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ORIGINAL ARTICLE

EVALUATION OF THE ROLE OF BEDSIDE LUNG ULTRASOUND VERSUS CHEST X-RAY IN CRITICALLY ILL PATIENTS

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ABSTRACT

Background: Although chest X-ray is the main imaging approach in many settings, many limitations for it exist. Ultrasound has quite similar performances to CT with many advantages. **Methods:** From January 2017 till May 2018, a prospective cohort study conducted in emergency ICU at Zagazig university hospitals including 124 critically ill patients older than 18 years with respiratory distress, cough, fever, or hypoxemia. We excluded from the study pregnant females, patients with massive chest wall emphysema or hematoma, morbidly obese and finally patients with risk of transportation. All patients underwent thorough physical examination, history, laboratory investigations & Chest radiology (X-rays, chest ultrasound & CT). We measured the sensitivity and specificity of chest ultrasound and chest X-rays in comparison with CT with measurement of the learning curve of chest US. **Results:** 124 patients were assessed for eligibility. 24 patients were excluded for different causes and 100 patients (69 males & 31 females) completed the study with mean age of 49.22±11.52 years. Regarding all study population, whatever diagnosis, sensitivity and specificity of chest ultrasound and chest X-rays were 91.4%, 98.3% and 61.7%, 96.2% respectively. Concordance of the results of ultrasound with results of X-rays and clinical diagnosis increased sensitivity, specificity and overall accuracy to highly comparable results with chest computed tomography. Sensitivity, specificity and accuracy of chest ultrasound increased with time and with number of patients. **Conclusions:** Chest ultrasound is reliable, quick, bedside, low-cost, non-invasive, non-ionizing, more accurate, and easily educated for early detection of chest diseases and their follow up.

Keywords: Critically ill, lung ultrasound, BLUE protocol

INTRODUCTION

Critical illness is a life-threatening condition that can result in significant morbidity or mortality. All clinical staff has an important role in implementing an effective "Chain of Response" that includes accurate recording of vital signs with recognition and interpretation of abnormal values, patient assessment and appropriate intervention (1). Good outcomes rely on rapid diagnosis and definitive treatment. All physicians should possess the skills to recognize the critically ill patient and investigate appropriate initial management (2). Lung imaging in critically ill patients was performed traditionally either by bedside chest radiography (CXR) or thoracic computed tomography (CT). Both techniques have limitations which constrain their usefulness. Critically ultrasound, apparently a recent field, is in fact the outcome of a slow process, initiated since 1946. The lung was traditionally not considered as a part of ultrasound, now it is included as a priority in the critical ultrasound [3]. The possibility of exploring the lung using bedside ultrasound is gaining popularity among intensivists. The Bedside Lung Ultrasonography in Emergency department (BLUE-protocol) is an exclusive diagnostic ultrasound approach intended to be combined with simple clinical data. It proposes a step-by-step analysis, which can be achieved within three minutes [4]. The aim of this study is to compare the lung ultrasound in diagnosis of the majority of pathologic pulmonary problems in ICU with bedside chest radiography.

METHODS

This is a prospective cohort study conducted in emergency ICU at Zagazig university hospitals including critically ill patients older than 18 years of both sexes presented with or newly developed respiratory distress, cough with fever, purulent expectoration, or hypoxemia from January 2017 till May 2018. Respiratory distress included, but not limited to, patients in whom ventilation was indicated due to respiratory failure, impending failure, hypoxemia despite conventional oxygen therapy, and troubleshooting of the mechanically ventilated patient especially if there is high probability of pneumothorax. We excluded from the study pregnant females, patients with inapplicable lung ultrasound e.g massive chest wall emphysema or hematoma, heavy dressing and morbidly obese and finally patients with risk of transportation for CT. This work has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for studies involving humans. After institutional ethics committee approval and an informed written consent were taken from the patient or from his relatives, if not aware. Four pathologic conditions were evaluated by each radiological imaging technique: pneumothorax, pleural effusion, lung consolidation and pulmonary edema. Each hemi-thorax was evaluated for absence or presence of those conditions. All patients of the study were subjected to thorough medical history taking, clinical examination and laboratory testing. All patients were subjected to lung ultrasound, chest X-ray and chest CT scan within a time limit of four hours for logistic reasons.

