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Original Contribution

Evaluation of lung ultrasound for the diagnosis of pneumonia in the ED

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Abstract

Objectives: The aim of this study is to assess the ability of bedside lung ultrasound (US) to confirm clinical suspicion of pneumonia and the feasibility of its integration in common emergency department (ED) clinical practice.

Methods: In this study we performed lung US in adult patients admitted in our ED with a suspected pneumonia.Subsequently, a chest radiograph (CXR) was carried out for each patient. A thoracic computed tomographic (CT) scan was made in patients with a positive lung US and a negative CXR. In patients with confirmed pneumonia, we performed a follow-up after 10 days to evaluate clinical conditions after antibiotic therapy.

Results: We studied 49 patients: pneumonia was confirmed in 32 cases (65.3%). In this group we had 31 (96.9%) positive lung US and 24 (75%) positive CXR. In 8 (25%) cases, lung US was positive with a negative CXR. In this group, CT scan always confirmed the US results. In one case, US was negative and CXR positive. Follow-up turned out to be always consistent with the diagnosis.

Conclusion: Considering that lung US is a bedside, reliable, rapid, and noninvasive technique, these results suggest it could have a significant role in the diagnostic workup of pneumonia in the ED, even if no sensitivity nor specificity can be inferred from this study because the real gold standard is CT, which could not be performed in all patients.

1. Introduction

Community-acquired pneumonia (CAP) in adults is a common disorder, potentially life threatening [1], with a high hospitalization rate [2]. It is the only acute respiratory tract infection in which delayed antibiotic therapy has been associated with increased risk of death [3]. Therefore, a correct and rapid diagnosis is mandatory.

Currently, chest radiograph (CXR) is recommended for the routine evaluation of a patient suspected of having pneumonia because medical history and physical examination cannot provide certainty in this diagnosis [4]. However, especially in the emergency department (ED) setting, CXR might have many limitations due to patient conditions, waste of time, and interobserver variability in its interpretation [5].

Computed tomography (CT), on the other hand, is considered to be the gold standard technique, but it is often not available, has high radiation dose, and has high cost [6].

Lungs are traditionally considered poorly accessible to ultrasound (US) investigation because of their air content [7]. Only in the last decade, it has been shown that the US assessment of the lung could have a role in common clinical practice [8].

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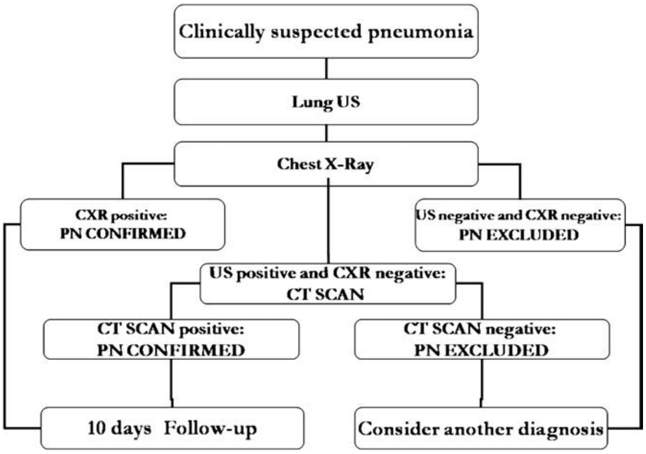

Fig. 1 The design of the study. Computed tomography was performed only in patients with positive US and negative CXR.

In lung consolidations, air is replaced by fluid, leading to a good US transmission if there is a direct contact of the lesion with pleural surface [9,10]. Not many studies were performed in the last years for the evaluation of lung US in the diagnosis of infectious lung diseases [11-15].

The aim of this study is to assess the ability of bedside lung US to confirm clinical suspicion of pneumonia and the feasibility of its integration in common ED clinical practice.

2. Methods

2.1. Setting

The study was conducted in the ED of S. Antonio Abate Hospital, Tolmezzo, Italy, a second-level general hospital, during a 4-month period (from October 4, 2006, to January 15, 2007). This ED usually has about 20 000 visits per year.

