



Original Contribution

Diagnostic performance of emergency physician-performed point-of-care ultrasonography for acute appendicitis: A meta-analysis

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ABSTRACT

Objective: To assess the sensitivity and specificity of emergency physician-performed point-of-care ultrasonography (EP-POCUS) for diagnosing acute appendicitis (AA).

Material and methods: The PubMed and EMBASE databases were searched, and the diagnostic performance of EP-POCUS was evaluated using bivariate modeling and hierarchical summary receiver operating characteristic curves. Subgroup analysis was performed for pediatric patients to compare EP-POCUS and radiologist-performed ultrasonography (RADUS). Meta-regression analyses were performed according to patient and study characteristics.

Results: In 17 studies (2385 patients), EP-POCUS for diagnosing AA exhibited a pooled sensitivity of 84% (95% confidence interval [CI]: 72%–92%) and a pooled specificity of 91% (95% CI: 85%–95%), with even better diagnostic performance for pediatric AA (sensitivity: 95%, 95% CI: 75%–99%; specificity: 95%, 95% CI: 85%–98%). A direct comparison revealed no significant differences ($p = 0.18$ – 0.85) between the diagnostic performances of EP-POCUS (sensitivity: 81%, 95% CI: 61%–90%; specificity: 89%, 95% CI: 77%–95%) and RADUS (sensitivity: 74%, 95% CI: 65%–81%; specificity: 97%, 95% CI: 93%–98%). The meta-regression analyses revealed that study location, AA proportion, and mean age were sources of heterogeneity. Higher sensitivity and specificity tended to be associated with an appendix diameter cut-off value of 7 mm and the EP as the initial operator.

Conclusion: The diagnostic performances of EP-POCUS and RADUS were excellent for AA, with EP-POCUS having even better performance for pediatric AA. Accurate diagnoses may be achieved when the attending EP is the initial POCUS operator and uses a 7-mm cut-off value.

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1. Introduction

Acute appendicitis (AA) is the most common acute abdominal disorder that requires surgery, with a lifetime incidence of 7–8% [1, 2]. Early diagnosis and management are crucial because of this condition's high morbidity and mortality rates. The diagnosis of AA is based on history taking, a physical examination, and laboratory testing, although it remains challenging because the findings are often atypical and overlap with those of other conditions [3, 4]. Although the diagnosis of AA depends on a clinical suspicion and physical examination, imaging before surgery plays an important role in confirming or ruling out the diagnosis [5], with ultrasonography (US), computed tomography (CT), and magnetic resonance imaging being common diagnostic modalities. Previous reports [6, 7] have recommended US as the initial imaging modality for adult and pediatric patients, as there is no requirement for a contrast agent or radiation exposure. This is important, as there are increasing concerns regarding ionizing radiation exposure, particularly for young

adults and pediatric patients, with 0.7–2% of cancer cases being attributed to CT-related radiation exposure and a multiplicative and cumulative effect observed after multiple CT examinations [8, 9].

The limitations of US are its highly operator-dependent interpretation and the fact that radiologists are not available 24 h per day for on-demand US in many emergency departments (ED), which can delay the diagnosis and prolong the ED stay. Thus, emergency physicians performing point-of-care ultrasonography (EP-POCUS) at the patient's bedside are gradually becoming important in the ED. Furthermore, the American College of Emergency Physicians' 2008 revision of their Emergency Ultrasound Guideline policy statement supports an expanded role for POCUS.

Previous reports and meta-analyses have examined clinician-performed POCUS, which included emergency physicians (EP), surgeons, pediatricians, and gastroenterologists [10, 11]. However, those studies did not focus on EP-POCUS for diagnosing AA. In addition, the data regarding the diagnostic performance of EP-POCUS have revealed broad ranges of sensitivity and specificity. Therefore, the relative value of EP-POCUS for AA should be fully explored, and high-level evidence should be gathered through the quantitative synthesis of data from

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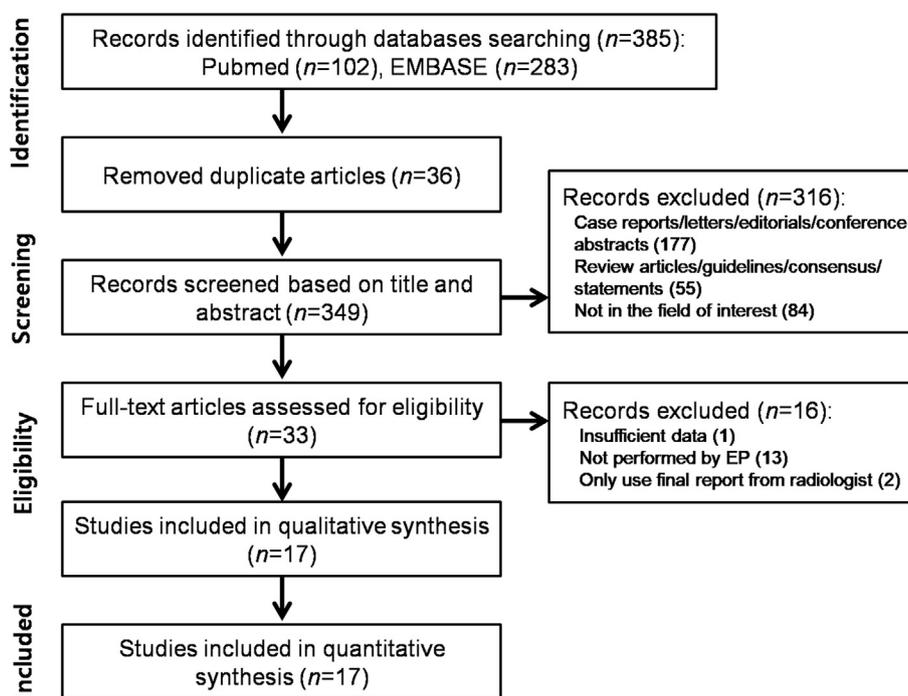


Fig. 1. The study selection process for the meta-analysis.

the existing studies. The pooled results will also be interesting, as the published studies have used different study designs, patient ages, and cut-off values.

This systematic review and meta-analysis aimed to assess the diagnostic performance of EP-POCUS for AA, with a subgroup analysis of pediatric AA, and to compare the results to those for radiologist-performed US (RADUS).

2. Methods

This meta-analysis followed the revised guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses of Diagnostic Accuracy Studies (PRISMA-DTA) statement [12].

2.1. Data sources

The Pubmed and EMBASE databases were searched up to April 20, 2018 to identify English-language reports regarding EP-POCUS for diagnosing AA. Search terms that were related to “acute appendicitis”, “emergency physician”, or “ultrasound” were combined with “appendectomy” and “diagnosis”, “sensitivity”, “specificity”, or “receiver operating characteristic” as follows: ((appendicitis)) AND ((emergency physician) OR (emergency physicians) OR (emergency medicine resident) OR (emergency medicine residency)) AND (“POCUS” OR (point-of-care) OR (bedside) OR (“US”) OR (“USG”) OR (ultrasound) OR (ultrasonography) OR (sonogram) OR (sonography)) AND ((pathology) OR (pathological) OR (histology) OR (histopathological) OR (appendectomy) OR (surgery) OR (surgical)) AND ((diagnosis) OR

Table 1

The included patients' demographic characteristics

Author	No. of patients	No. of AA	AA (%)	Mean age	Age range	No. of male	No. of female	Male (%)
Chen SC, et al. [36]	147	110	74.8	37.1	8–84	82	65	55.8
Fathi M, et al. [39]	97	43	44.3	34.4	9–82	56	41	57.7
Fox JC1, et al. [40]	155	69	44.5	NR	NR	85	70	54.8
Fox JC2, et al. [41]	126	57	45.2	NR	2–81	NR	NR	NR
Gungor F, et al. [42]	264	169	64.0	30	>18	151	113	57.2
Kang B, et al. [43]	166	40	24.1	10.6	<19	94	72	56.6
Karimi E, et al. [44]	108	37	34.3	23.9	NR	66	42	61.1
Kim C, et al. [45]	115	36	31.3	10.6	<19	65	50	56.5
Lam SH, et al. [46]	116	46	39.7	20.2	4–	59	57	50.9
Mallin M, et al. [48]	97	34	35.1	28	10–51	NR	NR	NR
Sivitz AB, et al. [50]	231	85	36.8	Median age, 10.2	2–20.9	60	171	26.0
Topin F, et al. [51]	104	25	24.0	33.2	5–73	62	42	59.6
Unluer EE, et al. [52]	100	45	45.0	32.9	NR	43	57	43.0
Siu AYC, et al. [49]	85	29	34.1	31.6	8–85	45	40	52.9
Elikashvili I, et al. [38]	150	50	33.3	12	2–19	66	84	44.0
Lin WC, et al. [47]	284	112	39.4	6	1–8	NR	NR	NR
Doniger SJ, et al. [37]	40	16	40.0	9.3	2–18	20	20	50.0

No., number; AA, acute appendicitis; NR, not reported.

