The Diagnostic Contribution of Systematic Lung Ultrasonography in Patients Admitted to a Conventional Pulmonology Hospitalization Unit

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Objective—Although the evidence to date remains limited, we hypothesized that performing protocolized lung ultrasound (LUS) in patients, admitted to a conventional pulmonology hospitalization unit, could improve diagnostic precision. The main objectives of this study were to evaluate the diagnostic contribution and changes in the treatments administered after performing a protocolized LUS in patients hospitalized in a Pulmonology Department ward.

Methodology—This was a prospective, observational study, which included patients admitted from the Emergency Department to a conventional Pulmonology Department hospitalization unit, after first being evaluated by a pulmonologist. LUS was performed within the first 48 hours of admission. The diagnosis at the time of discharge was used as the reference diagnosis.

Results—A total of 180 patients were included in this study. The admitting diagnoses were the decompensation of an underlying obstructive disease in 60 patients (33.3%), respiratory infection in 93 (51.7%), pulmonary thromboembolism (PE) in 9 (5%), exacerbation of an interstitial lung disease in 14 (7.8%), and other causes in 4 cases (2.2%). Ultrasonography provided new information, unsuspected at the patient's admission, in 117 (65%) of the patients by capturing images suggestive of infection in 63 patients (35%), 1 new case of ILD, 23 (12.7%) cases of cardiogenic edema, and pleural pathology in 19 (10.5%), as well as two tumors and indirect data related to a PE. The use of LUS resulted in the decision to change the already established treatment in 17.2% of the cases.

Conclusions—LUS provided additive information in more than half of patients that ended up reclassifying or potentially changing diagnosis or treatment. Thus, including LUS in management algorithms could reduce the need for other complementary tests or unnecessary treatments.

Key Words—LUS; POCUS; ultrasonography

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Abbreviations

BMI, body mass index; CT, computed tomography; ILD, interstitial lung disease; LLL, lower left lobe; LUS, lung ultrasound; PA, posteroanterior; PA-LAT, posteroanterior and lateral; RLL, lower right lobe; SD, standard deviations

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Lung ultrasound (LUS) has been established as a useful imaging technique for diagnosing and monitoring different pulmonary pathologies. To date, its use has been most developed and is best established in the field of Emergency and Critical Care[1–3] because it can easily be implemented during bedside examinations to obtain information in real-time and to capture dynamic images. Compared to conventional techniques, the use of LUS is now preferable for the etiological diagnosis of dyspnea, and the protocolized incorporation of this technique into examinations carried out upon patient admissions to Critical Care and Emergency Services Units has led to a change in therapeutic attitudes among many physicians.[4]

Pulmonologists first started using LUS during the diagnosis of pleural effusion and to guide pleural procedures,[5] but in recent years, its use has increased in many other situations including the evaluation of pneumothorax, tumors, diaphragmatic pathologies, and parenchymal alterations.[6] There are several situations in which patients admitted to a conventional inpatient pulmonology unit may require an LUS to confirm a suspected diagnosis or to rule out the presence of complications. However, because this tool is often not available, a chest X-ray or computed tomography (CT) scan is usually requested as the first option, thus subjecting the patient to ionizing radiation, delaying the diagnosis, and increasing the use of healthcare resources.

Performing a protocolized LUS in hospitalized patients could improve diagnostic precision, lead to better-targeted treatments, and provides better supporting evidence for the request of more specific imaging tests such as chest CTs, as has already been demonstrated in the intensive care unit.[7] Its integration into the conventional physical examination could lead to an improvement in diagnostic yield. Thus, the main objective of this study was to evaluate the diagnostic accuracy of a new protocolized method for lung exploration using LUS performed at the bedside by a pulmonologist. Second, we also analyzed the role of LUS in the diagnostic and therapeutic decisions taken regarding patients hospitalized in a conventional Pneumonology Department hospitalization ward.

Methods

Study Design

This was a prospective observational study, which included patients admitted to a conventional inpatient Pulmonology Department unit ward via the Emergency Department in a tertiary hospital with more than 800 beds, from March 2019 to January 2020. All the LUS examinations were performed by a single operator (RHC), within the first 48 hours of admission in to a conventional Pneumology Department hospitalization unit, after assessment by the Emergency Department and medical area staff, and following an initial evaluation by a pulmonologist. The operator (RHC) was a pulmonologist with at least 5 years of experience in LUS, who had access to the patient's clinical information. The scanning pulmonologist (RHC) was never the attending physician for these patients. The exclusion criteria were refusal by the patient to participate in the study or a clinical status that will disable the patient to understand and sign the informed consent (Figure 1).