2.2. Inclusion criteria

Patients not consecutively admitted to our ED with signs and symptoms of CAP were studied. According to the international guidelines [16-19], the suggestive clinical elements were cough, fever or dyspnea, sputum production, and pleuritic chest pain. In elderly (>75 years), altered mental status, failure to thrive, and falls were also considered. Patients were admitted from Monday to Friday, in the daytime (from 8:00 AM to 8:00 PM). The presence of the expert in lung US was necessary for patient enrollment.

2.3. Exclusion criteria

We excluded children (<16 years old) and pregnant women because of the restrictions in the use of CT required for these patients. We also excluded patients with respiratory insufficiency associated with vomiting, because of the clinical suspicion of aspiration pneumonia, due to the peculiarity of this condition.

2.4. Design

In patients with history and examination suggestive of pneumonia (Fig. 1), one unblinded emergency physician (30 years experienced in general and cardiac US and 10 years trained in lung US) performed all the lung US examinations.

Chest radiography was always carried out after US. A positive CXR was considered sufficient for the diagnosis, irrespective of US results. On the other hand, a positive lung US and a negative CXR called for CT, according to preexisting protocols. Chest radiography and CT scans were read by the senior radiologist on duty, aware of the clinical suspicion but not of the US findings. Before the CT, a second blinded radiologist confirmed the CXR findings.

In all patients with confirmed pneumonia, we performed a 10-day follow-up to verify clinical and laboratory improvement of patients after antibacterial therapy (Fig. 1). We obtained informed consent only from patients undergoing CT scan because US examination and CXR are routine procedures.

2.5. Statistics

Statistical analysis was done using k statistic and McNemar tests to assess concordance and symmetry between lung US and CXR results.

2.6. Instrumental examinations

A convex 3.5- to 5-MHz probe (Megas CVX, Esaote Medical Systems, Firenze, Italy) was used. At bedside, the probe was set perpendicular, oblique, and parallel to the ribs in the anterior, lateral, and posterior (lower and upper) thorax. Sitting position and lateral decubitus were used to scan the posterior chest wall.

In agreement with literature [9,20,21], each hemithorax was divided into 5 areas: 2 anterior, 2 lateral, and 1 posterior. The anterior chest wall was marked off from parasternal line to anterior axillary line. This zone was splitted into an upper region (from collar bone to the second-third intercostal space) and a lower region (from the third intercostal space to diaphragm). Also, the lateral area, from the anterior to the posterior axillary line, was divided into upper and lower halves. Finally, the posterior zone was identified from the posterior axillary line to the paravertebral line.

The superficial layers of the thorax consist of subcutaneous tissue and muscles. The ribs, on longitudinal scan, appear as curvilinear structures associated with posterior acoustic shadowing. Pleura looks like an echogenic line, showing a continuous intrinsic movement during breathing, called "lung sliding sign." The air-filled lung parenchyma prevents any further echographic visualization under the

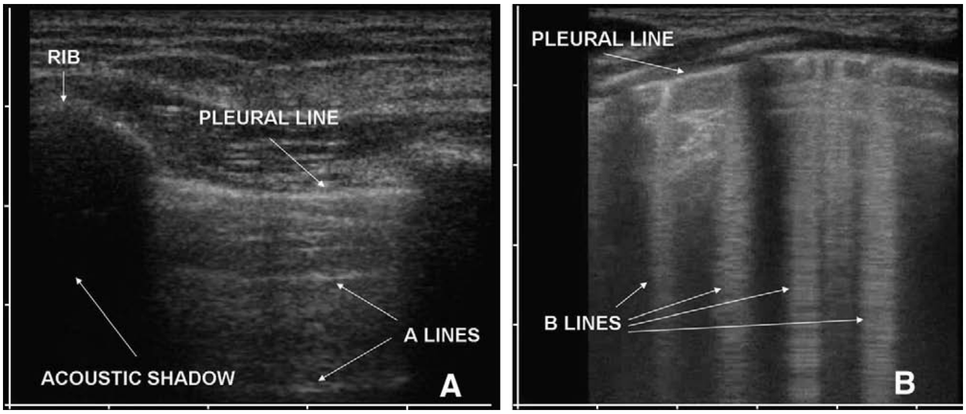

Fig. 2 A normal echographic lung is shown in a longitudinal view (A). Between the ribs, pleural line and multiple A lines are clearly visualized. B lines indicate alveolar-interstitial syndrome: they arise from pleural line reaching the bottom of the screen and erasing A-line pattern (B).

