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ORIGINAL ARTICLE

Diagnostic role of thoracic ultrasound in patients with acute respiratory failure at emergency service

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Abstract

Background and aim This study aimed to elucidate the effectiveness of bedside thoracic ultrasound according to BLUE protocol and to investigate its superiority over other imaging methods in the emergency service.

Methods A total of 120 patients admitted to our institution's emergency care department due to respiratory distress have been enrolled in this prospective research. Thorax USG has been performed in the right and left hemithorax at the points specified in the BLUE protocol for each patient. Pleural sliding motion, A-lines, B-lines, consolidation, effusion, and the presence of barcode signs were evaluated individually. Age, sex, comorbid diseases, other radiological examination findings, laboratory findings, final clinical diagnosis, and hospitalization-discharge status of the patients were recorded.

Results When a correct diagnosis of pneumonia has been analyzed for imaging techniques, the diagnostic rate of chest radiography was 83.3%, CT was 100.0%, and USG was 66.6%. The correct diagnostic rate of chest radiography was 94.5%; CT and USG were 100.0%. The correct diagnosis of pulmonary edema on chest radiography was 94.5%; CT and USG were 100.0%. While the correct diagnosis of pleural effusion on chest radiography and CT was 100.0%, it was 92.3% in USG imaging. Finally, CT and USG imaging performed better than chest radiography in patients with pneumothorax (chest radiography 80.0%, CT and USG 100%).

Conclusion USG imaging could be preferred in the diagnosis of pneumonia, pulmonary edema, pleural effusion, pneumothorax, pulmonary embolism, and differential diagnosis at the emergency service.

Keywords BLUE protocol · Dyspnea · Emergency service · Thoracic ultrasonographic evaluation

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Abbreviations

APE	Acute pulmonary edema
ARF	Acute respiratory failure
BLUE	Bedside lung ultrasound in emergency protocol
BNP	B-type natriuretic peptide
CHF	Congestive heart failure
COPD	Chronic obstructive pulmonary disease
CT	Computerized tomography
ICU	Intensive care unit
PE	Pulmonary embolism
SPSS	Statistical Package for the Social Sciences
USG	Ultrasound imaging

Introduction

Acute respiratory failure (ARF) has a wide diagnostic diversity. The most common causes of acute respiratory failure are acute pulmonary edema (APE), chronic obstructive pulmonary disease (COPD) attack/exacerbation, pneumonia, pulmonary embolism (PE), pneumothorax, and massive pleural effusion. All these severe diseases can be diagnosed via thoracic USG (ultrasound imaging) [1]. With the developments in USG technology in recent years, the spectrum of thoracic USG has gradually expanded, and USG has been described as the visual stethoscope of the twenty-first century. It has also been actively used in patients with acute respiratory syndrome, whose frequency has increased during the COVID-19 pandemic [2].

Due to the probable fatal outcomes of acute respiratory failure, urgent and accurate imaging techniques are crucial in identifying and treating patients. Chest radiography is a commonly utilized diagnostic tool for this purpose. Portable X-ray devices also allow patients to be examined in the emergency service intensive care unit (ICU), where they are monitored. Computerized tomography (CT) is another preferred imaging technique as it provides comprehensive information on lung pathologies compared to chest radiography. However, the downside of CT could be elaborated as the transportation of the patient to the radiology unit and the requirement of lying in the supine position.

In case of breathing difficulties, severe dyspnea, or respiratory distress, early intervention could be lifesaving in the ICU. Therefore, bedside ultrasonographic imaging has been popular for making an accurate and rapid differential diagnosis. The utilization of USG is since the lungs contain air, a bone cage surrounds the thorax, and bone and air prevent the passage of sound waves to deep tissues and cause artifacts. On the other hand, USG has significant advantages over other imaging techniques, such as chest radiography and CT, as it provides real-time imaging with a cost-effective and portable approach, thus leading to no radiation exposure or use of contrast agents [3].

Another advantage of ultrasonography is that it can be performed without interfering with other concomitant interventions. Reliable information about the etiology of acute respiratory failure can be obtained by ultrasonography in less than 3 min when integrated with a medical history, physical examination, and vital signs parameters [4].

