Lung Ultrasound Performed by Primary Care Physicians for Clinically Suspected Community-Acquired Pneumonia: A Multicenter Prospective Study

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ABSTRACT

PURPOSE We investigated whether lung ultrasound (US) performed in primary care is useful and feasible for diagnosing community-acquired pneumonia (CAP) compared with chest radiography, as most previous research has been conducted in hospital settings.

METHODS We undertook a prospective observational cohort study of lung US performed in 12 primary care centers. Patients aged 5 years and older with symptoms suggesting CAP were examined with lung US (by 21 family physicians and 7 primary care pediatricians) and chest radiograph on the same day. We compared lung US findings with the radiologist's chest radiograph report as the reference standard, given that the latter is the most common imaging test performed for suspected CAP in primary care. The physicians had varied previous US experience, but all received a 5-hour lung US training program.

RESULTS The study included 82 patients. Compared with chest radiography, positive lung US findings (consolidation measuring >1 cm or a focal/asymmetrical B-lines pattern) showed a sensitivity of 87.8%, a specificity of 58.5%, a positive likelihood-ratio of 2.12, and a negative likelihood-ratio of 0.21. Findings were similar regardless of the physicians' previous US training or experience. We propose a practical algorithm whereby patients having consolidation measuring greater than 1 cm or normal findings on lung US could skip chest radiography, whereas patients with a B-lines pattern without consolidation (given its low specificity) would need chest radiography to ensure appropriate management. Lung US was generally performed in 10 minutes or less.

CONCLUSION Point-of-care lung US in primary care could be useful for investigating suspected CAP (avoiding chest radiography in most cases) and is likely feasible in daily practice, as short training programs appear sufficient and little time is needed to perform the scan.

Ann Fam Med 2022;20:227-236. https://doi.org/10.1370/afm.2796

INTRODUCTION

Community-acquired pneumonia (CAP) is defined as a pulmonary infection developing in individuals who have not had recent contact with the health system.[1] The main causative pathogens are *Streptococcus pneumoniae, Hemophilus influenzae, Staphylococcus aureus,* influenza viruses, and other respiratory viruses.

Affected adults may have general malaise, fever, cough, chills, expectoration, respiratory distress, tachycardia, tachypnea, and abnormal auscultation.[1] Frequently, elderly patients do not show many classic symptoms. Radiographic confirmation is not always necessary to establish the diagnosis in outpatient settings,[2] but some guidelines recommend performing chest radiography, even though this imaging is not perfectly sensitive or specific.[3]

The etiology of CAP in childhood depends on age. In patients younger than 5 years, viruses predominate (and other respiratory diseases, such as bronchiolitis or recurrent wheezing, are frequent and difficult to differentiate); in patients aged 5 years and older, the etiology is more similar to that in adults.[4] Pediatric guidelines outline CAP diagnosis based on clinical suspicion, allowing treatment without chest radiography in mild cases (avoiding exposure to ionizing radiation).[5,6] Unfortunately, without a unique clinical definition of pneumonia that can reliably differentiate CAP from other respiratory diseases,[7] forgoing imaging may increase overdiagnosis and antibiotic overuse.[8] This situation could explain why chest radiography is still frequently used in nonserious cases.[9] Use of lung ultrasound (US)

Conflicts of interest: authors report none.

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could retain the benefits of imaging while avoiding patients' exposure to ionizing radiation.

Several previous studies and meta-analyses support the role of lung US as a useful tool for CAP diagnosis with even higher sensitivity and specificity than chest radiography when compared with computed tomography (CT),[10-16] but almost all were performed in hospital settings. To our knowledge, in primary care, where most patients are less severely ill, the only published studies have focused on COVID-19, have been opinions or research projects (without results), or have been limited to children in poor-resource settings.[17-21] It seems neither lengthy training nor lengthy experience is required to perform lung US in patients with suspected CAP, with most studies showing adequate interobserver agreement between experts and inexperienced professionals,[16,20] although a recent meta-analysis concluded that there were differences between novice and advanced sonographers for pediatric patients.[22] Despite current evidence supporting the use of lung US for CAP diagnosis, the scarcity of evidence in primary care indicates a need for new studies.

The main aim of this study was therefore to assess the diagnostic utility of lung US performed by primary care physicians in patients aged 5 years and older with suspected CAP, compared with chest radiography. Secondary objectives were to propose an algorithm to guide decision making in clinical practice; to explore differences in results by patient age-group (pediatric vs adult) and by levels of physicians' prior training and prior experience with US; and to assess time spent on each scan to determine its feasibility in primary care.