The standard of care at our institution is for the attending pulmonologist to provide primary interpretation of chest radiographs, unless specific consultation with a radiologist is requested. In our sample, 82% of studies did not receive additional radiologist overread.

The recruited patients were classified into the following diagnostic groups based on the main pathologies they presented upon admission to the Pulmonology Department ward: exacerbation of an underlying obstructive disease (asthma or COPD), severe respiratory infections (including bacterial pneumonias, viral infections, or a bronchiectasis infection with or without condensation), exacerbation of interstitial lung disease (ILD), or 'others' including pleural disease, tumors, and pulmonary thromboembolism (PE). Cardiogenic edema was not recorded as a diagnosis on admission because this disease usually enters in to Internal Medicine or Cardiology Department according to the protocol of our center. However, it was registered as a diagnosis at discharge since some patients with chronic respiratory diseases can develop this complication and be confused with an exacerbation of their underlying pathology.

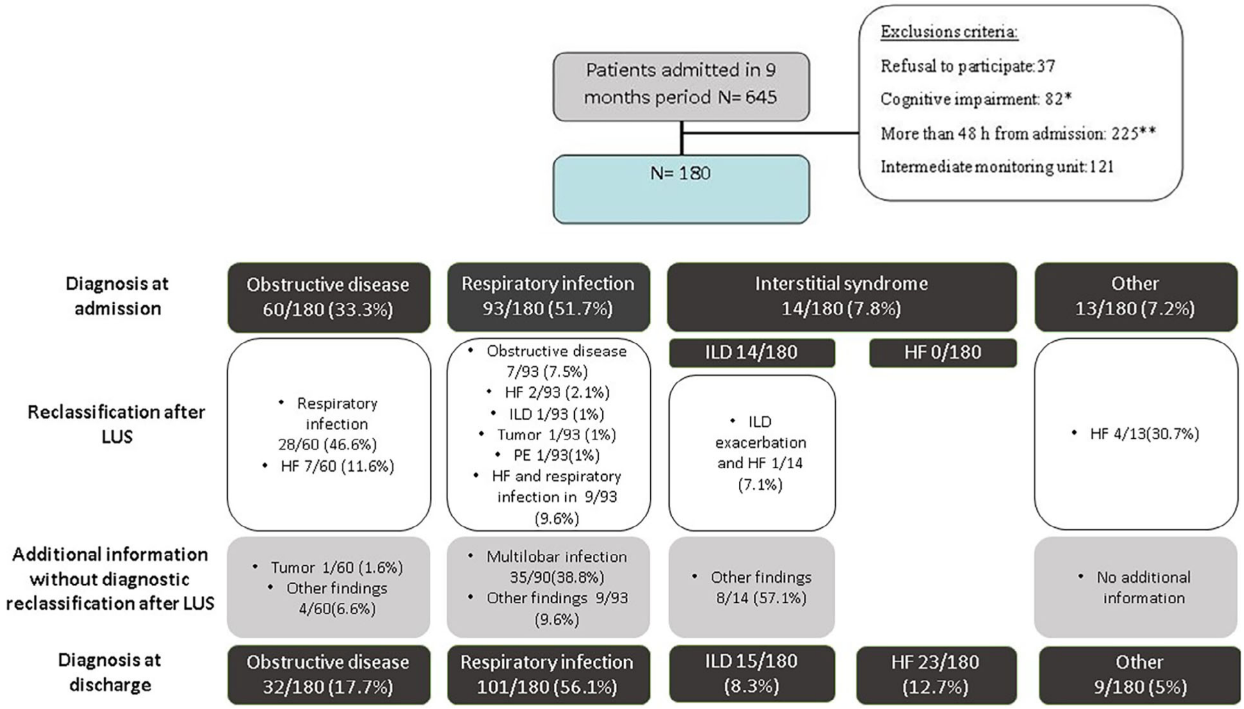
All the patients signed an informed consent document to their participation. This study was approved by the Galicia Ethics and Research Committee with case approval reference number 2018/526. The management of the collected data and medical records complied, at all times, with the requirements of the Spanish Organic Law on Data Protection (3/2018) and the European Regulation 2016/679 for data processing.