Studies conducted in emergency services and intensive care units have concluded that thoracic ultrasound was highly correlated with thoracic CT, which is considered the gold standard in lung and pleural pathologies such as pneumonia, pulmonary edema, pneumothorax, pleural effusion, and differential diagnosis of respiratory failure [5, 6].

The diverse etiology of respiratory failure and the different interpretation attributes required an algorithmic approach. Respiratory distress can be due to many different reasons such as pulmonary, cardiac, CNS, systemic, or toxic causes. In this regard, the most common algorithm could be elaborated as the BLUE protocol (bedside lung ultrasound in emergency protocol) [7]. BLUE protocol is a bedside lung ultrasonography application protocol that allows differential diagnosis in acute respiratory failure patients in less than 3 min [8].

The aim of this study was to elucidate the causes of acute respiratory failure of pulmonary origin, to evaluate the effectiveness of bedside thoracic ultrasound according to BLUE protocol, and to investigate its superiority over other imaging methods in the emergency department.

Materials and method

A total of 120 patients who were admitted to the emergency care department of our institution due to respiratory distress have been enrolled in this prospective research. The non-interventional clinical research ethics committee has approved the study at protocol number 2017/33. Informed consent has been obtained from all participants or their relatives in case of unconsciousness.

The USG evaluation was performed by the same physician with advanced ultrasound training in an average of 3 min, using a linear probe of the bedside Fujifilm FC1 ultrasound device. The BLUE protocol was used to standardize the ultrasonographic evaluation, and a standard form was prepared for the study.

Thorax USG has been performed in the right and left hemithorax at the points specified in the BLUE protocol for each patient. Pleural sliding motion, A-lines, B-lines, consolidation, effusion, and the presence of barcode signs were evaluated individually. Additionally, age, sex, comorbid diseases, other radiological examination findings, laboratory findings, final clinical diagnosis, and hospitalization-discharge status of the patients were recorded on the evaluation form.

Patients ≤ 18 years old, individuals with dyspnea or acute respiratory failure whose USG imaging could not be performed, or the distress was due to non-respiratory causes were excluded from the study.

In the study, the gold standard was determined as CT. In cases where CT is not indicated or CT is contraindicated, the final diagnosis of the patients was determined according to the patient's ultrasound and X-ray images, clinical condition, and laboratory findings (leukocyte, CRP, BNP levels, etc.). It is advantageous in terms of standardization and homogenization that the study is performed by a single person who has received ultrasound training.

Statistical analysis

SPSS (Statistical Package for the Social Sciences) version 15.0 software was utilized for data analysis. Numbers and percentages were used to present descriptive analyses. Chi-square and Fisher's tests were performed to compare

Table 1 Examination of kappa correspondences in related parameters

		Pneumonia				Pulmonary edema				Pneumothorax	
		Yes	No			Yes	No			Yes	No
		n	*n*			*n*	*n*			*N*	*N*
Consolidation	Yes	48	–	B-lines	Yes	37	14	Barcode signs	Yes	5	–
	No	24	48		No	–	69		No	–	115
p		**< 0.001****		***p***		**< 0.001****		***p***		**< 0.001****	
κ		0.615		κ		0.752		κ		1.000	

*$p<0.05$; **$p<0.001$

κ: kappa correspondence analysis

categorical data. Kappa correspondence analysis was processed in the correspondence of the data. A p value less than 0.05 was considered statistically significant. A figure of 0.5 represents moderate correspondence, above 0.7 represents good correspondence, and above 0.8 represents very good correspondence for the kappa agreement scores.

Results

A total of 120 patients, 77 (64.2%) males and 43 (35.8%) females, were included in this prospective study. The median age of the patients was 68 years (ranging between 58.5 and 77.0 years). The baseline demographic characteristics of the patients are denoted in Table 1. As the final status, 21 (17.5%) patients were discharged, and 99 (82.5%) were hospitalized.

A moderate but significant correspondence has been achieved between USG imaging and the diagnosis of pneumonia ($p<0.001$, $\kappa=0.615$) (Table 1). Additionally, the sensitivity and specificity have been determined as 66.6% and 100%, respectively. The correspondence between B-lines on USG and the diagnosis of pulmonary edema is strong and significant ($p<0.001$, $\kappa=0.752$) (Table 1). It was determined that sensitivity was 100% and specificity was 83.1%. The correspondence between barcode signs on USG and the diagnosis of pneumothorax revealed a very strong and significant association ($p<0.001$, $\kappa=1.000$) (Table 1). Both sensitivity and specificity were determined as 100%.

