SL). All reviewers had completed an emergency ultrasound fellowship and two were ARDMS certified. If these individuals were involved in the index POCUS or familiar with the clinical details of a given case, the blinded overread was delegated to another emergency ultrasound fellowship–trained member of the ED faculty.

Outcomes

The primary outcome of the study was POCUS-mediated diagnosis of SBO, confirmed by CT. Secondary outcomes included the diagnosis of SBO by blinded expert interpretation of POCUS images and diagnostic accuracy of each of the five specific sonographic parameters.

Any POCUS classified as indeterminate was considered "positive" for SBO. This approach was chosen to align with typical ED practice, namely, the tendency to pursue equivocal results with further workup or consultation. Similarly, noncommittal CT interpretations (i.e., "ileus versus SBO") were treated as SBO. Unequivocal CT diagnosis of ileus was considered negative for SBO. Obstructive processes seen on CT that did not specifically involve the small bowel were also classified as negative for SBO, including large-bowel obstruction, volvulus, and pseudo-obstruction.

Data Analysis

Analysis of patient demographics was descriptive with continuous and categorical variables reported as medians with interquartile ranges (IQRs) and percentages, respectively. Standard 2 × 2 tables were used to calculate sensitivity, specificity, and positive/negative likelihood ratios (LR+/LR–) with 95% confidence intervals (CIs) for POCUS and blinded expert interpretation. Subgroup analysis included analogous calculations based on sonographer level of training. Inter-rater reliability between POCUS and blinded expert review was assessed using Cohen's kappa coefficient (κ).

Given the unilateral treatment of indeterminate imaging results in the primary analysis, sensitivity analysis was performed. Primary analysis was repeated with 1) reclassification of all indeterminate POCUS as negative for SBO and 2) removal of patients with indeterminate POCUS or CT interpretations. Additionally, we assessed the reliability of CT as the reference standard by recalculating POCUS test characteristics based on final discharge diagnosis. This incorporated additional clinical information beyond the initial CT, including subsequent diagnostics, operative findings, and hospital course.

Previously published literature examining ultrasound for SBO predicted an average sensitivity and specificity of approximately 90 and 91%, respectively, with an expected SBO incidence of 40%.[4,6–8] With these assumptions, it was calculated a priori that 96 patients would be required to yield precision of 0.10 and confidence level of 95%. We initially planned a single-site enrollment of 106 patients anticipating an approximate 10% exclusion rate; however, prior prospective studies had enrolled similar numbers and our study subsequently expanded to include additional sites. Thus, a total enrollment of 212 patients was planned across all participating centers.

Data were compiled using Remark Office OMR 7 (Gravic) and Microsoft Excel 2010 (Microsoft). Data analysis was performed using IBM SPSS Statistics for Windows version 24.0 (IBM Corp, Armonk, NY) and MedCalc statistical software 18.10.2 (MedCalc Software bvba; https://www.medcalc.org; 2018).

RESULTS

Characteristics of Study Subjects

A total of 232 subjects were initially enrolled across the three hospitals. Fifteen (6.5%) patients did not receive CT imaging and were excluded, leaving 217 subjects for the primary analysis consisting of 111 (51.2%), 103 (47.5%), and three (1.4%) patients at the three study sites, respectively. Figure 1 depicts the overall study flow chart.