Information Gathering

Clinical, Analytical, and Demographic Variables

We recorded data about the patient age, sex, weight, and comorbidities, as well as the results of the following tests performed in the Emergency Department: blood analytics (hemogram, biochemistry, and coagulation), X-ray, CT if it had been performed, and the suspected diagnosis at the time of admission

Figure 1. Flow chart. *: Cognitive impairment: clinical status that will disable the patient to understand and sign the informed consent. **: LUS was performed by a single operator, so in the absence of this, LUS could not be performed. In periods of care overload, patients delayed their transfer to the ward, and patients hospitalized during weekends had more than 48 hours from admission at the time of LUS. PE, pulmonary embolism; ILD, interstitial lung disease; HF, Heart failure; Other, including pleural disease, tumors, and pulmonary thromboembolism.



(Table 1). Retrospective chart review was used to identify what the treating physician considered the most likely pathology and recommended treatment on the day prior to receiving the LUS results from the scanning physician (RHC). The treating physician registered in the electronic health record whether having performed specifically the LUS, and no other diagnostic studies, had changed diagnosis or management. The diagnosis established at the time of discharge by the attending clinician during hospitalization, based on radiological, functional, and analytical findings, was considered the 'gold standard' for the purposes of this study. Up to two clinical diagnoses could be registered in each patient. Authors (NFM, GMA, MRC) reviewed every chart 3 months after discharge while blinded to the LUS results, and determined what the attending pulmonologist's final diagnosis was. One hundred and eighty charts were reviewed by all three authors, and in events of disagreement (of which there were 17), majority of the consensus was achieved through open discussion.

Ultrasonography Variables

LUS was performed following current lung ultrasonography recommendations.[8] We used a Sonosite M—Turbo (Bothell, Washington, EE. UU) with abdomen preset. The depth of field was initially set between 12 and 15 cm (with convex probe) and 6 cm (with linear probe), after having a complete image of reference organ was reduced to 6–8 cm depth (with convex probe) and to 4 cm depth (wit linear probe). The gain was set between −5 and −20. We set the single focal point on the pleura line and achieved the highest frame rate possible. For patients who were unable to sit, eight of the intercostal spaces were examined,[9] while in patients whose

Table 1. Demographic and Baseline Characteristics

		Diagnosis at Admission			
	Overall 180	**Obstructive Disease, $n = 60$**	**Respiratory Infection, $n = 93$**	**Exacerbation of ILD, $n = 14$**	**Other, $n = 13$**
Age (years [SD])	63.5 (16.8)	62.2 (15.9)	63.6 (17.1)	70.1 (22.4)	71.2 (22.4)
Gender (%men)	110/180 (61.1%)	35/60 (58.3%)	61/93 (65.6%)	8/14 (57.1%)	6/13 (46.1%)
Obese (%)	75/180 (41.7%)	23/60 (38.3%)	40/93 (43%)	7/14 (50%)	5/13 (38.4%)
BMI (kg/m^2 [SD])	30.2 (6.5)	29.4 (5.9)	30 (7.5)	36 (30.1)	35.5 (0.7)
Comorbidities (%)					
Emphysema	32/180 (17.8%)	22/60 (36.7%)	7/93 (7.5%)	1/14 (7.1%)	2/13 (15.3%)
Bronchiectasis	24/180 (13.3%)	12/60 (16.7%)	12/93 (12.9%)	0/14 (0%)	0/13 (0%)

SD, Standard deviation; ILD, interstitial lung disease; BMI, Body mass index; Other, including pleural disease, tumors, and pulmonary thromboembolism.

condition allowed them to sit, the dorsal area was also explored.[10] A 2–5 MHz convex transducer was used in patients with a high body mass index (BMI > 30), or otherwise, a 5–10 MHz linear transducer was used. The LUS results were immediately communicated to the attending pulmonologist by recording them in the electronic health record. Up to two LUS diagnoses could be registered in each patient. If after 24 hours from the LUS information there was no consensus with the attending pulmonologist, a confirmatory imaging test (CT, echocardiogram) was requested.

