Diagnostic performance of transthoracic ultrasound in patients with pulmonary embolism

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Background
Pulmonary embolism (PE) is an acute, significant, and life-threatening condition. Transthoracic ultrasound (TUS) is one of the noninvasive diagnostic modalities that has been presented for detection of numerous chest disorders as well as PE.
Objectives
The goal of this work was to estimate the accuracy, sensitivity, and specificity of bedside TUS in PE detection.
Patients and methods
Fifty patients with moderate-to-high clinical suspicion of PE were examined by TUS. Diagnosis of PE depended on clinical suspicion and was confirmed by computed tomography pulmonary angiography.
Results
Most of the lesions related to PE and detected by US examination were on the right side (60%) and posterior lower lobe (70%) with predominance of A profile. Sensitivity, specificity, accuracy, negative, and positive predictive values of TUS in diagnosis of PE were 93.3, 65, 82, 86.7, and 80%, respectively.
Conclusion
TUS is an important diagnostic tool as a noninvasive bedside test in detecting PE principally for critically ill or unmoving patients with high sensitivity and moderate specificity.

Keywords:
computed tomographic pulmonary angiography, pulmonary embolism, thoracic ultrasound

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Introduction

Pulmonary embolism (PE) is considered an acute, significant and life-threatening situation [1]. PE is a usually undiscovered disorder. Since clinical manifestations are vague, PE detection might be troublesome and needs a high level of suspicion. The technical approach, such as D-dimer, computed tomographic pulmonary angiography (CTPA), ventilation/perfusion scintigraphy, and spiral computed tomography essentially affect PE detection, elevating recognition rates, particularly for segmental PE [2]. Likewise, complications that may follow contrast dye injection and radiation exposure can occur. Consequently, alternative strategies could help doctors in certain settings. Likewise, PE is a possibly lethal disorder requiring instant anticoagulant treatment [3]. Transthoracic ultrasound (TUS) is one of the noninvasive diagnostic modalities that have been presented for detection of numerous chest disorders as well as PE. To be recognizable by TUS, the lesions need to reach out to the pleural surface of a completely expanded lung. Moreover, parenchymal changes might be observable in the lung separated from the chest wall when an acoustic window such as atelectasis or pleural effusion is existing, permitting the US to enter into more profound tissue so that thromboembolic lesions become apparent to sonographic assessment of whether pleural effusion presents or not [4]. PE-related changes are that the 'pleural line' compared with the PE-related regions may lose its echogenicity and appear irregular or fragmented. Also, mechanical changes related to atelectatic lung tissue, and elevated capillary pressure in addition to high vessel wall permeability resulting from inflammatory mediator release, may cause increased exudation of fluid into the pleural space [5]. This work aimed to evaluate the accuracy, sensitivity, and specificity of bedside TUS for the detection of PE.

Materials and methods

Ethics

This prospective study was done in Benha University Hospital in the period between November 2019 and July 2022. The research was accepted by the Ethical Committee of Benha University, Faculty of Medicine

(No. RC 17-9-2019). Written informed consent was acquired from the participants.

Study design

This research was performed in Chest Department and included 50 patients who had moderate-to-high clinical supposition of PE. PE detection was based on clinical manifestations of venous and pulmonary thromboembolism, including dyspnea of unknown etiology, tachypnea, or chest pain, separately or together. Confirmation of the diagnosis was established by CTPA with a filling imperfection illustrated by contrast material or by deep-vein thrombosis (DVT) revealed by lower limb duplex examination [6].

Exclusion criteria

Patients who had superficial lesions or diseases that interfere with using the US probe such as subcutaneous emphysema or fractured ribs were excluded.

Inclusion criteria

All patients suspected to have PE according to original and simplified Geneva criteria.

Patients were subjected to history taking, full clinical examination, plain chest radiograph (posterior–anterior and left lateral view), arterial blood gases, laboratory investigations, echocardiography, CTPA (which was investigated by the radiologist who knew nothing about clinical manifestation), and lower limb duplex examination in suspected cases of DVT. TUS was carried out for all patients using an US device (Philips Hd5 Color Doppler Ultrasound Machine, 2013 GE LOGIQ_P5 Ultrasound Machine, made in Japan). TUS was performed via the convex probe (2.5–5-MHz frequency) for the lung and linear probe (7.5–10 MHz) for pleura examination, respectively. TUS was performed utilizing grayscale (B-mode), time-motion mode (M-mode), and color Doppler mode.

