Diagnostic performance of cardiopulmonary ultrasound performed by the emergency physician in the management of acute dyspnea

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ABSTRACT

Objective: The etiologic diagnosis of acute dyspnea in the emergency department (ED) remains difficult, especially for elderly patients or those with previous cardiorespiratory medical history. This may lead to inappropriate treatment and potentially a higher mortality rate. Our objective was to evaluate the performance of cardiopulmonary ultrasound compared with usual care for the etiologic diagnosis of acute dyspnea in the ED.

Methods: Patients admitted to the ED for acute dyspnea underwent upon arrival a cardiopulmonary ultrasound performed by an emergency physician, in addition to standard care. The performances of the clinical examination, chest x-ray, N-terminal brain natriuretic peptide (NT-proBNP), and cardiopulmonary ultrasound were compared with the final diagnosis made by 2 independent physicians.

Results: One hundred thirty patients were analyzed. For the diagnosis of acute left-sided heart failure, cardiopulmonary ultrasound had an accuracy of 90% (95% confidence interval [CI], 85-94) vs 81% (95% CI, 73-89), P = .001 for clinical examination, and 81% (95% CI, 72-88), P = .04 for the combination "clinical examination–NT-proBNP-x-ray". Cardiopulmonary ultrasound led to the diagnosis of pneumonia or pleural effusion with an accuracy of 86% (95% CI, 80-92) and decompensated chronic obstructive pulmonary disease or asthma with an accuracy of 95% (95% CI, 92-99). Cardiopulmonary ultrasound lasted an average of 12 ± 3 minutes.

Conclusions: Cardiopulmonary ultrasounds performed in the ED setting allow one to rapidly establish the etiology of acute dyspnea with an accuracy of 90%.

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1. Introduction

The etiologic diagnosis of acute dyspnea in the ED remains difficult, especially in elderly patients or those with previous medical history of cardiorespiratory disease [1–6]. If the diagnostic hypothesis and the resulting treatment are wrong, mortality increases significantly among elderly subjects with acute heart failure [7], stressing the importance of finding reliable diagnostic tools. The European Society of Cardiology has recently reviewed the limitations of commonly used methods: electrocardiogram, chest x-ray, N-terminal brain natriuretic peptide (NT-proBNP) testing, or blood samples [8]. Performance of an echocardiogram is recommended, but in practice, this is rarely possible because of lack of an available cardiologist in the ED. The significant value of lung ultrasound for the diagnosis of acute respiratory failure has also been suggested [9,10]. Recently, the interest of early chest ultrasonography for the diagnosis of severe dyspnea cases admitted into intensive care units has been shown [11], but there is little data concerning acute dyspnea in the ED [12–15].

The aim of our study was to evaluate the performance of cardiopulmonary ultrasound performed by an emergency physician in the ED setting for the etiologic diagnosis of acute dyspnea, considering routine examinations as the standard of care.

2. Methods

This prospective cohort study was conducted between January 2012 and December 2012 in the ED of a general hospital with approximately 19,000 ED visits per year. The study protocol was approved by the local ethics committee (ref. 130627), which did not require the signing of a written consent form.

2.1. Patients

Patients 18 years or older and admitted for nontraumatic acute dyspnea, defined as the sudden onset of shortness of breath, were eligible
and included in the study if an ED physician trained in cardiopulmonary ultrasound was available. Patients who received prehospital medical care, except oxygenotherapy administration, were not included as well as patients with very unstable medical condition requiring mechanical ventilation and patients who received hospital care before inclusion. The following reasons were causes for secondary exclusion: the impossibility of a precise final diagnosis by the experts, dyspnea not being the main reason for admission, and the duration of hospitalization being less than 24 hours.