Chest ultrasonography: Siemens Acuson x300 ultrasound was used in this study using two probes (phased array low frequency 5 MHz probe mainly and a linear high frequency 7-10 MHz probe occasionally) using the gray-scale (B-mode) and time motion (M-mode). Patients were examined posteriorly in a semi lateral position and anteriorly in a supine position. Lung ultrasound was done by the same operator and revised by expert radiologist in lung ultrasonography who gave the final diagnosis. Both the operator and the expert radiologist were oriented by the clinical situation of the patient and unaware of the other chest radiography findings. Three standardized points were examined. Determination of these points can be achieved by two hands touching each other with thumbs excluded on the patient chest (the upper hand touching the clavicle). The upper point is at the middle of the upper hand, while the lower point is at the middle of the lower palm. The third point is called PLAPS (postero-lateral alveolar or pleural syndrome) point and is by transection of a horizontal plane at the level of the lower BLUE point and a vertical line at the posterior axillary line.

Three signs with dual answers were assessed in each of the previously mentioned points, as follow: A lines (repetitive horizontal artifact arising from the pleural line generated by sub-pleural air that blocks ultrasound waves) or B Lines (artifact with seven features: A hydroaeric comet-tail artifact, arising from the pleural line, hyperechoic, well defined, spreading up indefinitely, erasing A lines, and moving with lung sliding when lung sliding is present) and absent or present lung sliding or alveolar consolidation and/or pleural effusion.

According to the BLUE protocol, combination of these signs results in eight profiles. These profiles are the A-profile (associates anterior lung-sliding with A-lines), the A'-profile (an A-profile with abolished lung-sliding), the B-profile (associates anterior lung-sliding with lung-rockets), the B'-profile (a B-profile with abolished lung-sliding), the C-profile (indicates anterior lung consolidation, regardless of size and number), the A/B profile (a half A-profile at one lung, a half B-profile at another), the PLAPS-profile (designates Postero-lateral Alveolar and/or Pleural Syndrome), and the nude profile (is an A-profile with no DVT and no PLAPS).

Chest X-rays: Using Arab precise industries company (APiC) MR300 portable X-ray device, antero-posterior chest radiography was done with the patient in supine position. The evaluation of chest X-rays was performed by a radiologist unaware of the lung ultrasound and CT findings. Different lung pathologies were defined using the nomenclature committee of the Fleischner society terminology [(5)].

Chest computed tomography (CT): A low-dose CT scan without contrast using Toshiba Prime Aquilion - 64 slice high speed device was ordered for all patients to confirm diagnosis. CT scan was done using 120 kv, 20-40 mA, and reconstructed layer thickness of 4 mm and effective radiation dose of 0.4 mSv. CT scan was done while the patient was in supine position from the apex of the thorax to the lung bases, lung images were displayed in both lung and soft tissue window. Different lung pathologies were defined using the terminology of the nomenclature committee of the Fleischner society [(5)].

Primary goal of this study is measuring the sensitivity and specificity of chest ultrasound and chest X-rays in comparison with chest CT. While, the goal is measuring of the learning curve of chest ultrasonography.

As the average number of cases with inclusion criteria is about 8 cases per month in a study period of one year, sample size was calculated with using a priori test with an effect size of 0.5 for the Wilcoxon signed-rank test with an error protection of 0.05 provided 80% power for the sample size of about 100 cases according to approval of IRB committee, Zagazig University.

Statistical analysis

The collected data were organized, tabulated and statistically analyzed, using statistical package for social science (SPSS) version 19 (SPSS Inc, Chicago, USA). Mean, standard deviation, frequency and percentage were used as descriptive. Sensitivity, specificity, positive predictive value, negative predictive value, positive likelihood ratio, negative likelihood ratio, and accuracy were used as measurements of validity for chest X-rays and chest ultrasonography results in comparison to CT chest. The latter was regarded as the standard reference.

RESULTS

In this prospective study 124 patients was assessed for eligibility. Twenty four patients were excluded for different causes (14 patients: died before doing CT, 6 patients: can't be transferred to CT, and 4 patients: CT was done after 4 hours from US)(Figure 1) and 100 patients completed the study. Sixty nine of them were males and 31 were females with mean age of 49.22 ± 11.52 years. The rest of patient characteristics were shown in (Table 1).