We classified the presence of at least two areas in each hemithorax with more than two B lines as diffuse interstitial syndrome.[11] The diagnosis leaned toward ILD when subpleural alterations with a heterogeneous distribution and areas of pleural thickening with a slight decrease in sliding were present, or toward cardiogenic edema when the involvement was homogeneous, without pleural nodules nor pleural irregularities, preserved lung sliding, and the distances between B lines were narrower (3 mm), whether in association with the presence of pleural effusion or not (Figure 2A).[4,9] Under the LUS diagnosis of interstitial syndrome, there is also ARDS and viral pneumonia. We did not include ARDS because this disease in our center is admitted to an intermediate monitoring unit or critical care unit, not in a conventional pulmonology hospitalization. The viral pneumonia was not a common diagnosis until the arrival of COVID-19 and this study was developed before the beginning of the pandemic.

The presence of focal interstitial syndrome (the presentation of localized B lines), with or without subpleural alterations, was suggestive of a respiratory infection diagnosis (Figure 2B).[2,11] Consolidation was defined as the presence of a hypoechoic subpleural lesion with tissue echogenicity. Depending on the margins, size, pleural invasion, vascular pattern, and presence or absence of fluid on the standard and dynamic air bronchograms, an infectious, vascular, atelectasis, or tumor etiology was more likely (Figure 2C).[6,10]

We considered pleural invasion when the consolidation extended beyond the visceral pleura and was in contact with the parietal pleura or chest wall. Air bronchograms were defined as punctiform or linear hyperechoic artifacts within the consolidation. Dynamic air bronchogram was the term used for the inspiratory dynamic of air bronchograms with more than 1 mm of movement and static air bronchogram in case of absence of dynamic.[3]

Statistical Analysis

Quantitative variables were expressed as means and standard deviations (SD) and qualitative variables as numbers (n) and percentages. The diagnostic contribution was evaluated both in the overall sample and for the diagnostic subgroups (decompensated obstructive pathology, severe respiratory infections, exacerbation of PID, and others—including PTE and pleural and tumor pathologies). Contingency tables were created to compare the qualitative variables using Chi-squared X^2 or Fisher exact tests. The

Figure 2. Ultrasonography patterns. **A**, Diffuse interstitial syndrome. On the left: an image obtained with a linear probe on the anterior surface of the second intercostal space. The presence of pleural deflection and an increase in bilateral B lines affecting at least two areas in each hemithorax and compatible with cardiogenic edema. On the right, an image obtained with a convex probe in the lower right lobe showing the presence of pleural thickening and bilateral B lines in at least two areas in each hemithorax, in the context of ILD. **B**, Focal interstitial syndrome. Two images obtained with a convex probe at the level of the lower lobes are shown. The image on the left corresponds to the lower right lobe (RLL) and shows a localized increase in B lines. The image on the right represents the lower left lobe (LLL) and shows an adequate aeration pattern with the presence of A lines. **C**, Consolidation. The image on the left shows consolidation with poorly defined edges, a sign of lung sliding, as well as tissue echogenicity, in the context of a respiratory infection. The image in the center was obtained with a linear probe and shows a triangular hypoechoic artifact measuring less than 3 cm, with a pleural base and central echogenic axis, related to a pulmonary infarction. The image on the right was obtained with a linear probe and shows a well-defined lesion measuring at least 3 cm, that respected the pleura and was related to a tumor mass.