2.2. Clinical, laboratory, and radiographic data

The patient's medical history, hospital examination, and vital signs were recorded by the ED physician in charge of the patient. Thereafter, a conclusion for initial clinical diagnosis had to be made by the ED physician in charge of the patient: acute left-sided heart failure (ALSHF), non-ALSHF, or “do not know”. All the patients then benefited from additional tests as part of this study (electrocardiogram, arterial blood gases, chest x-ray, blood assessment, and NT-proBNP testing obtained within 60 min on average in our hospital).

The laboratory diagnosis of ALSHF by NT-proBNP assay was chosen taking into account the thresholds redefined according to the patient's age [16]: NT-proBNP was considered negative if less than 300 pg/mL and, in favor of an ALSHF, if greater than 1800 pg/mL in patients older than 75 years, 900 pg/mL in patients from 50 to 75 years old, and 450 pg/mL in patients younger than 50 years. In all other situations, NT-proBNP was considered noncontributory (“gray zone”).

An x-ray diagnosis was made a posteriori from the interpretation of chest x-rays by an independent radiologist: presence or absence of ALSHF signs.

Finally, an overall diagnosis “clinical examination–NT-proBNP–chest x-rays” was established: ALSHF, non-ALSHF, or “unability to conclude” if the clinical, biologic, and radiographic diagnoses were discordant.

2.3. Ultrasounds data

In the absence of an immediate life-threatening condition and before any medication, a trained ED physician performed cardiopulmonary ultrasound at the bedside, without knowledge of the clinical data. He was not in charge of the patient and did not provide care to patients at the same time. The total duration of the ultrasonography examination was recorded.

The competence required to carry out this review included, in accordance with the recommendations of the American College of Emergency Physicians [17,18], a 4-day theoretical and practical training in an approved center, a companionship practice with the cardiologists of our structure, and a maintenance of knowledge by “e-learning”. Three of 10 emergency physicians who account the department met the ultrasound training requirement. They had an average of 2 years of practice in cardiac and thoracic ultrasound. The ultrasound system used was a SONOSITE Fujifilm M Turbo (Bothell, WA) equipped with a sector probe (3-5 MHz) for the cardiac ultrasounds and with an abdominal probe (3-5 MHz) for the pulmonary ultrasounds.

Cardiac ultrasound performed at the bedside included firstly the acquisition of a left parasternal long axis view and a view of the 4 chambers for a visual estimation of left ventricular ejection fraction (LVEF), which was considered to be decreased when less than 45% or normal when LVEF is 45% or greater. Then, on the apical 4-chamber view, a mitral Doppler in pulsed mode was performed (Fig. 1A). The maximum speed of the E and A waves expressed in centimeters per second and the decay time of the waveform E (TDE) expressed in milliseconds were then measured and the E/A ratio calculated. Finally, in the same view, a tissue Doppler of the lateral edge of the mitral ring was performed (Fig. 1B), for gathering the maximum speed of the wave e′ expressed in centimeters per second and therefore to calculate the E/e′ ratio. The left ventricular filling pressure (LVFP) was then evaluated according to a predefined algorithm (Fig. 2). Left ventricular filling pressure was in favor of an ALSHF if elevated.

Lung ultrasound was performed in the thoracic region anteriorly, laterally, and posteriorly of each lung [9,19,20]. Several lung ultrasound signs were searched to conclude on typical profiles [9] (Fig. 3): B profile in favor of ALSHF; AB, C, or PLAPS profile in favor of pneumonia or pleural effusion; normal profile in favor of decompensated chronic obstructive pulmonary disease (COPD) or asthma. The abolition of pleural sliding in the anterior thoracic region was considered as a sign of pneumothorax.

2.4. Final diagnosis

The final diagnosis of acute dyspnea was determined by 2 independent experts who reviewed the entire medical chart of each patient, taking into account the evolution of the patients. Without knowledge of the ultrasound data collected in the ED, they had to classify patients into 2 groups: ALSHF or non-ALSHF. In the latter group, the etiologic diagnosis of dyspnea was also investigated. The primary end point was to compare the diagnosis performance of cardiopulmonary ultrasound and standard examinations (clinical, NT-proBNP, and x-ray diagnosis) for the diagnosis of ALSHF. The secondary end point was to evaluate the performance of cardiopulmonary ultrasound to diagnose other causes of acute dyspnea.