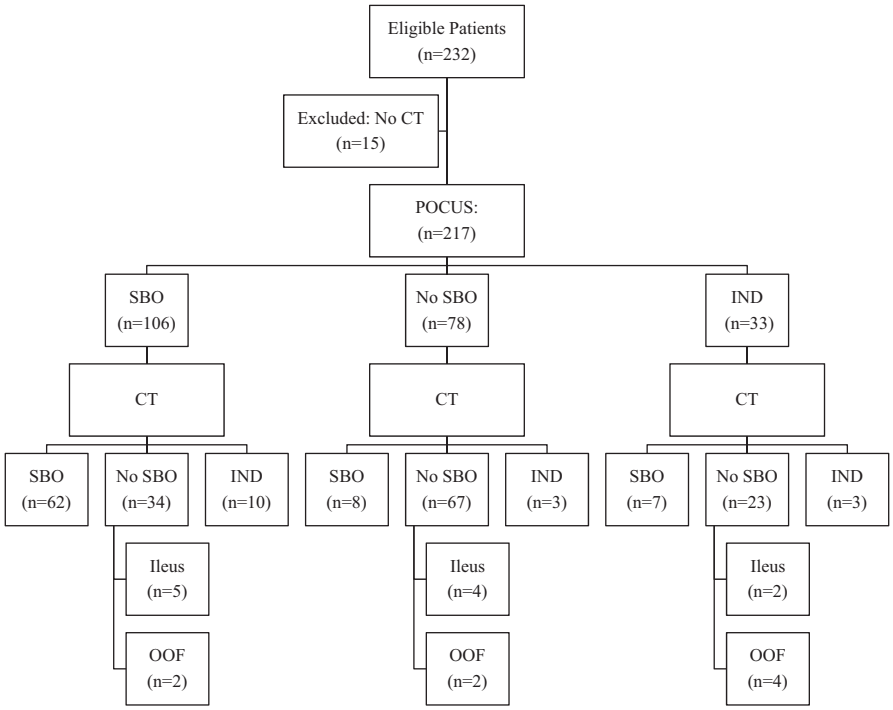

Figure 1. Study flow diagram. IND = indeterminate; OOF = other obstructive finding; POCUS = point-of-care ultrasound; SBO = small-bowel obstruction.

The median (IQR) age of the included cohort was 55 (45–67) years and 114 (52.5%) patients were female. The overall prevalence of SBO was 42.9%. Patient characteristics were generally similar between study sites and are presented in Table 2.

Point-of-care ultrasound was performed by an attending, fellow, or resident physician in 77 (35.5%), 72 (33.2%), and 68 (31.3%) subjects, respectively. A total of 41 unique physicians performed a median (IQR) of 4 (2.5–15.5) POCUS examinations each with individual counts ranging from 1 to 35.

Main Results

The performance of POCUS for the diagnosis of CT-confirmed SBO is displayed in Table 3, illustrating the 11 false-negative and 57 false-positive POCUS examinations. The corresponding CT findings and discharge diagnoses for these divergent cases are reported in Data Supplement S1, Tables S1 and S2 (available as supporting information in the online version of this paper, which is available at http://onlinelibrary.wiley.com/doi/10.1111/acem.13713/full).

The overall POCUS sensitivity, specificity, LR+, and LR– were 0.88 (95% CI = 0.80 to 0.94), 0.54 (95% CI = 0.45 to 0.63), 1.92 (95% CI = 1.56 to 2.35), and 0.22 (95% CI = 0.12 to 0.39), respectively (Table 4).

Point-of-care ultrasound performed by trainees (fellows/residents) demonstrated a sensitivity of 0.91 (95% CI = 0.80 to 0.97) and specificity of 0.51 (95% CI = 0.40 to 0.62), compared to a sensitivity of 0.85 (95% CI = 0.70 to 0.94), and specificity of 0.61 (95% CI = 0.43 to 0.76) for attending-performed POCUS. Subgroup analysis of trainee-performed POCUS by level of training is reported in Table 4.

Secondary Results

Blinded expert interpretation of deidentified POCUS images was performed for 216 subjects, due to missing images for a single patient (Table 3). The sensitivity of expert review for SBO was similar to that of POC sonographers (0.89 [95% CI = 0.81 to 0.95]), while specificity was significantly greater (0.82 [95% CI = 0.74 to 0.88]; Table 4). Accuracy of expert interpretation was significantly higher than that of POC sonographers (0.85 [95% CI = 0.80 to 0.90] vs. 0.69 [95% CI = 0.62 to 0.75]). Comparison of original POC and expert interpretation of POCUS for SBO (positive, indeterminate, or negative) yielded a percentage agreement of 68.1% with associated $\kappa = 0.468$ (95% CI = 0.378 to 0.558), $\rho < 0.001$. After reclassification of all indeterminate cases as positive, percentage agreement increased to 78.2% with associated $\kappa = 0.568$ (95% CI = 0.464 to 0.672), $\rho < 0.001$.