As regard pleural effusion, it was diagnosed by clinical examination in 30 (30%) patients, while it was diagnosed with chest ultrasound, chest X-rays, and chest CT in 63 (63%), 49 (49%) and 65 (65%) patients respectively (Table 2, 3 & Figure 1, 2A). In diagnosing pleural effusion, sensitivity and specificity of chest ultrasound and chest X-rays in comparison to chest CT were 95.4%, 97.1% and 70.7%, 91.45% respectively. With combination of the results of chest ultrasound, chest X-rays and clinical examination, sensitivity and specificity were 98.5% and 100% respectively (Table 4).

Regarding pneumothorax, it was diagnosed by clinical examination in 11 (11%) patients, while it was diagnosed with chest ultrasound, chest X-rays, and chest CT in 29 (29%), 18 (18%), and 32 (32%) patients respectively (Table 2, 3 & Figure 1, 2B). In diagnosing pneumothorax, sensitivity and specificity of chest ultrasound and chest X-rays in comparison to chest CT were 87.5%, 98.5% and 53.1%, 98.5% respectively. Sensitivity and specificity of combined results of chest ultrasound, chest X-rays and clinical examinations were 93.7% and 98.5% respectively (Table 4).

As for pneumonia, it was diagnosed by clinical examination in combination with laboratory findings in 29 (29%) patients, while it was diagnosed with chest ultrasound, chest X-rays, and chest CT in 51 (51%), 38 (38%), and 56 (56%) patients respectively (Table 2, 3 & Figure 1, 2C). In diagnosing pneumonia, sensitivity and specificity of chest ultrasound and chest X-rays in comparison to chest CT were 89.3%, 97.7% and 60.7%, 90.9% respectively. Sensitivity and specificity of combined results of chest ultrasound, chest X-rays and clinical examinations were 94.6% and 100% respectively (Table 4).

Regarding pulmonary edema, it was diagnosed by clinical examination in 5 (5%) patients, while it was diagnosed with chest ultrasound, chest X-rays, and chest CT in 9 (9%), 4 (4%), and 9 (9%) patients respectively (Table 2, 3 & Figure 1, 2D). In diagnosing pulmonary edema, sensitivity and specificity of chest ultrasound and chest X-rays in comparison to chest CT were 88.9%, 98.9% and 33.3%, 98.9% respectively. Sensitivity and specificity of combined results of chest ultrasound, chest X-rays and clinical examinations were 100% and 100% respectively (Table 4).

Regarding all population of the study, whatever diagnosis, sensitivity and specificity of chest ultrasound and chest X-rays were 91.4%, 98.3% and 61.7%, 96.2% respectively. Concordance of the results of chest ultrasound with results of chest X-rays and clinical diagnosis increased sensitivity, specificity and overall accuracy to highly comparable results with chest computed tomography (Table 4).

Sensitivity, specificity and accuracy of chest ultrasound, in our study, increased with time and with number of patients. In the first 30 cases, the overall accuracy of chest ultrasound increased rapidly to reach 80.3%. In the next 30 cases, slow increase in the overall accuracy occurred to reach 97.2%. A plateau occurred after that in the next 20 cases. At the end of the study, the overall accuracy of chest ultrasound reached 95.5%. We can use the change in accuracy of chest ultrasound by time as an indicator for the learning curve of chest ultrasound (Figure 3).

Table 1. Patient demographics

Characteristics	All study population (n = 100)	
	No.	%
Age (years) Mean ± SD Range	 49.22 ± 11.52 22 – 85	
Weight (Kg) Mean ± SD Range	 61.43 ± 7.14 45 – 87	
Sex Male Female	 69 31	 69% 31%
Comorbidities - Absent - Present Hypertension Diabetes Mellitus Cardiac disease Renal disease Hepatic disease	 47 53 23 13 10 5 2	 47% 53% 23% 13% 10% 5% 2%
Causes of ICU admission Poly-trauma Respiratory failure Heart failure Others	 63 17 10 10	 63% 17% 10% 10%