pleural line. However, the wide acoustic impedance difference between pleura and the underlying parenchyma creates typical horizontal artifacts. These are a series of echogenic parallel lines equidistant to one another, arising from the pleural line. These artifacts were defined "A lines" by Lichtenstein [24] (Fig. 2A).

Other vertically oriented "comet-tail" artifacts (B lines according to Lichtenstein et al [22] and Volpicelli et al [21]) might be present. B lines arise from pleural-lung interface, reach the edge of the screen, erase A lines, move with lung sliding, and are absent in the normal lung [22]. These artifacts result from the fluid-rich subpleural interlobular septae that, in a pathologic condition defined as alveolar-interstitial syndrome, are surrounded by air. Computed tomographic correlations showed that B lines are related to the presence of interstitial or interstitial-alveolar edema [8] (Fig. 2B).

Each patient able to maintain orthostatic position underwent posterior-anterior and lateral radiographs with a fixed machine (Diagnostic 96; Philips Medical System, Amsterdam, the Netherlands). If the patient, because of his clinical conditions, could not be moved to the radiology ward, we

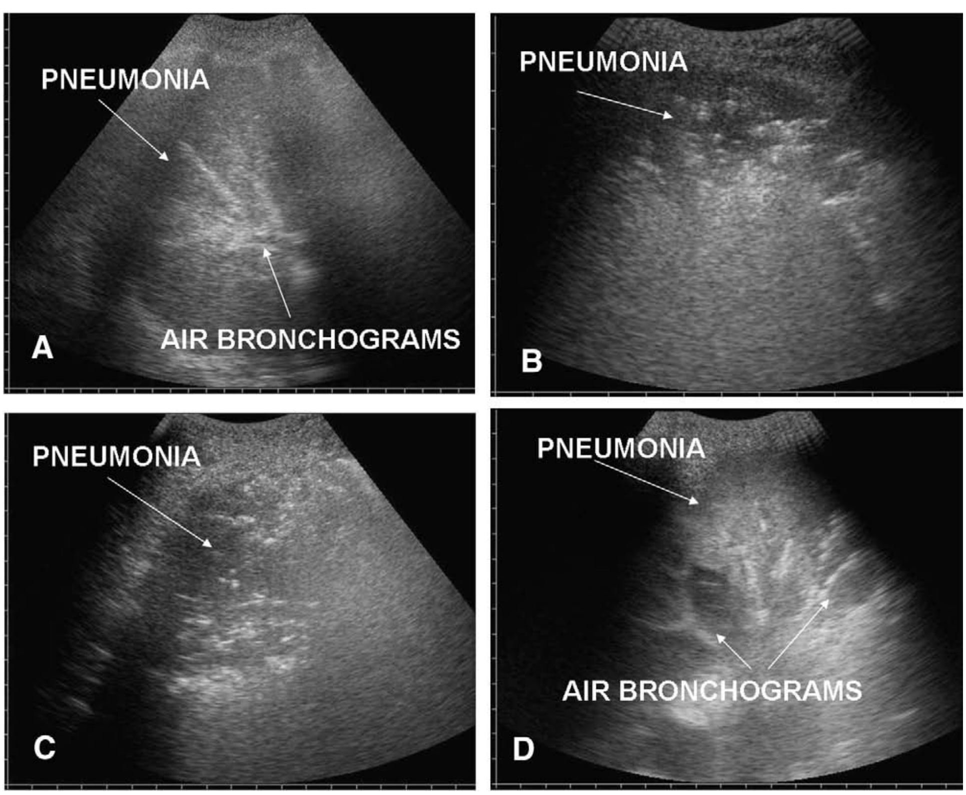

Fig. 3 The echographic appearance of pneumonia. It is an irregular subpleural hypoechogenic area with air bronchograms (A, D) or many hyperechogenic spots (B, C). Pleural line is often hypoechogenic (B).