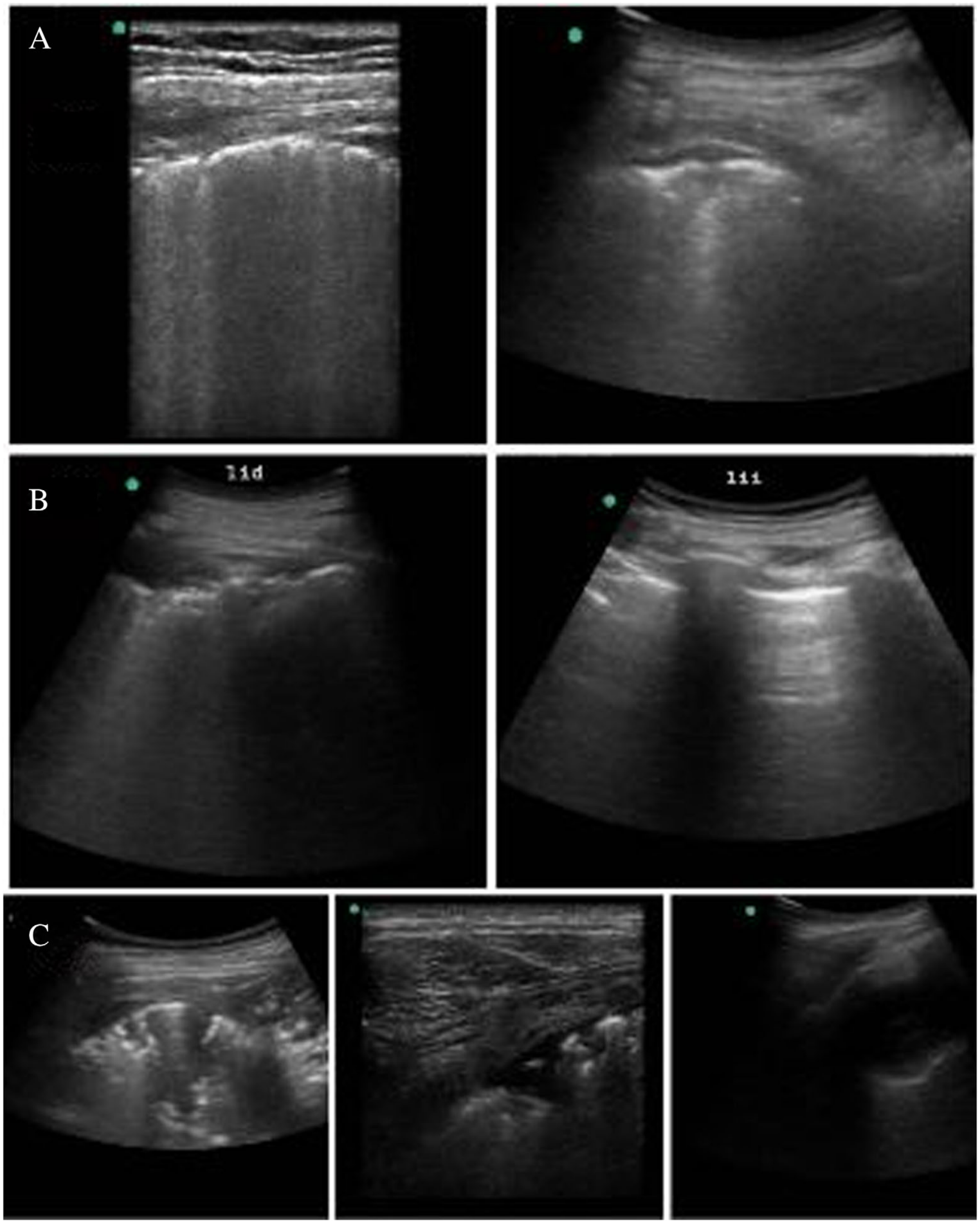
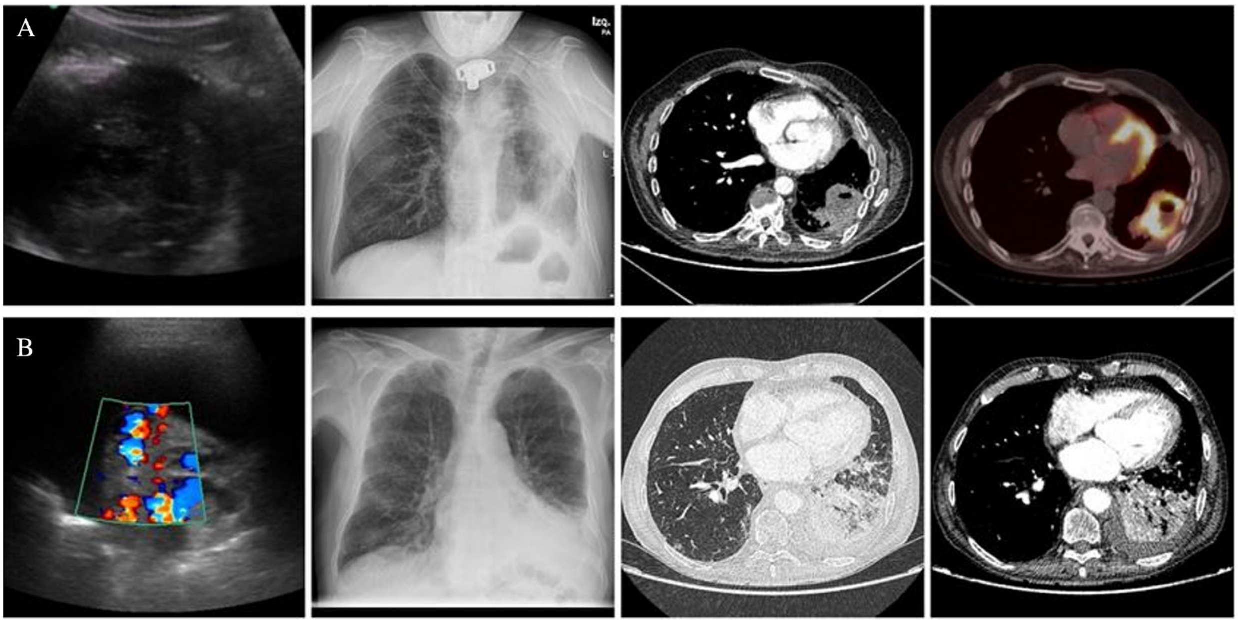