SD: Standard deviation
ICU: Intensive care unit

Table 2: Results lung ultrasound and chest X-rays compared to chest CT

Pathology	US/CXR	CT+	CT-
Pleural effusion	US +	62	1
	US –	3	34
	CXR +	46	3
	CXR –	19	32
Pneumothorax	US +	28	1
	US –	4	67
	CXR +	17	1
	CXR –	15	67
Pneumonia	US +	50	1
	US –	6	43
	CXR +	34	4
	CXR –	22	40
Pulmonary edema	US +	8	1
	US –	1	90
	CXR +	3	1
	CXR –	6	90

US: Ultrasound
CXR: Chest X-rays
CT: Computed tomography

Table 3: Ultrasound lung profiles in different diseases

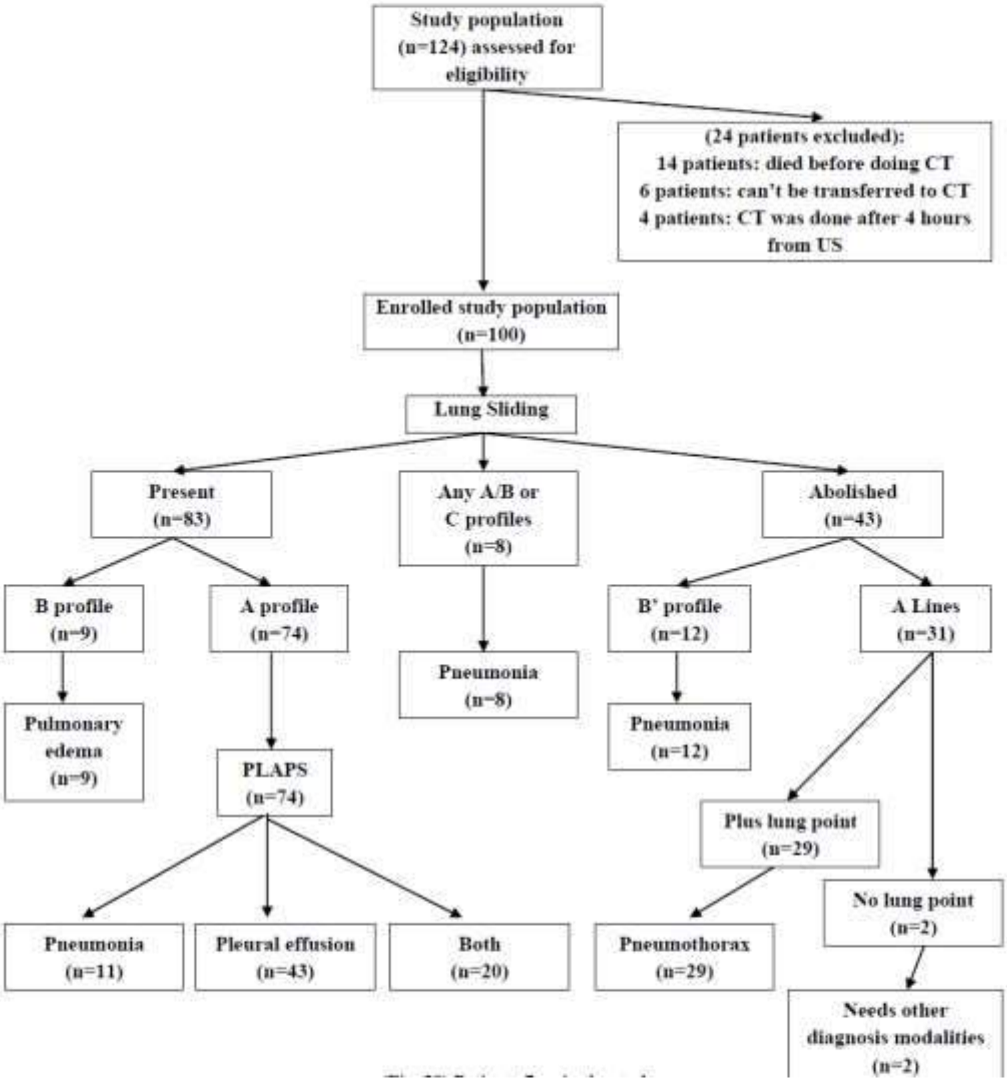
Diagnosis	Profile	No. (%)
Pleural effusion	A profile + PLAPS	63 (100%)
Pneumothorax	A' profile + Lung point	29 (100%)
Pneumonia	A/B profile	3 (6%)
	C profile	5 (10%)
	A profile + PLAPS	31 (60%)
	B' profile	12 (24%)
Pulmonary edema	B profile	9 (100%)

