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Diagnostic accuracy of Point Of Care UltraSound (POCUS) in clinical practice: A retrospective, emergency department based study

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Abstract

Aims: Point-of-care ultrasound (POCUS) is the acquisition and interpretation of ultrasound imaging at the bedside to solve specific clinical questions based on signs and symptoms of presentation. While several studies evaluated POCUS diagnostic accuracy for a variety of clinical pictures in the emergency department (ED), only a few data are available on POCUS diagnostic accuracy performed by physicians with different POCUS skills. The objective of this research was to evaluate the diagnostic accuracy of POCUS compared to standard diagnostic imaging in the ED.

Materials and Methods: This was a retrospective study conducted in the ED of a third-level university hospital. Patients who underwent cardiac, thoracic, abdominal, or venous lower limb POCUS and a standard imaging examination between June 2021 and January 2022 were included.

Results: 1047 patients were screened, and 844 patients included. A total of 933 POCUS was included (102, 12.09%, cardiac; 466, 55.21%, thoracic; 336, 39.8%, abdominal; 29, 3.44%, lower limb venous POCUS), accounting for 2029 examinations. POCUS demonstrated 96.6% (95% CI 95.72–97.34) accuracy, 47.73 (95% CI 33.64–67.72) +LR, 0.09 (95% CI 0.06–0.12) −LR. +LR was greater than 10 for all investigations but for hydronephrosis (5.8), and −LR never exceeded 0.4.

Conclusions: POCUS exhibited high diagnostic accuracy for virtually all conditions when performed by emergency department physicians.

KEYWORDS
critical care, diagnostic imaging, emergency care, point of care, ultrasound

1 | INTRODUCTION

The American College of Emergency Physician (ACEP)[1] defines Point-Of-Care Ultrasound (POCUS) as an ultrasound test performed by attending emergency physicians at the bedside. The results are interpreted and integrated into care in real time to assess acute or critical medical conditions and guide procedures and therapy. Although some authors advocate POCUS as the "fifth pillar of bedside physical examination"[2] and the increasing evidence on its accuracy and clinical usefulness,[3–10] there is no complete agreement on the effectiveness of POCUS.[11] In addition, POCUS accuracy is often based on POCUS findings obtained by experts. However, in clinical practice POCUS is commonly performed by physicians with different levels of training and experience due to the lack of a consistent training programme.[12] Thus, the practice of POCUS in the ED is still limited, while the predominant use of standard diagnostic techniques (x-ray, computed tomography, and US performed by radiologists or cardiologists) may lead to diagnostic or therapeutic delays or overexposure to harmful radiation. Demonstrating that the diagnostic accuracy of POCUS is comparable to that of standard imaging may allow emergency physicians to integrate POCUS more consciously into their clinical practice. This approach is expected to accelerate and refine the diagnosis and treatment of patients with acute pathology.

This study aimed to establish the diagnostic accuracy of POCUS performed by a heterogeneous cohort of emergency physicians for major acute cardiac, pulmonary, abdominal, and vascular diseases compared with standard imaging and final ED diagnoses. The secondary aim was to understand the causes of discrepancy, if any, between POCUS and standard diagnostic methods.

2 | MATERIALS AND METHODS

This single-center retrospective study was conducted at a tertiary-level university hospital located in a province with approximately 350 000 inhabitants, with more than 70 000 visits per year. This study was conducted in accordance with the principles of the Declaration of Helsinki and has been approved by the local ethics committee.

2.1 | Patient selection

2.1.1 | Inclusion criteria

Adult patients who visited the ED between June 2021 and January 2022, underwent a point-of-care ultrasound, and subsequently underwent a standard examination to confirm or exclude the pathological findings on POCUS were eligible for the study.

2.1.2 | Exclusion criteria

For this study, patients were excluded if reference standard tests were performed after more than 48 h of hospitalization.