Table 1 Results of the instrumental examinations

	RX+	RX−	Total		US+, CXR−
ECO+	23	8	31	CT+	8
ECO−	1	17	18	CT−	0
Total	24	25	49	Total	8

CT, computed tomography; CXR, chest x-ray; US, lung ultrasound. Findings in the group examined with CT are listed in right side of the table.

obtained only the posterior-anterior view, using a mobile device (Mobildrive AR15; SIAS s.p.a., Bologna, Italy).

Computed tomographic scans were executed using always intravenous contrast with GE Lightspeed Advantage Multidetector 16 CT scan (General Electric, Little Chalfont, UK).

In patients confirmed of having pneumonia, we performed a follow-up after 10 days to evaluate clinical conditions and laboratory analysis (C-reactive protein, blood cell count), after adequate antibacterial therapy.

To evaluate their potential influence on lung US feasibility, we collected data on body mass index, as well as associated clinical conditions and pneumonia severity (using Pneumonia Outcome Research Team [PORT] index) [23].

The criterion to determine the echographic diagnosis of pneumonia was the finding of subpleural lung consolidation with evidence of static or dynamic air bronchograms (Fig. 3).

3. Results

We studied 49 patients: 18 (36.7%) females and 31 (63.2%) males with a mean age of 60.9 years (SD, 21.8). Positive CXR or CT scan and indirectly the 10 days clinical follow-up confirmed pneumonia in 32 cases (65.3%). In this group, we had 31 (96.9%) positive lung US and 24 (75%) positive CXR (Table 1). Follow-up was always consistent with the diagnosis, showing an improved clinical picture (no fever, cough, or dyspnea) and a drop in inflammatory laboratory indexes such as C-reactive protein.

Concordance between lung US and CXR is quite good (k statistic = 0.63; 95% confidence interval, 0.43-0.84), but the number of cases with positive lung US and negative CXR is sharply superior to the number of patients with negative US and positive CXR (McNemar $P = .0196$).

We could perform a complete lung US examination (scanning anterior, lateral and posterior chest wall) in all the patients, whereas we obtained both posterior-anterior and lateral CXR views in 28 (66%) cases. Of the 8 patients assessed using CT, 3 (37.5%) had also lateral CXR.

In Table 2, echographic findings are shown. Pneumonia (Fig. 3) appears as a hypoechogenic area with irregular shape touching the pleural line. Very often, the consolidation area is surrounded by multiple and close B lines, that is, alveolar-interstitial syndrome, an expression of inflammatory perilesional edema. Pleural line next to the lesion is hypoechogenic and lung sliding is reduced or absent. Branching echogenic structures are often visible within the consolidation representing air bronchograms and can have an intrinsic centrifuge movement with breathing: this finding is called dynamic air bronchogram and rules out atelectasia [24]. Air trapped in the small airway creates multiple millimetric hyperechogenic spots within the lesion. These findings are consistent with former studies in the literature and well described also in a recent experience by Reissig and Kroegel [15] (Table 2).

To assess the feasibility of the integration of this technique in the common ED clinical practice, we deemed it appropriate to set a 5-minute cutoff for the execution times of lung US. As reported in our data collection forms through a "yes/no" question, no examination exceeded that time limit.

4. Discussion

In the present study, the use of CT to clarify contrasting results between lung US and CXR was crucial: if we had considered CXR as the gold standard, we would have had 8 false-positive echographic results (25% of 32 confirmed diagnoses), actually proven to be pneumonia. One of these cases is shown in Fig. 4. This was not caused only by patients' conditions hindering good CXR images: 3 of these patients, as said before, had a double-view CXR. Besides, the 8 negative CXRs were evaluated by a second expert blind radiologist. Furthermore, the percentage of false-negative CXR of this study concerning diagnosis of pneumonia is in line with literature data: Syriala et al [6], comparing high-resolution computed tomography with CXR ability in the diagnosis of pneumonia, found 8 (30.8%) negative CXR cases of 26 confirmed pneumonias.