Figure 3. Tumor detection. **A**, This was a tracheostomy patient (due to supraglottic carcinoma, COPD, and severe emphysema) admitted because of a respiratory infection. From left to right, ultrasonography showed the presence of a consolidation measuring at least 6 cm, tissue echogenicity, well-defined borders, and an abscess infiltrating the chest wall. The thoracic radiograph showed a loss of volume in the left hemithorax but did not highlight any changes with respect to the previous X-ray, and consolidation in the LLL. The computed tomography showed consolidation in the LLL and superinfected bullae. Positron emission tomography showed a mass in the LLL in wide contact with the pleural wall, with a probable infiltration, cavitation, and an interior air-fluid level with a maximum SUV of 16.4 g/ml. Bronchoscopy confirmed an epidermoid bronchogenic carcinoma. **B**, A COPD patient admitted because of a respiratory infection and pleural effusion. From left to right, the ultrasonography showed a moderately echogenic pleural effusion affecting at least four intercostal spaces with parenchymal atelectasis and images of abscess with Doppler uptake highlighted in its interior. The radiography showed impingement of the left costophrenic sinus and increased retro-cardiac density. The computed tomography showed passive atelectasis of the LLL with an air bronchogram in its interior and moderate left pleural effusion. A bronchoscopy showed mucosal infiltration of the left basal pyramid by a squamous cell carcinoma.



statistical analyses were conducted with SPSS software (version 21, IBM Corp., Armonk, NY, USA).

Results

Sample Description

A total of 180 patients were included, of which 110 (61.1%) were male, with a mean age of 63.5 years (SD = 16.8), and a mean BMI of 30.2 kg/m^2 (SD = 6.5). Of these, 66 (36.7%) had a history of COPD, 26 (14.4%) of asthma, 22 (12.2%) had bronchiectasis, and 29 (16.1%) had ILD. The reason for admission was decompensation of an underlying obstructive disease in 60 cases (33.3%), respiratory infection in 93 (51.7%), vascular alterations in 9 (5.0%), exacerbation of ILD in 14 (7.8%), and other causes in 4 patients (2.2%). In the Emergency Department, chest X-rays had been performed in the anteroposterior (AP) projection in 51 (28.3%) patients, posteroanterior (PA) in 5 (2.8%), and posteroanterior and lateral (PA-LAT) in 110 (61.1%). The radiologist's report was available for only 33 (18.3%) of them. Eleven (6.1%) patients had undergone a CT scan directly upon admission and three did not receive a chest radiograph because they were pregnant.

Results of the Ultrasonography Examination

A total of 154 patients (85.5%) underwent a complete ultrasonography examination and in 26 cases

(14.4%) only eight intercostal spaces were examined. LUS provided information in 117 (65%) patients: images consistent with an infection (consolidation or focal interstitial syndrome) that had not been identified by the X-ray performed at the time of admission were obtained in 63 cases (35%); 28 of these patients had been admitted with suspected decompensation due to an obstructive pathology with normal X-ray results upon admission and 35 with a suspected respiratory infection but LUS detected multifocal involvement not identified by the initial X-ray.