2.2 | Point-of-care ultrasound

The results of POCUS were retrospectively obtained from the ED report. The evaluated pathological findings included the presence of pericardial effusion[13]; visual assessment of right ventricular dilatation (reported as right ventricle/left ventricle <1 (RV/LV <1) and left ventricular ejection fraction (EF)[14] for heart POCUS; pleural effusion[15] and diffuse B-lines[16] consistent with cardiogenic pulmonary oedema; irregular pleural line, focal B-lines, and subpleural thickening as signs of pneumonia[17]; absence of pleural sliding and presence of lung point for pneumothorax (PNX)[18] for thoracic POCUS; thickening of the gallbladder wall (≥3 mm), presence of free fluid in the peri-cholecystic space, and positive echographic Murphy's sign for cholecystitis,[19] hypoechoic calico-pyelic dilatation[20] for hydronephrosis; abdominal effusion in the main recesses or between the intestinal loops for free peritoneal fluid[21]; pathological dilatation of the abdominal aorta[22] for abdominal POCUS; and the results of compression ultrasonography (CUS) of the venous vessels of the lower extremities searching for deep venous thrombosis were included in the data collection.[23] The accuracy of detecting sonographic pathological findings for each anatomical region studied was calculated for the entire population with abnormal POCUS, regardless of the level of training of the physicians. Subsequently, any discrepancy between POCUS and the reference test or final diagnosis was analyzed and described as a false positive or false negative. POCUS examinations were performed with an ESAOTE MyLab XPRO30 (Esaote, Genoa, Italy) using a convex, phased array, or linear probe according to the site investigated. All emergency physicians reporting results of POCUS in the final ED report participated in a basic course on POCUS organized by different emergency medicine national societies and ultrasound societies, while 10% have an advanced POCUS certification and one is an instructor of POCUS. All residents in emergency medicine underwent at least one course of POCUS and are currently attending a one-year program on POCUS.

2.2.1 | Comparison with reference test

The POCUS results were compared with those of the reference tests performed during the 48 h of hospital stay. Cardiac POCUS was compared with formal trans-thoracic echocardiography (TTE) performed by the hospital's Cardiology department; thoracic POCUS was compared with chest radiography or chest computed tomography (CT) for the diagnosis of pneumothorax (PNX) or pneumonia, or with the final ED diagnosis for pleural effusion and cardiogenic pulmonary oedema, because the accuracy of chest radiography in diagnosing pleural effusion and pulmonary oedema is low compared with ultrasonography[24,25]; abdominal POCUS was compared with formal abdominal ultrasound performed by the emergency radiology service or with abdominal CT; POCUS for the detection of deep vein thrombosis (DVT) of the lower extremities was compared with formal complete venous echodoppler of the lower extremities performed by the hospital vascular diagnostic service.

TABLE 1 General characteristics of included patients.

	All patients, $N = 844$	In-hospital death No, $N = 804$, 94,5%	In-hospital death Yes, $N = 38$, 4.5%	*p*-value
Man	418 (49.6)	403 (50.1)	14 (36.8)	0.11
Age, years	71 (50–83)	70 (50–82)	84 (80–91)	<0.001
Medical cause of admission	689 (81.8)	652 (81.1)	37 (97.4)	0.011
RR, ppm	18 (16–24)	18 (16–22)	25 (18–30)	0.023
SpO2, %	97 (95–98)	97 (96–98)	95 (94–98)	0.135
FiO2, %	0.21 (0.21–0.21)	0.21 (0.21–0.21)	0.21 (0.21–0.28)	<0.001
HR, ppm	85 (75–100)	85 (75–100)	100 (85–117)	0.002
SBP, mmHg	130 (115–150)	130 (120–150)	108 (90–130)	0.009
DBP, mmHg	70 (60–80)	70 (60–80)	60 (60–70)	0.001
NRS (0–10)	4 (2–6)	4 (3–6)	3 (2–5)	0.3
Abnormal mental status	77 (9.1)	59 (7.3)	18 (47.4)	<0.001
RASS >0	35 (4.2)	31 (3.9)	4 (10.5)	0.044
RASS <0	39 (4.6)	26 (3.2)	13 (34.2)	<0.001
Reduced EF[a]	32 (21.9)	27 (20.5)	5 (38.5)	0.135
RV > LV[a]	8 (6.1)	8 (6.6)	0 (0)	0.428
Pericardial effusion[a]	14 (5.8)	13 (5.7)	1 (9.1)	0.637
Pleural effusion[a]	137 (29.7)	122 (28)	15 (60)	0.001
Cardiogenic pulmonary edema[a]	80 (30.5)	76 (30.5)	4 (30.8)	0.985
PNX[a]	5 (1.7)	5 (1.8)	0 (0)	0.618
Pneumonia[a]	52 (21.6)	47 (20.4)	5 (45.5)	0.049
Abdominal effusion[a]	39 (10.8)	33 (9.6)	6 (40)	<0.001
Abdominal aortic aneurism[a]	6 (4.6)	4 (3.3)	2 (25)	0.004
Cholecistytis[a]	14 (10.2)	13 (9.9)	1 (16.7)	0.009
Hydronephrosis[a]	59 (28.8)	57 (29.2)	2 (20)	0.529
Deep vein thrombosis[a]	14 (21.9)	13 (21.7)	1 (25)	0.867
Cardiac POCUS	276 (32.7)	258 (32.1)	17 (44.7)	0.17
Abdomial POCUS	501 (59.4)	481 (59.8)	20 (52.6)	0.378
Thoracic POCUS	488 (57.8)	463 (57.6)	25 (65.8)	0.317
Lower limbs POCUS	29 (3.4)	29 (3.6)	0 (0)	0.384
Number of different body districts exanimated	1 (1–2)	1 (1–2)	2 (1–2)	0.009