Direct signs of PE were assessed, including straddling clots at the bifurcation of the pulmonary artery or suspended embolus in the right side of the heart [7]. Lung sliding was evaluated (the 'to-and-fro' twinkling lung motion throughout breath, which was noticeable at the pleural line), likewise, artifact types and lung profiles were identified and incorporated A profile [anterior overwhelming bilateral A lines (horizontal hyperechoic lines beneath, parallel to the pleural line and connected with lung sliding)], A´ profile [A profile with nullified lung sliding), B profile (anterior-dominating bilateral B line) vertical hyperechoic lines emerging from the pleural line, which extend the whole distance to the boundary of the screen)], B´ profile (B profile with or without lung sliding), A/B profile (anterior-dominant B lines at one side and A lines on the other one), C profile (anterior lung consolidation), and PLAPS (posterior–lateral alveolar consolidation as well as pleural effusion syndrome). Unusual sonographic discoveries of consolidation were checked out such as subpleural, poor echogenic area or tissue-like appearance, with air (dynamic hyperechogenic foci) and/or fluid bronchograms (anechoic tube-shaped constructions). Pleural effusion was viewed as a homogeneous, anechoic area in-between the pleural bilayer [8]. Patients were separated into five groups that rely upon the accompanying characters of sonographic discoveries: group I (at least two typical wedge-formed or circular hypoechoic pleura-based lesions ± pleural effusion), group II (one typical wedge-formed or circular hypoechoic pleura-based abnormalities with pleural effusion), group III (one typical wedge-formed or circular hypoechoic pleura-based lesions), group IV (nondefinite subpleural abnormalities >5 mm in diameter or pleural effusion only), and group V (usual sonographic discoveries). PE was suspected if at least one characteristic subpleural hypoechoic abnormality±pleural effusion was detected by TUS. In the existence of nonspecific subpleural abnormalities exceeding 5 mm in diameter, free pleural effusion, or normal sonographic discoveries, PE diagnosis was not assumed. Patients were considered to have PE by TUS if they had A profile with positive DVT or several, hypoechoic, subpleural abnormalities usually triangular, rounded, or polygonal [9].

Statistical analysis

Statistical analysis was carried out utilizing the Statistical Package for the Social Sciences, version 11.2 for Windows software (STATA Corporation, College Station, Texas, USA). Continuous data were demonstrated as the mean±SD and range, and categorical data were demonstrated as a number and percentage. Student t test and Mann–Whitney test (Z) were utilized to differentiate two groups of normally and non-normally disseminated data. One-way analysis of variance (F) and Kruskal–Wallis test (χ^2) were utilized to differentiate more than two groups accompanied by post-hoc tests utilizing the Bonferroni procedure. The percentage of categorical variables was differentiated utilizing the χ^2 test and Fisher's exact test. The sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and diagnostic value of the TUS in detecting PE were determined.

Results

The studied group included 50 patients: 21 (42%) females and 29 (58%) males with mean age of 53.6 ± 8.83. Seventy-two percent of patients were obese (36 patients). The median Geneva score was 11 upon which patients were divided into high clinical

Table 1 Differences between ultrasonographic findings among the studied group regarding their sociodemographic characteristics and pulmonary embolism-related data

Variables	Ultrasonographic findings		χ^2 test	*P* value
	Positive (*N*)	Negative (*N*)		
Sex				
Male	20	9	0.035	0.85
Female	15	6		
Age (mean±SD)	53.17±9.0	54.87±8.58	Student *t* test =0.618	0.53
BMI				
Normal	11	3	0.68	0.409
Obese	24	12		
Geneva score [median (IQR)]	11	9	*Z* Mann–Whitney test 4.77	0.001 (HS)
Postpartum	11	0	6.044	0.014 (S)
Postoperative	13	0	7.529	0.006 (HS)
History of previous pulmonary embolism or DVT	17	0	11.039	0.001 (HS)
Fracture	9	6	4.704	0.030 (S)