Table 2
Characteristics of the included studies

Author	Year	Locale	Study period	Study design	Reference standard for AA	Reference standard for No AA	Blinding	Initial US performer	Separate US training for AA
Chen SC, et al. [36]	2000	Taiwan	1997.9–1999.6	Prospective, consecutive	Surgical/patholog-ical finding	Clinical follow-up (2 weeks)	Blinding	Attending EP	Yes
Fathi M, et al. [39]	2015	Iran	2013.5–2014.4	Prospective, consecutive	Surgical/patholog-ical finding	Clinical follow-up	Blinding	Resident/attending EP	Yes
Fox JC1, et al. [40]	2007	United States	2002.1–2004.1	Retrospective, consecutive	Surgical/patholog-ical finding	Radiologist-performed US or CT	NR	Resident/attending EP	NR
Fox JC2, et al. [41]	2008	United States	2004.2–2004.11	Prospective, consecutive	Surgical/patholog-ical finding	Clinical follow-up (2 weeks–3 months)	Blinding	Resident/attending EP	Yes
Gungor F, et al. [42]	2017	Turkey	2014.5–2015.5	Prospective, consecutive	Surgical/patholog-ical finding	Surgical/pathological finding, CT, or clinical follow-up	Blinding	NR	Yes
Kang B, et al. [43]	2015	South Korea	2011.9–2013.2	Retrospective, consecutive	Surgical/patholog-ical finding	Clinical follow-up (1–3 days)	Blinding	Attending EP	NR
Karimi E, et al. [44]	2017	Iran	2014–2015	Prospective, consecutive	Surgical/patholog-ical finding	Clinical follow-up (48 h)	Blinding	NR	NR
Kim C, et al. [45]	2015	South Korea	2014.6–2015.2	Prospective, consecutive	Surgical/patholog-ical finding	Clinical follow-up (at least 3 months)	Blinding	Resident with supervision	Yes
Lam SH, et al. [46]	2014	United States	NR	Prospective, consecutive	Surgical/patholog-ical finding	Surgical/pathological finding, CT, or clinical follow-up	Blinding	NR	Yes
Mallin M, et al. [48]	2015	United States	2011.8–2013.11	Prospective, consecutive	Surgical/patholog-ical finding	Pathological finding	Blinding	Resident with supervision	Yes
Sivitz AB, et al. [50]	2014	United States	2009.8–2012.5	Prospective, consecutive	Surgical/patholog-ical finding	Clinical follow-up (1 week–6 months)	Blinding	Attending EP	NR
Topin F, et al. [51]	2016	Republic of Djibouti	2010.11–2011.1	Prospective, consecutive	Surgical/patholog-ical finding	Clinical follow-up (2 days–3 months)	Blinding	Attending EP	Yes
Unluer EE, et al. [52]	2016	Turkey	2015.1–2015.3	Prospective, consecutive	Surgical/patholog-ical finding	Clinical follow-up (1 week–1 month)	Blinding	Attending EP	Yes
Siu AYC, et al. [49]	2007	Hong Kong	2004.1–2006.6	Prospective, consecutive	Surgical/patholog-ical finding	Clinical follow-up via chart review	Blinding	Attending EP	NR
Elikashvili I, et al. [38]	2014	United States	2011.5–2012.10	Prospective, consecutive	Surgical/patholog-ical finding	Clinical follow-up (3 weeks)	Blinding	Attending EP	Yes
Lin WC, et al. [47]	2013	Taiwan	2004.12–2006.6	Retrospective, consecutive	Surgical/patholog-ical finding	Clinical follow-up	NR	Attending EP	NR
Doniger SJ, et al. [37]	2018	United States	2009.6–2010.6	Prospective, consecutive	Surgical/patholog-ical finding	Surgical/pathological finding, CT, or clinical follow-up (2 weeks–12 months)	Blinding	Resident/attending EP	Yes

No., number; AA, acute appendicitis; EP, emergency physician; NR, not reported.

(accuracy) OR (sensitivity) OR (specificity) OR (receiver operating characteristic) OR (ROC curve)). The bibliographies of the identified articles were also screened to identify additional relevant studies. Two investigators screened the titles and abstracts for potential eligibility, and disagreements were resolved through discussion.

2.2. Study selection

We included studies that fulfilled the following criteria: (1) patients with right-lower quadrant pain, (2) EP-POCUS was performed as the index test, (3) use of surgical or pathological findings as the reference standard for AA, (4) availability of sufficient information to reconstruct 2×2 contingency tables regarding sensitivity and specificity, and (5) original research article as the publication type.

The exclusion criteria were: (1) case reports, case series, review articles, guidelines, consensus statements, letters, editorials, clinical trials,

and conference abstracts; (2) studies that did not pertain to the field of interest; (3) insufficient data to create 2×2 tables; (4) the POCUS was not performed by EPs; and (5) studies that only used the radiologists' final report.

2.3. Data extraction and quality assessment

Two investigators independently extracted data regarding the patient and study characteristics. The same investigators evaluated methodological quality using the Quality Assessment of Diagnostic Accuracy Studies-2 tool [13]. Inconsistencies between the reviewers were resolved through discussion.

A standardized form was used to extract data regarding (1) patient characteristics (number of patients, AA proportion, clinical features, mean age, age range, and sex), (2) study characteristics (study location, publication year, study design, reference standard, interval between EP-

Table 3
Technical parameters and interpretative characteristics of the included studies

Author	Technical parameters			Interpretation	
	Vendor	Model	Frequency (MHz)	Cut-off value of appendiceal diameter	Other findings for acute appendicitis
Chen SC, et al. [36]	Toshiba	SSA-340A	3.75	7	Noncompressible appendix, obstructing appendicolith, discontinuity of the echogenic submucosa, periappendiceal fluid collection.
Fathi M, et al. [39]	Medison	SonoAce ×8	7.5	7	Noncompressible, aperistaltic appendix, target sign, sonographic McBurney sign, peri-appendiceal fat infiltration/increased vascular flow/fluid collection
Fox JC1, et al. [40]	BK medical	Hawk 2102	5.5	6	Noncompressible appendix
Fox JC2, et al. [41]	BK medical/sonosite	Hawk 2102/Titan	5.5, 5	6	Noncompressible, aperistaltic appendix
Gungor F, et al. [42]	ESAOTE	MYLAB CLASS-C US	3–13	6	Noncompressible, aperistaltic appendix
Kang B, et al. [43]	NR	NR	NR	6	Appendicolith with an obstructive dilatation, periappendiceal fat infiltration
Karimi E, et al. [44]	Honda	HS2000	5–7.5	6	Noncompressible, appendicitis, loss of bowel movements, peri-appendiceal fluid collection
Kim C, et al. [45]	NR	NR	NR	6	Periappendiceal fat infiltration, obstructing appendicolith
Lam SH, et al. [46]	Zonare/sonosite	Z. One/M-Turbo	5–10	6	Appendix wall thickness > 2 mm, periappendiceal fluid, visualization of the appendix tip, sonographic Mcburney's sign
Mallin M, et al. [48]	Mindray	M7 portable Ultraound	4–10	7	Noncompressible appendix
Sivitz AB, et al. [50]	Sonosite	M turbo	8–10 or 3–5	6	Noncompressible, aperistaltic appendix
Topin F, et al. [51]	Hitachi	EUB-525 Odyssey	5–10	6	Enlarged and noncompressible appendix
Unluer EE, et al. [52]	Mindray	M7 portable Ultraound	5–10	6	Noncompressible and aperistaltic appendix, periappendiceal anechoic fluid collection, appendix wall thickness > 2 mm, obstructing appendicolith, sonographic McBurney sign.
Siu AYC, et al. [49]	NR	NR	7.5	6	Noncompressible, localised ileus or local collection of peritoneal fluid
Elikashvili I, et al. [38]	Sonosite	M Turbo	5–10	6	Noncompressible tubular structure
Lin WC, et al. [47]	Sonosite	Titan	5	NR	Noncompressible tubular structure, target sign on short axis scan, obstructing appendicolith, pus collection in the lumen of the appendix
Doniger SJ, et al. [37]	Sonosite	M Turbo	8–10	6	Noncompressible, aperistaltic appendix

NR, not reported.