Note: All data are expressed as median (IQR) or Number (percentage).
Abbreviations: DBP, diastolic blood pressure; HR, heart rate; LV, left ventricle; NRS, 11-point numeric ranking scale for pain evaluation (0 no pain, 10 the worst pain ever); PNX, pneumothorax; POCUS, point of care ultrasound; RASS, Richmond agitation-sedation scale; RR, respiratory rate; RV, right ventricle; SBP, systolic blood pressure; SpO2, peripheral oxygen saturation.
[a]According to the POCUS.

2.2.2 | Data collection

The hospital informatics system was queried to determine which ED patients were admitted or discharged daily. If POCUS was performed upon each patient's ED discharge, the patient was eligible for inclusion in the study. The patient's first and last name, admission date, admission reason, clinical characteristics on admission, POCUS district of examination, ED discharge diagnosis, and admission location were all recorded. Once the list of patients to be included was available, a second investigator blinded to the POCUS results confirmed that the reference diagnostic test had been performed. In this context, the patient participated in this study. If available, hospital mortality statistics were also collected. A third blinded examiner reviewed the data. If there were discrepancies between POCUS data and the reference standard, the ED records and diagnostic reports were reviewed, and the physician was interviewed to determine potential causes of the discrepancy. Due to the lack of an international standard reference for POCUS training, POCUS "advanced skills" were ED physicians who attended an advanced course and had at least three years of experience in POCUS, while POCUS "standard skills" were ED physicians who attended a basic or intermediate course regardless of the years of experience, or those who had an advanced course with <3 years of experience Table 1.

2.2.3 | Statistics

Continuous data were reported as median and interquartile range (IQR) and compared using Mann Whitney U-test; categorical data were reported as absolute numbers and percentages and compared using Pearson's chi-square test. The values of the main diagnostic indicators of accuracy (sensitivity, specificity, positive predictive value [PPV], negative predictive value [NPV], and overall percentage accuracy) were calculated using the pROC package for MedCalc. Conventionally, diagnostic accuracy is defined as excellent for values >90%, good for values >80%, moderate for values >70%, and poor for values >70%. The diagnostic utility of POCUS for major pathological conditions in the ED was assessed by calculating the likelihood ratio (LR). By convention, a clinically useful diagnostic tool should have positive LR (+LR) values of 10 (corresponding to a 45% increase in post-test probability) or negative LR (−LR) values of 0.1 (corresponding to a 45% decrease in post-test probability).[26] The pretest probability used to calculate the posttest probability corresponded to the prevalence of the respective diseases in the tested population. Statistical significance was set at a *p*-value of 0.05. Analyses were performed using the MedCalc software (version 20.217).

