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DIAGNOSTIC ACCURACY OF LUNG POINT-OF-CARE ULTRASONOGRAPHY FOR ACUTE HEART FAILURE COMPARED WITH CHEST X-RAY STUDY AMONG DYSPNEIC OLDER PATIENTS IN THE EMERGENCY DEPARTMENT

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☐ **Abstract—Background: Acute heart failure and exacerbation of chronic obstructive pulmonary disease (COPD) are sometimes difficult to differentiate in the emergency department (ED). Objectives: We sought to determine the classification performance of lung point-of-care ultrasound (POCUS) compared with chest x-ray study to identify acute heart failure in an older population. Methods: We conducted a cohort study with additional health records review between March and September 2017. We included consecutive patients aged 50 years and older with shortness of breath from suspected acute heart failure or COPD. The reference standard was discharged diagnosis, ED diagnosis with confirmation by another physician, or diagnosis made by health record reviews. We calculated the classification performance of lung POCUS to diagnose acute heart failure as well as that of chest x-ray study, and compared them by exact McNemar test. Results: There were 81 patients evaluated with lung POCUS, and 67 had acute heart failure. Emergency physicians identified acute heart failure by lung POCUS with sensitivity of 92.5% (95% confidence interval [CI] 83.4–97.5%) and specificity of 85.7% (95% CI 57.2–98.2%). The radiology reading of chest x-ray study had sensitivity of 63.6% (95% CI 50.9–75.1%) and specificity of 92.9% (95% CI 66.1–99.8%). The sensitivity of lung POCUS was significantly higher than that of chest x-ray study (p = 0.0003). Conclusions: Lung POCUS in a real clinical setting was highly sensitive and specific in identifying acute heart failure, and performed better than chest x-ray in an older population.** © 2021 Elsevier Inc. All rights reserved.

☐ **Keywords—point-of-care ultrasonography; shortness of breath; acute heart failure; emergency medicine**

INTRODUCTION

Acute heart failure and exacerbation of chronic obstructive pulmonary disease (COPD) are common in the emergency department (ED) (1,2). It is occasionally difficult to differentiate acute heart failure from acute COPD exacerbation because the clinical information is not specific to one condition or the other, especially in elderly patients (3,4). Severely ill patients may have more overt

This study was approved by the Ottawa Health Science Network Research Ethics Board (OHSN-REB) in March 2017 (Protocol Number: 20160893-01H). It was conducted under a waiver of informed consent because patients were not being intervened upon: POCUS is already part of the current clinical practice, and routine care of patients was not altered for the research; and no identifiable private information was collected from patients for the research.

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signs and symptoms of their specific medical condition, leading to a quick diagnosis and initiation of aggressive life-saving respiratory management. On the other hand, patients with relatively moderate signs and symptoms may be more difficult to differentiate in the ED, especially in older patients having overlapping risk factors for both heart failure and COPD.

Recent systematic reviews have shown that point-of-care ultrasound (POCUS) can identify acute heart failure and pulmonary edema (by assessing B-lines) with high sensitivity and specificity (5,6). Previous studies reported that lung POCUS had better sensitivity than chest x-ray study for the recognition of pulmonary edema among all adult dyspneic patients (7,8). There is, however, a lack of evidence comparing lung POCUS with chest x-ray study among older patients suspected of having either acute heart failure or acute COPD exacerbation. The contribution of POCUS, in such cases, is to help identify heart failure as an alternative diagnosis to COPD.

Objectives

Among older patients visiting the ED with undifferentiated dyspnea who were suspected of having either acute heart failure or COPD, we sought to determine the classification performance of lung POCUS compared with chest x-ray study in its ability to recognize acute heart failure.

MATERIALS AND METHODS

Study Design and Time Period

We performed a cohort study with additional health records review of patients who were exposed to lung POCUS between March and September 2017. There is no conceptual overlap with our previous study, which focused on the time effectiveness of lung POCUS (9).