METHODS

Between July 2019 and February 2020, patients with clinically suspected CAP were recruited using nonprobability consecutive sampling by 28 physicians (21 family physicians, 7 primary care pediatricians) from 12 primary care centers having US devices in Madrid, Spain. Inclusion and exclusion criteria are detailed in Table 1. The study was approved by the Clinical Research Ethics Committee of Puerta de Hierro Majadahonda University Hospital (reference number 03.19) and the Primary Care Northwest Research Ethics Committee of Madrid region (reference number 07-2018). All patients (or their parents in the case of children) gave written informed consent for use of their personal and clinical data for research purposes.

The flow of patients is outlined in Figure 1. Each patient had a clinical evaluation (history, physical examination, and peripheral oxygen saturation [SpO_2] measurement) and, if the primary care physician suspected CAP (and inclusion and exclusion criteria were met), the patient was invited to participate and included in the study after providing informed consent. Immediately thereafter, the same physician performed a lung US scan without assistants. Despite varied previous US training and experience, all physicians had to have previously completed the 40-hour Madrid Health System's basic abdominal US training (to ensure fundamental knowledge about the modality), and all completed a dedicated 5-hour theoretical and practical lung US training just before beginning the study.

Several US devices were used: the MyLabSix (Esaote Group; used by 12 physicians in 35 patients); the MyLab 40 (Esaote Group; 6 physicians, 15 patients); the DC-N3

Table 1. Inclusion and Exclusion Criteria

Inclusion criteria[a]
Aged 5 years or older with clinically suspected CAP and either of the following features:
Fever[b] characterized by 1 of following:
>72 hours of fever and cough without any improvement
Fever >72 hours with purulent sputum
Fever with ≥1 of following: pleuritic pain; focal or asymmetric auscultation of crackles or hypoventilation; dyspnea (subjective); signs of breathing distress such as tachypnea, retractions, or nasal flaring (objective); SpO_2 <95%; hemoptysis
Isolated fever without focus lasting >4 days
Reappearance or worsening of fever after clinical improvement of a respiratory condition
No fever, but presence of 1 of following:
Cough and purulent sputum lasting >4 days
Cough with ≥1 of following: pleuritic pain; focal or asymmetric auscultation of crackles or hypoventilation; dyspnea (subjective); signs of breathing distress such tachypnea, retractions, or nasal flaring (objective); SpO_2 <95%
Cough lasting >4 weeks, even as an isolated symptom
Dyspnea in patients aged >75 years
Exclusion criteria[c]
Hospital admission within past 30 days (ie, possible nosocomial pneumonia instead of CAP)
Pneumonia already diagnosed during current illness by an imaging test
Receipt of antibiotics for current illness
Previous diagnosis of chronic obstructive pulmonary disease
Previous diagnosis of asthma, or suspicion of asthma attack or bronchial spasm in current illness
Children with previous diagnosis of recurrent wheezing related to viral infections in whom current illness suggests same diagnosis
Lung or pleural cancer
Previous pleurodesis
Previous thoracic surgery
Other chronic lung diseases (eg, pulmonary fibrosis)
Terminal disease (life expectancy <6 months)
Hemodynamic instability
Declined lung ultrasound and/or chest radiograph
Inability to go to the hospital for chest radiograph the same day
Declined to sign informed consent

CAP = community-acquired pneumonia; SpO_2 = peripheral oxygen saturation.

[a] Inclusion criteria were selected to avoid inclusion solely for *clinical suspicion of pneumonia*, a term that has greater potential subjectivity in its interpretation.

[b] Temperature ≥38°C not explained by extrathoracic symptoms.

[c] Exclusion criteria were primarily selected to avoid clinical conditions that might confound lung ultrasound findings.

(Mindray Medical International Limited; 4 physicians, 12 patients); the Logiq F6 (General Electric; 4 physicians, 9 patients); the Logiq C5 Premium (General Electric; 1 physician, 7 patients); and the MicroMaxx (Sonosite Inc; 1 physician, 4 patients). No handheld devices were used.

For the lung US, with the patient preferably seated, the physician fully scanned the entire area of both hemithoraces (including all intercostal spaces of the posterior, lateral, and anterior areas), rather than just obtaining several static views. Convex probes (3-7 MHz, primarily for adults) and linear probes (8-14 MHz, primarily for children) were used. Immediately after lung US, each patient went to the referral hospital for a chest radiograph (not available at most primary care centers in our setting), which was later read by a radiologist from that hospital. The radiologist's report was considered the reference standard for comparison. No blood tests were performed before the imaging tests. Treatment and follow-up data were not considered, as the aim was to compare diagnosis between the 2 imaging modalities. All data were recorded anonymously.

