# Effectiveness of Lung Ultrasound in Comparison with Chest X-Ray in Diagnosis of Lung Consolidation

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## Abstract

**BACKGROUND:** Lung ultrasound (US) is an available and inexpensive tool for the diagnosis of community-acquired pneumonia (CAP); it which has no hazards of radiation and can be easily used.

**AIM:** To evaluate the efficacy of lung ultrasound in the diagnosis and follow-up of CAP.

**PATIENTS AND METHODS:** 100 patients aged from 40 to 63 years with a mean age of 52.3 ± 10 years admitted to the Critical Care Department, Cairo University with pictures of CAP. Lung US was performed for all patients initially, then a plain chest X-ray (CXR) was performed. Another lung ultrasound was performed on the 10th day after admission.

**RESULTS:** Initial chest X-ray was correlated with the initial chest ultrasound examination in CAP diagnosis (R-value = 0.629, P < 0.001). Cohen's κ was run to determine if there is an agreement between the findings of the initial chest X-ray findings and those of the initial chest ultrasound in CAP diagnosis. A moderate agreement was found where κ = .567 (95% CI, 0.422 to 0.712) and P < 0.001. Upon initial examination, the CXR diagnosed CAP in 48.0% of patients, while lung US diagnosed the disease in 70% of patients. Moreover, lung US was more sensitive than CXR (P-value < 0.001). Compared to the accuracy of computed tomography (CT) chest (100%) which is the gold standard for CAP diagnosis, the accuracy of lung US was 95.0%, while the accuracy of CXR was 81.0%.

**CONCLUSION:** This study proved the effectiveness of lung ultrasound in CAP diagnosis.

## Introduction

Acute pneumonia is considered as a fatal infectious disease in the Western world which frequently leads to sepsis and septic shock.

Nowadays, lung ultrasound (US) can be used in the diagnosis of many chest diseases such as pneumothorax, cases of pneumonia, pleural effusions, and pulmonary contusions [4], [5], [6].

The current study aimed to evaluate the efficacy of lung ultrasound in diagnosing community-acquired pneumonia (CAP) in comparison with chest X-ray (CXR).

## Patients and Methods

This study is a prospective observational study which was conducted on 100 consecutive patients with suspected CAP who were admitted to the Critical Care Department at Cairo University. The study was conducted after the approval of the ethical committee of the Faculty of Medicine, Cairo University.

All patients were admitted from the emergency department to the hospital in the period from December 2014 to January 2016.

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### Inclusion criteria

Patients whose age > 18 years and those who were presenting with symptoms of chest infection (e.g. Dyspnea, cough, expectoration, fever, tachypnea and tachycardia) were included in the study.

### All patients upon admission are subjected to:

- Detailed history taking

- Screening of the symptoms of dyspnea, cough, expectoration and fever

- Demographic data collection including age and gender

- Clinical examination for fever, rales, wheezes, heart rate, and respiratory rate. In this study, fever is considered significant if temperature > 38 c, tachycardia is considered significant if the heart rate > 100 bpm, and tachypnea is considered significant if the respiratory rate > 30 bpm

- Routine labs including liver functions where liver impairment is considered significant if the liver enzymes elevated more than 3 folds or the liver functions are impaired, and kidney functions are considered impaired if creatinine > 2gm/l or the patient is oliguric (urine output < 0.5 ml per hour)

- Complete blood count where anaemia is considered significant if Hb < 10gm/dl, leukocytosis is considered significant if WBCs > 11000/cc, and C-reactive protein (CRP) where it is considered significant if above 10

- Electrocardiogram (ECG)

### Chest X-ray

Plain CXR was done in anteroposterior and lateral views using a portable machine most of the time.

The presence of air bronchogram or localised opacity in the lung field was considered positive for CAP.

### Lung Ultrasound

A 3.5 to 5.0 MHz transducer with a convex sector design was used.

We used an ultrasound machine manufactured by Philips Affinity 70 in most of the cases and other cases, and we used cardiac transducer. Hypoechogenic lung lesions, bronchogram sign (i.e. hyperechoic area within the consolidation), and the lung respiratory mobility impairment (absence or decrease of "lung sliding") all help to diagnose lung consolidation.