Study Setting

The study was conducted at tertiary care facilities in Canada. The ED serves a population with a volume of more than 172,000 patients annually at the two campuses. The Emergency Medicine Ultrasonography team has been delivering practical training of POCUS to all the residents and ED staff since 2003. Residents and staff physicians may be credentialed for lung POCUS after completing a combination of existing on-line material, image review cases, and supervised scanning. Approximately 70% of the ED staff are already credentialed for core POCUS skill, including lung POCUS. All POCUS images and findings are archived electronically by sonographers regardless of the modality. All POCUS scans archived undergo quality improvement and are reviewed by the Emergency Medicine Ultrasonography team to confirm findings.

Population

We screened all consecutive patients who were assessed for shortness of breath or cough, were 50 years of age or older, and had suspected diagnoses of acute heart failure or COPD exacerbation by emergency physicians. We included patients who were 50 years or older because heart failure and COPD as a cause of shortness of breath or cough are not prevalent in a younger population (4,10). Among those, only patients evaluated with lung POCUS were included. We considered documented ED diagnoses in physician records as suspected diagnoses in the ED. We only included patients with recorded lung POCUS performed with a clinical indication (scans with an educational purpose were labeled in the POCUS documentation and were not included). We excluded patients diagnosed with acute ST-segment elevation myocardial infarction on arrival electrocardiogram. We also excluded those who had known history of interstitial fibrosis, extensive lung cancer, pneumonectomy or lobectomy, or pneumothorax, because lung POCUS can provide only limited findings to diagnose heart failure in these patients.

POCUS Protocol

During the study period, emergency physicians evaluated all patients in their usual clinical practice without any additional interventions. When lung POCUS was performed, we used an eight-zone technique where the chest is divided into four zones on each side for assessing pulmonary edema, as described by Volpicelli et al (11,12). Pulmonary edema is considered to be present if positive scans are present in more than two zones per side. Each scan is deemed to be positive when at least three B-lines are identified (11,13). A Zonare (Shenzhen Mindray Bio-Medical Electronics Co., Shenzhen, China) or a GE Logiq E (GE Healthcare, General Electric Company, Boston, MA) ultrasound machine with a phased-array 3.5-MHz probe were used for lung POCUS. All POCUS findings and interpretations were electronically documented by sonographers, and reviewed by the Emergency Medicine Ultrasonography team, who were blinded to patients' outcomes. This review by the Emergency Medicine Ultrasonography team was performed solely for quality-assurance purposes, and as a secondary measure of the agreement between their interpretation and the ED diagnosis by study investigators.

Definition of Diagnostic Reference Standard

We used the following hierarchical criteria to define the reference standard: 1) a discharge diagnosis for admitted patients, 2) an ED diagnosis with a repeat ED visit or a follow-up visit to outpatient clinic for the same initially presumed diagnosis within a month after the first ED visit, or 3) in all other cases where a diagnosis was only made by an emergency physician after seeing a patient once and sending them home after treatment. Study investigators (SN, MW) reviewed health records of the ED care independently and determined the final diagnosis by consensus. The health records review was performed using only the information from the health records, and the reviewers were blinded to the archived POCUS images and the sonographers' interpretations. However, if there was documentation of POCUS findings or interpretations in the ED health records, the reviewers were not blinded to it.

Data Collection

We developed a standardized data collection tool a priori to facilitate the extraction of data from existing records. We collected information on patient demographics and results of investigations from triage notes, ED health records by emergency physicians, nursing documentation, and radiological reports. Information on treatment received was obtained from ED records of treatment and nursing documentation. We collected POCUS findings and interpretations by sonographers from ED health records.