At admission 14 patients had ILD; 14 (7.8%), however, at discharge, 1 new diagnosis of ILD was detected by LUS and was later confirmed by CT. In 23 (12.7%) patients LUS provided new information compatible with cardiogenic edema verified by attending physician opinion, based on clinical, radiological, and analytical findings, detecting elevated NT-proBNP marker levels (with a mean value of 4097.4 pg/ml; 95% CI 3439.7–4755) and adequate response to diuretics.

LUS also identified two cases of tumors in patients who had been admitted for exacerbation of COPD and a respiratory infection, respectively; the malignancy was verified by histological examination of a biopsy in both cases (Figure 3). In terms of incidental findings, LUS provided evidence for a pleural pathology in 19 (10.5%) patients, indirect data suggestive of PE in one case (consisting of pleural-based, echo-poor triangular, parenchymal lesions of at least 1 cm with a central hyperechoic structure[11]) confirmed by a perfusion ventilation scan, chest wall pathology in three individuals, one pericardial effusion, one lung abscess, and confirmed diaphragmatic paralysis in one patient.

Having undergone LUS resulted in a change in the implemented treatment in 31 (17.2%) patients: antibiotic therapy was started in 9 (5%) patients, diuretic treatment was intensified in 15 (8.3%), which represents a change in treatment of 62.5% in patients diagnosed with cardiogenic edema, antibiotic therapy was prolonged in one case after detecting an abscess, three pleural procedures were performed, anticoagulation was started after detecting a PE and in two patients, and the tumor pathology was treated in two other cases.

There were 10 (5.5%) misdiagnoses on LUS, based on pathology seen on other tests. Among them, 4 patients with diffuse interstitial syndrome had been wrongly classified (2 cases that had been identified as cardiogenic edema presented normal NT-proBNP levels, 1 individual diagnosed with suspected ILD had elevated NT-proBNP levels, and another case classified as ILD was in fact a multi-lobar infection). In addition, the LUS did not detect any evidence of infection in 5 patients (2 of them with consolidations shown on the X-rays performed at admission and 3 with the presence of infiltrates indicated on CT scans). Finally, in another case, the LUS did not detect a central mass seen in the admission X-ray.

In our cohort, patients with an admission diagnosis of obstructive lung disease or respiratory infection were more likely for LUS to change the diagnosis (68.3%; 95% CI: 56–80%; $P = .01$ and 68.8%; 95% CI: 59–78%; $P = .009$, respectively) than in the interstitial or other groups (Figure 1).

Discussion

The usefulness of performing LUS has already been demonstrated (a) at the time of admission by the Emergency and Critical Care Services for respiratory distress,[12,13] (b) to rule out a cardiogenic origin for dyspnea in outpatients,[14] and (c) to assess specific pathologies such as COVID-19 infection[15] or heart failure in patients on hospital wards.[16] However, this is the first study that has analyzed the value of LUS when assessing patients for the most frequent pathologies at the time of admission to a conventional Pulmonary Department inpatient unit.

The ultrasonography examination protocol we used[10] covers more areas than other protocols published elsewhere,[1,9] which means that LUS will take longer time (on average, about 8 ± 2 minutes). The protocols that only explore the anterolateral aspect have been validated in Emergency Services settings where ultrasonography is usually the first diagnostic test performed. However, the clinical stability of hospitalized patients makes it possible to perform a protocolized examination on them while in a sitting position. In our opinion, the extra data gathered by performing this extended LUS examination, exploring the dorsal area, provide added value to the other complimentary tests performed, although this has not yet been proven.

In studies conducted at the prehospital level,[14] performing LUS to differentiate between cardiogenic edema or the exacerbation of COPD meant a change of treatment in 42.3% of cases. A great deal of the evidence for LUS is in differentiating pulmonary edema from other etiologies of dyspnea, but this sample was specifically designed to try to exclude pulmonary edema (as those patients would go to another department). In spite of this, 23 (12.7%) patients were identified to have cardiogenic edema by LUS, and treatment was changed in 62%. This supports the idea that performing LUS at the patient bedside can help optimize therapeutic management and provides data that can further support requests for tests such as NT-proBNP marker levels, as well as help in decision-making for patients with borderline values of this biomarker, a common occurrence among individuals with chronic respiratory disease.

