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The Accuracy of Lung Ultrasonography Versus Chest Radiography for Diagnosis and Follow-up of Pneumonia in Critically Ill Patients

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Abstract

Background: Pneumonia is a common and serious infectious disease that can cause high mortality. Lung ultrasonography is being increasingly utilized in emergency and critical settings. The role of Lung Ultrasound (LUS) in the diagnosis and follow-up of pneumonia is becoming more and more important.

Aim of the Work: To compare the diagnostic accuracy of LUS against a referent Chest X-Ray (CXR), chest contrast-enhanced Computerized Tomography (CT) scan and/or clinical criteria for diagnosis and follow-up of pneumonia in critically ill adult patients.

Patients and Methods: We enrolled 32 (11M, 21F) multimorbid patients aged 61.31 ± 12.13 years from March 2016 to October 2016. Each participant underwent CXR and bedside LUS within 6 hours from Intensive Care Unit (ICU) admission. LUS was performed by skilled clinicians, blinded to CXR results and clinical history. The final diagnosis (pneumonia vs. no-pneumonia) was established by another clinician reviewing clinical and laboratory data independent of LUS results and possibly prescribing chest contrast-enhanced CT. Diagnostic parameters of CXR and LUS were compared.

Results: 28 patients (87.5%) out of 32 patients with positive LUS had a final diagnosis of pneumonia. LUS was falsely positive in two cases (6.2%) and false negative in two patients (6.2%). The sensitivity and the specificity of LUS were 87.5% (95% CI 78.9-92.7%) and 89.3% (95% CI78.3-91.9%) respectively.

Conclusion: The study supports that LUS when conducted by highly-skilled sonographers, performs well for the diagnosis of pneumonia. Intensivist and Emergency Medicine physicians should be encouraged to learn LUS since it appears to be an established diagnostic tool in the hands of experienced physicians.

Key Words: *Pneumonia – Lung ultrasound – Chest X-Ray – Chest contrast – Enhanced computerized tomography.*

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Introduction

PNEUMONIA is a major health problem worldwide, failure of early detection and distribution of treatment may lead to significant morbidity and mortality [1]. Despite the rapid advances of therapeutic strategy, community-acquired pneumonia (CAP), Hospital-Acquired Pneumonia (HAP) and Ventilator-Associated Pneumonia (VAP) remain a dramatic clinical burden. It has been well-documented that timely administration of antibiotics to patients admitted with pneumonia improves prognostic outcome [2].

The diagnosis of pneumonia can be difficult and challenge in the emergency setting or in critically ill patients. Many of the commonly used radiological signs are non-specific [3].

In daily practice, pneumonia diagnosis is based on clinical presentation through patient history and physical exam, plus radiological imaging commonly chest X-ray (and infrequently CT scan) that may help to confirm the diagnosis particularly with equivocal clinical status. Early diagnosing of pneumonia is very important to promptly start the treatment; otherwise, it can be life-threatening or associated with high morbidity particularly in critically ill patients who need immediate decision [4].

The signs and symptoms localizing to the respiratory system, commonly referring as dyspnea, cough and fever, laboratory alterations (leukocytosis and increased C-reactive protein/procalcitonin) in conjunction with radiographic pulmonary infiltrates, point to a convincing diagnosis of pneumonia. Imaging evaluation approaches recommended on current guidelines are chest radiograph and chest CT.

Thoracic CT scan is considered the "gold standard" for detection of pneumonia and other pulmonary lesions, but it cannot be used as a first-line radiological examination in all patients with suspected pneumonia. This is mainly due to the fact that it is often costly, not a bedside technique and that it involves a high radiation dose [5].

Relatively recently, lung ultrasound was promoted as a modality that can overcome many of the above-mentioned limitations of other tools in the diagnosis of pneumonia in multiple settings [6]. In the last 2 decade, the ultrasound has shown that it could play a major role in medicine and common practice in assessing the lung [7].