During the diagnosis of pleural effusion, thoracic USG generated a significantly higher rate of diagnostic value ($p<0.001$) (Table 2). When the diagnosis of pulmonary embolism and USG results were compared, it was determined that the rate of pleural sliding motion and presence of A-lines was statistically significantly higher in patients with a diagnosis of pulmonary embolism ($p=0.008$ and $p=0.014$, respectively). Effusion was significantly lower in pulmonary embolism patients ($p<0.001$). No significant difference was found between other variables (B-lines, consolidation, barcode finding) and the diagnosis of pulmonary embolism ($p>0.05$) (Table 2).

When a correct diagnosis of pneumonia has been analyzed for imaging techniques, the diagnostic rate of chest radiography was 83.3%, CT was 100.0%, and USG was 66.6% (Table 3). The correct diagnosis of pulmonary edema on chest radiography was 94.5%, and CT and USG were 100.0% (Table 3). While the correct diagnosis of pleural effusion on chest radiography and CT was 100.0%, it was 92.3% in USG

Table 2 Comparison of lung USG findings with pleural effusion and p. embolism diagnostic findings

	Pleural effusion		*p*	Pulmonary embolism		*p*
	Yes (*n* = 13)	No (*n* = 107)		Yes (*n* = 3)	No (*n* = 117)	
	n (%)	*n* (%)		*n* (%)	*n* (%)	
Pleural sliding motion	9 (69.2)	102 (95.3)	**0.008****[,a]	3 (100)	108 (92.3)	**0.008****[,a]
A-lines	6 (46.2)	85 (79.4)	**0.014***[,a]	3 (100)	88 (75.2)	**0.014***[,a]
B-lines	3 (23.1)	48 (44.9)	0.134[b]	3 (100)	48 (41.0)	0.152[b]
Consolidation	5 (38.5)	43 (40.2)	0.905[b]	–	48 (41.0)	> 0.999[b]
Effusion	12 (92.3)	–	**< 0.001****[,a]	–	12 (10.3)	**< 0.001****[,a]
Barcode signs	–	5 (4.7)	> 0.999[a]	–	5 (4.3)	> 0.999[a]

*$p<0.05$; **$p<0.001$

[a]Fisher test

[b]chi-square test

Table 3 Distribution of correct diagnosis on chest radiography, CT, and USG for the diagnosis of pneumonia, pulmonary edema, pleural effusion, and pneumothorax

	Pneumonia ($n=72$)	
	N	**Percentage (%)**
Infiltration (chest radiography)	60/72	83.3
Infiltration (CT)	28/28	100.0
Consolidation (USG)	48/72	66.6
	Pulmonary edema ($n=37$)	
	n	**Percentage (%)**
Pulmonary edema (chest radiography)	35/37	94.5
Pulmonary edema (CT)	5/5	100.0
B-lines (USG)	37/37	100.0
	Pleural effusion ($n=13$)	
	n	**Percentage (%)**
Pleural effusion (chest radiography)	13/13	100.0
Pleural effusion (BT)	10/10	100.0
Pleural effusion (USG)	12/13	92.3
	Pneumothorax ($n=5$)	
	n	**Percentage (%)**
Pneumothorax (chest radiography)	4/5	80.0
Pneumothorax (CT)	5/5	100.0
Barcode signs (USG)	5/5	100.0

imaging (Table 3). Finally, CT and USG imaging performed better than chest radiography in patients with pneumothorax (chest radiography 80.0%, CT and USG 100%).

Discussion

Individuals admitted to the emergency service with acute respiratory failure might have other underlying comorbid conditions. Established protocols and guidelines on imaging techniques contribute to correct diagnosis, thus increasing the window of opportunity for the patients. The use of ultrasound in patients with respiratory distress has become important in recent years due to the evolution in image quality, technological development, and advanced devices.

In a study by Bekgöz and Bildik, 383 consecutive patients admitted to the emergency service due to complaints of dyspnea were examined [9]. They reported that the sensitivity and specificity of the "BLUE protocol" were 87% and 97% for cardiogenic pulmonary edema, 82% and 99% for pneumonia, 98% and 67% for COPD/asthma, 71% and 100% for pneumothorax, and 46% and 100% for pulmonary embolism. Bekgöz and Bildik suggested that pericardial effusion should also be examined in emergency service in the presence of dyspnea.