3 | RESULTS

A total of 1047 patients underwent POCUS at the ED during the study period. Of these, complete data were available for 844 patients, included in the study. Of the patients, 49.6% were male, with a median age of 71 years (IQR 50–83 years), admitted for a medical cause in 689 cases (81.8%). Cardiac POCUS was performed and compared with the reference standard in 276 cases (32.7%; for EF fraction number of cases (N) =68, for RV/LV, $N = 58$, and for pericardial evaluation, $N = 83$), thoracic POCUS in 488 cases (57.8%, for pleural effusion $N = 462$, for cardiogenic pulmonary oedema $N = 263$, for pneumonia $N = 221$, and for PNX $N = 298$), abdominal POCUS in 501 cases (59.36%, for abdominal effusion $N = 243$, for abdominal aortic aneurysm $N = 81$, for cholecystitis $N = 93$, and for hydronephrosis $N = 160$) and proximal lower limb (CUS) in 29 cases (3.4%). Overall, 2059 unique POCUS evaluation were included in the present study and a median of 1 (IQR 1–2) different district were analyzed for patient. A total of 38 patients (4.5%) died in hospital and compared to survived patients, they were older, had a higher respiratory rate and lower peripheral oxygen saturation, a higher heart rate and lower systolic and diastolic blood pressure, and were more likely to have abnormal mental status. At POCUS, signs of pleural effusion, pneumonia, cholecystitis, free fluid in the abdomen, or abdominal aorta aneurysm, were associated with in-hospital mortality. In addition, the in-hospital mortality group was more likely to undergo multiorgan POCUS.). Overall, POCUS demonstrated an accuracy of 96.6% (95% CI 95.72–97.34), a +LR of 47.73 (95% CI 33.64–67.72), a −LR of 0.09 (95% CI 0.06–0.12). Table 3 shows the sensitivity, specificity, +LR, −LR, and overall accuracy of POCUS for each of the investigated findings. Among the included POCUS, 94 cardiac POCUS were compared with echocardiography performed by a cardiologist (Transthoracic Echocardiography, TTE). Eight additional cardiac scans were part of a FAST focusing on the evaluation of pericardial effusion and were compared with the chest CT scans. The ejection fraction (EF) was evaluated in 68 cases, resulting in 18 cases of reduced EF, with one false positive and two false negative cases. The false positive one was an EF underestimation (35% EF vs. 55% of the standard TTE), and both false negative examinations did not detect a mildly reduced EF without segmental defects, as rated with TTE. The right ventricle dimensions were estimated in 58 cases, with six having pathological features on POCUS, no false positives and one false negative. Pericardial effusion was searched in 83 and detected in 12 cases. Among these, there were one false negative and one false positive result. In the first, a formal echocardiography revealed a slight effusion along the right sections with a maximum thickness of 0.9 cm; in the false positive case, the presence of epicardial fat was recognized by formal TTE. Pleural effusion was investigated 462 times and 137 positive cases were identified. All cases with positive POCUS results were confirmed by the standard reference, while six negative POCUS results were incorrect in comparison to a chest CT scan demonstrating a slight posterior pleural effusion. The presence of cardiogenic pulmonary oedema was assessed in 263 cases; 80 patients with positive POCUS presented clinical and laboratory tests suggestive of heart failure (HF) and received a final diagnosis of HF with pulmonary oedema. None of the patients with negative POCUS were diagnosed with pulmonary oedema, and all were treated for other causes of dyspnoea. Chest POCUS was performed in 221 cases of suspected pneumonia; US signs compatible with pneumonia were found in 50 cases, including 7 false positives, who were eventually diagnosed with pulmonary fibrosis or presented with nonspecific thickening of the pleural line. Two cases indicated as negative on POCUS were positive on chest radiography, including COVID-19 interstitial pneumonia and alveolar pneumonia in a patient with HF. Pleural sliding and/or presence of lung point was investigated in 298 patients; in 5 cases, POCUS detected PNXs that were all confirmed by the reference standard. In three patients with trauma who underwent the E-FAST protocol, PNXs were identified on chest CT; hence, these POCUS were deemed false negative. The gallbladder has been studied 93 times in patients with suspected acute cholecystitis. Overall, signs of cholecystitis were reported in 12 cases, of which 8 were confirmed by standard abdominal ultrasound and 1 by CT abdominal scan, with 9 acute cholecystitis finally diagnosed and 3 false-positive cases. The presence of hydronephrosis was investigated in 160 cases, of which 57 were judged as positive by POCUS. Of these, abdominal ultrasound performed by radiologists or abdominal CT confirmed 42 pathological dilatations of the renal pelvis, while 15 cases resulted in false positives, all presenting with parapyelic cysts. In eight of these patients, hydronephrosis was excluded by CT scan and in seven by abdominal ultrasound performed by a radiologist. Ten of the remaining patients, who were recumbent or uncooperative, had false negative results. The presence of abdominal effusion was evaluated in 243 cases: 34 exams were reported as positive by POCUS with two false positives, in which both standard abdominal ultrasound and abdominal CT scan excluded the presence of a slight effusion in favor of visceral fat. Of the 13 false-negative cases, 9 abdominal effusion was found on abdominal CT and 4 on abdominal ultrasound performed by radiologists. All false-negative results showed evidence of retro bladder mild free fluid effusion. The abdominal aorta was evaluated in

81 patients. Aortic aneurysm was found in four cases by POCUS, and all of them were confirmed by abdominal ultrasound and/or abdominal CT scan. In one case, POCUS was negative, but further abdominal ultrasound by the radiologist revealed an abdominal aneurysm. CUS of the lower limb venous axis was performed and compared with standard whole-leg Doppler Ultrasonography in 29 patients. POCUS was judged positive for vein thrombosis in 10 cases, of which 8 were true and 2 were false positives, with no false negatives. The two false positives both presented clinically suggestive of DVT; in the first case, a suspected thrombosis of the lesser saphenous vein on POCUS was excluded by the standard, and the definitive diagnosis was hematoma with compartment syndrome. In the second case, suspicion of DVT of the popliteal vein resulted in Baker's cysts.