2.5. Statistical analysis

Data were assigned to the laboratory of biosatistics of the university hospital and analyzed using the STATA software 11.2 (StataCorp; College Station, TX).
Quantitative variables were expressed as mean ± SD for variables of normal distribution and otherwise as a median with interquartile range. Qualitative variables were expressed by a number and percentage.

For quantitative variables, the P values were obtained using a Student t test or a Wilcoxon Mann-Whitney if the application conditions were not met. For qualitative variables, comparisons were made using a χ² of Pearson.

The performance of different diagnostic tools was analyzed and comparisons made between them, using the sensitivity, specificity, positive predictive value, negative predictive value, and the accuracy defined by the proportion of true results. Confidence intervals (CI) at 95% were calculated for sensitivity, specificity, predictive values, and accuracy. Diagnostic accuracies were compared using a McNemar test, with a level of significance set at P = .05. It was not possible to calculate

**Lung ultrasound signs:**

- **A-lines:** horizontal lines arising from the pleural line and separated by regular intervals that are equal to the distance between the skin and the pleural line.
- **B-lines:** discrete laser-like vertical hypoechoic reverberation artefacts that arise from the pleural line, extend to the bottom of the screen without fading, and move synchronously with lung sliding.
- **Alveolar syndrome:** subpleural echo-poor region or one with tissue-like echotexture.
- **Pleural effusion:** an anechoic space between the parietal and visceral pleura, and respiratory movement of the lung within the effusion.

**Typical profiles:**

- **B profile:** bilateral presence of at least 3 B lines by lung field in the anterior or lateral thoracic region or both.
- **AB profile:** anterior or axillary unilateral B lines.
- **C profile:** unilateral or bilateral anterior alveolar syndrome.
- **PLAPS profile:** unilateral postero-lateral alveolar syndrome and/or pleural effusion.
- **Normal profile:** predominance of A lines on the two lungs.

**Fig. 2.** Interpretation of cardiac ultrasound data.

**Fig. 3.** Lung ultrasound signs used and typical profiles searched.
Fig. 4. Distribution of patients according to the result of the 2 ultrasounds and, depending on the final diagnosis, by the independent experts.

Table 1
Main clinical, biological, and electrocardiogram characteristics of the population according to the final diagnosis by the independent experts

<table>
<thead>
<tr>
<th></th>
<th>Non-ALSHF (n = 49)</th>
<th>ALSHF (n = 81)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>79.0 ± 11.1</td>
<td>81.9 ± 10.2</td>
<td>.13</td>
</tr>
<tr>
<td>Sex, M</td>
<td>26 (53.1)</td>
<td>44 (54.3)</td>
<td>.89</td>
</tr>
<tr>
<td>F</td>
<td>23 (46.9)</td>
<td>37 (45.7)</td>
<td></td>
</tr>
<tr>
<td>Vital signs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SaO2 (%)</td>
<td>93 (90, 96)</td>
<td>94 (89, 96)</td>
<td>.61</td>
</tr>
<tr>
<td>Oxygen therapy (l/min)*</td>
<td>Yes n = 36</td>
<td>2 (2, 2)</td>
<td>.0023</td>
</tr>
<tr>
<td></td>
<td>No n = 94</td>
<td>4 (3, 6)</td>
<td></td>
</tr>
<tr>
<td>HR (bpm)</td>
<td>89.9 ± 20.0</td>
<td>90.2 ± 23.8</td>
<td>.94</td>
</tr>
<tr>
<td>RR (mvt/min)</td>
<td>22.0 ± 7.1</td>
<td>25.0 ± 9.5</td>
<td>.19</td>
</tr>
<tr>
<td>Syst P (mm Hg)</td>
<td>150.5 ± 26.7</td>
<td>149.8 ± 36.5</td>
<td>.49</td>
</tr>
<tr>
<td>Diast P (mm Hg)</td>
<td>82.5 ± 13.2</td>
<td>81.7 ± 20.4</td>
<td>.49</td>
</tr>
<tr>
<td>T (°C)</td>
<td>37.5 ± 1.1</td>
<td>37.1 ± 0.9</td>
<td>.03</td>
</tr>
<tr>
<td>ECG</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td>11 (22.5)</td>
<td>40 (49.4)</td>
<td>.002</td>
</tr>
<tr>
<td>Serum biology</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PaO2 (mm Hg)*</td>
<td>62 (54, 71)</td>
<td>59 (49, 74)</td>
<td>.32</td>
</tr>
<tr>
<td>PaCO2 (mm Hg)*</td>
<td>41 (36, 49)</td>
<td>40 (34, 47)</td>
<td>.31</td>
</tr>
<tr>
<td>NT-proBNP (pg/mL)*</td>
<td>679 (366, 1762)</td>
<td>4337 (2064, 10827)</td>
<td>.0001</td>
</tr>
</tbody>
</table>