Although BLUE protocol does not promise 100% accuracy, it is a useful algorithm that allows rapid and accurate evaluation of dyspnea patients. Additional sonographic examinations and this protocol may allow for more accurate detection of relatively fewer diseases. In our study, we determined a sensitivity of 66.6% and specificity of 100% for the diagnosis of pneumonia, a sensitivity of 100% and specificity of 83.1% for the diagnosis of pulmonary edema, and a sensitivity and specificity of 100% for the diagnosis of pneumothorax in bedside USG performed using the BLUE protocol in patients with acute respiratory failure at the emergency service.

The pleural sliding motion indicates that the visceral and parietal pleura are in contact with each other and can slide over with respiration. Pneumothorax is the main example where pleural sliding disappears. However, pleural sliding may not be observed in atelectasis, dense pneumonic consolidation, pleural adhesions, or pleural effusion. In this research, we tried to avoid misinterpretation and conducted a comprehensive examination from different points.

The concordance of USG consolidation findings in patients with pneumonia was examined, and a moderately significant agreement was found ($p<0.001$, $\kappa=0.615$). Since our patients were older, had more comorbidities, and some had more subcutaneous adipose tissue, women with large breasts, in cases with no consolidation, denoted poor echogenicity. In such cases, diagnosis of pneumonia was based on clinical features (development of cough, sputum, fever, presence of leukocytosis) rather than controversial imaging results. B-lines in one hemithorax, alveolar air in bronchogram, hepatization sign, and pleural changes increased the effectiveness of ultrasound in diagnosing pneumonia in patients without consolidation.

When the distribution of correct diagnosis of pneumonia in terms of consolidation in chest radiography, CT, and USG was examined, it was found that the correct diagnosis rate of chest radiography was 83.3%, the correct diagnosis rate of CT was 100.0%, and the correct diagnosis rate of ultrasound was 66.6%. Parlamento et al. stated that the presence of consolidation on ultrasonographic imaging was shown in 96.9% of pneumonia [10]. They concluded that ultrasound was as effective as chest radiography and tomography in diagnosing pneumonia.

Tierney et al. investigated the diagnostic performance of computerized tomography, portable chest radiography, and ultrasonography in intubated intensive care unit patients. They claimed that 9-point lung ultrasonography (5 points in the right hemithorax and 4 points in the left hemithorax) was a superior diagnostic tool to be preferred over portable chest radiography for pathologic side detection and lobe-specific localization [11].

B-lines are vertical striations observed in the presence of pleural sliding motion and indicate the presence of fluid in the lung [12, 13]. In the study by Prosen et al., the presence of bilateral B-lines supported the diagnosis of congestive heart failure (CHF) with a specificity of 91.7% for patients with B-type natriuretic peptide (BNP) > 500 pg/ml [14]. Vitturi combined BNP value with thoracic USG evaluation, showing that heart failure and pulmonary edema patients can be differentiated 100% from COPD and asthma patients [15]. Lichtenstein and Meziere reported that B-lines had high sensitivity and specificity for pulmonary edema in the differential diagnosis of dyspnea [7]. It should be noted that Prosen and Lichtenstein excluded renal failure patients; thus, renal failure also causes pulmonary edema. Vitturi published that fluid withdrawn from patients can be monitored via thoracic USG before and after dialysis [15]. A recent meta-analysis by Maw et al. stated that thoracic USG was a more sensitive method than chest radiography in diagnosing pulmonary edema due to acute heart failure [16]. In our study, the correspondence between B-lines on USG and those with pulmonary edema was examined and a strong significant correspondence was found between them ($p < 0.001$, $\kappa = 0.752$). The distribution of the correct diagnosis rate of chest radiography was 94.5%, the correct diagnosis rate of tomography was 100.0%, and the correct diagnosis rate of ultrasound was 100.0%. When the results of the studies are considered, one can say that USG was as effective as chest radiography and CT in diagnosing pulmonary edema.