Data Analysis

Patient clinical and demographic characteristics at baseline were described using means and standard deviations for continuous variables, or medians and interquartile ranges if skewed, and frequencies and proportions for categorical variables. Cohen's kappa was used to assess inter-rater agreement for ED diagnosis by study investigators and for the lung POCUS interpretations by study investigators. The classification performance of lung POCUS to diagnose acute heart failure was determined using sensitivity, specificity, positive predictive value, and negative predictive value, together with a 95% confidence interval (CI) by comparing the lung POCUS interpretation in the ED and the final diagnosis among patients who received lung POCUS. We similarly described the classification performance of chest x-ray study for

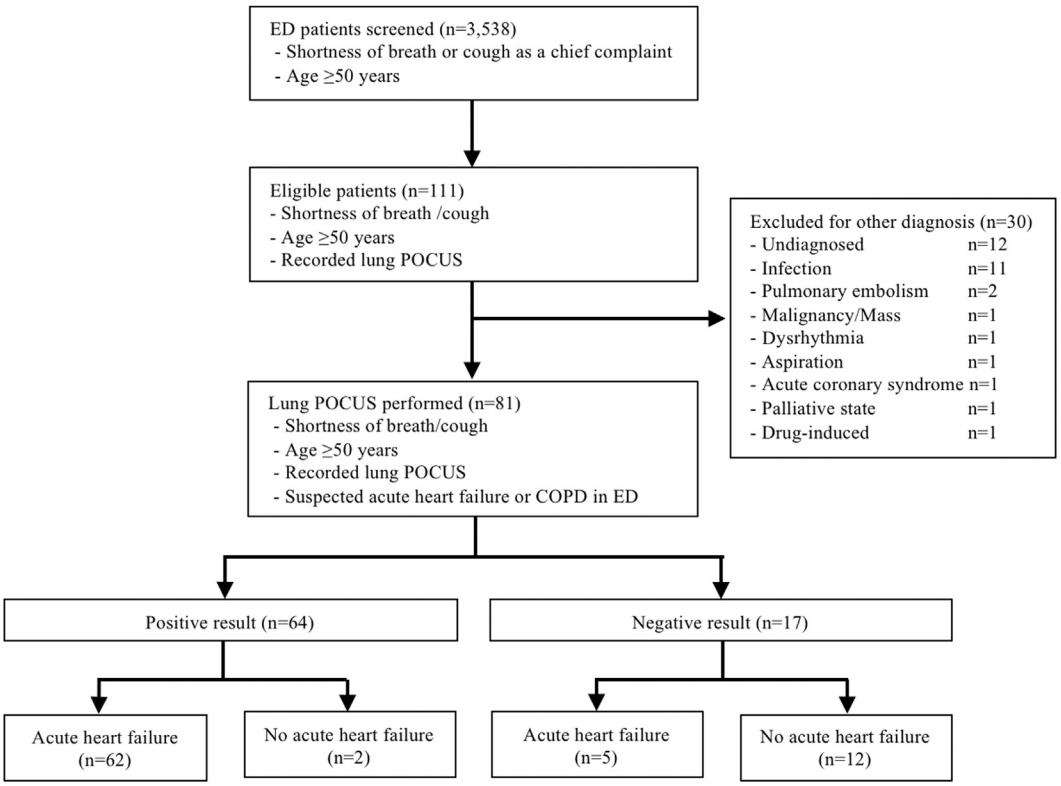

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Figure 1. Patient flow. ED = emergency department; POCUS = point-of-care ultrasound; COPD = chronic obstructive pulmonary disease.

identifying acute heart failure by radiologists. Then, we compared the test performance of lung POCUS with that of chest x-ray study for identifying heart failure by exact McNemar test. We used SAS 9.4 (Cary, NC) for all statistical analyses.

RESULTS

Study Patients

Figure 1 summarizes the inclusion and exclusion of patients, adhering to the Standard for Reporting of Diagnostic Accuracy flow diagram (14). Among 3538 patients aged 50 years or older who visited the ED with shortness of breath or cough as a chief complaint during the study period, 81 (2.3%) were included in our study. The lung POCUS users were of various skill levels.

The characteristics of the enrolled patients are summarized in Table 1. The median age of the total study cohort was 79 years. Half of the patients were female (50.6%). More than half had heart failure (55.6%), and one-third had COPD (33.3%) as a past medical history. Using our described reference standard, 67 (82.7%) patients were diagnosed with acute heart failure. There was substantial inter-rater agreement on ED diagnosis by study investigators, as demonstrated by Cohen's kappa of 0.79.