Traditionally, the accessibility of the lung by ultrasound was considered poor due to the air barrier. However, this position has been dramatically changed with the tremendous amount of literature supporting the use of LUS in multiple conditions [8]. This diagnostic tool can be used easily and immediately as a bedside tool which gives it a huge advantage [9]. Lung ultrasound was reported with high accuracy in many pathological lung conditions such as consolidation, pleural effusion, and interstitial syndrome compared to bedside chest radiography [10].

The aim of our study is the diagnostic power of lung ultrasound versus chest radiological imaging specially CXR for the diagnosis and follow-up of pneumonia in adult population through estimation of the pooled diagnostic accuracy measures.

Patients and Methods

The study was conducted from March 2016 to October 2016 on 32 patients admitted to ICU in Aswan University Hospital suspected of pneumonia by history and physical examination, after recording a written consent.

All patients underwent: Complete history taking, thorough general and local chest examination, laboratory investigation including. CBC, ESR, renal and hepatic profile, CURB-65 score assessment, plain chest radiography, computerized tomography chest scan, and transthoracic ultra-sound were done for all patients.

Criteria for pneumonia diagnosis:

- Suggestive history (fever, cough, sputum production, dyspnea).
- General and local physical signs suggestive of pneumonia.

Criteria for I. C. U admission: CURB-65 score ≥3:

CURB-65 score: The score is an acronym for each of the risk factors measured. Each risk factor scores one point, with a maximum score of 5 [11].

- Confusion of new onset.
- Urea greater than 7mmol/l (19mg/dL).
- Respiratory rate of 30 breaths per minute or greater.
- Blood pressure less than 90mmHg systolic or 60mmHg diastolic.
- Age 65 or older.

Exclusion criteria: Pregnant women were excluded because of the restrictions in the use of CT chest which is required in the study.

Lung ultrasonography was performed before and within 3h from chest CT by one of the investigators who participated in the study. The investigators were intensivists with at least 5 years' experience on point-of-care emergency ultrasonography.

The investigator was aware of the presenting symptoms and the evident physical signs but was blinded to all the other general clinical information including any radiologic finding and laboratory results.

LUS was performed using PHILIPS ultrasound machine (Clear Vue 350) with a 3-to 6MHz convex transducer and was targeted to evaluate lung consolidations with the morphologic characteristics of pneumonia.

Chest radiography was performed using Practix 300 Bucky diagnostic equipment (Philips Medical Systems, Hamburg, Germany) by posterior-anterior and lateral views in the upright patients and anterior-posterior view in the supine patients, following standardized hospital diagnostic protocol. The film was digitally reviewed by an expert radiologist blinded to the results of LUS and CT.

The radiologist had the possibility to review also the previous CXR, when available, as part of standard clinical care. The radiologist was asked to detect and locate the opacities that might correlate with the diagnosis of pneumonia. CXR was considered positive when at least one typical consolidation was visualized.

Chest CT was performed by one Somatom Definition AS 128 (Siemens, Erlangen, Germany), only for clinical purposes independent of the study protocol. An expert radiologist blinded to LUS and

CXR results reviewed the studies investigating one or more consolidations related to pneumonia, defined as a homogeneous increase in pulmonary parenchymal attenuation obscuring the margins of vessels and airway walls, with or without air bronchograms.

Statistical analysis:

The sample size was calculated considering a prevalence of pneumonia of 50% among suspected patients in ED and a sensitivity of LUS for the diagnosis of pneumonia when chest CT was used as the gold standard of 80%. Data analysis using SPSS "Ver. 23" and Fisher exact test to compare between categorical variables.

Results

In this study, 32 patients were included in the final analysis. These patients had a mean age of 61.31 ± 12.13 years (range 29.0-65.0) and 21 (65.6%) were female.

The patient's characteristics according to the presence of pneumonia, alternative diagnoses in patients without pneumonia are reported in (Tables 1,2).

Table (1) shows demographic data and clinical assessment in the study group. With a mean of age 61.31 years and there were (65.6%) female vs. (34.4%) male. As regard, there were (25%) of patients confused vs. (75%) of patients were normal.