POCUS and reference standard, blinding to reference standard, and operator characteristics), and (3) POCUS characteristics (probe, technical parameters, and interpretation). Study outcomes were also extracted

to create the 2 × 2 tables (i.e., true-positive, true-negative, false-positive, and false-negative results). The 2 × 2 tables were calculated using the Bayesian method (data were back-calculated based on

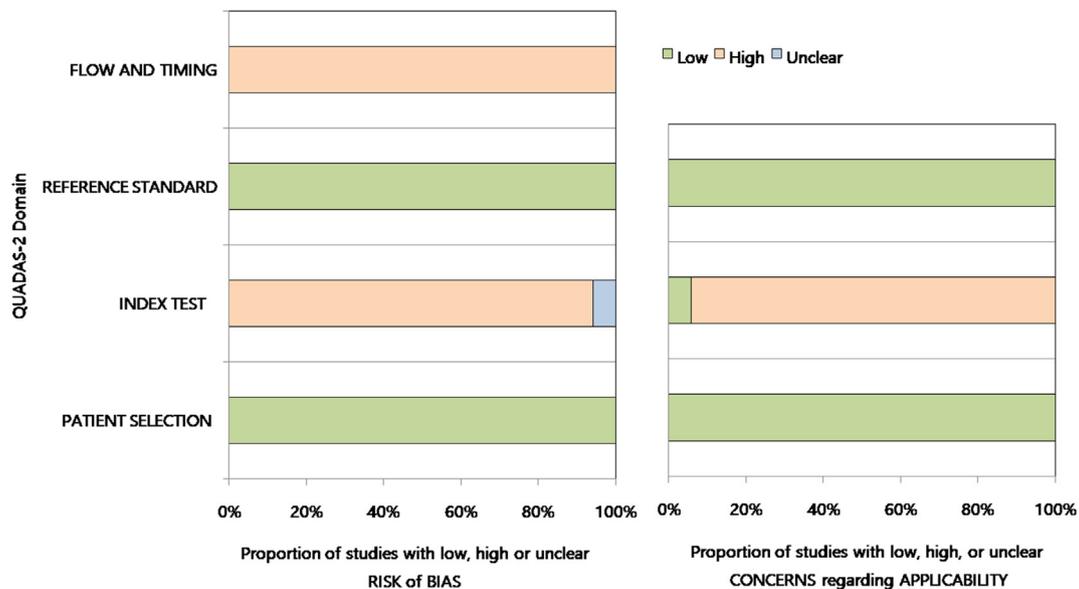


Fig. 2. Grouped bar charts showing the risk of bias (left) and applicability concerns (right) for the 17 included studies, using the Quality Assessment of Diagnostic Accuracy Studies-2 domains.

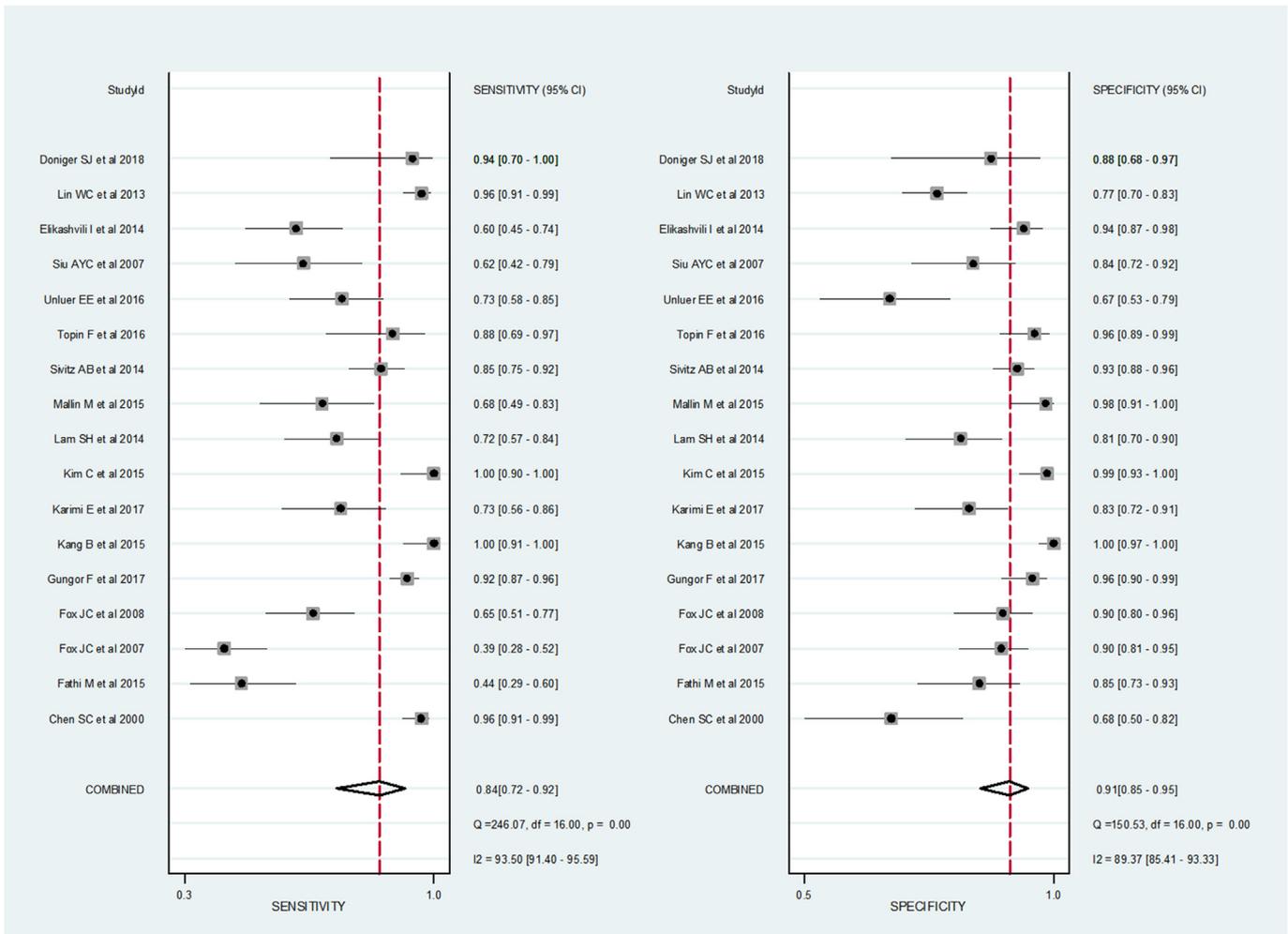


Fig. 3. Coupled forest plots for the pooled sensitivity and specificity of emergency physician-performed point-of-care ultrasonography for diagnosing acute appendicitis. Dots in squares represent sensitivity and specificity. Horizontal lines represent the 95% confidence interval (CI) for each included study. The combined estimate (“Summary”) is based on the random-effects model and is indicated using diamonds. Corresponding heterogeneities (I^2) with 95% CIs are provided in the bottom right corners: $I^2 = 100 \times (Q - df) / Q$, where Q is Cochran’s heterogeneity statistic and df is the degrees of freedom.

prevalence and sample size) if only sensitivity and specificity were presented for an eligible study. If two or more EPs independently assessed the diagnostic accuracy, the result with the highest accuracy was extracted.

