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Diagnostic Accuracy of Bedside Lung Ultrasound in Critically Ill Respiratory Failure Patients

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ABSTRACT

The aim of the current study was to assess the accuracy of lung ultrasound algorithm in ICU patients with respiratory failure. Thus, this randomized comparative study included 80 patients admitted to the intensive care unit, Shebin El-Kom teaching hospital during three years from October 2017-October 2020. The study received the approval of ethical committee of faculty medicine, Kasr-El-Einy, Cairo university. History, clinical examination, chest X ray, CT chest, lung US, and Echocardiography were done. Results showed that, US showed sensitivity and specificity 100 %, 100% respectively in diagnosis of pneumothorax regarding pneumonia, sensitivity and specificity of US were (68.2%, 86.2% respectively). Regarding ILD, sensitivity and specificity of US were (55.6%, 98.6%). Additionally, as regard pulmonary edema and pleural effusion, US sensitivity and specificity were (66.7%, 97.4%) and (78.9%, 98.4%) respectively.

Keywords: Ultrasonography; Bedside; Acute Respiratory Failure (ARF)

INTRODUCTION

A critical illness is a condition that poses a significant risk of mortality or morbidity. The implementation of an efficient Chain of Response, which involves precise vital sign recording with recognition and interpretation of aberrant data, patient assessment, and appropriate response, involves all healthcare staff significantly. Rapid diagnosis and conclusive therapy are necessary for positive results. All doctors should be able to identify critically unwell patients and investigate the best first care [1,2]. Acute Respiratory Failure (ARF) is a serious illness that needs constant monitoring and treatment.

A noninvasive, widely accessible imaging technique called bedside Lung Ultra Sonography (LUS) can support clinical evaluation and physical examination [3]. The fundamental benefit of bedside LUS is that it can be used right away to diagnose thoracic diseases. Other benefits include delaying or even avoiding the need for patient transportation to the radiology suite or for radiation exposure, as well as directing life saving therapies in the event of an urgent situation. Numerous studies have documented the use of LUS by pulmonologists, intensivists, and emergency doctors [4].

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Traditionally, Thoracic Computed Tomography (TCT) or bedsides Chest Radiography (CXR) were used for lung imaging in critically unwell patients (CT). Both methods have drawbacks that restrict how beneficial they can be. Critically, although appearing to be a new area, ultrasonography is the result of a long effort that started in 1946. The lung was traditionally not considered as a part of ultrasound, now it is included as a priority in the critical ultrasound [5]. Among intensivists, the idea of employing bedside ultrasound to examine the lung is growing in popularity. A unique diagnostic ultrasonography method called the Bedside Lung Ultrasonography in Emergency department (BLUE protocol) is designed to be used in conjunction with straightforward clinical data. It suggests a methodical study that can be completed in three minutes [6]. Therefore, the current study's objective was to assess the lung ultrasound algorithm's (BLUE protocol) diagnostic efficacy in ICU patients hospitalized with respiratory failure.

MATERIALS AND METHODS

This randomized comparative study included 80 patients admitted to the intensive care unit, Shebin El-Kom teaching hospital during three years from October 2017-October 2020.

Inclusion Criteria

Adult patients admitted with clinical and laboratory manifestations of ARF.

Exclusion Criteria

Age younger than 18 years, sever morbid obesity (BMI>35 kg/m^2) due to poor visualization of chest by US.

All Patients Included in the Study Subjected to the Following

Full history taking including name, age, habits and history of any disease, full clinical examination: focusing on: Physical examination: Including measurement of height, weight, BMI, and blood pressure. General examination: Chest and cardiac auscultation, blood pressure, heart rate, temperature, and Respiratory Rate (RR), laboratory results ABG, CRP, TLC, and cultures, Echocardiography, chest X-ray, CT, and chest Lung U/S were investigated [7-12].

Sample Size

80 patients with ARF were included in this study (e.g., interstitial lung disease, IPF, acute pulmonary oedema, COPD exacerbation, pneumothorax, ARDS, etc.

Methods of Blindness

For the duration of data collection and analysis, members of the study group involved in gathering functional data were blinded to randomization. Ultrasound apparatus used: Wed-2018 full digital ultrasound diagnostic system, probe selection: No one probe has been shown to be superior to another; instead, a single high-resolution micro-convex probe with a broad frequency range (3–5 MHz) can be employed. The patient was sitting up straight, lying sideways, or both. The patient was lying flat for the duration of this post.

