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A M E R I C A N C O L L E G E O F



P H Y S I C I A N S<sup>®</sup>



## Can Chest Ultrasonography Replace Standard Chest Radiography for Evaluation of Acute Dyspnea in the ED?

Maurizio Zanobetti, MD; Claudio Poggioni, MD; and Riccardo Pini, MD

**Background:** We examined the concordance between chest ultrasonography and chest radiography in patients with dyspnea, using chest CT scanning as the gold standard in case of mismatch between the two modalities.

**Methods:** A prospective, blinded, observational study was conducted in the ED of a university-affiliated teaching hospital. All consecutive patients presenting for dyspnea during a single emergency physician shift were enrolled independently from the underlying disease. Only patients with trauma were excluded.

**Results:** Both ultrasonography and radiography were performed in 404 patients; CT scanning was performed in 118 patients. Ultrasound interpretation was completed during the scan, whereas the average time between radiograph request and its final interpretation was 1 h and 35 min. Ultrasonography and radiography exhibited high concordance in most pulmonary diseases, especially in pulmonary edema ( $\kappa = 95\%$ ). For lung abnormalities such as free pleural effusion, loculated pleural effusion, pneumothorax, and lung consolidation, the concordance was similar for both left- and right-side lungs (all  $P$  not significant). When ultrasound scans and radiographs gave discordant results, CT scans confirmed the ultrasound findings in 63% of patients ( $P < .0001$ ). Particularly, ultrasonography exhibited greater sensitivity than radiography in patients with free pleural effusion ( $P < .0001$ ).

**Conclusions:** When performed by one highly trained physician, our study demonstrated high concordance between ultrasonography and radiography. When ultrasound scans and radiographs disagreed, ultrasonography proved to be more accurate in distinguishing free pleural effusion. Thus, considering the short time needed to have a final ultrasound report, this technique could become the routine imaging modality for patients with dyspnea presenting to the ED.

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**Abbreviations:** EP = emergency physician; PE = pulmonary embolism; PTX = pneumothorax

Rapid and accurate identification of the cause for acute dyspnea is a challenge to the emergency physician (EP) because it is the common presenting symptom in the ED.<sup>1</sup> Currently, a standard chest radiograph

is the first routine examination performed in patients presenting in the ED for shortness of breath. Its advantages are the relatively low dose of ionizing radiations administered to the patients and the complete and immediate visualization of the whole chest. However, this modality also has significant disadvantages: It cannot be administered to some groups of patients (eg, pregnant women),<sup>1,2</sup> both projections (posteroanterior and laterolateral) often are impossible to acquire in the ED, and, above all, chest radiographs exhibit a limited accuracy for use in the diagnosis of some illnesses. Moreover, the time requested to carry out standard chest radiography and to draw up a report may lead to a delay in diagnosis and a prolonged stay in the ED, contributing to ED overcrowding.

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Chest CT scanning represents the gold standard examination for most pulmonary diseases. Although it is still an important and necessary method to evaluate some patients, CT scanning raises some important issues, such as the high dose of radiation administered to the patient,<sup>3,4</sup> the need to move the patient into the radiology room, and the lack of CT scanning in some EDs. Chest ultrasonography, on the other hand, enables a quick bedside examination of the patient,<sup>5</sup> the patient does not absorb any ionizing radiations, and the scan can be performed by the EP, who can immediately integrate the findings with the clinical data. Thus, the aim of this study was to verify the concordance between ultrasonography and traditional radiography in different pathophysiologic conditions causing dyspnea, using CT scanning as the gold standard in case of mismatch between the two modalities.

## MATERIALS AND METHODS

A prospective, blinded, observational study was performed. The study, which is consistent with the principles of the Declaration of Helsinki on clinical research involving human subjects, was approved by an ad hoc ethics committee.

The study was performed between January 2006 and January 2008 in the ED of an urban academic level I trauma center and a tertiary-care facility with an annual ED census of 70,000 visits. The ED is the primary teaching site for emergency medicine residency.

All consecutive patients presenting to the ED for dyspnea during a single EP shift (M. Z.) were enrolled in the study independently from the underlying disease. The EP performing all chest ultrasound scans had 2 years experience in chest ultrasonography in the ED. Only patients presenting for trauma were excluded from the study because these patients were already enrolled in a structured dedicated protocol.