Another key point in the design of this study is that lung US was performed before CXR by a sole expert operator: this allows the assess of the technique itself but not the interobserver variability in lung US image interpretation. However, whereas the execution of US examination is strictly dependent on the operator experience, the echo-

Table 2 Echographic findings in patients with or without radiologically confirmed pneumonia

	Patients without confirmed pneumonia	Patients with confirmed pneumonia
Consolidation	2 (11.8%)	31 (96.9%)
Alveolar-interstitial syndrome	5 (29.4%)	22 (68.8%)
Air bronchogram	0 (0%)	16 (50.0%)
Pleural effusion	3 (17.6%)	11 (34.4%)
Normal pattern	10 (58.8%)	0 (0%)

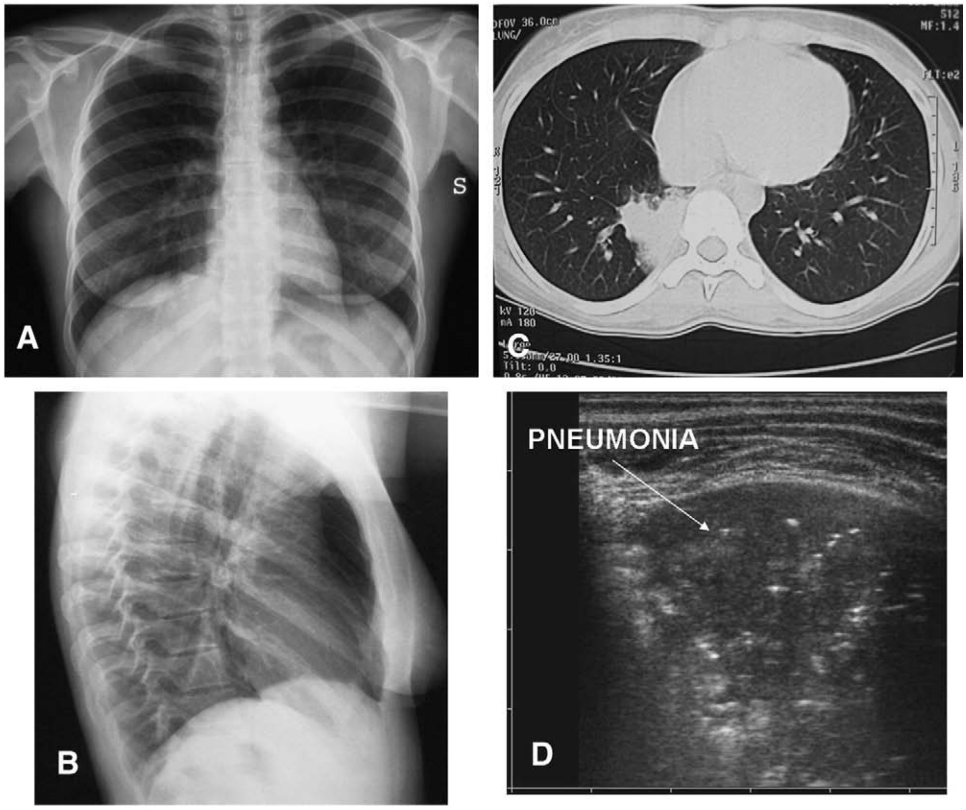

Fig. 4 A 22-year-old patient presenting with pleural pain and cough. Results of instrumental examinations are shown: double-view CXR showed no sign of pneumonia (A and B), whereas CT scan (C) confirmed the right basal consolidation shown by lung US (D).

graphic image interpretation itself is definitely less dependent on the operator: the US pattern of a lung consolidation is indeed completely different from an alveolar-interstitial syndrome or a normal pattern [8].