Gazon et al. enrolled 50 patients with the interstitial syndrome, alveolar consolidation, and pleural effusion. Regarding their results, 41 of the 329 abnormalities could not be detected via USG, while 142 were detected via USG but not on direct radiography. Additionally, they claimed that USG imaging was faster than direct radiography [17]. In our study, 48 of 72 pneumonia patients, 12 of 13 pleural effusion patients, 37 pulmonary edema patients, and 5 pneumothorax patients were diagnosed by ultrasound.

In a study conducted by Lichtenstein et al. in intensive care unit patients comparing the performance of USG, chest radiography, and auscultation with thoracic CT in the diagnosis of pleural effusion, consolidation, and interstitial syndrome, it was found that the sensitivity of chest radiography was 39–68% and specificity was 85–100%, while the sensitivity of auscultation was 8–42% and specificity 90–100%. In this study, the order of performance, from high to low, was USG, chest radiography, and auscultation for consolidation and interstitial syndrome, and USG, auscultation, and chest radiography for pleural effusion [18]. In our study, while ultrasound was superior in diagnosing pneumothorax, chest radiography provided better results in pneumonia, pulmonary edema, and pleural effusion than ultrasound. Because of our study was conducted under emergency service conditions, the clinical condition of the patients was unstable, the patients could not be positioned appropriately, and detailed examination could not be performed. Our results supported that USG was effective in diagnosing pneumonia, pulmonary edema, pleural effusion, and pneumothorax in the emergency service and could be rapidly performed with an average of 3 min.

In diagnosing pulmonary embolism, the presence of pleural sliding motion and A-lines, absence of B-lines, consolidation, and barcode signs on ultrasound, and detection of venous thrombus in the legs were diagnostic properties according to BLUE protocol. When the diagnosis of pulmonary embolism and USG findings were compared, pleural shear movement ($p = 0.008$) and A-lines ($p = 0.014$) were statistically significant in patients with pulmonary embolism. No significant correlation has been achieved between B-lines, consolidation and barcode signs, and the diagnosis of pulmonary embolism ($p > 0.05$). The low number of pulmonary embolism patients ($n = 3$) might have caused these results.

Frassi et al. investigated the 16-month mortality rate of individuals admitted to the ICU due to dyspnea. They found that the higher the B-lines were observed in USG, the higher the mortality rate and re-hospitalization [19]. In our study, there were 37 patients with pulmonary edema according to the BLUE protocol; 31 were hospitalized, and 6 were discharged. No patient died in the emergency service.

Regarding this study's results, applying the BLUE protocol in patients with acute respiratory failure at the emergency service was a significant diagnostic parameter. USG imaging training could benefit emergency service physicians, contributing to early diagnosis and effective treatment in acute situations. The data we found in our study were compatible with other studies on this subject.

Limitation of study

Among the patients included in the study, the number of pulmonary embolism patients was low.

Conclusion

The outcomes of this research confirmed the benefits of USG imaging in diagnosing pneumonia, pulmonary edema, pleural effusion, pneumothorax, and differential diagnosis. USG could be utilized in pregnant women and children as it does not emit radiation. The ease of use, cost-effectiveness, and patient comfort are other upsides of USG for diagnosing pneumonia, pulmonary edema, pneumothorax, pulmonary embolism, and pleural effusion.

Author contribution Dr. Samet Ocel, Dr. Zeynep Kekec, Dr. Omer Taskin, Dr. Fuat Belli, Dr. Mustafa Oguz Tugcan: conceptualization, methodology, investigation, and writing—original draft. Dr. Samet Ocel, Dr. Zeynep Kekec, Dr. Omer Taskin, Dr. Fuat Belli, Dr. Mustafa Oguz Tugcan: resources, formal analysis, and writing—review and editing. Dr. Samet Ocel, Dr. Zeynep Kekec, Dr. Omer Taskin, Dr. Fuat Belli, Dr. Mustafa Oguz Tugcan: conceptualization, methodology, and writing—review and editing. All authors read and approved the final version of the manuscript.

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Availability of data and materials Data and materials are reachable from hospital automation information systems.

Declarations

Ethical approval The ethics committee of Cukurova University approved the study.

Compliance with ethical standards The study was performed according to the recommendations set by the Declaration of Helsinki on Medical Research involving Human Subjects.

Human rights This manuscript was carried out in accordance with the Declaration of Helsinki and Good Clinical Practice guidelines.

Informed consent Informed consent was obtained from all individual participants included in the study.

Conflict of interest The author declare no competing interests.

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