After the initial evaluation, consisting of medical history, physical examination, 12-lead ECG, arterial blood gas determination, and standard laboratory tests, all patients underwent a chest ultrasound scan followed by a standard chest radiograph. Echographic chest scanning in our ED is part of routine primary assessment in patients presenting with respiratory distress, so no written informed consent was asked.

A 5- to 8-MHz vascular transducer connected to a multidisciplinary ultrasonographic instrument (Acuson Sequoia 512; Siemens AG; Erlangen, Germany) was used to perform the bedside chest examination. With the patient in supine position, longitudinal and transversal scanning of both hemithoraces were performed along the parasternal, midclavicular, anterior, middle, and posterior axillary lines. Next, with the patient in a sitting position, echographic images were acquired from the posterior paravertebral lines. The average amount of lubricant for each examination was 30.5 g; an aid removed the lubricant. All images were interpreted during the ultrasound scan, and a written report was filed at the end of the echographic examination. For each echographic acquisition, we investigated the following four ultrasonographic markers. (1) Lung gliding or sliding was defined as evidence of pleural movement; lung gliding presence indicates a pulmonary region in contact with the thoracic wall and excludes pneumothorax (PTX). (2) A-lines, defined as horizontal reverberation (transducer reverberation), reflect the pleural line in depth; the presence of

A-lines is a normal finding (Fig 1). (3) Ultrasound lung comets or B-lines,<sup>6,7</sup> defined as ring down, vertical reverberation, extend to the inferior margin of the screen, masking A-lines. They define interstitial syndrome (pulmonary edema and interstitial disease) (Fig 2). (4) Alveolar syndrome, defined as organization (hepatization) of the pulmonary field with a solid appearance, can sometimes show evidence of aerated bronchi (air bronchogram), which when present, indicate a consolidation or a partially aerated alveolar syndrome<sup>8</sup> (Fig 3). These four markers alone or in combination enabled the identification of various ultrasonographic clinical patterns<sup>8,9</sup> (Table 1).

The absence of dynamic air bronchograms associated with the presence of a parallel course of bronchi and “lung pulse,” defined as replacement of lung sliding by a pulsation synchronized with heart activity,<sup>21</sup> characterized the ultrasonographic findings of atelectasis. To allow the comparison with radiographic findings, the ultrasonographic patterns of alveolar syndrome<sup>22</sup> and atelectasis<sup>21</sup> were combined under the term “lung consolidation”<sup>16-18,23</sup> because of their frequent overlapping in the ED radiologic reports. When present, lung consolidation, PTX,<sup>12-14</sup> and pleural effusion (Fig 4)<sup>10</sup> were classified as unilateral (left or right) or bilateral; pulmonary fibrosis pattern (Fig 5),<sup>24</sup> pulmonary edema,<sup>7</sup> and ARDS pattern<sup>25</sup> were indicated as present or absent only.

When the ultrasound scanning ended, patients underwent standard radiography. The radiologist was informed about the clinical indication but he or she was blinded regarding the echographic findings. Radiographs were acquired with patients in supine position (Bucky Diagnost System CS 3000 [Philips Healthcare; Amsterdam, The Netherlands] with CR 85× digitalizer [AGFA Healthcare; Morstel, Belgium]). The delay between the radiologic request and the final report also was recorded for each patient.

When a mismatch between ultrasonograph and radiograph results was present, a chest CT scan was performed (Somatom Sensation 4; Siemens AG; 4 slice) without contrast enhancement. In 31 subjects, an angio-CT scan was performed to rule out pulmonary embolism (PE). All CT images were analyzed by a radiologist blinded to the ultrasonograph and standard radiograph results.