In 35% of the sample, ultrasonography data suggestive of infection that had not been detected by other complementary tests at admission (consolidation or a local increase in B lines) were detected. It is especially noteworthy that 28/60 admitted with suspected decompensation due to an obstructive pathology with normal X-ray at admission were reclassified to infection due to LUS results. However, LUS carried out in this group only resulted in a change in the treatment strategy in 11% of cases. This is probably because most of the patients hospitalized for decompensation of their underlying obstructive disease (asthma or COPD) were started on antibiotic therapy at the time of their admission, regardless of the radiological indications. Moreover, in 55% of these cases, LUS detected foci that had not been identified on the X-ray and which were potentially relevant for follow-up to ensure their resolution.

Also of interest, we would like to highlight the detection of two tumors among these patients. In both cases, the admission X-ray suggested the possibility of alternative diagnoses, but the LUS findings supported the need for a bronchoscopy and biopsy collection, leading to the confirmation of the tumor lesions in these histological samples. However, we also reported 10 (5.5%) cases in which the diagnostic capacity of ultrasonography was lower than other complementary tests. Nonetheless, half of these (five patients) presented lesions not in contact with the pleural wall, which were therefore inaccessible by LUS.

LUS is an emerging tool in pulmonology, and given its clear advantages, its everyday use in hospitalization units would be advisable. In this particular study, it was able to identify unsuspected pathologies or complications in 65% of the patients we studied. Conducting an LUS examination also facilitates the selection of, and provides supporting evidence for, the need for further more specific tests. In this work, the tests ordered based on the information initially gathered using LUS were CTs (5 cases), a D-dimer test (1 case), NT-proBNP determinations (17 cases), abdominal ultrasonographies (2 cases), and regulated echocardiograms (3 cases). This means that we could potentially limit further diagnostic testing, which also reduced hospital costs, but this should be confirmed in future studies specifically designed for this purpose. This could improve the orientation of the diagnosis and treatment optimization, thereby may also improve the prognosis of these patients, perhaps even helping to reduce their hospital stay length for certain pathologies.

It is possible that ultrasonography performed by inexperienced personnel could lead to overdiagnosis and unnecessary complementary tests such as CT being requested. However, in our case, of the five CTs ordered, two confirmed the presence of tumors and one confirmed the presence of ILD. While the other two resulted from a possible overdiagnosis via the LUS, one of them was requested with the suspicion of a tumor, which was subsequently shown to be a round atelectasis, and the other ruled out the presence of a PTE.

Finally, it is important to highlight that this study had some limitations. Firstly, we did not systematically carry out a chest CT in these patients as a 'gold standard'. Rather the LUS results were compared to the diagnosis noted for the patient by their attending clinician at the time of their discharge. This may have caused us to underestimate the false negatives resulting from the LUS, although the patients were followed up via their electronic medical records for 3 months after their discharge to reduce this bias. Nevertheless, we consider the added value LUS contributes to conventional examinations is still worth highlighting, because the use of this noninvasive technique by pulmonologists in their day-to-day practice can help them make more effective diagnoses.

Secondly, an X-ray report from the radiologist was not available for all the patients upon their admission, which could have biased their results given that the LUS was performed by an operator with extensive experience in the field. However, all the radiographs were evaluated by a pulmonologist, who is perfectly qualified for the interpretation of X-ray as it is part of their training program and despite this, further information was provided by the LUS for 20 of the 33 patients for whom a chest X-ray report was available when they were admitted. Another limitation is that the presence of a focal interstitial syndrome in this study has been interpreted as an infection but this finding can be found in other entities such as atelectasis, pulmonary contusion, pulmonary infarction, pleural disease, or even neoplasia, which could have supposed an ultrasound overdiagnosis of this pathology,[3] but in this study the operator had access to clinical information as the perfect complement to emit a differential diagnosis with LUS. Lastly, this was a single-center study developed by a single operator with an unblinded design with a convenience sample (because many patients were excluded due to arguments explained in Figure 1), so the results should be validated in the future in multicenter studies.

In conclusion, performing a protocolized LUS in patients hospitalized in a conventional inpatient Pulmonology Department ward improved the diagnostic accuracy by providing additional information in more than half of the cases. Therefore, the use of this technique is recommended, especially among patients admitted for decompensation of an underlying obstructive disease or presenting a respiratory infection. Thus, including LUS in management algorithms could reduce the need for complementary tests or unnecessary treatments. These results should be validated in multicenter clinical trials that include a gold-standard CT comparison for every case.[17]

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