Upper Anterior Point

On the upper hand, this corresponds to the base of the middle and ring fingers. It is located above the top lobe. The middle of the palm of the lower hand is the lower anterior point (close to the nipple in a man). It is located above the lingular or middle lobe. The left heart will be missed by these points. Move as far posteriorly and laterally as you can from the lower anterior point to the posterior axillary line (limited by the bed). The bottom lobe is covered by it. By turning a curvilinear probe just enough to lie between the ribs (the cephalad will still be on the left of the picture), rib shadows can then be reduced [13-15].

Statistical Analysis

Microsoft Excel 2019 and SPSS v.25 for Microsoft Windows 10 were used to organize the results and perform statistical analysis. For quantitative data, the data were described using the mean (±) SD, and for qualitative data, frequency, and proportion. *Chi-Squared* is a statistical method for comparing two groups or more about a single qualitative variable. P ≤ 0.05 was regarded as a significant value [16,17].

RESULTS

In this investigation, eighty patients were evaluated. The average BMI was 29.35 3.12 kg/m^2, and the age was 57.35 13.30 years. 53 % of them were men, 47% were women, 15% had IHD, 11% had CKD, 9% had CVS, 6% had an old stroke, 5% had AF, 10% had COPD and asthma, and 66% had no significant medically significant behaviors. 26% of people smoked, as shown in **Table 1**.

Table 1: Demographic characteristics and co-morbidity of the studied patients (n=80).

Variable	Studied patients (n=80)	
	No.	**%**
	Age	
Mean ± SD	57.35 ± 13.30	
Range	19– 83	
	BMI (kg/m^2)	
Mean ±SD	29.35 ± 3.12	
Range	2 –32	
	Sex	
Male	42	53
Female	38	47
	Special habit	
No	53	66
Smoker	21	26
Ex-smoker	3	4
Addict	1	1
Smoker and addict	2	3
	DM	
Yes	46	58
No	34	42
	HTN	
Yes	41	51
No	39	49
	IHD	
Yes	12	15
No	68	85
	CKD	
Yes	9	11
No	71	89
	CVS	
Yes	7	9
No	73	91
	Old stroke	
Yes	5	6
No	75	94
	AF	
Yes	4	5

No	76	95

The mean of CRP level, TLC count were 59.35 and 17.34 respectively. Diaphragmatic excursion and diaphragmatic thickness fraction were 6 cm and 32.1% respectively. Regarding ABG, the mean PH, PCO_2, HCO_3 and P/F ratio were 7.30, 49.7, 22.57 and 212.94, respectively. Also, sputum, urine and blood culture were positive in (33.8%, 13.8% and 8.8%, respectively), of the studied group 56.3% were on invasive mechanical ventilation, as shown in **Table 2**.

Table 2: Laboratory investigations of the studied patients.

Variable	Studied patients (n=80)	
	Mean ± SD	**Range**
CRP	59.35 ± 67.16	6-300
TLC	17.35 ± 7.1	6-39
	ABG	
PH	7.30 ± 0.13	7.01-7.59
PCO_2	49.7 ± 17.71	19-93
HCO_3	22.57 ± 6.01	7-38
P/F ratio	212.94 ± 60.1	90-360
	Diaphragmatic parameters	
Diaphragmatic excursion (cm)	6 ± 1.77	0.5-9
Diaphragmatic thickness fraction %	32.1 ± 9.8	10-72
	No.	%
	CRP	
+ve	53	66
-ve	27	34
	Blood culture	
+ve	7	8.8
-ve	73	91.3
	Sputum culture	
+ve	27	33.8
-ve	53	66.3
	Urine culture	
+ve	11	13.8
-ve	69	86.3
	Ventilatory support	
Oxygen mask	11	13.8
Nasal cannula	17	21.3
Noninvasive CPAP	7	8.8

Invasive MV	45	56.3

In chest X-ray finding 32.5% of the studied group had normal lung, 18.8% had pneumonia and 20% showed pleural effusion of the studied group, also heterogeneous opacities has been detected in 10%. Parapneumonic effusion has been dedicated in 3.8%, 6.3% had pulmonary edema and 6.3% showed pneumothorax and ILD detected in 2.5% of studied patients. Regarding CT chest findings 20% had normal lung, 27.5% had pneumonia and 23.8% showed pleural effusion, 6.3% showed pneumothorax. Interstitial syndrome detected in 11.3% of studied patients, as shown in **Table 3**.