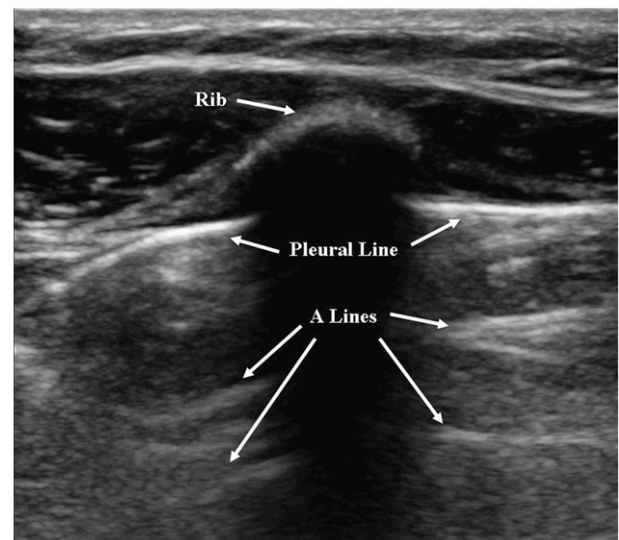


FIGURE 1. Conventional two-dimensional echographic imaging of the normal lung. The pleural line is visualized as a bright hyper-echogenic interface lateral to the rib. Normal horizontal artifacts are shown (A-lines).

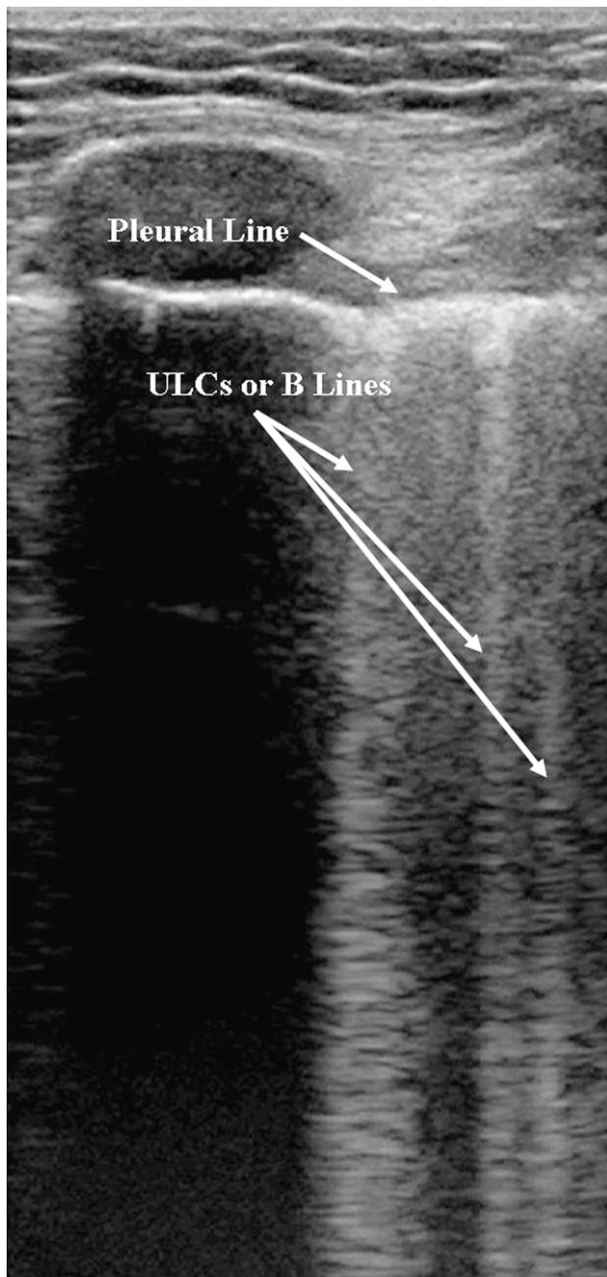


FIGURE 2. Ultrasonograph patterns of interstitial syndrome with several ULCs (or B-lines) arising from the pleural line. ULCs = ultrasound lung comets.

#### Statistical Analysis

The concordance between ultrasonography and radiography was analyzed using the Cohen  $\kappa$  test. In patients with discordant diagnosis, chest CT scanning was performed, and ultrasonographic and radiographic sensitivity and specificity were calculated with the CT scan as gold standard. Frequencies were compared by  $\chi^2$  test. A two-tailed  $P < .05$  was considered significant. SPSS, version 17.0 (SPSS Inc; Chicago, Illinois) was used for all statistical analyses.