Values are given as n (%) or mean ± SD.

Abbreviations: M, male; F, female; SaO2, oxygen saturation; HR, heart rate; RR, respiratory rate; Syst P, systolic pressure; Diast P, diastolic pressure; T, temperature; ECG, electrocardiogram; PaO2, oxygen pressure; PaCO2, carbon dioxide pressure; CRP, C-reactive protein.

* Non-normal variables distribution.
a sample size because of the absence of previous studies comparing cardio-pulmonary ultrasound and standard examination in the ED setting.

3. Results

3.1. Population characteristics

One hundred thirty patients were analyzed of the 147 patients initially included. According to the final diagnosis by the 2 experts, 81 patients (62%) had ALSHF and 49 patients (38%) had dyspnea secondary to respiratory pathology (Fig. 4). The main characteristics of the population are detailed in Table 1.

3.2. ALSHF diagnostic accuracy

Echocardiography was not able to conclude on LVFP for 45% of patients (58 patients including 49 gray zone of which 36 atrial fibrillation; 1 wave A and 5 wave e' measurement failure; 3 poor window). When LVFP was conclusive (normal or elevated), it diagnosed an ALSHF (increased LVFP) with an accuracy of 85% (95% CI, 74-92). The results of echocardiography are presented in Table 2. Lung ultrasound allowed to affirm or deny the presence of B profile with 100% reliability and diagnosed an ALSHF with an accuracy of 88% (95% CI, 82-93). When cardiac ultrasound showed normal LVFP and pulmonary ultrasound found no B profile (n = 22), all patients were categorized in the group non-ALSHF. When the 2 ultrasound scans showed increased LVFP associated with B profile (n = 34), only 1 patient was not in the group ALSHF.

When the results of the 2 scans were contradictory (n = 16), it appeared that, if the cardiac ultrasound showed non increased LVFP but the lung ultrasound showed the presence of a B profile, 9 of 12 patients actually had an ALSHF. On the contrary, if the cardiac ultrasound showed increased LVFP but lung ultrasound found no B profile, only 1 of 4 patients had no ALSHF. Interpretation of the results of the 2 ultrasound scans, according to steps 1 and 2 of the algorithm in Fig. 4, allowed one then to obtain the best diagnosis performance possible by cardiopulmonary ultrasound with an accuracy of 90% (95% CI, 84-95). Cardiopulmonary ultrasound lasted on average 12 ± 3 minutes. This cardiopulmonary ultrasound diagnostic of ALSHF was more accurate than the clinical examination alone (90% vs 67%, respectively; P = .0001). It was also more accurate than the usual combination clinical examination–NT-proBNP–x-ray (90% vs 81%, respectively; P = .04), which could not conclude for 22% of patients. Performances of the different tests for ALSHF diagnosis are listed in Table 3.