2.4. Data synthesis and analysis

The primary outcome of this meta-analysis was the diagnostic performance of EP-POCUS for AA in all included studies. The secondary outcomes were the diagnostic performance of EP-POCUS for pediatric AA and the relative performances of EP-POCUS and RADUS for diagnosing AA.

Patient demographic characteristics and extracted covariates were summarized using standard descriptive statistics. Continuous variables were expressed as means and 95% confidence intervals (CIs), while categorical variables were expressed as frequencies or percentages, unless stated otherwise.

A bivariate random-effects model was used to analyze and pool the diagnostic performance measurements (sensitivity and specificity) across studies. Summary estimates of the diagnostic performance were created by plotting the estimates of the observed sensitivities and specificities for each test in the forest plots and hierarchical summary receiver operating characteristic (HSROC) curves, which were derived from the individual study results [14–16]. These results were

plotted using HSROC curves with 95% confidence and prediction regions.

Heterogeneity was evaluated using Cochran’s Q test ($p < 0.05$ indicates the presence of heterogeneity) and the I^2 test (0–40%: heterogeneity might not be present, 30–60%: moderate heterogeneity, 50–90%: substantial heterogeneity, and 75–100%: considerable heterogeneity) [17]. Spearman’s correlation coefficient for the sensitivity and false-positive rate was calculated to identify any threshold effect, with a coefficient of >0.6 indicating a considerable threshold effect [18]. We omitted Deeks’ funnel plots [19] of the individual studies to check for publication bias according to the PRISMA-DTA guidelines.

Meta-regression analyses using several covariates were performed to explore the potential causes of heterogeneity: (1) study design (prospective vs. retrospective), (2) study location (United States vs. other countries), (3) total patients (≥ 150 vs. < 150), (4) proportion of AA ($\geq 40\%$ vs. $< 40\%$), (5) proportion of male patients ($\geq 50\%$ vs. $< 50\%$), (6) mean age (≥ 30 years vs. < 30 years), (7) cut-off appendix diameter for diagnosing AA (7 mm vs. 6 mm), (8) initial US operator (attending EP vs. resident), (9) separate US training for diagnosing AA (yes vs. not reported), and (10) blinding (blinding vs. not reported).

All statistical analyses were performed by one author (S.J.Y.) who has 3 years of experience performing systematic reviews and meta-analyses. The statistical analyses were performed using the “midas” and “metandi” modules in Stata software (version 10.0; StataCorp LP, College Station, TX) and the “mada” package in R software (version

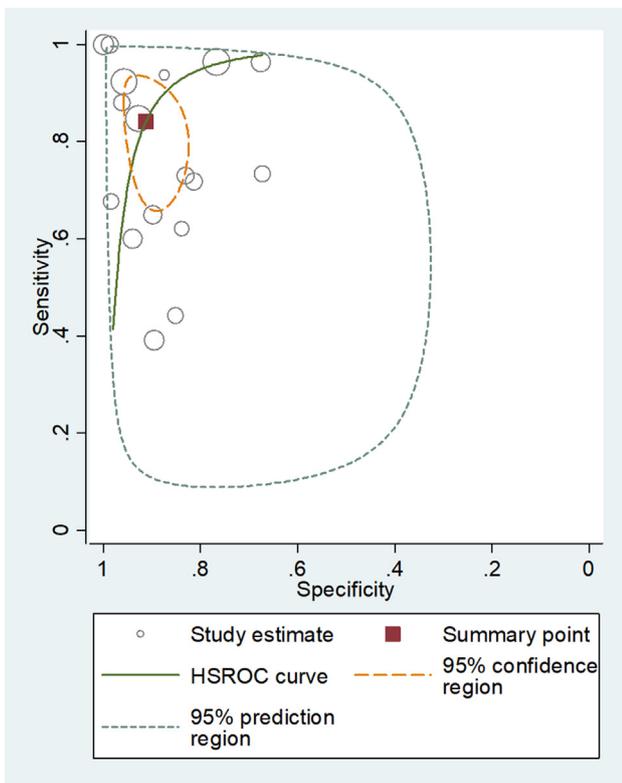


Fig. 4. Hierarchical summary receiver operating characteristic (HSROC) curve for using emergency physician-performed point-of-care ultrasonography to diagnose acute appendicitis. The summary point (red box) indicates that the summary sensitivity was 0.84 (95% CI: 0.72–0.92) and the summary specificity was 0.91 (95% CI: 0.85–0.95). The 95% confidence region represents the 95% CIs of summary sensitivity and specificity, and the 95% prediction region represents the 95% CIs of sensitivity and specificity for each included study. The study estimates indicate the sensitivity and specificity estimated using the data from each study. The size of the marker is scaled according to the total number of patients in each study.

3.4.1; R Foundation for Statistical Computing, Vienna, Austria). Results were considered statistically significant at a p -value of <0.05 .

3. Results

3.1. Literature search

Fig. 1 shows the study selection process. The initial search identified 385 reports, although 36 duplicates were removed before reviewing the titles and abstracts of 349 reports. A total of 316 studies were excluded because they were case reports, letters, editorials, or conference abstracts ($n = 177$); review articles, guidelines, or consensus statements ($n = 55$); or were not related to the field of interest ($n = 84$). After reviewing the full texts of 33 eligible reports, 16 reports were subsequently excluded because of insufficient data to construct the 2×2 table ($n = 1$) [20], the POCUS was not performed by EPs ($n = 13$) [21–33], and the study used the radiologist's final report ($n = 2$) [34, 35]. Thus, 17 studies [36–52] were included that evaluated the diagnostic performance of EP-POCUS in 2385 patients.

3.2. Patient and study characteristics

The patient characteristics are summarized in Table 1. The numbers of patients ranged from 40 to 284. The mean age range was 6–37.1 years, and the mean proportions of male patients were 26–61.1%.

The study characteristics are summarized in Table 2. Fourteen studies used a prospective design [36–39, 41, 42, 44–46, 48–52] and 3 studies

used a retrospective design [40, 43, 47]. All studies [36–52] were single-center studies, included consecutive patients, and used the surgical/pathological findings as the reference standard for AA. The appendix diameter cut-off values for diagnosing AA were 7 mm in 3 studies [36, 39, 48] and 6 mm in 13 studies [37, 38, 40–46, 49–52]. The technical and interpretative characteristics are summarized in Table 3.

3.3. Quality assessment

Fig. 2 shows the risk of bias and applicability concerns for the 17 included studies. No studies were considered seriously flawed based on the Quality Assessment of Diagnostic Accuracy Studies-2 tool, and all studies satisfied ≥ 4 of the 7 items. All studies [36–52] were considered to have a low risk of bias regarding patient selection and the reference standard. The risk of bias regarding the index test domain was considered high in 16 studies [36–46, 48–52] because a specific appendix diameter cut-off value was used to diagnose AA, while the risk of bias was unclear for one study [47] because the blinding from the reference standard was not explicitly described. The risk of the flow and timing domain was considered high in all studies [36–52] because the assessment of the reference standard was not the same (e.g., surgical/pathological specimens, clinical follow-up, or CT). All studies had limited concerns regarding the applicability to our research question in the patient selection and reference standard domains. However, there were substantial concerns regarding the index test domain for 16 studies [36–46, 48–52] because the diagnostic performance might vary according to the appendix diameter cut-off value for diagnosing AA.

3.4. Overall diagnostic performance of EP-POCUS

The 17 studies [36–52] had sensitivity values that ranged from 0.39 to 1.00 and specificity values that ranged from 0.67 to 1.00. The pooled sensitivity and specificity values were 0.84 (95% CI: 0.72–0.92) and 0.91 (95% CI: 0.85–0.95), respectively. The Q test revealed significant heterogeneity ($Q = 100.575, p < 0.001$), with considerable heterogeneity detected for sensitivity ($I^2 = 93.50\%$) and specificity ($I^2 = 89.37\%$). A threshold effect was observed in the coupled forest plot of sensitivity and specificity (Fig. 3) and in the correlation between sensitivity and the false-positive rate ($-0.041, 95\% \text{ CI: } -0.512, 0.448$). The area under the HSROC curve was 0.95 (95% CI: 0.92–0.96) (Fig. 4).