DVT, deep venous thrombosis; HS, highly significant; IQR, interquartile range; S, significant.

suspicion for PE (26 patients) and intermediate suspicion (24 patients) and the median pulmonary embolism severity index (PESI) score was 60 (45–67). Regarding US findings among the studied group, the percentage of US-positive findings was more in males and more in obese patients. There was a highly significant relation between positive lesions in the US and a high Geneva score, the presence of risk factors such as postpartum, postoperative, fracture, and history of previous PE or DVT (Table 1). Radiograph findings among the studied group included pulmonary infarction (90%), pleural effusion (24%), pulmonary oligemia (28%), enlarged pulmonary artery (20%), and normal chest radiograph in 8% of patients. While US findings included wedge-shape pleural-based lesions among 52% of patients, rounded lesions (12%), pleural effusion (24%), and absence of flow perception in colored Doppler examination of the infarcted area in 60% of patients. Most of the lesions found by US examination were on the right side (60%) and in the posterior lower lobe (70%), while the left-lung lesion and bilateral lesion represented 10% each. The most frequent lung profiles in US in PE-suspected cases were A profile (94%). Mean pulmonary artery pressure (PAP) and right ventricular function were elevated in the studied group (Table 2). Also, there was a significant positive correlation between PAP and PESI (Table 3). It was found that eight patients had a single parenchymal lesion, while the other 20 had multiple parenchymal lesions+pleural effusion. Those 28 patients also confirmed with CTPA to have PE (true-positive cases), the remaining seven cases that had ultrasonic pictures suggesting PE were confirmed to be negative PE with CTPA (false-positive cases). We had two cases that show an insignificant sonographic picture of PE but confirmed with CTPA to be PE (false negative), the remaining 13 cases were true negative with US and CTPA. So, the total number of patients with positive US findings (true and false positive) was 35 (Table 4) (Table 5). Chest US showed high sensitivity and specificity in the diagnosis of PE compared with CTPA (Table 6 and Fig. 1).

Table 2 Echocardiography findings among patients with proved pulmonary embolism

Variables	Median (IQR)
PAP	40 (33–48) mmHg
RV FAC	20% (17–23)
TAPSE	1–1.5 cm

FAC, fractional area change; IQR, interquartile range; PAP, pulmonary artery pressure; RV, right ventricle; TAPSE, tricuspid annular plane systolic excursion.

Table 3 Spearman correlation between pulmonary artery pressure and pulmonary embolism severity index of the studied group

	Spearman r_s	*P* value
PESI and PAP	0.328	0.02 (S)

PAP, pulmonary artery pressure; PESI, pulmonary embolism severity index; S, significant.

Discussion

PE considers significant cardiovascular emergencies that are habitually found in the clinical situation. Nonetheless, its detection considers a challenge in numerous cases, consequently, an imaging confirmation is required for that reason. Numerous diagnostic procedures were carried out in the detection of PE, and everyone owns its advantages and disadvantages involving the gold standard CTPA [10]. Prompt management of PE is possibly lifesaving that requires the existence of a simple, harmless, and an exact imaging methodology that is quickly carried out for unmoving and critically ill patients as a bedside procedure. Recently, TUS was utilized in such a manner for this reason, additionally, it keeps away from dangerous subjection to radiation and contrast media that are