PLAPS: Postero-lateral alveolar or pleural syndrome

Table 4: Sensitivity, Specificity & Accuracy in diagnosing chest diseases

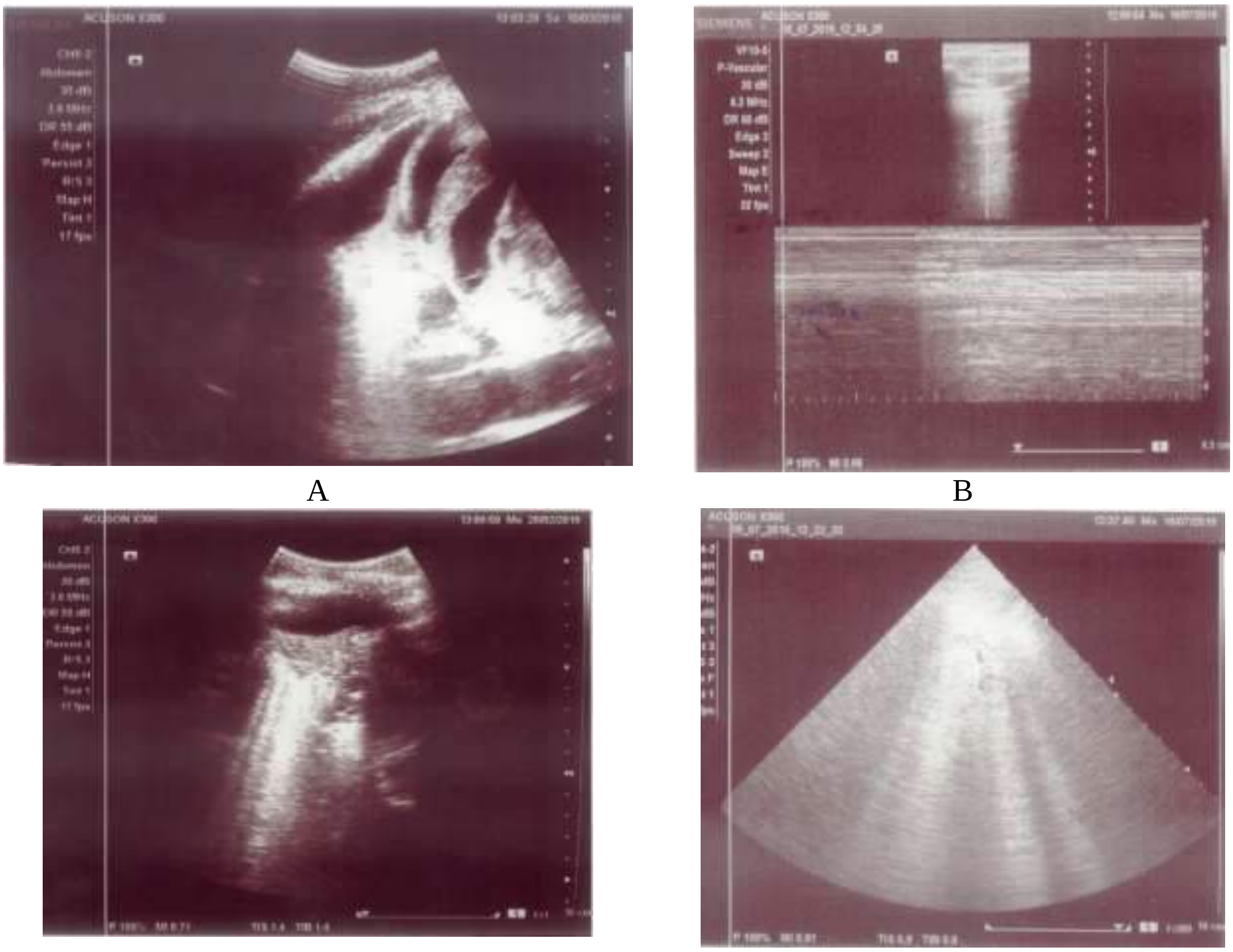
Disease	Radiology	Sensitivity %	Specificity %	PPV %	NPV %	LR+	LR-	Accuracy %
Pleural Effusion	Ultrasound	95.4%	97.1%	98.4%	91.8%	32.9	0.047	96%
	X-rays	70.7%	91.45%	93.8%	62.7%	8.27	0.32	78%
	Combination	98.5%	100%	100%	97.2%	_	0.015	99%
Pneumothorax	Ultrasound	87.5%	98.5%	96.5%	94.3%	58.3	0.063	95%
	X-rays	53.1%	98.5%	94.4%	81.7%	35.4	0.476	84%
	Combination	93.7%	98.5%	96.8%	97.1%	62.4	0.027	97%
Pneumonia	ultrasound	89.3%	97.7%	98%	87.8%	38.8	0.11	93%
	X-rays	60.7%	90.9%	89.4%	64.5%	6.67	0.43	74%
	Combination	94.6%	100%	100%	93.6%	_	0.054	97%
Pulmonary Edema	ultrasound	88.9%	98.9%	88.9%	98.9%	80.81	0.112	98%
	X-rays	33.3%	98.9%	75%	93.7%	30.27	0.674	93%
	Combination	100%	100%	100%	100%	_	0	100%
All study population	ultrasound	91.4%	98.3%	97.3%	94.4%	53.76	0.087	95.5%
	X-rays	61.7%	96.2%	91.7%	78.7%	16.23	0.398	82.2%
	Combination	96.3%	99.1%	98.7%	97.5%	107	0.037	98.2%