3.5. Diagnostic performance of EP-POCUS for pediatric AA

We identified 7 studies [37, 38, 41, 43, 45, 47, 50] that analyzed the diagnostic performance of EP-POCUS for pediatric AA. Six studies [37, 38, 43, 45, 47, 50] only included pediatric patients, and 1 study [41] included both adult and pediatric patients but separately described the diagnostic performance for pediatric AA. The pooled sensitivity and specificity values were 0.95 (95% CI: 0.75–0.99) and 0.95 (95% CI: 0.85–0.98), respectively. The Q test revealed significant heterogeneity ($Q = 40.369, p < 0.001$), and the Higgins I^2 statistic revealed considerable heterogeneity for sensitivity ($I^2 = 94.91\%$) and specificity ($I^2 = 94.51\%$). A threshold effect was observed in the coupled forest plot (Fig. 5) and in the correlation between sensitivity and the false-positive rate ($-0.081, 95\% \text{ CI: } -0.786, 0.716$). The area under the HSROC curve was 0.98 (95% CI: 0.97–0.99) (Fig. 6).

3.6. Direct comparison of the diagnostic performances of EP-POCUS and RADUS

Five studies [37, 38, 42, 44, 52] directly compared the performances of EP-POCUS and RADUS for diagnosing AA. Although one study [41] described the numbers of true-positive, false-positive, false-negative, and true-negative cases, that study was excluded because it combined the cases with RADUS or CT as the reference standard and it did not focus on comparing EP-POCUS to RADUS. In the remaining studies, the pooled

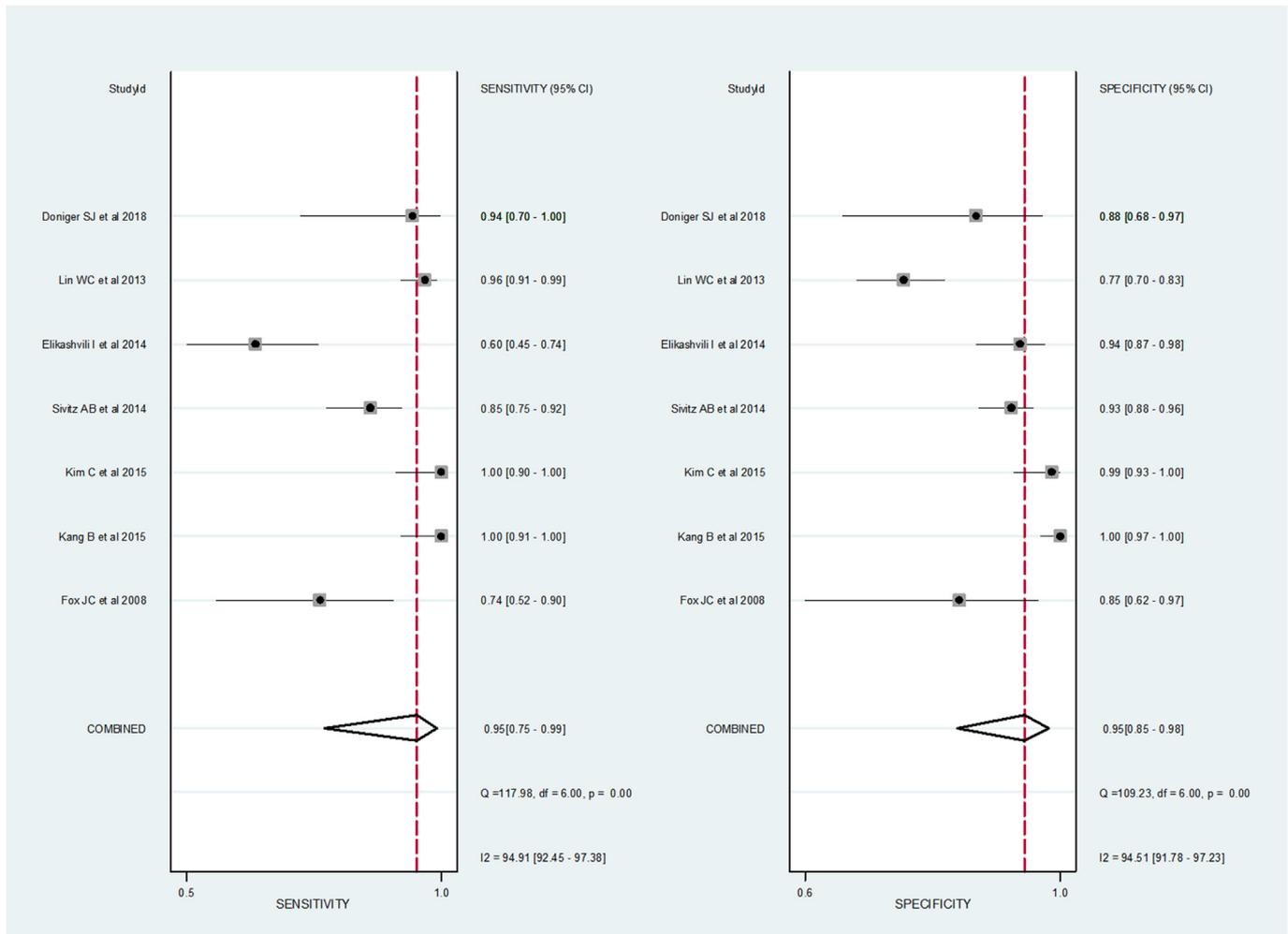


Fig. 5. Coupled forest plots of pooled sensitivity and specificity of emergency physician-performed point-of-care ultrasonography for diagnosing pediatric acute appendicitis. Dots in squares represent sensitivity and specificity. Horizontal lines represent the 95% confidence interval (CI) for each included study. The combined estimate (“Summary”) is based on the random-effects model and is indicated using diamonds. Corresponding heterogeneities (I^2) with 95% CIs are provided in the bottom right corners.

sensitivity and specificity of EP-POCUS were 0.81 (95% CI: 0.61–0.90) and 0.89 (95% CI: 0.77–0.95), respectively. For RADUS, the pooled sensitivity and specificity were 0.74 (95% CI: 0.65–0.81) and 0.97 (95% CI: 0.93–0.98), respectively. The results were not significantly different for sensitivity ($p = 0.18$) or specificity ($p = 0.85$), and the diagnostic performances were also not significantly different in a joint model ($p = 0.24$) (Table 4).

3.7. Meta-regression analyses

The results of the meta-regression analyses are summarized in Table 5. The only significant source of heterogeneity in terms of sensitivity was study location ($p = 0.03$), with higher sensitivity reported in countries other than the United States. The significant sources of heterogeneity in terms of specificity were the proportion of AA ($p < 0.01$, higher specificity at proportions of $<40\%$ vs. $\geq 40\%$) and mean age ($p = 0.02$, higher specificity at ages of <30 years vs. ≥ 30 years).

4. Discussion

The present meta-analysis revealed that EP-POCUS was excellent for diagnosing AA (sensitivity: 84%, specificity: 91%) and even better for diagnosing pediatric AA (sensitivity: 95%, specificity: 95%). In addition,

similar diagnostic performances were observed for EP-POCUS (sensitivity: 81%, specificity: 89%) and RADUS (sensitivity: 74%, specificity: 97%).