Fig. (1) shows that lung ultrasonography was feasible in all patients, but in 2 cases (6.2%) included in the study, the pulmonary examination was limited mainly due to uncooperative patients. 28 patients (87.5%) out of 32 patients with positive LUS had a final diagnosis of pneumonia. LUS was falsely positive in two cases (6.2%) and false negative in two patients (6.2%). The sensitivity and the specificity of LUS were 87.5% (95% CI 78.9-92.7%) and 89.3% (95% CI 78.3-91.9%) respectively.

Fig. (2) shows chest radiography was performed with positive CXR in 26 out of 32 patients (81.25%), who had a final diagnosis of pneumonia. CXR showed false-negative examination with no abnormal findings in 6 (18.75%) patients and false positive examination in 2 (6.2%) patients. The sensitivity was 81.25% (95% CI 73.8-95.6%).

LUS maintained a high diagnostic accuracy, but CXR did not (p=0.000) where thoracic CT was used as the gold standard for diagnosis of pneumonia. Inter-observer agreement for LUS, calculated in a subsample of 32 patients, was high (k=0.88).

Table (3) shows the relationship between the assessment of improvement by ultrasonography & CXR after 1 week. There was a non-significance difference between assessment by ultrasonography & CXR (p>0.05), with an agreement in (75%) at not improvement between ultrasound & CXR after 1 week although the diagnostic accuracy of LUS is higher.

Table (4) shows the relationship between the assessment of improvement by ultrasonography & CXR after 2 weeks. There was a non-significance difference between assessment by ultrasonography & CXR (p>0.05), with an agreement in (75%) at improvement between ultrasound & CXR after 2 weeks.

Table (1): On admission: Demographic data & clinical assessment in the study group.

Item	Descriptive "n=32"
1- Age "years"	61.31 ± 12.13
2- Sex:	
Female	21 (65.6%)
Male	11 (34.4%)
3- SBP (Systolic Blood Pressure)	93.28 ± 18.21
4- DBP (Diastolic Blood Pressure)	58.59 ± 14.09
5- Pulse	104.97 ± 9.26
6- Temperature	38.03 ± 0.56
7- Respiratory rate	33.25 ± 4.22
8- Conscious level:	
Confused	8 (25.0%)
Normal	24 (75.0%)

SBP : Systolic Blood Pressure.
DBP : Diastolic Blood Pressure.

Table (2): On admission: Laboratory & arterial blood gas assessment in the study group.

Item	Descriptive "n=32"
1- WBCs	12884.2 ± 5282.11
2- Hb	12.09 ± 2.11
3- ESR	80.96 ± 25.35
4- Bun	18.71 ± 5.34
5- PH	7.47 ± 0.4
6- PaO2	63.75 ± 1 5.38
7- PaCO2	32.84 ± 8.00
8- HCO3	23.49 ± 3.16
9- SaO2	92.46 ± 7.30

WBC : White Blood Cell.
HB : Hemoglobin.
ESR : Erythrocyte Sedimentation Rate.
Bun : Blood urea nitrogen.
PaO2 : Partial pressure of arterial oxygen.
PaCO2 : Partial pressure of arterial carbon dioxide.
HCO3 : bicarbonate in blood.
SaO2 : Arterial oxygen saturation.

Table (3): Relation between assessment of improvement by ultrasonography & CXR after 1 week.

CXR	By ultrasonography			p-value
	NAD "n=2"	Improved "n=14"	Not improved "n=16"	
NAD	1 (50.0%)	1 (7.1%)	4 (25.0%)	p<0.101
Improved	0.0	4 (28.0%)	0.0	
Not improved	1 (50.0%)	9 (64.3%)	12 (75.0%)	

Table (4): Relation between assessment of improvement by ultrasonography & CXR after 2 weeks.