Pleura was taken into consideration, if it exists, in diagnosing parapneumonic effusion.

We measured the hypoechoic lung lesion, both longitudinally and sagittally.

- High-resolution computed tomography (CT) chest without contrast was performed only if the chest X-ray was negative, and the lung ultrasound was positive for consolidation.

### Statistical methods

Data were statistically described in terms of mean and standard deviation for quantitative data and terms of frequencies (number of cases) and relative frequencies (percentages) for qualitative data. Comparison of quantitative variables was made using the unpaired t-test. For comparing categorical data, Chi-square ($\chi 2$) test was performed. Exact test was used instead when the expected frequency is less than 5. Logistic regression was done to identify models for detecting the cardiac disease as a cause of dyspnea using ultrasound, modified Boston criteria, and pet $CO_2$. Predicted values by different models were calculated and compared with the actual state using receiver operator characteristic (ROC) curves. Area-under-the curve (AUC) and 95% confidence interval were used to determine the model accuracy. Sensitivity, specificity, negative predictive value (NPV), positive predictive value (PPV), positive likelihood ratio (LR+), and negative likelihood ratio (LR-) were estimated in every model. ROC curves and AUC analysis were used to get the best cut-off values for detecting the cause of dyspnea in numerical data. Odds ratios (ORs) and 95% confidence interval (CIs) were calculated to examine the risk of a cardiac cause of dyspnea. A probability value (P-value) less than 0.05 was considered statistically significant. Cohen k is a value that measures the agreement between both sides. All statistical calculations were done using SPSS (Statistical Package for the Social Science; SPSS Inc., Chicago, IL, USA) version 21.

## Results

All patients were subjected to full history taking, full clinical examination, lab tests including WBCs and CRP, plain CXR, and Lung US. Only selected cases were subjected to CT chest. Accordingly, patients proved to have CAP were categorised as Group 1, while patients without CAP were categorized as Group 2. All the study patients (100) were subjected to initial (on admission) plain CXR. Consolidation was detected in 48 patients; 25 of them had the consolidation in the Rt lung, 16 in the Lt lung, and 7 patients had bilateral lung consolidation, as shown in Table 1.

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**Table 1: Site and percentage of consolidation**

| Patients with Consolidation | Number | Percentage |
|---|---|---|
| Rt side | 25 | 52.1 % |
| Lt side | 16 | 33.3% |
| Bilateral | 7 | 14.6% |
| Total | 48 | 100 % |

There was a significant difference between the number of males and that of females whose chest X-rays were positive for consolidation where the number of affected males was 17, and the number of affected males were 31 with P-value = 0.049. Moreover, there was a significant difference between diabetic and non-diabetic patients whose chest X-rays were positive for consolidation where the number of diabetic patients having consolidation was 19, and the number of non-diabetic patients having consolidation was 29 with P-value = 0.036.

**Table 2: Correlation between positive initial CXR and demographic data**

| | Positive | Negative | P-value |
|---|---|---|---|
| Gender (female) | 31(56.4%) | 17 (37.8%) | 0.049 |
| Diabetic | 19 (63.3%) | 29 (41.4%) | 0.036 |
| Smoker | 3 (25%) | 45 (51.1%) | 0.081 |

### I – Lung ultrasound

Lung ultrasound was done for all patients irrespective of the chest X-ray result. It was found that lung US was positive for consolidation in 70 patients where it shows consolidation in the Rt side in 39 patients, Lt side in 18 patients, and bilateral in 13 patients.

**Table 3: Number and percentage of patients with positive lung ultrasound**

| Positive Initial Lung US | Number | Percentage |
|---|---|---|
| Rt side | 39 | 55.7 |
| Lt side | 22 | 31.4 |
| Bilateral | 9 | 12.8 |
| Total | 70 | 100% |

There was a significant difference between males and females in terms of the proportion of cases with a positive finding in lung US suggestive of consolidation. This difference is shown in Table 3.