4 | DISCUSSION

This study showed that POCUS has a >95% diagnostic accuracy for the most common diseases presenting in the ED, with a specificity >90% and +LR >10 for the overall examination, except for hydronephrosis (Table 2). Moreover, the specificity of POCUS for pericardial and pleural effusions, cardiogenic pulmonary oedema, pneumonia, cholecystitis, and DVT is as high as >95%. Thus, with symptoms or signs suggestive of these diseases, POCUS findings can indicate or even define the diagnosis. In cases of suspected cardiogenic pulmonary oedema, acute cholecystitis, and lower limb venous thrombosis, the high sensitivity and low −LR of a negative POCUS may exclude the presence of the suspected disease. Low sensitivity and high −LR of POCUS for the evaluation of EF, PNX, abdominal effusion, aortic aneurysm, and hydronephrosis did not rule out diagnostic suspicion, making additional investigations essential. Nevertheless, as indicated in Table 3 characteristic, most errors can be attributed to the incomplete visualization of anatomical spaces or the misinterpretation of ultrasound images that are not specific to pathology, and due to the scanning of uncooperative patients (due to agitation or forced body position). Furthermore, the percentage of errors seems to be at least partly due to the level of experience, as ED doctors with advanced POCUS training were responsible for a lower percentage of false-positive and false-negative examinations. However, the relatively small number of patients prevents a clear conclusion (Table 3). Cardiac abnormalities assessed in this study are consistent with the recommendations for POCUS of the major critical care societies.[27] In this study, POCUS recognized a reduced EF with 96% accuracy, 98% specificity, and >10 + LR, with sensitivity not exceeding 90% because of two false negative cases. There were no false negative findings in patients with severely reduced ejection fraction, as reported in previous studies[28–30] proving a high agreement in qualitative estimation of EF between emergency physicians and cardiologists. The accuracy of POCUS in detecting pericardial effusion was 97.6%, similar to results of other studies where POCUS was performed by emergency physicians without advanced training.[31,32] In this study, there was a discrepancy between POCUS and echocardiography performed by specialists in two cases. The first was an extensive pleural effusion, and "the presence of an equivocal pericardial effusion" on POCUS was reported as epicardial fat on formal TTE. However, pleural effusion and pericardial fat are two common confounding factors while looking for pericardial fluid.[33] In the second case, the TTE described a false negative POCUS as a thin layer of effusion along the right heart with a maximum thickness of 0.9 cm, without cardiac tamponade. In unstable patients with suspected pulmonary embolism, immediate recognition of right ventricular dilatation in the emergency department is of critical importance. Visual estimation by simplified echocardiography and measurement of the right ventricular diameter at the end of diastole by a cardiologist agreed in 83% of cases.[30] In this study, the visual appraisal of the right ventricular shape achieved an accuracy of 98.3%, a specificity of 100%, and a sensitivity of 85% (due to a false negative result). POCUS achieved a diagnostic accuracy of 98.7%, specificity of 100%, and sensitivity of 95.80% for the detection of pleural effusion, in line with previously published data.[15,34,35] In all six false negative cases—five in traumatic patients undergoing the E-FAST protocol, and one in an agitated patient with exacerbated chronic obstructive pulmonary disease—chest CT detected a small pleural effusion (<2 cm in size) localized in the most posterior and lower thoracic areas. However, the E-FAST protocol was designed to rule out the presence of extensive pleural effusion and must be performed rapidly in trauma patients in a forced supine position[36] making this test unsuitable for detecting small amounts of fluid. In both cases, the amount of pleural effusion was minimal, thus not requiring evacuative thoracentesis. Concerning the diagnosis of pneumonia with POCUS, this study acquired results consistent with those shown in the systematic review published by Chavez et al.[37] who reported a sensitivity of 94%, specificity of 96%, 16.8 + LR and 0.07 −LR. In the studies included in this systematic review, thoracic ultrasonography was consistently performed by POCUS experts. Moreover, the trials included different reference standards, such as chest CT for positive cases and x-rays for negative cases,[17] chest CT only in case of disagreement between POCUS and x-ray[38] or chest CT.[39] In this retrospective study, in 7 cases POCUS and x-ray did not agree, and the latter was considered diagnostic without confirmatory chest CT. However, in five cases, the final diagnosis was "probable early pneumonia" due to the presence of irregularities of the pleural spaces and focal B-lines associated with inflammatory indices above cut-off values.[17,38] Two false positive cases due to irregular pleural spaces were hospitalized and did not develop pneumonia. However, chronic pulmonary fibrosis was a confounding factor in all seven patients.[40] One patient had a chest radiograph consistent with COVID-19 pneumonia, and one case had alveolar pneumonia in the right middle lung field with diffuse interstitial texture accentuation on chest radiography. The major limitation of POCUS in diagnosing pneumonia is the co-occurrence of other lung diseases (mainly pulmonary fibrosis). In this study, the diagnostic accuracy of point-of-care ultrasound for cardiogenic pulmonary oedema was 100%. All patients identified by POCUS as having diffuse interstitial syndrome with possible cardiac etiology received a definitive diagnosis of acute heart failure, and no patient with a negative POCUS for pulmonary oedema received such a definitive diagnosis. The accuracy reported in this study is better

TABLE 2 Summary of the main indicators of accuracy of POCUS.