CXR	By ultrasonography			*p*-value
	NAD "n=2"	Improved "n=28"	Not improved "n=2"	
NAD	1 (50.0%)	4 (14.3%)	1 (50.0%)	*p*=0.101
Improved	1 (50.0%)	21 (75.0%)	0.0	
Not improved	1 (50.0%)	3 (10.7%)	1 (50.0%)	

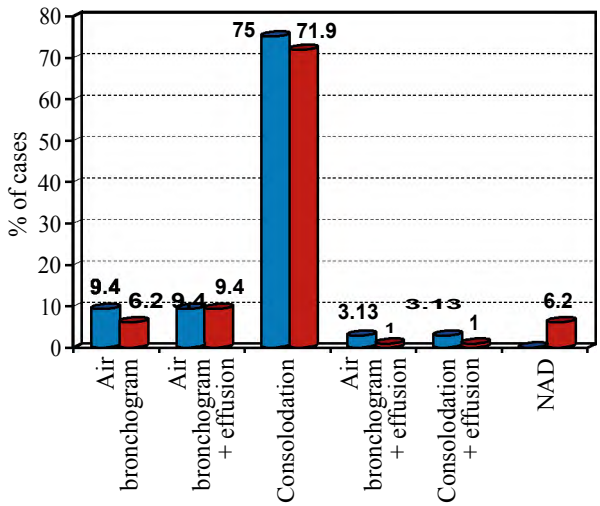

Fig (1): Chest CT vs. LUS assessment upon admission in study group.

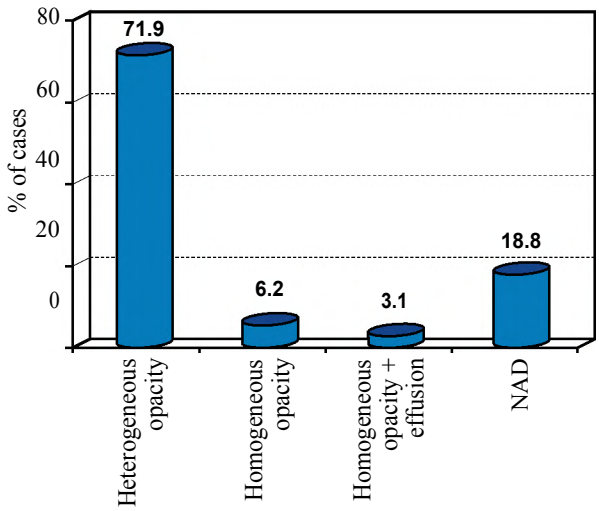

Fig. (2): Finding on admission X-ray assessment in the study group.