### RESULTS

From January 2006 to January 2008, 404 consecutive patients (51% men) presenting at the Careggi

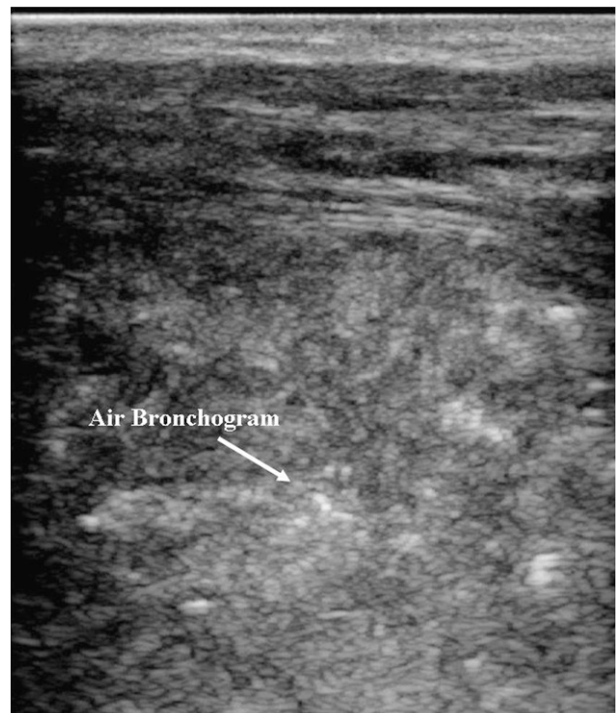


FIGURE 3. Ultrasonographic example of a pulmonary field with a solid appearance (hepatization) indicative of alveolar syndrome. The echographic evidence of aerated bronchi (air bronchogram) indicates the presence of a consolidated lung field.

University Hospital ED with a chief complaint of acute dyspnea were enrolled. Mean age was 73 years (range, 21-101 years). The majority (84%) of patients was admitted to the hospital, 11% were discharged, and 5% were admitted to the ED observation unit for 12 to 24 h and then discharged or admitted according to the final diagnosis and clinical conditions. One patient died in the ED.

As indicated by study protocol, all patients underwent both ultrasonography and radiography. In 118 patients with a mismatch between chest ultrasound scans and plain radiographs, chest CT scanning was performed. Although the final interpretation of the ultrasound scan was immediately available at the end of the examination, the average time between the radiograph request and its final interpretation was 1 h and 35 min (median, 1 h and 38 min).

Of the 404 patients, 157 exhibited a normal ultrasonographic examination, and 141 of these patients had a normal chest radiograph. When conventional radiograph was normal, the most frequent discharge diagnoses were COPD, heart failure, and acute bronchitis. When ultrasound scan did not show any significant pathologic pattern, the most frequent diagnoses were COPD and acute bronchitis.

When the entire study population was examined, the ultrasonograph and radiograph exhibited high

**Table 1—Ultrasonographic Markers Used to Define the Different Ultrasonographic Clinical Patterns**

Ultrasonographic Clinical Patterns	Ultrasonographic Markers
Free pleural effusion <sup>10</sup>	Anechoic area separating the two pleura Changes according to patient's position
Loculated pleural effusion	Anechoic area separating the two pleura Does not change according to patient's position
Pulmonary edema	Several ULCs spread over all lung fields without spared areas Vertical echogenic pattern formed by ULCs sometimes confluent
ARDS pattern <sup>11</sup>	Areas with focal coalescent ULCs Peripheral consolidation Absent or reduced lung gliding Presence of lung pulse (possible) Presence of spared areas
Pneumothorax	Absence of lung gliding Presence of "lung point" <sup>12</sup> Absence of ULCs Appearance of transverse fixed artifact <sup>13-15</sup>
Lung consolidation (alveolar syndrome)	Hypoechoic area with faded edge, varying with respiratory movement Presence of branched air bronchograms <sup>16,17</sup> or presence of hyperechogenic spots displaying air trapped in peripheral airways <sup>18-20</sup>
Lung consolidation (atelectasis)	Absence of dynamic air bronchograms Parallel course of bronchi, losing its branched aspect Presence of lung pulse <sup>21</sup>
Pulmonary fibrosis pattern	ULCs in lung fields (more than eight per field) associated with pleural alterations such as thickening and a fringed and irregular pleural line

ULC = ultrasound lung comet.

concordance (Table 2). The two modalities overlapped almost completely in the presence of PE ( $\kappa = 95\%$ ), but we also found a high concordance in detecting pulmonary fibrosis pattern ( $\kappa = 87\%$ ), PTX ( $\kappa = 85\%$ ), free pleural effusion ( $\kappa = 76\%$ ), and lung consolidation ( $\kappa = 70\%$ ). We found lowest concordance values for abnormalities with a very low prevalence, such as ARDS pattern and loculated pleural effusion.