utilized in CTPA [11]. In this study, the mean age of the studied group was found to be 53.6 ± 8.83 years with males 29 (58%) and females 21 (42%), 72% of patients were obese. Geneva score median range is 11, 52% of the cases were high clinically suspicious, and PESI median range is 60. This means that PE in our patients was more in patients above 50 years and in obese patients, a feature of PE known for a long time [12]. This was nearly similar to Comert *et al.* [13] who evaluated 100 patients with suspected PE. Of these patients, 54 males and 46 females, their age was 64.1 ± 17.9 (range, 19–85) years. A total of 76 cases were interpreted as high clinical suspicion and 24 cases as intermediate clinical suspicion. We observed that DVT history was elevated significantly in PE-confirmed group (P=0.001) and postoperative history was also higher (P=0.006). Kagima *et al.* [14] evaluated the risk factors in their patient groups and found that one risk factor exists in 72% of their cases and DVT was noticed significantly in PE-confirmed group (P<0.05). The habitual findings in chest radiograph of our patients were consolidation (90%), and 8% of them were normal. This agrees with Comert *et al.* [13] who found pulmonary consolidation to be the habitual chest radiograph findings (43.4%) in their PE-confirmed group. According to the distribution of US findings in the studied group (shape of lesion), we found 26 (52%) hypoechoic, triangular, or wedge-formed subpleural lesions and 12 (24%) pleural effusions. In a similar study done by Sayed *et al.* [15], they observed that the appearance of parenchymal lesions in their PE cases was triangular in 55.6%, which is similar to our results. In this study, pleural effusion was identified in 24% of our cases, which agreed with Comert *et al.* [13] who observed pleural effusion in 19% of cases. Colored Doppler signal was absent in 60% of the suspected lesions of PE in this study, similarly Sayed *et al.* [15] found that the color flow signal was missed in 44.4% of the studied group. The majority of the abnormalities (70%) were present in the posterior lower portion of the lungs and were more on the right side (60%) in this work. In a comparable study done on patients with PE, most of found abnormalities (85.4%) were on the lower part of the lungs and 55.7% were on the right lung [13]. The most frequent lung profiles in US in this study were A profile (94%). Profile A as the predominant

Table 4 Classification of groups in the light of sonographic abnormalities in pulmonary embolism and nonpulmonary embolism cases

Sonographic findings	Pulmonary embolism	
	Positive confirmed with CTPA (*N*)	Negative confirmed with CTPA (*N*)
Group I: two or more typical wedge-shaped lesions±pleural effusion	12	3
Group II: one wedge-shaped lesion with pleural effusion	8	3
Group III: one hypoechoic lesion	8	1
Group IV: nondefinite subpleural abnormailties greater than 5 mm in diameter or a free pleural effusion only	1	3
Group V: normal sonographic findings	1	10

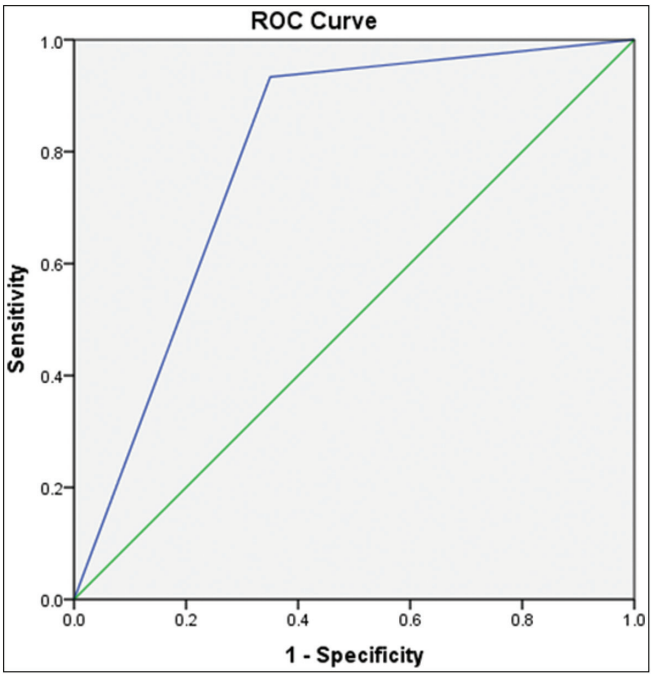
CTPA, computed tomography pulmonary angiography.

Table 5 Distribution of true-positive and true-negative findings by ultrasonography in the studied group

	CTPA [*n* (%)]		Total
	Positive	Negative	
Ultrasonography			
Positive	28 (93.3)	7 (35)	35
Negative	2 (6.7)	13 (65)	15
Total	30	20	50

CTPA, computed tomography pulmonary angiography.