Table 2
Patient Demographics and Clinical Characteristics

Characteristics	All Sites	Hospital 1	Hospital 2	Hospital 3
Number (%) of patients	217 (100.0)	111 (51.2)	103 (47.5)	3 (1.4)
Demographics				
Age (years)	55 (45–67)	61 (48–72)	52 (41–62)	73 (-)
Female	114 (52.5)	52 (46.8)	60 (58.3)	2 (66.7)
BMI	25 (22–30)	27 (22–32)	24 (21–28)	33 (-)
Clinical characteristics				
Diarrhea ≤ 24 hours	51 (23.5)	25 (22.5)	25 (24.3)	1 (33.3)
Diffuse abd pain	108 (49.8)	55 (49.5)	51 (49.5)	2 (66.7)
Diffuse abd tenderness	92 (42.4)	45 (40.5)	45 (43.7)	2 (66.7)
Last BM (days)	1 (0–3)	1 (0–2)	1 (0–3)	0 (-)
Sx duration (days)	2 (1–4)	2 (1–4)	2 (1–4)	2 (-)
Vomiting	129 (59.4)	65 (58.6)	61 (59.2)	3 (100.0)
Sonographer level of training				
Attending	77 (35.5)	51 (45.9)	23 (22.3)	3 (100.0)
Fellow	72 (33.2)	29 (26.1)	43 (41.7)	0 (0.0)
Resident (PGY-2/PGY-3)	68 (31.3)	31 (27.9)	37 (35.9)	0 (0.0)
Imaging				
AXR performed	64 (29.5)	48 (43.2)	15 (14.6)	1 (33.3)
CT contrast type				
None	34 (15.7)	25 (22.5)	8 (7.8)	1 (33.3)
IV	150 (69.1)	81 (73.0)	67 (65.0)	2 (66.7)
Oral	1 (0.5)	0 (0.0)	1 (1.0)	0 (0.0)
IV + oral	32 (14.7)	5 (4.5)	27 (26.2)	0 (0.0)
POCUS impression				
Indeterminate	33 (15.2)	16 (14.4)	16 (15.5)	1 (33.3)
No SBO	78 (35.9)	37 (33.3)	41 (39.8)	0 (0.0)
SBO	106 (48.8)	58 (52.3)	46 (44.7)	2 (66.7)
Discharge diagnosis				
Ileus	7 (3.2)	6 (5.4)	1 (0.9)	0 (0.0)
Other obstructive process	8 (3.7)	6 (5.4)	2 (1.9)	0 (0.0)
No SBO	115 (53.0)	57 (51.4)	58 (56.3)	0 (0.0)
SBO	87 (40.1)	42 (37.8)	42 (40.8)	3 (100.0)

Data are reported as *n* (%) or median (IQR).
Abd = abdominal; AXR = abdominal x-ray; BM = bowel movement; BMI = body mass index; CT = computed tomography; IQR = interquartile range; IV = intravenous; POCUS = point-of-care ultrasound; SBO = small-bowel obstruction; Sx = symptoms.

The relative incidence, sensitivities, specificities, and LRs of the specific POCUS parameters for the diagnosis of CT-confirmed SBO are reported in Table 5. The more sensitive sonographic parameters for both POC sonographers and expert reviewers were small-bowel dilation ≥ 25 mm (0.87 [95% CI = 0.79 to 0.93], 0.87 [95% CI = 0.79 to 0.93]) and abnormal peristalsis (0.82 [95% CI = 0.72 to 0.89], 0.85 [95% CI = 0.76 to 0.87]). The more specific parameters for both groups were transition point (0.82 [95% CI = 0.74 to 0.89], 0.98 [95% CI = 0.94 to 1.00]), intraperitoneal free fluid (0.82 [95% CI = 0.74 to 0.89], 0.93 [95% CI = 0.87 to 0.97]), and bowel wall edema (0.76 [95% CI = 0.67 to 0.83], 0.93 [95% CI = 0.87 to 0.97]).