For lung abnormalities such as free pleural effusion, loculated pleural effusion, PTX, and lung consolidation, we analyzed the concordance between ultrasonograph and radiograph, considering the anatomic distribution in the two hemithoraces (Figs 6A-6D). In patients with free pleural effusion and PTX, ultrasound scans were highly concordant with radiographs without significant differences between left- and right-side lungs (all *P* not significant). Loculated pleural effusion was detected by ultrasonographs in three of five patients with this abnormality on radiographs without significant differences between the two lungs (*P* not significant). No significant difference between

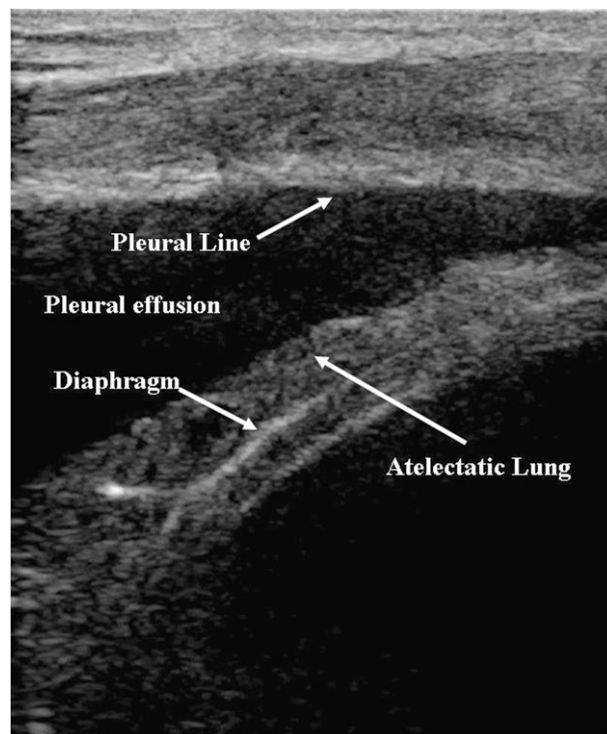


FIGURE 4. Two-dimensional echographic image of a basal free pleural effusion appearing as an anechoic free space between the pleural line and the diaphragm. A portion of atelectatic lung is shown.

the two lungs was present for lung consolidation. In the 118 patients with discordances between the ultrasonograph and radiograph, chest CT scanning was performed (Table 3). CT scan confirmed the ultrasound-based diagnosis in the majority (63%, 74/118) of patients, whereas radiograph-based diagnosis was confirmed in 37% (44/118) ( $P < .0001$ ). Particularly, ultrasonography exhibited greater sensitivity than radiography in patients with free pleural effusion ( $P < .0001$ ).

When free pleural effusion was analyzed separately in the two hemithoraces, ultrasonography exhibited higher sensitivity than radiography in both hemithoraces ( $P < .0001$ ); specificity was 50% in the right hemithorax for both modalities, whereas ultrasonography had higher specificity than radiography in the left hemithorax (90% vs 10%;  $P = .0011$ ). In all patients with loculated pleural effusion by ultrasonograph and negative radiograph, the CT scan confirmed the presence of loculated pleural effusion (two cases in the left hemithorax and one in the right hemithorax); thus, for the absence of negative CT scan, the specificity was not calculated. Similar limitations were present in the analysis of patients with PTX; in fact, only two patients exhibited discordant ultrasonographic and radiographic results (one detected by ultrasonography and one by radiography), with a positive CT scan for PTX in both cases. When we analyzed