4.1. Strengths of our analyses

The present study has three useful attributes. The first attribute is that it focused on EP-POCUS, and revealed that it can be used clinically as the initial method for diagnosing AA. This is important because POCUS is a non-invasive, real-time, and repeatable diagnostic tool that is faster than CT and can be rapidly performed and interpreted at the bedside. These characteristics can improve decision-making, shorten ED stays, improve prognosis, lower costs, and reduce the cumulative radiation dose. The second attribute is the inclusion of a subgroup analysis for pediatric AA, as these patients are more vulnerable to radiation hazards than adults [53], and approximately 60% of American children who are diagnosed with acute appendicitis undergo preoperative CT [54, 55]. Although the small number of studies ($n = 7$) that included pediatric patients may limit the interpretation of our findings, the diagnostic performance in pediatric studies was higher than that in studies of adults. Therefore, EP-POCUS should be used for children with suspected appendicitis, rather than CT, to limit the radiation-related cancer risk. The third attribute is the fact that EP-POCUS and RADUS did not have significantly different diagnostic performances, although EP-POCUS had better sensitivity than RADUS. It is possible that the EP’s awareness of the

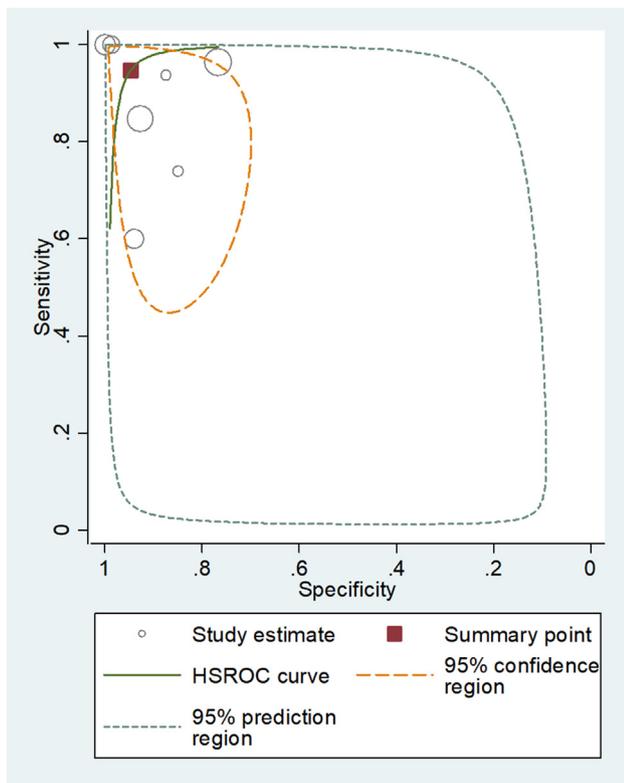


Fig. 6. Hierarchical summary receiver operating characteristic (HSROC) curve for using emergency physician-performed point-of-care ultrasonography to diagnose pediatric acute appendicitis. The summary point (red box) indicates that the summary sensitivity was 0.95 (95% CI: 0.75–0.99) and the summary specificity was 0.95 (95% CI: 0.85–0.98). The 95% confidence region represents the 95% CIs of summary sensitivity and specificity, and the 95% prediction region represents the 95% CI of sensitivity and specificity for each included study.

specific point of tenderness provided better sensitivity, although the sensitivity and specificity values for RADUS were lower than in previous meta-analyses [56, 57]. This may be related to the fact that radiology residents typically perform US for diagnosing AA during night and weekend shifts [38, 42].

4.2. Differences from previous meta-analyses related to POCUS

Two previous meta-analyses have evaluated the diagnostic performance of POCUS [10, 11], although those studies had several limitations. First, they did not use a hierarchical model (e.g., the bivariate model and the HSROC model), which are recommended statistical tools for the meta-analysis of studies regarding diagnostic accuracy [14, 15]. Second, they did not perform a thorough analysis of the potential sources of heterogeneity, as they did not distinguish between sensitivity and specificity for the covariates' effects, which precluded any recommendations regarding methods to increase the diagnostic performance of POCUS for AA. Third, they only included a limited number of studies, which is likely related to missing or restricted search terms. For example,

Benabbas et al. [10] omitted 3 studies [41, 43, 47] and one study [40] was mis-quoted because it did not report sensitivity and specificity for pediatric AA, while Matthew et al. [11] omitted 2 studies [40, 43]. Fourth, Matthew et al. [11] evaluated the diagnostic performance without distinguishing between EPs and other clinicians, and did not clearly describe the analyses that were used to evaluate the diagnostic performance of EP-POCUS. Fifth, the meta-analysis by Matthew et al. [11] included inaccurate data regarding the 2×2 tables for the studies by Lam et al. [46] and Lin et al. [47]. Finally, the technique of 2×2 table evaluation when two or more reviewers independently assessed their diagnostic accuracy remains unclear. In our meta-analysis, the result with the highest accuracy was extracted.

4.3. Sources of heterogeneity and suggestion for EP-POCUS

Our meta-regression analysis revealed that study location, AA proportion, and mean age were sources of heterogeneity. In particular, the pooled specificity was higher in studies with a low proportion of AA than in studies with a high proportion of AA. The pooled sensitivity and specificity were also higher in studies that used an appendix diameter cut-off of 7 mm than in studies with a cut-off of 6 mm, although the difference was not statistically significant. Similarly, the pooled sensitivity and specificity were higher in studies with the attending EP as the initial operator, rather than a resident, although this difference was also not statistically significant. Thus, we recommend that the attending EP perform the initial US using an appendix diameter cut-off value of 7 mm to more accurately diagnose AA.

4.4. Weakness of our analyses

This meta-analysis only examined studies where the diagnostic performance of EP-POCUS was based on conclusive cases, as the eligible studies did not include cases with equivocal or inconclusive findings. Moreover, the studies using POCUS emphasized its diagnostic performance alone and did not compare it to other modalities. Thus, a comprehensive study that includes equivocal and inconclusive cases and more advanced methodology (e.g., comparison to low-dose CT or magnetic resonance imaging) may be needed to confirm the usefulness of EP-POCUS as an initial diagnostic tool in routine clinical practice.

4.5. Limitations

The present study has several limitations. The first limitation is the relatively small number of included studies. Nevertheless, we were able to draw several important conclusions regarding the diagnostic performance of EP-POCUS and related factors (diameter cut-off value and initial US operator), which we believe provides a useful overview because we used broad search terms and only included easily accessible studies (published in English and available in the PubMed and EMBASE databases). The second limitation is that all included studies revealed positive results, and that fact could be attributed to publication bias, which is impossible to quantify. Although we omitted Deeks' funnel plots according to the PRISMA-DTA guidelines, we observed a low probability of publication bias ($p = 0.62$), which suggests that this factor did not undermine our results. The third limitation is the methodological differences between the included studies, and the extensive meta-

Table 4

Diagnostic performance of emergency physician-performed point-of-care ultrasonography (EP-POCUS) and radiologist-performed ultrasonography (RADUS)

	Sensitivity (95% CI)	p-value	Specificity (95% CI)	p-value	Area under the ROC curve (95% CI)	PLR (95% CI)	NLR (95% CI)	p-value (joint model)
EP-POCUS	0.81 (0.61–0.90)	0.18	0.89 (0.77–0.95)	0.85	0.92 (0.89–0.94)	7.0 (3.2–15.3)	0.22 (0.12–0.42)	0.24
RADUS	0.74 (0.65–0.81)		0.97 (0.93–0.98)		0.94 (0.91–0.95)	21.6 (10.4–44.7)	0.27 (0.20–0.36)	

CI, confidence interval; ROC, receiver operating characteristic; PLR, positive likelihood ratio; NLR, negative likelihood ratio.