Abnormality studied	Prevalence % (95% CI)	Sensitivity % (95% CI)	Specificity % (95% CI)	Accuracy % (95% CI)	PPV, % (95% CI)	NPV, % (95% CI)	+LR (95% CI)	−LR (95% CI)
Heart								
Reduced EF	27.94% (17.73–40.15)	89.5% (66.9–98.7)	97.96% (89.1–99.9)	95.59% (87.64–99.1)	94.44% (70.83–99.17)	96% (86.61–98.9)	43.8 (6.3–306.9)	0.12 (0.029–0.399)
RV > LV	12.07% (4.99–23.3)	85.7% (42.1–99.6)	100% (93–100)	98.28% (90.8–99.95)	100%	98.08% (89.26–99.68)	>100	0.143 (0.023–0.877)
Pericardial effusion	14.46% (7.7–23.89)	91.7% (61.5–99.8)	98.6 (92.4–99.96)	97.59% (91.6–99.70)	91.67% (60.93–98.73)	98.59% (91.46–99.78)	65.1 (9.2–459.1)	0.085 (0.013–0.552)
Chest								
Pleural effusion	30.95% (26.76–35.39)	95.80% (91.09–98.44)	100% (98.85–100)	98.70% (97.19–99.5)	100%	98.15% (96.05–99.15)	>100	0.042 (0.019–0.09)
Cardiogenic pulmonary edema	30.42% (24.92–36.37)	100% (95.49–100)	100% (98–100)	100% (98.6–100)	100%	100%	>100	<0.001
Pneumonia	20.36% (15.26–26.28)	95.56% (84.85–99.45)	96.02% (91.97–98.3)	95.93% (92.41–98.12)	86% (74.78–92.72)	98.83% (95.6–99.7)	24.03 (11.59–49.78)	0.046 (0.012–0.18)
PNX	2.69% (1.17–5.22)	62.50% (24.49–91.47)	100% (98.73–100)	98.99% (97.08–99.79)	100%	98.98% (97.53–99.58)	>100	0.375 (0.153–0.92)
Abdomen								
Abdominal effusion	9.68% (4.52–17.58)	71.11% (55.7–83.63)	98.99% (96.4–99.9)	93.83% (90.02–96.50)	94.12% (79.92–98.47)	93.78% (90.50–95.98)	70.4 (17.512–83.1)	0.292 (0.184–0.462)
Abdominal aortic aneurysm	32.50% (25.32–40.35)	80% (28.4–99.5)	100% (95.3–100)	98.77% (93.3–99.96)	100%	98.70% (92.94–99.77)	>100	0.333 (0.067–1.652)
Cholecystitis	18.52% (13.84–23.98)	100 (66.37–100)	96.43% 89.92–99.25)	96.77% (90.86–99.33)	75% (49.69–90.11)	100%	28 (9.22–85.065)	<0.001
Hydronephrosis	6.17% (2.03–13.82)	80.8% (67.5–90.4)	86.11% (78.2–92.01)	84.38% (77.80–89.6)	73.68% (63.2–82.02)	90.29% (84.13–94.23)	5.8 (3.57–9.473)	0.223 (0.127–0.392)
Lower limbs								
CUS	27.59% (12.73–47.24)	100% (63.1–100)	90.48% (69.62–98.82)	93.1% (77.23–99.15)	80% (51.7–93.73)	100%	10.5 (2.81–39.24)	<0.001

Note: CI, confident index; CUS, compression ultrasound; EF, ejection fraction; IC, confidence index; LV, left ventricle; LR, likelihood ratio; PNX, pneumothorax; RV, right ventricle.

TABLE 3 Summary of the causes of POCUS diagnostic errors.