Regarding echographic findings, we found 2 subpleural consolidations in patients without pneumonia confirmation: they were, respectively, an atelectasia caused by a large pleural effusion and a case of pulmonary embolism [25]. In the first case, we excluded the infection because of the static bronchograms course; in fact, they appeared parallel, whereas in pneumonia they are always branching. This is probably because the lung volume decreases in atelectasia, whereas it increases in infectious consolidations. In the embolism case, we observed many small bilateral subpleural consolidations, without any bronchogram images. These pictures, even considering the literature [26], suggested the diagnosis, subsequently confirmed by contrast CT.

In essence, a subpleural consolidation in itself is not a specific echographic sign of pneumonia, and the differential diagnosis could be difficult.

In our survey, 5 (29.4%) patients did not have any lung consolidation but a bilateral alveolar-interstitial syndrome: 3 of them had a diagnosis of acute pulmonary edema, and 2 of lung fibrosis. On the other hand, in 22 (68.8%) patients with confirmed pneumonia diagnosis, the alveolar-interstitial syndrome was close to consolidation, as expression of a perilesional inflammatory edema, as described before.

Fifty percent of the patients with confirmed pneumonia presented dynamic air bronchograms: this sign, as already shown in literature, excludes atelectasia [24]. In addition, we could find static air bronchograms in all patients with pneumonia.

We found pleural effusion in 3 patients without pneumonia in which the final diagnosis was acute pulmonary edema and in 11 patients with confirmed pneumonia. Pleural effusion is frequently associated with infectious consolidations, but also with many other diseases, as it is well known.

As said before, a lung consolidation becomes evident to US examination only if it reaches pleural surface. In the present study, all the consolidations interpreted as pneumonia satisfied this condition. In fact, even in the only case where we had with positive CXR and negative lung US, we could visualize the consolidation performing lung US once CXR response was acquired. We could not find in literature anatomopathologic data regarding the percentage of CAP reaching pleural surface, but from some previous experiences [9,27], it appears to be definitely elevated.

In this study, we did not describe localization, shape, and dimensions of pulmonary consolidations because this kind of assessment is far from the "goal-directed" approach of emergency US.

As stated above, we could obtain a complete lung US examination in all patients, aside from their body mass index, associated clinical conditions, and pneumonia severity: this demonstrates the high versatility of this technique. Furthermore, the execution rapidity, even if obtained by an expert operator, shows that bedside lung US does not interfere with common ED diagnostic workup of pneumonia.

4.1. Limitations

The main limitation of this study is the small number of patients enrolled; however, statistical analysis shows significant results, especially concerning the asymmetry of McNemar test, favorable to lung US.

It is not possible to infer conclusive data on sensitivity and specificity of bedside lung US in the diagnosis of pneumonia from this study as, because of ethical reasons, we did not perform CT (considered as the gold standard) in all patients.

Nevertheless, regarding sensitivity, it is encouraging that we had an alternative diagnosis (with consequent therapy) for each patient without confirmed pneumonia. Concerning specificity, beyond the CT results, follow-up results were an indirect evidence of the diagnosis correctness.

Finally, it is important to say that the lung US operator was not blind concerning clinical presentation of patients.

4.2. Conclusion

Considering the limitations of the present study, further close examinations are needed to assess the sensitivity and specificity of bedside lung US in the diagnosis of pneumonia.

We clearly confirmed the feasibility of lung US in an ED setting, already reported in the literature [21].

Considering it is a bedside, reliable, rapid and noninvasive technique, these results suggest it could have a significant role in the diagnostic workup of pneumonia in the ED.

In particular, if the accuracy of lung US is confirmed, execution rapidity of this examination will appear very relevant for the emergency and critical care area, especially if it is compared to the time required to obtain the results of radiologic surveys.

Noninvasivity is also a striking quality of this technique, especially concerning its use in children, pregnant women, and, as recently shown in literature [15], even for the follow-up of lung lesions.

In conclusion, we believe that lung US in emergency physician hands, for the first approach to patients with pneumonia suspicion, could be an interesting tool for these patients' management.

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