In the sonographer group, there was significant association between all POCUS parameters ($\rho \leq 0.025$). There were similar associations observed in the expert reviewer group ($\rho < 0.001$) with the exception of transition point, which was not demonstrably associated with bowel wall edema ($\rho = 0.822$) and intraperitoneal free fluid ($\rho = 0.330$).

Sensitivity Analysis

Reclassification of indeterminate POCUS interpretations as "negative" for SBO decreased sensitivity to 0.77

Table 3
2 × 2 Tables Comparing POCUS and Blinded Expert Review to CT Interpretation

	CT Interpretation		
	SBO	No SBO	Totals
POCUS interpretation			
SBO	82	57	139
No SBO	11	67	78
Totals	93	124	217
Expert reviewer interpretation			
SBO	83	22	105
No SBO	10	101	111
Totals	93	123	216

CT = computed tomography; POCUS = point-of-care ultrasound; SBO = small-bowel obstruction.

(95% CI = 0.67 to 0.85) and 0.82 (95% CI = 0.72 to 0.90) and increased specificity to 0.73 (95% CI = 0.64 to 0.80) and 0.87 (95% CI = 0.80 to 0.92) for POC sonographers and expert reviewers, respectively.

Exclusion of all cases with an indeterminate POCUS (n = 33) yielded a similar sensitivity of 0.87 (95% CI = 0.78 to 0.93) and improved specificity of 0.66 (95% CI = 0.56 to 0.75) for POC sonographers. Expert reviewers classified fewer examinations as indeterminate (n = 14) and exclusion of these cases resulted in a reviewer sensitivity of 0.88 (95% CI = 0.80 to 0.94) and specificity of 0.86 (95% CI = 0.79 to 0.92).

Removal of all cases with an indeterminate CT interpretation (n = 16) yielded a sensitivity of 0.90 (95% CI = 0.81 to 0.95) and specificity of 0.54 (95% CI = 0.44 to 0.63) for POC sonographers. Sensitivity and specificity of expert reviewers were 0.95 (95% CI = 0.87 to 0.99) and 0.82 (95% CI = 0.74 to 0.88), respectively.

Exclusion of all cases with either an indeterminate POCUS or CT interpretation (n = 43) yielded a slightly lower sensitivity of 0.85 (95% CI = 0.75 to 0.92) and improved specificity to 0.66 (95% CI = 0.56 to 0.75) for POC sonographers. Expert review showed slightly improved sensitivity and specificity of 0.94 (95% CI = 0.86 to 0.98) and 0.86 (95% CI = 0.79 to 0.92).

Recalculation of POCUS test characteristics based on discharge diagnosis in lieu of CT interpretation resulted in findings similar to the primary analysis. For POC sonographers, sensitivity was 0.91 (95% CI = 0.82 to 0.96) and specificity was 0.53 (95% CI = 0.44 to 0.62), while for expert reviewers, sensitivity was 0.92 (95% CI = 0.83 to 0.97) and specificity was 0.79 (95% CI = 0.71 to 0.85). There were six false-negative and 13 false-positive CT interpretations compared to discharge diagnosis, representing a sensitivity of 0.93 (95% CI = 0.85 to 0.97) and specificity of 0.90 (95% CI = 0.84 to 0.95) for SBO. Percentage agreement between CT and discharge diagnosis was 91.2% with associated κ = 0.820 (95% CI = 0.744 to 0.896), $\rho < 0.001$.