Table 5
Meta-regression analyses for potential source of the heterogeneity

Covariate	No. of studies	Sensitivity (95% CI)	p-value	Specificity (95% CI)	p-value
Study design			0.37		0.21
Prospective	14	0.82 (0.70–0.94)		0.91 (0.85–0.96)	
Retrospective	3	0.92 (0.79–1.00)		0.94 (0.86–1.00)	
Locale			0.03		0.15
United States	7	0.71 (0.50–0.91)		0.92 (0.86–0.98)	
Country other than United States	10	0.90 (0.82–0.98)		0.91 (0.84–0.97)	
No. of patients			0.99		0.40
≥ 150	6	0.88 (0.75–1.00)		0.94 (0.89–0.99)	
< 150	11	0.82 (0.69–0.95)		0.89 (0.82–0.96)	
AA (%)			0.19		<0.01
≥ 40%	7	0.79 (0.61–0.97)		0.86 (0.77–0.96)	
< 40%	10	0.87 (0.77–0.98)		0.94 (0.89–0.98)	
Male (%)			0.37		0.89
≥ 50%	11	0.87 (0.76–0.98)		0.92 (0.87–0.98)	
< 50%	3	0.74 (0.40–1.00)		0.88 (0.74–1.00)	
Mean age (years)			0.21		0.02
≥ 30	6	0.82 (0.65–0.99)		0.87 (0.75–0.98)	
< 30	8	0.90 (0.80–0.99)		0.94 (0.89–0.99)	
Cut-off			0.60		0.18
7-mm	3	0.77 (0.49–1.00)		0.88 (0.74–1.00)	
6-mm	12	0.84 (0.72–0.95)		0.93 (0.88–0.97)	
Initial US performer			0.77		0.16
Attending EP	8	0.93 (0.76–1.00)		0.99 (0.87–1.00)	
Resident	2	0.89 (0.78–1.00)		0.90 (0.82–0.98)	
Separate US training for AA			0.56		0.13
Yes	11	0.84 (0.71–0.96)		0.91 (0.86–0.97)	
Not reported	6	0.85 (0.69–1.00)		0.91 (0.83–0.99)	
Blinding			0.63		0.66
Blinding	15	0.85 (0.75–0.95)		0.92 (0.88–0.96)	
Not reported	2	0.80 (0.46–1.00)		0.84 (0.63–1.00)	

Boldface type indicates statistical significance ($p < 0.05$). CI, confidence interval; No., number; AA, acute appendicitis; US, ultrasound; EP, emergency physician.

regression analysis revealed that these variables were also significant sources of heterogeneity. This methodological diversity might affect the pooled estimates, especially as the POCUS technical parameters were not assessed in the meta-regression analysis because not all studies reported the values for gain, dynamic range, and mechanical index. Further studies with larger sample sizes are needed to determine the optimal parameters for POCUS.

5. Conclusion

In conclusion, the present meta-analysis revealed that EP-POCUS had excellent performance for diagnosing AA, which was similar to that of RADUS, and even better diagnostic performance for pediatric AA. We recommend that the attending EP perform the initial POCUS using a diameter cut-off value of 7 mm to more accurately diagnose AA.

Declaration of interest

There is no potential conflict of interest related to this article.

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Conflicts of interest

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References

- [1] Callahan MJ, Rodriguez DP, Taylor GA. CT of appendicitis in children. *Radiology* 2002;224(2):325–32.
- [2] Hale DA, Molloy M, Pearl RH, Schutt DC, Jaques DP. Appendectomy: a contemporary appraisal. *Ann Surg* 1997;225(3):252–61.
- [3] Birnbaum BA, Wilson SR. Appendicitis at the millennium. *Radiology* 2000;215(2):337–48.
- [4] Irvin TT. Abdominal pain: a surgical audit of 1190 emergency admissions. *Br J Surg* 1989;76(11):1121–5.
- [5] Yun SJ, Ryu CW, Choi NY, Kim HC, Oh JY, Yang DM. Comparison of low- and standard-dose CT for the diagnosis of acute appendicitis: a meta-analysis. *AJR Am J Roentgenol* 2017;208(6):W198–207.
- [6] Mostbeck G, Adam EJ, Nielsen MB, Claudon M, Clevert D, Nicolau C, et al. How to diagnose acute appendicitis: ultrasound first. *Insights into imaging* 2016;7(2):255–63.
- [7] Parker L, Nazarian LN, Gingold EL, Palit CD, Hoey CL, Frangos AJ. Cost and radiation savings of partial substitution of ultrasound for CT in appendicitis evaluation: a national projection. *AJR Am J Roentgenol* 2014;202(1):124–35.
- [8] Brenner DJ, Hall EJ. Computed tomography—an increasing source of radiation exposure. *N Engl J Med* 2007;357(22):2277–84.
- [9] Hall EJ, Brenner DJ. Cancer risks from diagnostic radiology: the impact of new epidemiological data. *Br J Radiol* 2012;85(1020):e1316–7.
- [10] Benabbas R, Hanna M, Shah J, Sinert R. Diagnostic accuracy of history, physical examination, laboratory tests, and point-of-care ultrasound for pediatric acute appendicitis in the emergency department: a systematic review and meta-analysis. *Academic emergency medicine : official journal of the Society for Academic Emergency Medicine* 2017;24(5):523–51.
- [11] Matthew Fields J, Davis J, Alsup C, Bates A, Au A, Adhikari S, et al. Accuracy of point-of-care ultrasonography for diagnosing acute appendicitis: a systematic review and meta-analysis. *Academic emergency medicine : official journal of the Society for Academic Emergency Medicine* 2017;24(9):1124–36.
- [12] McInnes MDF, Moher D, Thoms BD, McGrath TA, Bossuyt PM. The P-DTAG, et al. preferred reporting items for a systematic review and meta-analysis of diagnostic test accuracy studies: the PRISMA-DTA statement. *JAMA* 2018;319(4):388–96.
- [13] Whiting PF, Rutjes AW, Westwood ME, Mallett S, Deeks JJ, Reitsma JB, et al. QUADAS-2: a revised tool for the quality assessment of diagnostic accuracy studies. *Ann Intern Med* 2011;155(8):529–36.
- [14] Kim KW, Lee J, Choi SH, Huh J, Park SH. Systematic review and meta-analysis of studies evaluating diagnostic test accuracy: a practical review for clinical researchers-part I. General guidance and tips. *Korean J Radiol* 2015;16(6):1175–87.