Figure 1



ROC curve of ultrasonography findings among the studied group. ROC, receiver operating characteristic.

Table 6 Sensitivity, specificity, positive, negative predictive values, and accuracy of ultrasonography

Ultrasonography	AUC	95% CI	Sensitivity %	Specificity %	PPV	NPV	Accuracy %
Pulmonary embolism	0.792	0.651–0.932	93.3	65	80	86.7	82

AUC, area under the curve; CI, confidence interval; NPV, negative predictive value; PPV, positive predictive value.

profile seen in TUS was also found in 50% of patients studied by Sayed *et al*. [15]. Also, this was in consensus with Elkholy *et al*. [16] who found that the common profile in the PE group was A profile (55.6%). The median range of PAP in patients with proven PE was 40 mmHg and other echocardiography findings among patients with proven PE such as tricuspid annular plane systolic excursion (TAPSE) and fractional area change to assess right ventricular function all were suggestive for diagnosis of PE in suspected cases. Comert *et al*. [13] found elevated PAP (>36 mmHg) as detected by echocardiographic examination in 43.4% of PE-positive group. Also, Daley *et al*. [17] optimized the measurement cutoff of TAPSE for the diagnosis of PE, using an abnormal cutoff of less than 2.0 cm, and concluded that TAPSE has moderate diagnostic value in patients with suspected PE. Similarly, Karimialavijeh *et al*. [18] examined 66 patients suspected to have PE, and 28 of them confirmed with CTPA. The mean TAPSE was 16.36 ± 1.59 mm in the PE-confirmed and 21.68 ± 2.87 mm in the PE-negative groups ($P \leq 0.0001$). Also, Kossaify [19] measured fractional area change to assess right ventricular function and concluded that a fractional area change less then 35% indicates right ventricular systolic dysfunction. In this work, a significant positive correlation between PAP and PESI was found, which matched a study done by Jiménez *et al*. [20] who found that high-risk patients with high pulmonary pressure had high PESI. The distribution of our patient groups depends on sonographic findings in PE and non-PE cases as follows: groups I, II, and III had 28 cases with positive US findings confirmed with CTPA and seven cases had positive US findings but the negative result with CTPA. In a study done by Bitar *et al*. [4], they noticed that a conclusion of PE was proposed if pleural-based wedge-formed or circular hypoechoic abnormality (regardless of the presence of pleural effusion) was described utilizing TUS. In this work, true-positive cases were 28, false-positive cases were seven, false-negative cases were two, and true-negative were 13 cases. Nazerian a *et al*. [21] evaluated 352 patients with suspected PE and found that PE was confirmed in 194 patients. On the US, PE true-positive cases were 144, PE false-positive were eight, PE true-negative were 150, and PE false-negative were 50 cases. In this study, sensitivity, specificity, accuracy, NPV, and PPV of TUS in the identification of PE were 93.3, 65, 82, 86.7, and 80%, respectively. In a similar study done by Reissig and Kroegel, they compared TUS with CTPA in the identification of peripheral PE. A total of 33 patients with manifestations suggesting PE were registered in the study. TUS and CTPA were done within 24 h from the beginning of clinical signs. The reported sensitivity, specificity, PPV, NPV, and accuracy of TUS were 80, 92, 95, 72, and 84%, sequentially [9]. Also, Pfeil *et al*. [22] revealed the sensitivity of TUS for PE diagnosis as 70% and specificity as 69.6%, NPV and PPV were 84.25 and 50%. Similarly, another study reported a sensitivity of 71.4%, a specificity of 80.9%, and an accuracy of 87.1% [15]. Also, Nazerian *et al*. [21] found that the sensitivity of TUS for the diagnosis of PE was 81.5%, while specificity was 95.4%. Another similar study found that TUS had a sensitivity of 74%, a specificity of 95%, a PPV of 95%, an NPV of 75%, and an accuracy of 84% in PE identification, which matches our results [4].

Conclusion

TUS is an important diagnostic tool as a noninvasive bedside test in detecting PE principally for critically ill or immobile patients with high sensitivity and moderate specificity.

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Conflicts of interest

There are no conflicts of interest.

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