PPV: Positive predictive value
NPV: Negative predictive value
LR+: likelihood ratio of a positive test
LR-: likelihood ratio of a negative test



The A-profile: associates anterior lung-sliding with A-lines.
The A'-profile: is an A-profile with abolished lung-sliding.
The B-profile: associates anterior lung-sliding with lung-rockets.
The B'-profile: is a B-profile with abolished lung-sliding.
The C-profile: indicates anterior lung consolidation.
The A/B profile: is a half A-profile at one lung, a half B-profile at another.
The PLAPS-profile: designates Postero-lateral Alveolar and/or Pleural Syndrome.

Fig. 1. Patient flow in the study



A B

C D

Fig. 2. Lung ultrasound pictures from our patients: A: Septated pleural effusion, B: Lung point of Pneumothorax, C: Shred sign of pneumonia, D: B-profile of Pulmonary edema.

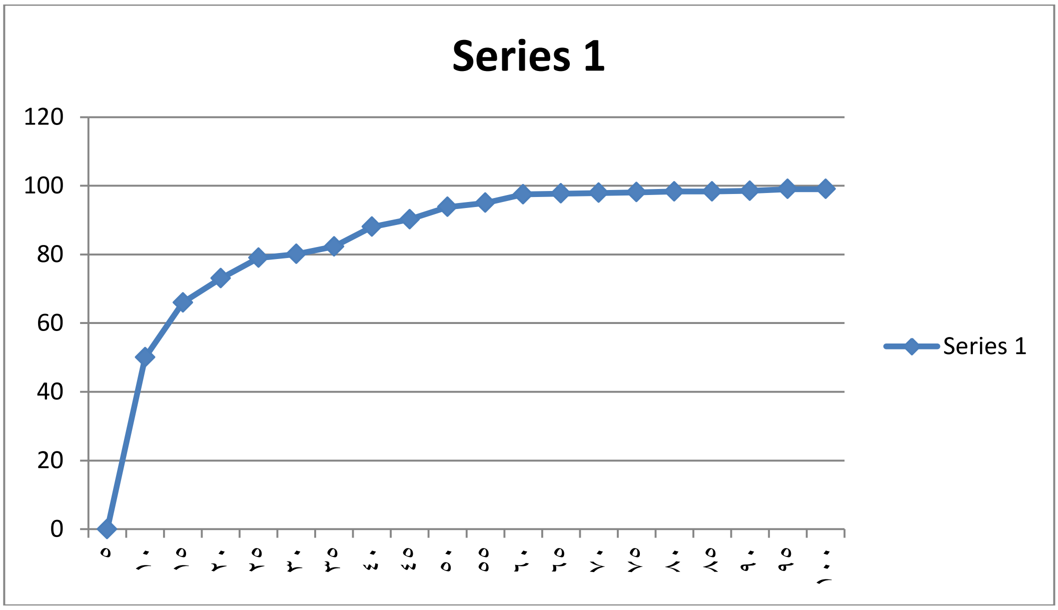


Fig. 3. **Learning curve of chest ultrasound.**

DISCUSSION

In the critically ill patients, adequate treatment depends on early and accurate detection of problem, but the diagnosis is not always easy from the early moments of presentation. Shortly after initial resuscitation, ICU team should combine the results of physical examination, laboratory and radiological investigations rapidly to achieve accurate diagnosis, definitive treatment and best outcomes (6). Although chest X-ray is the main imaging approach in many settings, many limitations exist for it e.g poor sensitivity. Chest CT scan remains the gold standard test in diagnosis of the most of chest diseases. Despite its higher diagnostic accuracy, it has many limitations. It is expensive, time consuming, impractical especially in the critically-ill patients, unsuitable with metallic prosthesis and has higher radiation exposure than chest X-rays (6, 7).

From the traditional point of view, air has been considered as a major obstacle of ultrasound. For long time, the lung has been considered an organ non-amenable to examination with ultrasonography. The main principle of lung ultrasonography is reduction of lung aeration with different diseases resulting in changing the lung surface and generating distinct profiles or patterns characteristic for each (6). The main advantages of ultrasound are that it is a relatively inexpensive, broadly available, rapid procedure, easily learned, and free from ionizing radiation or contrast. Chest ultrasound has comparable results with chest CT in some diseases and can supplement other imaging modalities of the chest and guides a variety of diagnostic and therapeutic interventional procedures (8).