3.3. Other etiologic diagnosis of acute dyspnea

When LVFP was nonelevated and the B profile not present (step 3, Fig. 4), lung ultrasound diagnosed a pneumonia or a pleural effusion (profile AB or C or PLAPS) with an accuracy of 86% (95% CI, 80-92) and a decompensated COPD or asthma (normal profile) with an accuracy of 95% (95% CI, 92-99).

No pneumothorax has been observed. An atypical profile (bilateral posterolateral alveolar syndrome and/or bilateral pleural effusion) was observed in 3 patients.

4. Discussion

This work shows a benefit of coupled heart and lung ultrasound compared with standard care for the diagnosis of ALSHF in the ED: in the first few minutes, 90% of the patients were correctly classified by ultrasounds.
vs 67% by clinical examination alone and 81% by standard examinations. In the ED, the choice of initial treatment of acute dyspnea is often based on clinical examination alone. Thus, 23% of patients could have received a more appropriate treatment upon their arrival because of the use of cardiopulmonary ultrasound. The cardiopulmonary ultrasound was statistically more accurate than the usual combination clinical–NT-proBNP–x-ray (accuracy of 90% vs 81%, P = .04). Compared with usual care, cardiopulmonary ultrasound had the advantage of a shorter delay for diagnosis (12 min compared with 60 min for getting NT-proBNP results in our structure). The inability to conclude for 22% of patients with the combination clinical–NT-proBNP–x-ray was explained by situations of gray area for the NT-proBNP associated with a discrepancy between clinical and radiographic diagnoses or by a noncontributory clinical diagnosis with divergent NT-proBNP and x-ray. Recently, the interest of adding point-of-care ultrasonography to routine examinations for the diagnosis of the causes of dyspnea in the ED has been shown [14,15]: the diagnostic accuracy was 88% to 94% for standard diagnostic tests supplemented with point-of-care ultrasonography of the heart, lungs, and deep veins vs 50% to 63.7% for standard diagnostic strategy. However, the results of our study show that cardiopulmonary ultrasound allows accurate and rapid diagnosis without waiting for the results of standard examinations.

If the realization of cardiac and pulmonary ultrasound gives a better diagnostic performance, there may be conflicting results: increased LVFP and no B profile or no increased LVFP and presence of B profile. By showing a B profile in 7% of our patients, lung ultrasound allowed to correct false-negative echocardiography (not increased LVFP) but had no benefit in cases of increased LVFP. It has been shown that, using 3 ultrasound modalities together (LVFP <45%, inferior vena cava collapsability index <20%, and B-line count in the entire thorax >10), sensitivity and specificity for the presence of ALSHF were 36% and 100%, respectively [12,21]. In the emergency medicine setting, it is important to affirm but also to exclude the diagnosis of ALSHF. Our study shows that interpretation of the results of the 2 ultrasound scans, according to steps 1 and 2 of the algorithm in Fig. 4, allows one to obtain the best compromise between sensitivity and specificity. Our results are comparable with those found in the literature for the diagnosis of ALSHF: accuracy is 93% for cardiopulmonary ultrasound performed by a cardiologist within 3 minutes of the arrival time of a dyspneic patient at the ED [22], which is difficult to achieve in practice in terms of availability of a cardiologist.

We chose a visual estimation of LVEF because some studies have shown its accuracy when performed by noncardiologist physicians who have received a brief training in echocardiography [23-25].