	Expert				Non-expert				
	N of POCUS	FP	FN	% of POCUS with a FP or FN	*N* of POCUS	FP	FN	% of POCUS with a FP or FN	Potential source of error reported
Cardiac POCUS	165	1	1	1.2	44	1	2	6.8	EF moderately reduced (45% on formal TTE in both cases), "not adeguate visualization" reported, RV/LV = 1 at chest CT "slightly non haemodynamically effusion", reported as "epicardial fat" at formal TTE; presence of 0.9 mm pericardial effusion at chest CT and no pericardial effusion at further formal TTE (after 5 days). 1 patient reported as obese and with sever COPD
Thoracic POCUS	315	5	0	1.6	846	2	11	1.5	Supine position on traumatic patients (*N* = 3); respiratory distress and agitation (RASS reported: +3) (*N* = 1); comorbidities: pulmonary fibrosis (*N* = 2), COPD (*N* = 3); presence of PNX in a not classical studied position (lateral chest wall), in the context of multiple ribs and pulmonary contusion (*N* = 3); other not reported.
Abdomen POCUS	153	5	3	5.2	424	15	21	8.4	Obese patients early E-FAST, not repeated. At CT presence of bleeding in abdominal sites not evaluated during the E-FAST protocol; distended ileum, abdominal pain and obesity in a patient with diverticulitis (seminal vesicles?) in suspected mild retro-vescical free fluid in a male patient "incomplete visualization" of the abdominal aorta reported. 1 older woman with parenteral nutrition multiple renal cists agitate, uncooperative patient needing rapid tranquilization.
Vein district of lower extremities POCUS	9	0	0	0	19	2	0	10.5	One Baker's cist, older obese patient.

Note: COPD, chronic obstructive pulmonary disease; CT, computed tomography; E-FAST, extended-focused assessment with sonography for trauma; EF, ejection fraction; FN, false negative; FP, false positive; LV, left ventricle; *N*, number; RASS, Richmond agitation-sedation scale; RV, right ventricle; TTE, trans-thoracic echocardiography.

than those of Maw et al.[41] in their meta-analysis of six studies comparing ultrasound diagnosis with definitive diagnosis of heart failure made by combining clinical, echocardiographic, and laboratory tests in 1827 patients, with a sensitivity and specificity of 88% and 90%, respectively. This study confirms that the presence of diffuse, homogeneously distributed B-lines with or without bilateral pleural effusion in a patient with dyspnoea is an excellent sonographic indicator for the diagnosis of heart failure.[42–45] In this study, the specificity and +LR of POCUS for the diagnosis of pneumothorax were higher than the values obtained in a systematic review by Staub et al.[46] for traumatic pneumothorax, and the absence of pleural sliding and/or pulmonary spots had a specificity of 100%, as there were no false positives. The same specificity was reported by Khosravian et al.,[47] where PNX was only evaluated using the E-FAST protocol, and by Soldati et al.,[46] as the only false positive result was from a false evaluation of the lung point on the pleura at the heart level. In the study by Fissore et al.[47] lung ultrasound achieved a sensitivity of 54% and specificity of 98%, like the results of our study. However, the primary aim of the E-FAST protocol is to exclude the presence of extensive pneumothorax in the anterior paravertebral regions,[36] whereas all false-negative cases reported in this study had a small PNX in a lateral and atypical location that did not undergo therapeutic drainage. There is some disagreement in the literature regarding the diagnostic accuracy of point-of-care ultrasound for cholecystitis. Despite the 100% sensitivity reported in the present study, the sensitivity of POCUS was only 33% in the retrospective study by Wehrle et al.[48] In the study by Hasani et al.,[49] POCUS correctly identified only 35.7% (5/14) of cholecystitis cases, while conventional sonography correctly identified 12/14 cases. The poor agreement between POCUS and conventional echography was confirmed by Rosen et al.,[50] Summers et al.[51] (with a sensitivity of 85% for POCUS), and Seyedhosseini et al.[52] The agreement between emergency department residents and radiologists in identifying typical signs of cholecystitis ranged from 75% to 95%, depending on the sign considered. All reviewed studies indicate that POCUS has a high degree of specificity, which is consistent with the 95% specificity observed in this study. In false positives, the gallbladder was described as distended with thickened walls in patients without typical right hypochondrium pain, where the cholecystitis was ruled out by abdominal computed tomography (CT) or standard abdominal ultrasound. However, if cholecystitis is suspected, it is sufficient for an experienced doctor to recognize the typical ultrasound signs to establish a definitive diagnosis. Despite the relatively low diagnostic accuracy of POCUS for hydronephrosis, in this study the overall accuracy was greater than those reported by Sibley et al.,[53] with a +LR of 5.8, and a −LR of 0.22, which is consistent with the meta-analysis by Wong et al.[8] while maintaining the potential to reduce treatment time.[54] In all 15 false positives, the presence of multiple parapyelic cysts without hydronephrosis was a confounding factor, while in the ten false negatives, incomplete renal pelvic scans in recumbent or uncooperative patients and the presence of parapyelic cysts were the main causes of error (Table 3). In this study, the presence of abdominal effusion due to traumatic and non-traumatic causes was assessed using POCUS, with a specificity of 98.99% and sensitivity of 71.1%. The E-FAST protocol provided the largest number of false-positive and false-negative results in patients with trauma. However, the sensitivity and specificity values calculated in the present study for the presence of abdominal effusion are comparable to those of Khosravian et al.[45] and the meta-analysis by Netherton et al.[55] In that study, two false-positive findings were reported due to the presence of visceral fat that had been incorrectly declared as fluid. This finding, known as a "double line sign" (DLS), is a relatively common finding, accounting for 27% of diagnostic errors.[56] In all 13 false-negative POCUS cases, the standard examination detected mild effusion in the vesico-uterine, retto-uterine, or recto-vesical punch, which may be more difficult to exclude in patients with an empty bladder. Additionally, the presence of mild retrouterine free fluid is common and does not indicate per se a pathological finding, especially in women in reproductive age.[56] Therefore, POCUS is sufficient to diagnose an effusion—when identified—due to its high specificity and +LR, whereas small-volume effusions cannot be excluded in cases of POCUS negativity. Conventional ultrasonography is the gold standard for the diagnosis and monitoring of abdominal aortic aneurysms.[22] According to a systematic review by Rubano et al.,[57] the sensitivity of POCUS in the ED was 99% and the specificity was 99%. Our study showed a specificity of 100%, a sensitivity of 80%, and a −LR of 0.33 due to a false negative result. In a study by Mai et al.,[58] medical students using bedside ultrasound were able to detect 15 of 16 aneurysms in a population of 57 patients without false positives. The one false negative finding in our study was due to a purely and incomplete visualization of the abdominal aorta, without accurate measurement of the aortic diameter. According to our data the sensitivity and specificity of the CUS for venous thrombosis of the lower limb were 100% and 90.5%, respectively. These results are consistent with those of a meta-analysis by Bhatt et al.[59] who calculated a sensitivity and specificity of 90.1% and 98.5%, respectively, for proximal lower extremity venography. In our study, there were two false-positive results. In one case, CUS alone raised the suspicion of great saphenous vein thrombosis in a patient with clinical signs of DVT who had compartment syndrome due to spontaneous hemorrhage. In the second false positive, CUS diagnosed thrombosis of the popliteal vein in a patient with a painful and oedematous limb due to reduced collapsibility. In the latter case, the final diagnosis was a Becker cyst, the rupture of which often mimics DVT.[60]