There was a significant difference between diabetic and non-diabetic patients in terms of the proportion of cases with a positive finding in the lung US suggestive of consolidation. This difference is shown in Table 2.

Furthermore, there was a significant difference between smokers and non-smokers in terms of the proportion of cases having a positive finding in the lung US suggestive of consolidation. This difference is shown in Table 4.

**Table 4: Correlation between positive initial lung ultrasound and demographic data**

| | Positive | Negative | P value |
|---|---|---|---|
| Gender (female) | 45 (81.8%) | 25 (55.6%) | 0.004 |
| Diabetic | 26 (86.7%) | 44 (62.9%) | 0.013 |
| Smoker | 12 (100.0%) | 58 (65.9%) | 0.010 |

### II- CT Chest

High-resolution CT chest was done for cases with positive lung US and negative CXR for consolidation. This was done for 22 patients, and it proved consolidation (CAP) in 17 patients, while the other 5 patients had negative CT chest for consolidation and hence not having CAP as shown in Table 5.

**Table 5: High-resolution CT chest**

| CT Chest showing consolidation | Number | Percentage |
|---|---|---|
| Positive | 17 | 77.3% |
| Negative | 5 | 22.7% |

### CAP and imaging

Initial imaging data (chest X-ray and lung ultrasound) were correlated with the diagnosis of CAP. The following table shows the correlation between the initial chest X-ray, initial chest ultrasound examination, and the diagnosis of CAP. Lung ultrasound showed a strong correlation with CAP diagnosis, while a chest X-ray showed a moderate correlation with CAP diagnosis, as shown in Table 6.

**Table 6: Correlation between initial CXR, lung US and CAP**

| Community-acquired Pneumonia | | |
|---|---|---|
| CXR (initial) | Correlation coefficient | 0.663 |
| | P value | < 0.001 |
| Lung US (initial) | Correlation coefficient | 0.892 |
| | P value | < 0.001 |

Initial chest X-ray was correlated with the initial chest ultrasound examination in diagnosing CAP (R-value 0.629, P-value < 0.001). Cohen's κ was run to determine if there is an agreement between the findings of initial chest x-ray and those of the initial chest ultrasound in the diagnosis of CAP. A moderate agreement was found where κ = .567 (95% CI, 0.422 to 0.712) and P-value < 0.001.

**Table 7: Chest X-ray vs Lung Ultrasound**

| | Chest X-ray | Lung Ultrasound |
|---|---|---|
| Sensitivity | 72.3% | 100.0% |
| Specificity | 97.1% | 85.7% |
| PPV* | 97.9% | 92.9% |
| NPV** | 65.4% | 100.0% |
| Accuracy | 81.0% | 95.0% |

*PPV: positive predictive value; **NPV: negative predictive value.

Initial CXR diagnosed CAP in 48.0% of patients, while the initial lung US diagnosed CAP in 70% of patients. Lung US outperformed the CXR in diagnosing and excluding CAP upon initial examination. Besides, it was more sensitive than CXR (P-value < 0.001).

**Table 8: Chest X-ray vs Lung Ultrasound with demographic data**

| | | Chest x-ray | lung ultrasound |
|---|---|---|---|
| Gender(female) | Correlation coefficient | -0.185 | -0.285 |
| | P value | 0.033 | 0.002 |
| Diabetes | Correlation coefficient | 0.201 | 0.238 |
| | P value | 0.023 | 0.009 |
| Smoking status | Correlation coefficient | -0.170 | 0.242 |
| | P value | 0.045 | 0.008 |

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Compared to CT chest accuracy (100%), which is the gold standard in diagnosing CAP, the lung US accuracy was 95.0%, while the CXR accuracy was 81.0%.

It is noteworthy that both initial CXR and lung US assessments were correlated with diabetes status, female gender, and smoking status.

### *Follow-up*

Follow-up chest X-ray had a strong correlation with the follow-up chest ultrasound (P-value < 0.001). Besides, the follow-up chest X-ray and chest ultrasound were correlated with the clinical picture (P-value < 0.001).