DISCUSSION

Overall, we found emergency physician–performed POCUS to be relatively sensitive (0.88) for SBO, but considerably less specific (0.54), with attending and trainee physicians performing similarly. Blinded overread of POCUS images by fellowship-trained faculty

Table 4
Test Characteristics of POCUS for the Diagnosis of SBO by POC Sonographer and Blinded Expert Interpretation

	n (%)	Sensitivity (95% CI)	Specificity (95% CI)	LR+ (95% CI)	LR– (95% CI)
POCUS interpretation	217 (100.0)	0.88 (0.80–0.94)	0.54 (0.45–0.63)	1.92 (1.56–2.35)	0.22 (0.12–0.39)
Attending	77 (35.5)	0.85 (0.70–0.94)	0.61 (0.43–0.76)	2.14 (1.41–3.25)	0.25 (0.12–0.55)
All trainees	140 (64.5)	0.91 (0.80–0.97)	0.51 (0.40–0.62)	1.86 (1.47–2.34)	0.18 (0.08–0.43)
Fellow (PGY-4)	72 (33.2)	0.93 (0.77–0.99)	0.40 (0.25–0.56)	1.54 (1.19–2.00)	0.25 (0.12–0.55)
PGY-3	41 (18.9)	0.92 (0.64–1.00)	0.57 (0.37–0.76)	2.15 (1.37–3.40)	0.13 (0.02–0.91)
PGY-2	27 (12.4)	0.83 (0.52–0.98)	0.73 (0.45–0.92)	3.12 (1.30–7.51)	0.23 (0.06–0.84)
Expert reviewer interpretation	216 (100.0)	0.89 (0.81–0.95)	0.82 (0.74–0.88)	4.99 (3.39–7.33)	0.13 (0.07–0.24)

CI = confidence interval; LR+ = positive likelihood ratio; LR– = negative likelihood ratio; PGY = postgraduate year; POCUS = point-of-care ultrasound; SBO = small-bowel obstruction.

Table 5
Test Characteristics of Specific Ultrasound Parameters for SBO

Parameter	*n* (%)	Sensitivity (95% CI)	Specificity (95% CI)	LR+ (95% CI)	LR– (95% CI)
POCUS interpretation (*n* = 217)					
Bowel ≥ 25 mm	141 (65.0)	0.87 (0.79–0.93)	0.60 (0.51–0.69)	2.20 (1.75–2.78)	0.21 (0.12–0.37)
Abnormal peristalsis	147 (67.7)	0.82 (0.72–0.89)	0.51 (0.42–0.60)	1.66 (1.36–2.04)	0.36 (0.23–0.57)
Bowel edema	75 (34.6)	0.43 (0.33–0.54)	0.76 (0.67–0.83)	1.78 (1.20–2.62)	0.75 (0.61–0.92)
Free fluid	57 (26.3)	0.34 (0.25–0.45)	0.82 (0.74–0.89)	1.94 (1.21–3.11)	0.8 (0.67–0.94)
Transition point	48 (22.1)	0.25 (0.16–0.35)	0.82 (0.74–0.89)	1.39 (0.83–2.34)	0.92 (0.79–1.05)
Expert reviewer interpretation (*n* = 216)					
Bowel ≥ 25 mm	104 (48.1)	0.87 (0.79–0.93)	0.81 (0.73–0.88)	4.66 (3.20–6.79)	0.16 (0.09–0.27)
Abnormal peristalsis	103 (47.7)	0.85 (0.76–0.87)	0.80 (0.72–0.87)	4.35 (3.01–6.30)	0.19 (0.11–0.31)
Bowel edema	34 (15.7)	0.27 (0.18–0.37)	0.93 (0.87–0.97)	3.67 (1.80–7.49)	0.79 (0.69–0.90)
Free fluid	23 (10.6)	0.15 (0.08–0.24)	0.93 (0.87–0.97)	2.06 (0.93–4.55)	0.92 (0.83–1.01)
Transition point	17 (7.8)	0.16 (0.09–0.25)	0.98 (0.94–1.00)	9.92 (2.33–42.3)	0.85 (0.78–0.93)

CI = confidence interval; LR+ = positive likelihood ratio; LR– = negative likelihood ratio; POCUS = point-of-care ultrasound; SBO = small-bowel obstruction.

was notably more accurate than POC interpretation for the diagnosis of SBO, demonstrating both greater sensitivity (89%) and greater specificity (82%). Small-bowel dilation ≥ 25 mm (0.87) and abnormal peristalsis (0.82 to 0.85) proved more sensitive for SBO, while transition point (0.82 to 0.98), intraperitoneal free fluid (0.82 to 0.93), and bowel wall edema (0.76 to 0.93) were more specific; however, almost all POCUS parameters were significantly correlated.