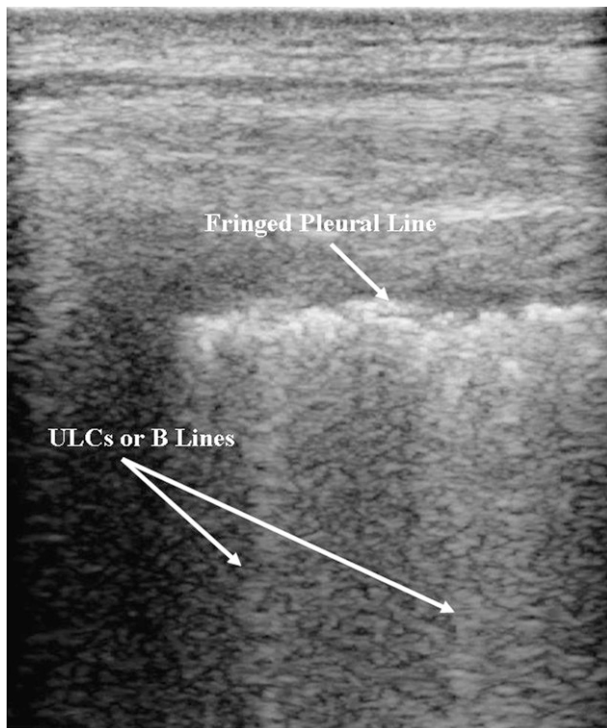


FIGURE 5. ULCs (or B-lines) associated with a fringed and irregular pleural line indicative of pulmonary fibrosis pattern. See Figure 2 legend for expansion of abbreviation.

the 49 cases of discordance between ultrasonography and radiography in patients with lung consolidation, both examinations exhibited similar specificity for both hemithoraces. Sensitivity was similar in the right hemithorax, whereas ultrasonography had higher sensitivity than radiography in the left hemithorax (72% vs 28%;  $P = .0184$ )

## DISCUSSION

In a consecutive series of patients presenting to the ED for dyspnea, our prospective study demonstrated that ultrasonography represents a diagnostic modality at least as accurate as standard radiography with the advantages of a shorter time delay necessary to have the final medical report and no ionizing radiation expo-

**Table 2—Concordance Between Ultrasonography and Radiograph**

Clinical Patterns	Positive Diagnosis		$\kappa$ %
	Ultrasonograph	Radiograph	
Free pleural effusion	87	76	76.2 <sup>a</sup>
Loculated pleural effusion	6	5	53.9 <sup>a</sup>
Pulmonary edema	21	21	95.0 <sup>a</sup>
ARDS pattern	3	1	49.8 <sup>a</sup>
Pneumothorax	7	7	85.5 <sup>a</sup>
Lung consolidation	122	111	70.5 <sup>a</sup>
Pulmonary fibrosis pattern	7	9	87.3 <sup>a</sup>

<sup>a</sup> $P < .0001$ .

sure. In fact, the most important result of our study is the high concordance between the two modalities in the majority of patterns we studied.

In the Bedside Lung Ultrasound in Emergency (BLUE) protocol, Lichtenstein and Mezière<sup>26</sup> performed ultrasonography on consecutive patients admitted to the ICU with acute respiratory failure, comparing lung ultrasonography on initial presentation with the final clinical diagnosis by the ICU team. In this clinical setting, ultrasonography provided correct diagnoses in 90.5% of cases. In the present study, however, we compared elementary radiographic and ultrasonographic patterns; therefore, only the concordance between the two modalities was examined. Assuming that all cases with concordant results between ultrasonography and radiography were correctly diagnosed and combining these results with the CT scan findings, we can speculate that the ultrasonographic diagnostic accuracy in our study is  $>90\%$  for all abnormalities investigated. In our study, the concordance between ultrasonography and radiography in patients with a radiologic pattern of pulmonary edema was 95%, supporting the hypothesis that chest ultrasonography can enable the EP to make a rapid diagnosis in patients with acute respiratory failure. Our results support previous evidence that ultrasound lung comets provide reliable information on interstitial pulmonary edema<sup>27</sup>; moreover, in critically ill patients, the predominance of an A-line indicates dry interlobular septa and is a strong predictor of normal pulmonary capillary wedge pressure.<sup>6</sup> We also found a high concordance in detecting pulmonary fibrosis pattern ( $\kappa = 87\%$ ). The exceptionally high diagnostic accuracy of ultrasonography in patients with pulmonary fibrosis can be explained, at least partially, by the small number of cases as indicated by the wide statistical range of the 95% CI.