Pleural effusion is a common problem in ICU patients with a variable range of incidence from 8% to 60%. Correlation of results of physical examination and chest radiograph in spite of decreased sensitivity and specificity was the only available method for diagnosis. So a new modality in diagnosis with high sensitivity and specificity is needed especially with positioning limitations for chest X-rays (9).

In our study, we found that, sensitivity, specificity and diagnostic accuracy of lung ultrasound in diagnosing pleural effusion were 95.4%, 97.1% and 96% respectively. While, sensitivity, specificity and diagnostic accuracy of chest X-rays in diagnosing pleural effusion were 70.7%, 91.45% and 78% respectively.

Our results were similar to the results obtained by El Mahalawy et al in 2017, including 130 mechanically ventilated and non-mechanically ventilated patients with thoracic ultrasound sensitivity of 94% and a specificity of 96% in comparison to 70% sensitivity and 90% specificity of chest X-rays (6).

In a meta-analysis done by Michiel Winkler et al in 2018, included 10 full text studies with 543 patients, with chest radiograph overall sensitivity of 49% (95% CI, 40-58%) and specificity of 92% (86-95%). In seven studies of this meta-analysis, lung ultrasound overall sensitivity was 95% (92-96%) and specificity was 94% (90-97%) (10).

The incidence of pneumothorax among mechanically ventilated patients is high and is considered as one of the most serious complications of positive pressure ventilation. Pneumothorax may be present in poly-trauma patients especially with chest trauma. However, unfortunately, it may be iatrogenic due to central venous catheter insertion, thoracocentesis and with positive pressure ventilation and all may necessitate chest tube insertion for drainage (6).

Throughout our study we found that chest ultrasound had a sensitivity of 87.5%, specificity of 98.5% and accuracy of 95% compared to 53.1%, 98.5% and 84% respectively for chest X-rays in diagnosing pneumothorax.

The results in our study matched with El Gendy et al in 2018 on 192 patients. The chest ultrasound showed a considerable higher sensitivity than bedside chest X-rays (86.1% versus 52.7%), it also showed higher, negative predictive values (96.8% versus 90.1%), and diagnostic accuracy (95.3% versus 90.6%). However, chest X-rays had a slightly higher specificity than lung US (99.4% versus 97.4%), and higher positive predictive values (95.0% versus 88.6%) (11).

In contrast to Hyacinthe et al in 2012 on 119 patients with chest trauma, sensitivity of chest ultrasound to pneumothorax was 53% [12].