Table 3: X-ray and CT chest findings of the studied patients.

Variable	Studied patients (n=80)	
	No.	**%**
	Chest X- ray findings	
Normal lung	26	32.5
Pneumothorax	5	6.3
ILD	2	2.5
Pulmonary edema	5	6.3
Pneumonia	15	18.8
Pleural effusion	16	20
Parapneumonic effusion	3	3.8
Heterogenous opacities	8	10
	CT chest findings	
Normal lung	16	20
Pneumothorax	5	6.3
Interstitial syndrome	9	11.3
Pulmonary edema	3	3.8
Pneumonia	22	27.5
Pulmonary embolism	4	5
Pleural effusion	19	23.8
Atelectasis	2	2.5

Pneumothorax was presented by absent lung sliding and present lung point in all patients; interstitial lung disease was presented by lung sliding and multiples B lines in (50%) patients. Pulmonary edema was presented by lung sliding and multiples B lines Pneumonia was presented by lung sliding and A lines and pneumonia in (39.1%) patients. Pleural effusion was presented by lung sliding and A lines and pleural effusion in (87.5%) patients. ARDS was presented by lung sliding and multiples B lines in all patients, as shown in **Table 4.**

Table 4: Ultrasound profile in relation of final diagnosis according to blue protocol.

	US profile									
US diagnosis according	Lung sliding and	Absent lung sliding and	Lung sliding and	Lung sliding and A lines and	Lung sliding and A lines and	Lung sliding and B lines and	lung sliding and multiple	Lung sliding and B	Lung sliding and A lines and	Total

to blue protocol	multiple A lines	present lung point	multiples B lines	pneumonia	pleural effusion	pneumonia	A and B lines	lines and effusion	pneumonia and effusion	
Normal lung	18 (78.30%)	-	-	4 (17.40%	1 (4.30%)	-	-	-	-	23
Pneumothorax	-	5 (100%)	-	-	-	-	-	-	-	5
Interstitial lung disease	-	-	3 (50%)	1 (16.70%)	-	-	1 (16.70%)	1 (16.70%)	-	6
Pulmonary edema	-	-	4 (100%)	-	-	-	-	-	-	4
Pneumonia	-	-	4 (17.40%)	9 (39.10%)	-	3 (13%)	4 (17.40%)	2 (8.7%)	1 (4.3%)	23
Pleural effusion	-	-	-	-	14 (87.50%)	-	-	-	2 (12.5%)	16
ARDS	-	-	3 (100%)	-	-	-	-	-	-	3
Total	18	5	14	14	15	3	5	3	3	80

The agreement of sonographic findings according to blue protocol and laboratory findings was found in 55 cases out of 80 cases (68.8%) where Kappa measure of agreement was moderate/substantial (K=0.61). There was highly statistically significant difference between US and CT Finding. US detected all cases of pneumothorax that have been diagnosed by the CT, US detected 15 cases of pneumonia out 22 cases diagnosed by the CT chest, 5 cases out of 9 cases of interstitial lung disease. And 2 cases out of 3 cases of pulmonary edema and 15 cases out of 19 of pleural effusion, as shown in Table 5.

Table 5: Ultrasound diagnosis in relation of CT diagnosis as a gold standard test in the studied group.

US diagnosis	CT diagnosis as a gold standard							Total
	Normal lung	**Pneumothorax**	**Pneumonia**	**Interstitial lung disease**	**Pulmonary edema**	**Pleural effusion**	**Others**	
Normal lung	13	0	5	1	0	1	0	23
Pneumothorax	0	5	0	0	0	0	0	5
Pneumonia	1	0	15	1	1	3	2	23
Interstitial lung disease	1	0	0	5	0	0	0	6
Pulmonary edema	1	0	0	0	2	0	0	4
Pleural effusion	0	0	0	1	0	15	0	16
Others	0	0	2	1	0	0	0	3
Total	16	5	22	9	3	19	2	80

The sensitivity and specificity of US in diagnosis of pneumothorax were (100%, 100%) respectively. Regarding pneumonia, sensitivity and specificity of US were (68.2%, 86.2%) respectively. Regarding ILD, sensitivity and specificity of US were (55.6%, 98.6%) respectively. As regard pulmonary edema and pleural effusion, US sensitivity and specificity were (66.7%, 97.4%) and (78.9%, 98.4%) respectively as shown in Table 6.