As mentioned previously, because radiographic reports often do not distinguish between atelectasis and pneumonia, we were forced to regroup under the term “lung consolidation” the ultrasonographic patterns of alveolar syndrome and atelectasis. However, ultrasonography is able to distinguish between these two patterns by the dynamic air bronchogram, potentially increasing its clinical accuracy.<sup>28</sup>

The concordance between ultrasonography and radiography in patients with lung consolidation and free pleural effusion was 70% and 76%, respectively. We did not find significant differences when the concordance was analyzed while considering the anatomic distribution in the two hemithoraces. Our data exhibited a high concordance in patients with PTX but were unable to confirm that ultrasonography had greater sensitivity and specificity than radiography when compared with CT scanning.<sup>12-15</sup>

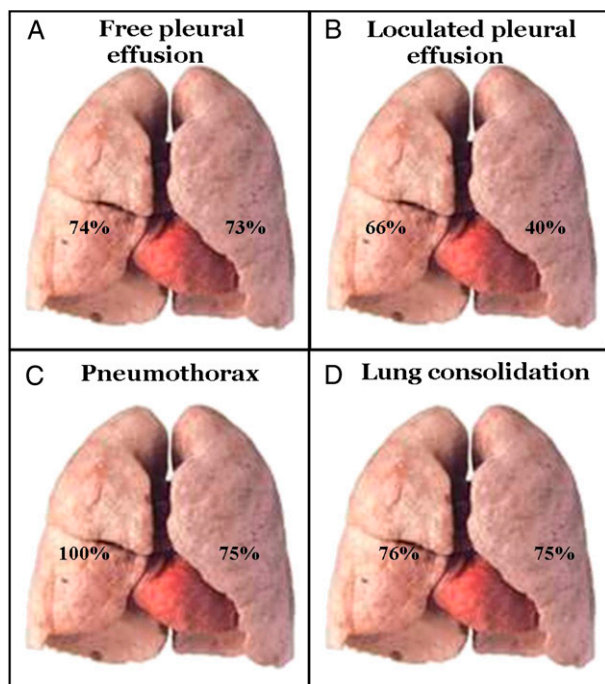


FIGURE 6. Measure of agreement (expressed as  $\kappa$  %) between chest ultrasonograph and chest radiograph according to their position in the hemithoraces. All  $\kappa$  values were highly significant ( $P < .0001$ ). A, Free pleural effusion. B, Loculated pleural effusion. C, Pneumothorax. D, Lung consolidation.

When the discordance cases of free pleural effusion were studied by CT scanning, 18 of the 21 patients originally classified as false-positive by ultrasonograph had this diagnosis confirmed by CT scan; 8 of the 10 patients classified as false-negative did not exhibit free pleural effusion by CT scan, suggesting a greater diagnostic accuracy of the ultrasonograph than plain radiograph for this disease. Additionally, the three cases of false-positive loculated pleural effusion were confirmed by the CT scan, with the ultrasonograph reaching 100% of positive predictive value.

Only ARDS pattern exhibited a concordance  $< 50\%$  in our series. Of note, only three patients had this disease, and the two cases initially classified as false-positive by ultrasonograph were instead confirmed by CT scan.

Our study compared ultrasonographic and radiographic findings independently from the final clinical diagnosis, but the ultrasound examinations were performed to help the EP to identify the correct diagnosis and treatment quickly. Several studies already demonstrated that ultrasonography can help to discriminate among the most important causes of acute dyspnea in the ED, such as COPD, PE, and myocardial dysfunction. The presence of diffuse comet tails or B-line artifacts is the ultrasonographic pattern of diffuse alveolar-interstitial syndrome, which often is a sign of acute pulmonary edema. This condition rules out exacerbation of COPD as the main cause of an acute dyspnea.<sup>7,26,29</sup> In our data set, when ultrasonographs did not exhibit diffuse comet tails or B-line artifacts, one of the most frequent discharge diagnoses was COPD. Another important diagnosis to consider in patients with dyspnea in the ED is PE. As published by Lichtenstein and Loubières,<sup>30</sup> the majority of patients with acute PE exhibited normal chest radiographs and ultrasound scans. Thus, we must emphasize the usefulness of the Wells score<sup>31</sup> to discriminate between patients with low or high clinical suspicion of PE. Furthermore, the echocardiography assessment of cardiac function and inferior vena cava diameter allows for the identification of cardiac etiology in patients with acute dyspnea. As demonstrated in a recent study, the echocardiogram performed by the EP is an accurate method to identify acute left ventricular heart failure and could be used as a first-line diagnostic tool for patients with acute dyspnea.<sup>32</sup>