4.1 | Strengths and limitations of the study

The strengths of this study are many. First, the population studied came from an ED and we studied a very large series evenly distributed in terms of men, women and by age. Second, the level of training in the use of POCUS is comparable to most Italian emergency departments.[61] Third, there are no studies evaluating the diagnostic accuracy of POCUS for most of its uses in an unselected cohort of ED patients.

There are also limitations. First, the retrospective nature of the based solely on the final ED report prevents us from evaluating the scanning technique, which may profoundly alter the diagnostic accuracy of POCUS. Second, only patients from a single emergency department were studied, so the frequency of pathologies studied could only reflect local epidemiology. Third, different reference standard methods were used, and accuracy could be variable depending on the standard evaluated. Fourth, the data are the result of different levels of training in POCUS, so accuracy may vary in a cohort of emergency physicians with a standard course certification.

5 | CONCLUSION

POCUS is a useful and easily accessible tool that can integrate and improve the physical examination performed for most patients admitted to the ED. As demonstrated, POCUS has high diagnostic accuracy with high +LR, allowing POCUS to confirm the suspected disease. However, in certain diseases the high −LR prevents definite diagnosis and further diagnostic testing is needed. Despite the multiple possible sources of errors, training appear of fundamental importance to decrease the percentage of errors and increase the accuracy and safety of POCUS in clinical practice, allowing the patient to avoid additional, time-consuming examinations and resultant therapeutic delays.

AUTHOR CONTRIBUTIONS

Michele Domenico Spampinato, Francesco Luppi, and Roberto De Giorgio have given substantial contributions to the conception and the design of the manuscript, Francesco Luppi, Tommaso Bachechi, Marcello Benedetto, Caterina Ghirardi, Enrico Cristofaro, and Antonella Cianci in the acquisition of data; Michele Domenico Spampinato, Francesco Luppi and Soccorsa Sofia in the analysis and interpretation of the data. Michele Domenico Spampinato, Francesco Luppi, Matteo Guarino and Benedetta Perna drafted the first version of the manuscript, Soccorsa Sofia, Angelina Passaro and Roberto De Giorgio revised it critically. All authors read and approved the final version of the manuscript. All authors contributed equally to the manuscript and approved the final version of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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