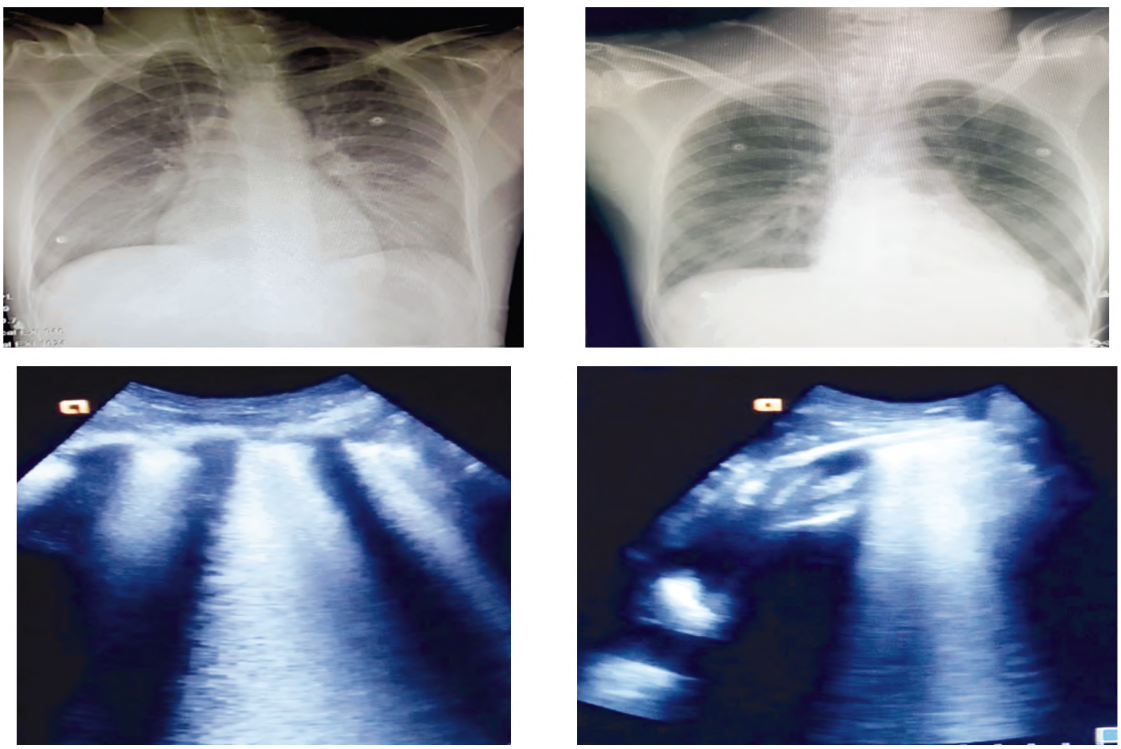

Fig. (3): 30 years old male patient presented by a picture of right lower lobe pneumonia and sepsis secondary to open infected wound post motor car accident and (Right), then after a completed antibiotic course, pneumonia resolved (Left).

Discussion

Thoracic CT scan is considered the "gold standard" for detection of pneumonia and other pulmonary lesions, but it cannot be used as a first-line radiological examination in all patients due to its high radiation dose and high cost, especially in critically-ill patients whose conditions usually change sharply and require repeated examinations to guide the interventions [1]. Our analysis confirmed the precise diagnostic accuracy of LUS on the detection of pneumonia. The following four signs are the major abnormalities linking to pneumonia under LUS: Interstitial syndrome; abnormal pleural line; alveolar consolidation and pleural effusion. Liu et al., compared different combinations of LUS patterns and found that combining four ultrasonographic signs led to the highest sensitivity (94.6%) for diagnosing CAP [12].

The routine application of LUS in this setting may significantly improve the diagnosis. The technique is very easy to perform, not time-consuming, rapidly available at the bedside and does not expose patients to ionizing radiation. Moreover, it can be easily learned by clinicians with a standard level of ability to handle an ultrasound probe for abdominal scans [13].

Several studies have demonstrated the superiority of LUS performed by Emergency Department physicians over standard CXR in the differential diagnosis of acute respiratory symptoms [14]. This technique can provide reliable diagnostic information even when performed by trained nurses in a busy emergency department setting, in the presence of a specific diagnostic question. Other studies have investigated the diagnostic performance of LUS in an internal medicine ward setting [15].

In the present study, interobserver agreements for LUS were (88.7%). This in agreement with Timmons et al., [16] who demonstrated that LUS was highly accurate in the detection of parenchymal consolidation in patients with acute respiratory failure admitted to ICUs. Xirouchaki et al., reported that the diagnostic performance of LUS is, in fact, superior to that of CXR in this setting and even comparable to that of contrast-enhanced [17].

Andrea et al., [13] were in agreement with our results as LUS maintained a high diagnostic accuracy, but CXR did not (p=0.0003). Interobserver agreement for LUS, calculated in a subsample of 29 patients, was high (k=0.90).

CT has the ability to detect pulmonary edema, asthma, COPD, and to raise the clinical suspicion of pulmonary embolism [10].

In the present study, the sensitivity of LUS was 87.5% vs. CXR 81.25%. This agrees with Nazerian et al., (2015) who reported in their study that LUS showed to be an accurate bedside tool for the diagnosis of pneumonia. Nazerian et al., [18] found that sensitivity of LUS alone ruled in pneumonia with a good positive (85.2%) likelihood ratio and ruled out this condition with a moderate negative likelihood ratio. The superiority of LUS over CXR is reported in literature done by Shah et al., [19].