The characteristics of lung POCUS are presented in Table 2. In our study period, one-third of emergency physicians (24 out of 74) recorded lung POCUS. Attending physicians performed 29.6% of all lung POCUS, and 48.1% were done by residents (postgraduate year 1 to 5). Most sonographers assessed and recorded the presence or absence of pleural effusions (71.6%) and their estimation of the left ventricular function (86.4%). There was substantial inter-rater agreement, as demonstrated by Cohen's kappa of 0.80 for the reviewed interpretations of lung POCUS by study investigators.

Main Results

The top half of Table 3 describes the classification performance of lung POCUS for identification of acute heart failure compared with the final diagnoses by the reference standard. Of 67 patients with acute heart failure and 14 without, emergency physicians correctly identified acute heart failure by lung POCUS with a sensitivity of 92.5% (95% CI 83.4–97.5%), specificity of 85.7% (95% CI 57.2–98.2%), positive predictive value of 96.9% (95% CI 89.2–99.6%), and negative predictive value of 70.6% (95% CI 44.0–89.7%).

The bottom half of Table 3 describes the classification performance of chest x-ray study for identification of acute heart failure by radiologists. Radiologists correctly identified acute heart failure by chest x-ray study in the official reports with a sensitivity of 63.6% (95% CI 50.9–75.1%), specificity of 92.9% (95% CI 66.1–99.8%), positive predictive value of 97.7% (95% CI 87.7–99.9%), and negative predictive value of 35.1% (95% CI 20.2–52.5%).

We compared the test performance of lung POCUS to that of chest x-ray study for identifying acute heart failure among the 66 patients who were diagnosed with acute heart failure with the reference standard (1 patient did not have interpretation by radiologists). Table 4 shows that the sensitivity of lung POCUS was significantly higher than that of chest x-ray study (p = 0.0003).

Table 1. Patient Characteristics

Characteristics	n = 81	
Age, median, Q1–Q3	79	73–86
Female sex, n (%)	41	(50.6)
Arrival by ambulance, n (%)	42	(51.9)
CTAS, n (%)		
1	8	(9.9)
2	41	(50.6)
3	30	(37.0)
4	2	(2.5)
5	0	(0)
Past history of heart failure or COPD, n (%)		
Heart failure only	29	(35.8)
COPD only	11	(13.6)
Heart failure and COPD	16	(19.8)
No heart failure or COPD	25	(30.9)
Other past history		
Hypertension	61	(75.3)
Diabetes	35	(43.2)
Smoking	31	(38.3)
Acute coronary syndrome	30	(37.0)
Atrial fibrillation	26	(32.1)
Chronic kidney disease	21	(25.9)
Asthma	4	(4.9)
Home oxygen, n (%)	5	(6.2)
Current medication, n (%)		
Diuretics	50	(61.7)
Nitrates	17	(21.0)
Inhaled beta agonists	33	(40.7)
Inhaled steroids	22	(27.2)
Inhaled anticholinergics	18	(22.2)
Oral steroids	8	(9.9)
Vital signs on arrival, mean (SD)		
Systolic blood pressure (mm Hg)	139.7	(29.3)
Heart rate (beats/min)	87.8	(23.5)
Body temperature (Celsius)	36.2	(0.82)
Respiration rate (breaths/min)	23.7	(7.3)
Oxygen saturation (%)	92.0	(6.7)
Chest x-ray study, n (%)	81	(100)
Fluid congestion on x-ray study	43	(53.1)
Disposition, n (%)		
Discharged home	34	(42.0)
Admitted to hospital	47	(58.0)
Final diagnosis, n (%)		
Acute heart failure only	64	(79.0)
COPD only	14	(17.3)
Acute heart failure and COPD	3	(3.7)
Other	0	(0)

CTAS = Canadian Triage and Acuity Scale; COPD = chronic obstructive pulmonary disease.