Table 6: Sensitivity, specificity and accuracy of US in diagnosing etiology of pleural effusion.

Disease	Sensitivity%	Specificity%	PPV%	NPV%	Accuracy
Pneumothorax	100%	100%	100%	100%	70%
Pneumonia	68.20%	86.20%	65.20%	87.72%	81.30%
ILD	55.60%	98.60%	83.30%	94.60%	83.80%
Pulmonary edema	66.70%	97.40%	50%	98.70%	96.30%
Pleural effusion	78.90%	98.40%	93.80%	93.70%	93.80%

DISCUSSION

In ICU patients admitted with respiratory failure, the current study sought to assess the diagnostic efficacy of the lung ultrasound algorithm (BLUE protocol). In the study by Ali, et al., it was discovered that 69% of the patients were men and 31% were women, and that the mean age of the participants was 49.2211.52 years. Additionally, 23% of people had hypertension, 13% had diabetes mellitus, 10% had heart disease, 5% had renal illness, and 2% had liver disease. These findings concur with our findings. While only 47% had concomitant conditions. Additionally, Mohsen, et al. discovered that the mean age of the patients under study was 59+13. 52.5% of people were female and 47.5% were male. In 15% of patients, hypertensive pulmonary edoema and iatrogenic PTX were the most common etiologies that led to respiratory symptoms, while pulmonary embolism and other systemic illnesses was least common (5% each). This runs counter to our findings.

As US recognized every case of pneumothorax that the CT had identified in our investigation, there was a highly statistically significant difference between US and CT findings. On the other hand, the US found 5 cases out of 9 cases of interstitial lung disease and 15 cases of pneumonia out of 22 cases identified by the CT chest. Additionally, pleural effusion occurs in 15 out of 19 instances and pulmonary edoema in 2 out of 3 cases. Using a different meta-analysis, Winkler, et al. discovered that the chest radiograph's overall sensitivity and specificity were 49% (95% CI, 40%-58%) and 92% (86%-95%), respectively. This meta-analysis of seven trials found that lung ultrasonography had an overall sensitivity of 95% (92%-96%) and specificity of 94%. According to the latest research, pleural effusion was diagnosed by US with a sensitivity and specificity of (78.9%, 98.4%) respectively. According to the current research, which was supported by Ali, et al. lung ultrasound had sensitivity, specificity, and diagnostic accuracy of 95.4%, 97.1%, and 96%, respectively, for pleural effusion. While chest X-rays' sensitivity, specificity, and diagnostic precision in identifying pleural effusion were, respectively, 70.7%, 91.45%, and 78%. Furthermore, these results were comparable to those attained by El Mahalawy, et al., who included 130 patients who were mechanically ventilated and those who were not and found that thoracic ultrasound had a sensitivity of 94% and a specificity of 96%, compared to chest X-rays 70% sensitivity and 90% specificity. These findings corroborated those of Lichtenstein, et al., who found that LUS had a sensitivity of 92%, specificity of 93%, and diagnostic accuracy of 93% for pleural effusion, compared to bedside CXR's sensitivity, specificity, and accuracy of 47%, 39%, and 82%, respectively. Further research by Mohsen, et al., indicated that CXR had worse diagnostic accuracy, sensitivity, and specificity than LUS in the diagnosis of pleural effusion, with values of 46 versus 100%, 90 versus 98%, and 76 versus 97%, respectively. The sensitivity and specificity of ultrasound for the diagnosis of pneumothorax were 100% in the current investigation. These findings are somewhat like those of Ali, et al., who discovered that chest ultrasound had a sensitivity of 87.5%, specificity of 98.5%, and accuracy of 95% compared to chest X-rays, which had sensitivity, specificity, and accuracy of 53.1%, 98.5%, and 84% respectively in diagnosing pneumothorax. Also, our findings agree with Soldati, et al., showed that (52%) of PTXs cases were revealed by bedside Chest Radiography (CXR) with (sensitivity, 52%; specificity, 100%), whereas (92%) of PTXs were identified by LUS with one false positive result (sensitivity, 92%; specificity, 99.4%). Furthermore, according to Xirouchaki, et al., bedside LUS has corresponding values of 75%, 93%, and 92%, while CXR has a sensitivity of 0%, specificity of 99%, and diagnostic accuracy of 89% for PTX. Additionally, numerous meta-analysis studies, including Ding, et al., produced results that matched those of our study. This study compares the use of Chest Radiography (CxR) with Lung Ultrasonography (LUS) for the diagnosis of pneumothorax, with CXR having sensitivity and specificity of 52% and 100%, respectively, and LUS having sensitivity and specificity of 78.6% and 98.4%, according to Alrajab, et al., 119 patients with chest injuries had a 53% sensitivity of chest ultrasonography to pneumothorax, in contrast to Hyacinthe, et al., findings. In addition, because of chest ultrasound's higher sensitivity than bedside chest X-rays (86.1% compared 52.7%), higher negative predictive values (96.8% versus 90.1%), and higher diagnostic accuracy (95.3% versus 90.6%), our results were superior to those of Abdalla et alstudy's 192 patients. However, compared to lung US, chest X-rays had slightly higher specificity (99.4%) and stronger positive predictive values (95.0% *vs.* 88.6%). Additionally, a recent study by Ali, et al., discovered that oblique CXR had a sensitivity and specificity of 61.4 and 99.2%, respectively, for detecting occult PTX. LUS has a 62.9 and 98.8% sensitivity and specificity, respectively. The high incidence of pneumothorax in mechanically ventilated patients, which is regarded as one of the most dangerous consequences of positive pressure ventilation, may be the cause of these discrepancies. According to the current research, chest X-rays had a sensitivity and specificity of (68.2%, 86.2%) when it came to detecting pneumonia, which is lower than that reported by Ali, et al., discovered (89.3% *vs.* 60.7%) and (97.7% compared