The use of this technique is also supported by the rapidity and probably by cheapness, although no studies have investigated the cost-effectiveness of LUS implementation in medical wards to date. Considering it is a bedside, reliable, rapid and noninvasive technique, LUS plays a critical role in the diagnostic workup of pneumonia in ICU and in patients from ED where usually asks for immediate decisions [20].

Execution rapidity, non-invasively and low cost make LUS a striking approach of evaluating pneumonia on different types of patients. Also, experienced physicians in 13 studies verses sonographers in only one study performed the LUS and they achieved identical results, implying the learning curve of LUS is not steep. However, the training time was extremely varied, ranging from several hours' course to ten years' clinical practice. Besides, it is noteworthy to highlight the situations that related to false positive and false negative results. In addition, Quantitative LUS (QLUS) was evident to be an impressive approach to pneumonia detection, showing a higher sensitivity and specificity than regular LUS [21,22].

In conclusion, the results of this study introducing QLUS for detection of community-acquired pneumonia are encouraging as this technique allowed recognizing 30 out of 32 (93.75%) cases of pneumonia diagnosed by CT. It cannot be expected that LUS will replace CT as the gold standard for the diagnosis of pneumonia because it does not provide a precise estimate of the size of consolidation and a whole assessment of both lungs. Nevertheless, LUS might become a suitable method for confirming the clinical diagnosis and for bedside monitoring of patients with community-acquired pneumonia as a useful complement to visual LUS with a significant increase of diagnostic accuracy.

Limitations of study:

There are some limitations to our analysis. We did not include articles in languages other than English, and did not try to identify studies that haven't published in peer-reviewed journals; the total number of studies was small and most studies included in our analysis did not have a large sample size; there was significant heterogeneity among studies; most were single-center studies and were conducted in settings from high-income countries. Despite all of these limitations, we have also to consider that it is not known if the consolidation identified at chest CT was due to bacterial, viral or other germ infection. Regarding the comparison between LUS and CXR, a consideration should be done on the criteria of enrolment. In fact, the patients enrolled in the study underwent chest CT once the physician was aware of CXR results, and this could have selected a population with not diagnostic CXR. Thus, these criteria probably affected the low sensitivity of CXR. However, in the real practice, the role of LUS is often to confirm negative chest films in patients with high suspicion of pneumonia.

In conclusion, based on currently available evidence, LUS is a valid alternative for diagnosing pneumonia in adults. This is a beginning of a new trend and a convenient bedside tool for diagnosis of a common health problem.

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دقة التصوير بالموجات فوق الصوتية للرئة مقابل الآشعة العادية والتصوير المقطعى للصدر لتشخيص ومتابعة الإلتهاب الرئوى للمرضى ذوى الحالات الحرجة

الإلتهاب الرئوى هو مرض شائع وخطير يمكن آن يسبب الوفاة. وقد آصبح دور الموجات فوق الصوتية الرئوية (LUS) فى تشخيص ومتابعة الإلتهاب الرئوى آكثر وآكثر آهمية حيث يتم إستخدامها بشكل متزايد فى حالات الطوارئ والظروف الحرجة.

وفى هذا البحث نقارن الدقة التشخيصية للموجات فوق الصوتية الرئوية مقابل الآشعة العادية للصدر(CXR) والتصوير المقطعى للصدر (CT) لتشخيص ومتابعة الإلتهاب الرئوى فى المرضى البالغين ذوى الحالات الحرجة.

وتدعم الدراسة آن الموجات فوق الصوتية الرئوية عندإجرائها من قبل ذوى المهارات العالية فى التصوير بالموجات فوق الصوتية للرئة يؤدى بشكل جيد لتشخيص الإلتهاب الرئوى. لذلك ينبغى تشجيع آطباء الطب المكثف وطب الطوارئ على تعلم الموجات فوق الصوتية الرئوية حيث يبدو آنها آداة تشخيصية ثابتة.