Table 2. Characteristics of Lung POCUS

Characteristics	n = 81	
Sonographers, n (%)		
Attending physicians	39	(29.6)
Residents (postgraduate year 1–5)	25	(48.1)
POCUS findings, n (%)		
B-lines		
Positive	64	(79.0)
Negative	17	(21.0)
Indeterminate	0	(0)
Pleural effusion		
Positive	35	(43.2)
Negative	23	(28.4)
Indeterminate	0	(0)
Not performed	23	(28.4)
Left ventricular function		
Normal/mild dysfunction	37	(45.7)
Moderate/severe dysfunction	31	(38.3)
Hyperactive	2	(2.5)
Indeterminate	5	(6.2)
Not performed	6	(7.4)

POCUS = point-of-care ultrasonography.

Table 5 shows that the specificity of lung POCUS was not significantly higher than that of chest x-ray study among the 14 patients who were not diagnosed with acute heart failure ($p = 1.00$).

DISCUSSION

Our study provided information on the classification performance of lung POCUS to identify acute heart failure among older patients in a real clinical setting. The sensitivity, specificity, positive predictive value, and negative predictive value of lung POCUS to identify acute heart failure in the ED were high. The classification performance of lung POCUS by emergency physicians was significantly better in sensitivity, and similar in specificity compared with those of chest x-ray study interpreted by radiologists.

Martindale and colleagues published a systematic review of lung POCUS in the ED for patients with undifferentiated dyspnea and included eight studies for test performance of lung POCUS for acute heart failure (6). They showed that the sensitivity was 85.3% (95% CI 82.8–87.5%) and the specificity was 92.7% (95% CI 90.9–94.3%). They also illustrated that chest radiographic findings of pulmonary edema had a sensitivity of 56.9% (95% CI 54.7–59.1%) and a specificity of 89.2% (95% CI 87.9–90.4%) (6). Maw and colleagues performed a systematic review describing that lung POCUS was more sensitive than chest x-ray study in detecting pulmonary edema in the evaluation of patients with dyspnea at risk of acute heart failure (8). They included six prospective cohort studies and showed that the pooled estimates for lung POCUS were 0.88 (95% CI 0.75–0.95) for sensitivity and 0.90 (95% CI 0.88–0.92) for specificity, and pooled estimates for chest x-ray study were 0.73 (95% CI 0.70–0.76) for sensitivity and 0.90 (95% CI 0.75–0.97) for specificity (8). Our results of classification performance for lung POCUS are very consistent with theirs. However, classification performance of chest x-ray study in our study was slightly lower than theirs. This may be due to the difference of population. Less severe patients with acute heart failure may not have obvious findings in chest x-ray study.

We created a reliable dataset with electronic documentations of lung POCUS and reviews of lung POCUS interpretation with substantial inter-rater agreement. Our reference standard for the final diagnosis was also reliable due to careful reviews with substantial inter-rater

Table 3. Classification Performance of Lung POCUS and Chest X-Ray Study for Identifying Acute Heart Failure

	Final Diagnosis of Acute Heart Failure	
Lung POCUS (n = 81)	Yes	No
Positive	62	2
Negative	5	12
Sensitivity; 0.925 (95% CI 0.834–0.975)		
Specificity; 0.857 (95% CI 0.572–0.982)		
Positive predictive value; 0.969 (95% CI 0.892–0.996)		
Negative predictive value; 0.706 (95% CI 0.440–0.897)		
Congestion in x-ray study (n = 80*)		
Positive	42	1
Negative	24	13
Sensitivity; 0.636 (95% CI 0.509–0.751)		
Specificity; 0.929 (95% CI 0.661–0.998)		
Positive predictive value; 0.977 (95% CI 0.877–0.999)		
Negative predictive value; 0.351 (95% CI 0.202–0.525)		

POCUS = point-of-care ultrasonography; CI = confidence interval.
* One patient did not have interpretation by radiologists.