90.9%), respectively. These findings concur with those of Nazerian, et al., who examined 285 patients and found that ultrasound had much greater sensitivity and specificity for detecting pneumonia than chest X-ray (81% versus 64% and 94% versus 90%, respectively). Also, the current findings are less conclusive than those of Cortellaro, et al., who reported that ultrasonography had significantly greater sensitivity and specificity than chest X-ray (99% versus 67%) and (95% versus 85%), respectively, on 120 patients. On the other hand, Alkhayat and Alam Eldeen's, investigation of 62 patients revealed that (74%) of the time, chest ultrasonography was diagnostic. Because areas of consolidation may only be identified with the transthoracic ultrasound technique when they are attached to the pleural surface, this variation in accuracy may be explained by El Mahalawy, et al.

Our findings indicated that the US had a sensitivity and specificity of (66.7%, 97.4%), respectively, for pulmonary edoema. This is in line with Ali, et al., findings, which showed that lung US provides a novel tool for pulmonary edoema diagnosis at the bedside. When compared to chest CT, chest X-rays and chest ultrasound had higher sensitivity and specificity 88.9% and 98.9%, respectively than the latter. These findings corroborated those of El Mahalawy, et al., who reported that the sensitivity and specificity of chest ultrasound were 93% and 93%, respectively. Another study by Xirouchaki, et al., found that chest ultrasonography had 94% sensitivity, 93% specificity, and 94% accuracy in identifying interstitial syndrome. Chest X-rays had a sensitivity, specificity, and accuracy of 46%, 80%, and 58% in detecting interstitial syndrome, respectively. These findings agreed with several investigations, including those by Agmy, et al., who studied 109 patients and reported that the overall sensitivity and specificity of chest ultrasound were 93.2% and 100%, respectively, and Lichtenstein who discovered that they ranged from 90% to 100%. The condition known as pulmonary edoema, which can be either cardiogenic or non-cardiogenic and manifests as fluid buildup in the lung parenchyma and air gaps that impairs gas exchange, may be the reason for ICU admission or may arise suddenly in the ICU. Although heart failure is widespread, the prevalence of acute cardiogenic pulmonary edoema is mostly unknown [18-22].

CONCLUSION

In comparison with bedside CXR, LUS was found to be a more reliable, accurate, and sensitive bedside tool in diagnosing most of the common chest diseases encountered in critically ill patients. In comparison with CT scan, bedside LUS seems to be a valuable substitute in cases where performing CT is problematic. We recommend starting the use of bedside LUS as routine tool to improve the diagnostic accuracy for most of the pulmonary presentations.

ETHICAL CONSIDERATION

The Kasr El-Einy faculty of medicine's ethical committee approved the study at Cairo university. The parents or caregivers were asked for their signed informed consent, which was then obtained.

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