Our LVFP evaluation algorithm (Fig. 2) is a simplified version of the one proposed by the American Society of Echocardiography [26] because we did not search for the additional sonographic parameters needed to assess the LVFP in the case of E/e’ ratio in gray area. These parameters require high-level qualification in echocardiography; by contrast, it has been shown that the realization of a mitral Doppler and a tissue Doppler to the mitral annulus by a noncardiologist physician after a quick training is as precise as that performed by an expert [27]. In our study, many patients with atrial fibrillation (35%) were not excluded, although LVFP is known to be difficult to assess [26,28]. This limitation is not found in the literature where patients with atrial fibrillation were excluded and ultrasound parameters used without gray area [29-32]. This explains the inability of the cardiac ultrasound in our study to evaluate the LVFP for 45% of patients and stresses the need for coupling cardiac with lung ultrasound. We can assume that, when cardiac ultrasound performed by a nonexpert fails to evaluate LVFP, lung ultrasound becomes essential for the correct etiologic diagnosis of acute dyspnea.

The pulmonary ultrasound alone was effective for the diagnosis of ALSHF, in a way similar to the data from the literature [9,33–35]. Its feasibility of 100% was a real advantage to distinguish dyspnea by left ventricular dysfunction from other causes of dyspnea, by highlighting a bilateral interstitial syndrome (B profile) [9,10,20,36–38]. A recent study has even shown that bedside lung ultrasonography performed by an emergency nurse can identify with a high degree of accuracy the patients with dyspnea as having a cardiac or a noncardiac cause according to the presence of a B or A profile [39].

However, interstitial pneumonitis, pulmonary fibrosis, and acute respiratory distress syndrome have the same echographic aspect and can report false positives as seen in 6 of our 130 patients. The semiology of the interstitial syndrome visualized by the pulmonary ultrasound, recently described, could correct these false-positive results [40]. However, it was recently recalled that chest radiography and thoracic computed tomography may be of help in the differential diagnosis of interstitial lung diseases or other causes of respiratory failure [41].

Lung ultrasound coupled with cardiac ultrasound also allowed one to diagnose other causes of dyspnea, with an accuracy comparable with that recently observed in patients in intensive care units (accuracy of 87% for pneumonia and 92% for COPD) [11].

Our study has several limitations. The ED physician “sonographer” could be influenced by a suggestive clinical presentation. However, the diagnosis chosen by the physician performing the ultrasound was based on predefined ultrasound criteria. The primary end point was the diagnosis on the patient discharge letter. Although the analysis has been made by 2 independent physicians, this criterion could be questionable because the final diagnosis was based on a body of evidence, including emergency examinations. The comparison of the ED physician results with those of a cardiologist performing an ultrasound examination in the same time frame would have been interesting.

The comparison of lung ultrasound results with those of thoracic computed tomographic scan would also have been of interest. Because of the additional irradiation induced by the scanner, this review has not been carried out.

Furthermore, patients were included in the study only if an ED physician trained in cardiopulmonary ultrasound was available, which represents a bias of selection, and only 3 of 10 emergency physicians met the ultrasounds training requirement. The identifiable performances are not transferable to all ED physicians.

Despite these limitations, our study has the advantage of not having excluded patients whose cardiac ultrasound data were difficult to realize and interpret. We have chosen to include patients 18 years or older because it is a usual inclusion criteria, but the population included in the present study was mainly composed of elderly patients, reflecting the population of patients presenting in the ED for dyspnea and in whom the etiologic diagnosis of acute dyspnea is difficult.

Moreover, this is one of the first studies publishing results of cardiopulmonary ultrasound performed by the ED physician at bedside of dyspneic patients.

5. Conclusions

Cardiopulmonary ultrasound carried out by an ED physician allows for the etiologic diagnosis of acute dyspnea in the ED with an accuracy of 90% within 12 minutes. This performance is superior to that of all other routinely used examinations, encouraging the use of cardiopulmonary ultrasound as a systematic complement to clinical examination in these situations.

Considering the limitations of the commonly used methods, point-of-care cardiopulmonary ultrasound for acute dyspnea management in the ED gives an important added value. The generalization of these results to other EDs must be confirmed. We can, however, assume that cardiopulmonary ultrasound, performed by a trained ED physician, will rapidly become the standard of care for patients presenting themselves at the ED for acute dyspnea.

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