- [15] Lee J, Kim KW, Choi SH, Huh J, Park SH. Systematic review and meta-analysis of studies evaluating diagnostic test accuracy: a practical review for clinical researchers-part II. *Statistical methods of meta-analysis*. *Korean J Radiol* 2015;16(6):1188–96.
- [16] Suh CH, Park SH. Successful publication of systematic review and meta-analysis of studies evaluating diagnostic test accuracy. *Korean J Radiol* 2016;17(1):5–6.
- [17] Higgins J, Green S. *Cochrane handbook for systematic reviews of interventions*. Version 5.1.0. The Cochrane Collaboration http://handbook.cochrane.org/chapter_9/9_5_2_identifying_and_measuring_heterogeneity.htm.
- [18] Deville WL, Buntin F, Bouter LM, Montori VM, de Vet HC, van der Windt DA, et al. Conducting systematic reviews of diagnostic studies: didactic guidelines. *BMC Med Res Methodol* 2002;2:9.
- [19] Deeks JJ, Macaskill P, Irwig L. The performance of tests of publication bias and other sample size effects in systematic reviews of diagnostic test accuracy was assessed. *J Clin Epidemiol* 2005;58(9):882–93.
- [20] Jang T, Chauhan V, Cundiff C, Kaji AH. Assessment of emergency physician-performed ultrasound in evaluating nonspecific abdominal pain. *American Journal of Emergency Medicine* 2014;32(5):457–60.
- [21] Abo A, Shannon M, Taylor G, Bachur R. The influence of body mass index on the accuracy of ultrasound and computed tomography in diagnosing appendicitis in children. *Pediatr Emerg Care* 2011;27(8):731–6.
- [22] Carney E, Kempf J, Decarvalho V, Yudd A, Nosher J. Preliminary interpretations of after-hours CT and sonography by radiology residents versus final interpretations by body imaging radiologists at a level I trauma center. *Am J Roentgenol* 2003;181(2):367–73.
- [23] Carrico CW, Fenton LZ, Taylor GA, Difiore JW, Soprano JV. Impact of sonography on the diagnosis and treatment of acute lower abdominal pain in children and young adults. *AJR Am J Roentgenol* 1999;172(2):513–6.
- [24] Imler D, Keller C, Sivasankar S, Wang NE, Vasanaswala S, Bruzoni M, et al. Magnetic resonance imaging versus ultrasound as the initial imaging modality for pediatric and young adult patients with suspected appendicitis. *Acad Emerg Med* 2017;24(5):569–77.
- [25] Leung YK, Chan CP, Graham CA, Rainer TH. Acute appendicitis in adults: diagnostic accuracy of emergency doctors in a university hospital in Hong Kong. *Emergency medicine Australasia : EMA* 2017;29(1):48–55.
- [26] Menoch M, Simon HK, Hirsh D, Shim Y, Baxter AL, Clifton M, et al. Imaging for suspected appendicitis: variation between academic and private practice models. *Pediatr Emerg Care* 2017;33(3):147–51.
- [27] Nasiri S, Mohebbi F, Sodagari N, Hedayat A. Diagnostic values of ultrasound and the Modified Alvarado Scoring System in acute appendicitis. *International Journal of Emergency Medicine* 2012;5(1).
- [28] Poonai N, Gregory J, Thompson G, Lim R, Van Osch S, Andrusiak T, et al. Is pelvic ultrasound associated with an increased time to appendectomy in pediatric appendicitis? *Journal of Emergency Medicine* 2014;47(1):51–8.
- [29] Ramarajan N, Krishnamoorthi R, Gharahbaghian L, Pirrotta E, Barth RA, Wang NE. Clinical correlation needed: what do emergency physicians do after an equivocal ultrasound for pediatric acute appendicitis? *Journal of clinical ultrasound : JCU* 2014;42(7):385–94.
- [30] Ross M, Selby S, Poonai N, Liu H, Minoosepehr S, Boag G, et al. The effect of a full bladder on proportions of diagnostic ultrasound studies in children with suspected appendicitis. *Canadian Journal of Emergency Medicine* 2016;18(6):414–9.
- [31] Talan DA, Krishnadasan A, Amii R, Pathmarajah K, Morim A, Moran GJ, et al. Antibiotics-First Versus Surgery for Appendicitis: A US Pilot Randomized Controlled Trial Allowing Outpatient Antibiotic Management. *Annals of Emergency Medicine* 2017;70(1):1–11.e9.
- [32] Uzunosmanoğlu H, Çevik Y, Çorbacıoğlu ŞK, Akıncı E, Buluş H, Ağladioğlu K. Diagnostic value of appendicular doppler ultrasonography in acute appendicitis. *Ulus Travma Acil Cerrahi Derg* 2017;23(3):188–92.
- [33] van Atta AJ, Baskin HJ, Maves CK, Rollins MD, Bolte RG, Mundorff MB, et al. Implementing an ultrasound-based protocol for diagnosing appendicitis while maintaining diagnostic accuracy. *Pediatr Radiol* 2015;45(5):678–85.
- [34] Bal A, Anil M, Nartürk M, Özdemir T, Arıkan A, Köylüoğlu G, et al. Importance of clinical decision making by experienced pediatric surgeons when children are suspected of having acute appendicitis: the reality in a high-volume pediatric emergency department. *Pediatr Emerg Care* 2017;33(9):e38–e42.
- [35] Mittal MK, Dayan PS, Macias CG, Bachur RG, Bennett J, Dudley NC, et al. Performance of ultrasound in the diagnosis of appendicitis in children in a multicenter cohort. *Academic emergency medicine : official journal of the Society for Academic Emergency Medicine* 2013;20(7):697–702.
- [36] Chen SC, Wang HP, Hsu HY, Huang PM, Lin FY. Accuracy of ED sonography in the diagnosis of acute appendicitis. *American Journal of Emergency Medicine* 2000;18(4):449–52.
- [37] Doniger SJ, Kornblith A. Point-of-care ultrasound integrated into a staged diagnostic algorithm for pediatric appendicitis. *Pediatr Emerg Care* 2018;34(2):109–15.
- [38] Elikashvili I, Tay ET, Tsung JW. The effect of point-of-care ultrasonography on emergency department length of stay and computed tomography utilization in children with suspected appendicitis. *Academic emergency medicine : official journal of the Society for Academic Emergency Medicine* 2014;21(2):163–70.
- [39] Fathi M, Hasani SA, Zare MA, Daadpey M, Hojati Firoozabadi N, Lotfi D. Diagnostic accuracy of emergency physician performed graded compression ultrasound study in acute appendicitis: a prospective study. *J Ultrasound* 2015;18(1):57–62.
- [40] Fox JC, Hunt MJ, Zlidenny AM, Oshita MH, Barajas G, Langdorf MI. Retrospective analysis of emergency department ultrasound for acute appendicitis. *The California journal of emergency medicine* 2007;8(2):41–5.
- [41] Fox JC, Solley M, Anderson CL, Zlidenny A, Lahham S, Maasumi K. Prospective evaluation of emergency physician performed bedside ultrasound to detect acute appendicitis. *Eur J Emerg Med* 2008;15(2):80–5.
- [42] Gungor F, Kilic T, Akyol KC, Ayaz G, Cakir UC, Akcimen M, et al. Diagnostic value and effect of bedside ultrasound in acute appendicitis in the emergency department. *Acad Emerg Med* 2017;24(5):578–86.
- [43] Kang B, Kim C, Park JB, Ha YR. The use of clinician-performed ultrasonography to determine the treatment method for suspected paediatric appendicitis. *Hong Kong Journal of Emergency Medicine* 2015;22(1):31–40.
- [44] Karimi E, Aminianfar M, Zarafshani K, Safaie A. The accuracy of emergency physicians in ultrasonographic screening of acute appendicitis; a cross sectional study. *Emergency* 2017;5(1):117–23.
- [45] Kim C, Kang BS, Choi HJ, Lim TH, Oh J, Chee Y. Clinical application of real-time tele-ultrasonography in diagnosing pediatric acute appendicitis in the ED. *American Journal of Emergency Medicine* 2015;33(10):1354–9.
- [46] Lam SH, Grippo A, Kerwin C, Konicki PJ, Goodwine D, Lambert MJ. Bedside ultrasonography as an adjunct to routine evaluation of acute appendicitis in the emergency department. *The western journal of emergency medicine* 2014;15(7):808–15.
- [47] Lin WC, Lin CH. Re-appraising the role of sonography in pediatric acute abdominal pain. *Iran J Pediatr* 2013;23(2):177–82.
- [48] Mallin M, Craven P, Ockerse P, Steenblik J, Forbes B, Boehm K, et al. Diagnosis of appendicitis by bedside ultrasound in the ED. *Am J Emerg Med* 2015;33(3):430–2.
- [49] Siu AYC, Chung CH. The use of ultrasonography to assess patients with right lower quadrant pain in the emergency department. *Hong Kong Journal of Emergency Medicine* 2007;14(2):70–3.
- [50] Sivitz AB, Cohen SG, Tejani C. Evaluation of acute appendicitis by pediatric emergency physician sonography. *Ann Emerg Med* 2014;64(4):358–64.e4.
- [51] Topin F, Thierry AL, Catrevaux O, Barnoux T, Menguy P, Bertani A, et al. Diagnostic accuracy of emergency physician-performed ultrasound for acute appendicitis in a remote location. *J Emerg Med* 2016;50(6):859–67.
- [52] Unluer EE, Urnal R, Eser U, Bilgin S, Hacıyanlı M, Oyar O, et al. Application of scoring systems with point-of-care ultrasonography for bedside diagnosis of appendicitis. *World J Emerg Med* 2016;7(2):124–9.
- [53] Donnelly LF, Emery KH, Brody AS, Laor T, Gylys-Morin VM, Anton CG, et al. Minimizing radiation dose for pediatric body applications of single-detector helical CT: strategies at a large Children's hospital. *AJR Am J Roentgenol* 2001;176(2):303–6.
- [54] Martin AE, Vollman D, Adler B, Caniano DA. CT scans may not reduce the negative appendectomy rate in children. *J Pediatr Surg* 2004;39(6):886–90; discussion —90.
- [55] York D, Smith A, Phillips JD, von Allmen D. The influence of advanced radiographic imaging on the treatment of pediatric appendicitis. *J Pediatr Surg* 2005;40(12):1908–11.
- [56] Giljaca V, Nadarevic T, Poropat G, Nadarevic VS, Stimac D. Diagnostic accuracy of abdominal ultrasound for diagnosis of acute appendicitis: systematic review and meta-analysis. *World J Surg* 2017;41(3):693–700.
- [57] Yu SH, Kim CB, Park JW, Kim MS, Radosevich DM. Ultrasonography in the diagnosis of appendicitis: evaluation by meta-analysis. *Korean J Radiol* 2005;6(4):267–77.