Table 4. Comparing Performance of Chest X-Ray Study and POCUS for Identifying Acute Heart Failure Among 66 Patients With Acute Heart Failure Who Received Both Tests

	Chest X-Ray Study	
Lung POCUS (n = 66*)	Positive	Negative
Positive	38	23
Negative	4	1

The sensitivity of lung POCUS was significantly better than that of chest x-ray study ($p = 0.0003$) by exact McNemar test.
POCUS = point-of-care ultrasonography.
* One patient did not have interpretation by radiologists.

agreement to include the patients who were discharged home from the ED. Our study provided classification performance of lung POCUS and chest x-ray study to identify acute heart failure in a real clinical setting.

Limitations

Our study had several limitations. First, the prevalence of using lung POCUS in our study population in the ED was low. The relatively low POCUS usage may have been due to various reasons, including limited machine availability, limited time to perform the lung POCUS, perception of limited POCUS benefit by emergency physicians, and lack of specific lung POCUS training for credentialing (15). Emergency physicians may have chosen not to perform lung POCUS if they were confident enough to make clinical decisions without it, because lung POCUS is not currently a broadly accepted standard of care for use in dyspneic patients (16). Second, a substantial number of patients who received lung POCUS also received a cardiac assessment. Because emergency physicians would make a clinical decision based on all available information, results of the cardiac assessment might also influence their decision. However, we assumed the impact of the cardiac assessment would be limited because the reported classification performance of the cardiac assessment was not as high for lung POCUS (6). Third, we could not determine the intended use of lung POCUS (i.e., whether it was for diagnosis, confirmation, or monitoring). The early diagnostic use of lung POCUS may have a different impact on classification performance compared with its later use. Furthermore, because we used the three different reference diagnostic criteria as a reference standard for the final diagnosis depending on discharge status of patients, differential verification bias might be introduced. The diagnosis for patients who were discharged from the ED may have been biased by the POCUS findings available during the initial visit, especially if they were written in the ED chart. This potential incorporation bias is greatly mitigated given that a majority of patients' diagnoses of acute heart failure (58%) were made after their admission to the hospital. Lastly, it is also recognized that clinicians may, on occasion, acquire images using POCUS and fail to document its use in their health records or document their interpretation of the acquired images. Unfortunately, it was not possible to determine how frequently this may have occurred.

Table 5. Comparing Performance of Chest X-Ray Study and POCUS for Identifying Acute Heart Failure Among 14 Patients Without Acute Heart Failure Who Received Both Tests

	Chest X-Ray Study	
Lung POCUS (n = 14)	Positive	Negative
Positive	0	2
Negative	1	11

The specificity of lung POCUS was not significantly better than that of chest x-ray study ($p = 1.00$) by exact McNemar test.
POCUS = point-of-care ultrasonography.

CONCLUSIONS

Lung POCUS performed by emergency physicians in a real clinical setting was highly sensitive and specific in identifying acute heart failure, and had higher sensitivity than chest x-ray study among older patients with suspected acute heart failure or COPD in their ED stay.

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ARTICLE SUMMARY

1. Why is this topic important?

Acute heart failure and exacerbation of chronic obstructive pulmonary disease (COPD) are sometimes difficult to differentiate in an older population in the emergency department (ED). However, there is a lack of evidence comparing lung point-of-care ultrasound (POCUS) compared with chest x-ray study to identify acute heart failure among older patients in a real clinical setting.

2. What does this study attempt to show?

We sought to determine the classification performance of lung POCUS compared with chest x-ray study to identify acute heart failure among older patients with undifferentiated dyspnea who were suspected of having either acute heart failure or COPD in a real clinical setting in the ED.

3. What are the key findings?

Emergency physicians identified acute heart failure by lung POCUS with sensitivity of 92.5% and specificity of 85.7%, and the radiology reading of chest x-ray study had sensitivity of 63.6% and specificity of 92.9%. The sensitivity of lung POCUS was significantly higher than that of chest x-ray study.

4. How is patient care impacted?

Although lung POCUS is not currently a broadly accepted standard care for use in dyspneic patients, lung POCUS performed by emergency physicians may provide better information than chest x-ray study to identify acute heart failure for dyspneic older patients with suspected acute heart failure or COPD.