Many meta-analysis studies showed results matching with our study results like Ding et al in 2011 with sensitivity and specificity of chest ultrasound of 88% and 99% respectively [13] and Alrajab et al in 2013 with US sensitivity and specificity of 78.6% and 98.4% respectively [14].

Pneumonia has high incidence in ICU patients either newly developed or related to the cause of admission. Nowadays, lung ultrasound represents a dependable diagnostic modality for pneumonia [6]. In our study, Sensitivity and specificity of ultrasound was higher than chest X-rays in diagnosing pneumonia (89.3% versus 60.7%) and (97.7% versus 90.9%) respectively.

These results were similar to Nazerian et al in 2015 on 285 patients with sensitivity and specificity for diagnosing pneumonia significantly higher with ultrasound than chest X-ray (81% versus 64%) and (94% versus 90%) respectively. Also, our results coincided with Cortellaro et al in 2012 on 120 patients who stated that the sensitivity and specificity was significantly higher with ultrasound than chest X-ray (99% versus 67%) and (95% versus 85%) respectively [6, 15, 16].

However on the other hand El khayat and Alam Eldeen in 2014 conducted a study on 62 patients and found that chest ultrasound was diagnostic in 46 (74%) patients. This difference in accuracy might be attributed to the fact that transthoracic ultrasound technique allows identification of areas of consolidation only when they are connected to the pleural surface [17].

Pulmonary edema is a life-threatening condition (either cardiogenic or non-cardiogenic) that shows fluid accumulation in the lung parenchyma and air spaces impairing gas exchange which may be the cause of ICU admission or newly develop in the ICU. Although heart failure is common, there is considerable uncertainty about the incidence of acute cardiogenic pulmonary edema [18].

Lung US offers a new tool for bedside diagnosis of pulmonary edema. In lung US, the B-line is always a comet-tail artifact, always arises from the pleural line and always moves in concert with lung-sliding. Briefly, air and water are simultaneously hit by ultrasound beams, as occurring when sub-pleural interlobular septa are edematous. Three or more B lines between two ribs are called lung-rockets [6].

Throughout our study, sensitivity and specificity of chest ultrasound and chest X-rays in comparison to chest CT were (88.9% versus 33.3%) and (98.9% versus 98.9%) respectively.

Our results agreed with El Mahalawy et al in 2017 who stated that chest ultrasound sensitivity and specificity were 93% and 93% respectively. While, chest X-rays sensitivity and specificity were 36% and 90% respectively [6].

Another study conducted by Xirouchaki et al in 2011 on 42 mechanically ventilated patients scheduled for CT with prospectively studying them with a modified lung ultrasound protocol. They concluded that, sensitivity, specificity and accuracy of chest ultrasound in diagnosing interstitial syndrome were 94%, 93% and 94% respectively. While, sensitivity, specificity and accuracy of chest X-rays in diagnosing interstitial syndrome were 46%, 80% and 58% respectively [19].

In the current study, the overall sensitivity, specificity and diagnostic accuracy of chest ultrasound and chest X-rays of all population of the study, whatever diagnosis, were (91.4% versus 61.7%), (98.3% versus 96.2%) and (95.5% versus 82.2%) respectively.

These results matched with many studies e.g Agmy et al in 2018 who found the overall sensitivity and specificity of chest ultrasound were 93.2% and 100% respectively and Lichtenstein et al in 2015 who found the overall sensitivity and specificity of chest ultrasound ranging 90% and 100% respectively [20, 21].

Limitations of the study: This study has some limitations. Firstly, a relatively small number of patients were studied. However, we overcome this by diagnosing more than one disease in the same patient. Secondly, the time interval between lung ultrasound and CT could not be controlled, and was up to 4 hours in some cases. This might contribute to the observed discrepancy between methods. Thirdly, patients were positioned laterally for ultrasound examination, and this might change the localization of some abnormalities (i.e., pleural effusions). The use of the micro-convex probe facilitates semi-posterior analyses with minimal or no patient mobilization. Finally, it is important to say that the lung ultrasound operator was not blind concerning clinical presentation of patients.

Conclusion: Chest ultrasound is reliable, quick, bedside, low-cost, non-invasive, non-ionizing, more accurate, and easily educated for early detection of chest diseases and their follow up.

Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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