**Table 9: Chest X-ray vs lung ultrasound after 10 days follow up**

| CAP after 10 days | | |
|---|---|---|
| CXR (follow-up) | Correlation coefficient | 0.896 |
| | P value | < 0.001 |
| Lung US (follow-up) | Correlation coefficient | 0.896 |
| | P value | < 0.001 |

Wilcoxon signed ranks test showed that there was a significant difference between the repeated chest X-ray assessment and the baseline one (P < 0.001). Moreover, Wilcoxon signed ranks test showed that there was a significant difference between the repeated lung ultrasound and the initial one (P < 0.001).

### *Multivariate Regression for Diagnosing Community-Acquired Pneumonia (CAP)*

Reviewing the significant correlations with CAP, multivariate regression showed that the initial lung ultrasound findings suggestive of CAP and CRP elevation were significant predictors of CAP.

The superiority of the lung US findings over CXR findings could be explained by the high sensitivity of Lung US in diagnosing CAP. However, the high specificity of CXR according to our results is due to depending on CXR in our methodology as a cornerstone in diagnosing CAP.

## Discussion

CAP is a leading cause of death. Effective treatment can markedly decrease mortality, which can be caused by this serious disease. However, the issue is that CAP can-not be easily diagnosed at presentation.

Using the lung ultrasound in the emergency department increase the efficacy and accuracy of CAP diagnosis.

Early and correct CAP diagnosis helps to start early and effective treatment. Hence, we can solve this serious issue or at least decrease the morbidity related to it.

In this study, we analysed the characteristic ultrasonography findings of CAP but concentrating only on consolidation for the diagnosis of the disease. Also, we compared the diagnostic sensitivity, specificity, and accuracy of ultrasonography with those of chest X-ray using CT chest as the gold standard in diagnosing pneumonia in the case of –ve CXR and +ve lung US.

In the current study, we found that lung US has a sensitivity of 100% and accuracy of 95% in CAP diagnosis compared to the sensitivity and accuracy of 72.3% and 81%, respectively for CXR.

The same fact was proved by Cortellaro et al., [6] and Parlamento et al., [8].

The results of our study go hand by hand with Emilia et al. 2016, and the same conclusion was achieved by Mengetal, 2014.

However, some studies have shown substantial variability in the interpretation of chest radiographs18 as well as the risk of cancer development after exposure to radiation in early life.

Reissig et al., [12] reported the first prospective study of CAP diagnosis in adults using ung US with an excellent sensitivity of 94% and specificity of 98%.

Recently published papers confirm the high efficacy and sensitivity of lung US.

In our study, we concentrated only on lung consolidation as the diagnostic finding in lung US to detect CAP although CAP can be detected from the interstitial infiltrate, which appears as ground-glass opacity on CT chest.

Lichtenstein et al., [26] concentrated on dynamic air bronchogram as a pathognomonic finding in lung US for CAP diagnosis.

Zhang M et al., [21] has found that the lung US is a rapid way to diagnose pneumothorax. These findings are along with Advanced Trauma Life Support (ATLS). Although lung ultrasound can detect pneumothorax, fluids, and lung contusion, still it is operator dependent.

We found that the assessment of the lung using ultrasound is an easy and rapid way to diagnose various lung diseases.

Although lung US was a new technique at the time of the study, it gained popularity later on and became an everyday practice in our department.

Currently, all physicians can perform lung US, especially after the advancement of critical care ultrasound which became a mandatory skill for every critical care physician.

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A study was performed by Chaves et al., [20] on how it is easy to learn and practice lung US.

### _Follow-up_

Follow-up after 10 days of admission CXR and lung US were correlated with the clinical picture.

The improvement in symptoms and signs were correlated with the improvement in CXR and lung US (correlation coefficient is 0.896 and P = 0.001).

We found a strong correlation between lung US and CXR during the follow-up.

The same results were achieved by Meng et al. 2014 [17], [20], [21].

In conclusion, our study proved that lung ultrasound is highly effective in the diagnosis and follow-up of lung consolidation. We recommend that lung ultrasound should be available in (ED) and that all doctors should be trained on how to deal with it easily.

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