Multiple studies have evaluated the diagnostic accuracy of ultrasound for SBO, but it is most appropriate to compare our findings to the two prospective trials examining emergency physician–performed POCUS for SBO published by Jang et al.[6] and Unluer et al.[13] These studies reported greater sensitivity (0.91, 0.98) and specificity (0.84, 0.93), respectively, with similar SBO prevalence (43%, 52%) and reference standards (CT and a combination of CT, operative reports, and phone follow-up).[6,13] These divergent results could be due to differences in the POCUS training of study participants: Jang et al. required each sonographer to amass five SBO-positive POCUS examinations prior to enrolling and Unluer et al. provided 6 hours of training. Physician sonographers in our study received a significantly shorter didactic session and did not have to demonstrate competency prior to enrolling patients. Moreover, the group of sonographers in our study likely represents a broader cross-section of emergency physicians with significantly less experience with POCUS for SBO, including resident physicians.

The overall impression of expert reviewers proved the most accurate method of diagnosing SBO and the heightened performance we observed with fellowship-trained experts aligns more with that seen in previously published literature. Sonographic diagnosis of SBO likely hinges more on recognizing a characteristic appearance or constellation of patterns and our findings suggest that successful application of POCUS for SBO is dependent on prior experience and exposure to normal/abnormal cases. This highlights the widely recognized operator-dependence of POCUS and reiterates the need for adequate education, via both didactics and hands-on experience. We propose that proficiency in POCUS for SBO likely necessitates dedicated training, as is the case for other more established POCUS applications, such as focused assessment with sonography in trauma and POC echocardiography. Future research should investigate methods of educating learners and assessing competency for this application, as well as the economic and operational effects of POCUS as a first-line test for SBO.

LIMITATIONS

There are several limitations to the study that warrant further address. The observational design and convenience sampling introduce an inherent potential for bias. Enrollment at the third site was relatively low due to changes in faculty. Participating physicians possessed variable ultrasound experience, received relatively limited training in POCUS for SBO, and did not receive additional retraining over the span of study enrollment. The study was conducted at centers that previously were not routinely using POCUS for the evaluation of SBO; thus the results may not generalize to more experienced providers. Multiple different ultrasound machines were used during the course of the study and the effect of any given machine on the accuracy of POCUS was not assessed. While efforts were made to standardize the ultrasound technique, there was not an explicit, "stepwise" algorithm that was universally employed.

Sonographers in our study had the unique option of interpreting the POCUS as "indeterminate" for SBO, and this may have resulted in the lower test specificity observed. A prospective study of radiologist-performed ultrasound for SBO by Schmutz et al.[15] included a subset of "gassy" patients, for which the ultrasound was essentially deemed indeterminate and were excluded from analysis. The study reported a specificity of 0.84, but recalculation of this value including gassy patients yields a lower specificity of 0.72. Similar findings were observed in the reanalysis of our data after the exclusion of indeterminate examinations, although the specificity remained low (0.66) relative to antecedent studies.

CONCLUSION

Point-of-care ultrasound is moderately sensitive for small-bowel obstruction, although notably less specific, as performed by a diverse group of emergency physicians across multiple EDs. Interpretation of acquired point-of-care ultrasound images is significantly more accurate when performed by physicians with prior emergency ultrasound fellowship training and familiarity with the typical sonographic appearance of small-bowel obstruction.

We thank Theodore Bell, MS, Rodney Grim, PhD, and Soheil Saadat, MD, PhD, for their assistance with the study.

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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.13713/full

Supplemental Table S1. CT interpretations and discharge diagnoses for false negative cases in the primary POCUS cohort (n = 11).

Supplemental Table S2. CT interpretations and discharge diagnoses for false positive cases in the primary POCUS cohort (n = 57).