The most important limitation of our study is that only one experienced EP performed all ultrasound examinations; if all physicians working in the ED were involved in the study, ultrasonography probably would have exhibited a lower accuracy. As recommended by the American College of Emergency Physicians, at least 150 ultrasound examinations need be performed and interpreted under supervision by an expert instructor to achieve sufficient competency.<sup>33</sup>

Another limitation is that lung CT scanning was performed only in patients who exhibited discordances

**Table 3—Comparison of Chest Ultrasonograph and Chest Radiograph With Chest CT Scan as a Reference Standard in the 118 Cases of Discordance Between the Two Modalities**

CT Scan Diagnosis	No.	Radiography			Ultrasonography			P Value	
		TC	Sensitivity %	Specificity %	TC	Sensitivity %	Specificity %	Radiograph	Ultrasonography
Free pleural effusion	31	5	10 (2/20)	27 (3/11)	26	90 (18/20)	73 (8/11)	$< .0001$	NS
Loculated pleural effusion	5	2	40 (2/5)	...	3	60 (3/5)	...	NS	...
Pulmonary edema	2	1	...	50 (1/2)	1	...	50 (1/2)	...	NS
ARDS pattern	2	0	...	...	2	100 (2/2)	...	...	...
Pneumothorax	2	1	50 (1/2)	...	1	50 (1/2)	...	NS	...
Lung consolidation	49	23	40 (14/35)	64 (9/14)	26	60 (21/35)	36 (5/14)	NS	NS
Pulmonary fibrosis pattern	2	2	100 (2/2)	...	0	...	...	...	...

NS = not significant; TC = total concordance (true-positive + true-negative).

between the chest ultrasonograph and plain radiograph. Chest CT scanning was not performed in all patients for ethical reasons, but this limitation does not allow the verification of the sensitivity and specificity of ultrasonography and radiography compared with CT scanning as the gold standard. In the present study, we did not record the ultrasound scanning time; therefore, we were unable to compare this time with the radiograph acquisition time. Finally, the prevalence of some abnormalities, such as ARDS patterns, loculated pleural effusion, PTX, and pulmonary fibrosis pattern was so limited that we could not reach definitive conclusions about the clinical utility of ultrasonography in these patients.

### CONCLUSIONS

Our study demonstrated high concordance between chest ultrasonograph and standard radiograph in most pulmonary diseases causing dyspnea. Moreover, in patients with normal chest ultrasound scans, chest radiographs were normal in the majority (90%) of cases. This result suggests that in the ED, when chest ultrasonography is normal, the radiographic examination can be avoided in a large number of patients.

When a chest ultrasonograph and chest radiograph reached discordant clinical conclusions, the comparison of these two modalities with a chest CT scan as the gold standard demonstrated that ultrasonography was more accurate than radiography when diagnosing free pleural effusion. In other pathologies, the two modalities were similarly accurate.

Considering the shorter time delay necessary to have a final medical report from an ultrasound scan compared with the standard radiographic examination, without patient exposure to ionizing radiations, chest ultrasonography could replace standard chest radiography as the first routine imaging modality used in patients with dyspnea admitted to the ED.<sup>5,7,26</sup> Further investigations will be necessary to evaluate the accuracy of ultrasonography for specific pathologies and its cost-effectiveness compared with radiography.

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**Author contributions:** Dr Zanobetti: contributed to the study design, performance of all echographic examinations, statistical analysis, and writing of the manuscript.

Dr Poggioni: contributed to the data collection, the statistical analysis, and writing of the manuscript.

Dr Pini: contributed to the statistical analysis and writing of the manuscript.

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