The result of lung US (the index test) was the primary analyzed variable. With the clinical suspicion of CAP, lung US was considered positive if any of the following were present: 1 or more consolidations (defined as subpleural hypoechogenic areas with an echogenic air bronchogram) greater than 1 cm in diameter, or a focal, unilateral, or asymmetrical bilateral B-lines pattern (including coalescent B-lines) (Figure 2).[23] It was considered negative when it showed a bilateral A-lines pattern.

Chest radiograph (the reference test) was considered positive if the conclusion of the radiologist's report stated a finding of any alveolar consolidation or interstitial pneumonia. It was considered negative if the report indicated normal findings or peribronchial thickening without evident infiltrates.

Secondary variables were patients' clinical data, physicians' previous accredited training in and experience using US, and time spent performing each lung US scan.

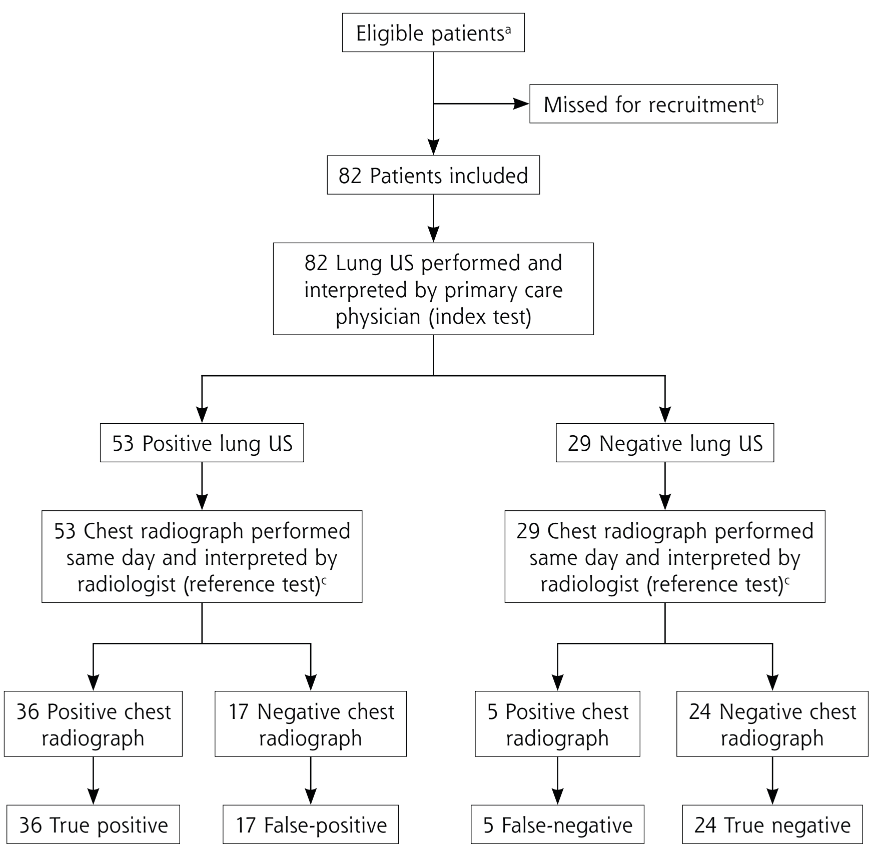
We performed statistical analysis using the χ^2 test for categorical variables (if expected frequencies were low, we applied the Yates correction or likelihood ratio test, accepting the most conservative result); the Student *t* test for continuous variables (when normal distribution was shown by the Kolmogorov-Smirnov-Lilliefors test); and the Mann-Whitney U test or Spearman ρ test (for other distributions). The significance level was less than .05. We calculated sensitivity, specificity, predictive values, and positive and negative likelihood ratios of lung US, as well as their 95% confidence intervals. All analyses were prespecified and performed with SPSS version 24.0 software (IBM Corp).

RESULTS

Characteristics of the study's 82 patients and 28 primary care physicians are detailed in Table 2. The patients had a median age of 47 years; the majority had a fever (70.7%), cough (97.6%), expectoration (70.7%), and crackles on auscultation (59.8%). Their median SpO_2 was 97%. The physicians were predominantly family physicians (75%); they had a median of 85 hours of previous accredited US training and 4.5 years of previous US experience.

On lung US, 25 patients (30.5%) had at least 1 consolidation exceeding 1 cm; 28 patients (34.1%) had a B-lines pattern without consolidations; and 29 patients (35.4%) had a negative result (Table 3). Chest radiograph findings were positive in 41 patients (50%).

Figure 1. STARD diagram showing flow of patients in the study.



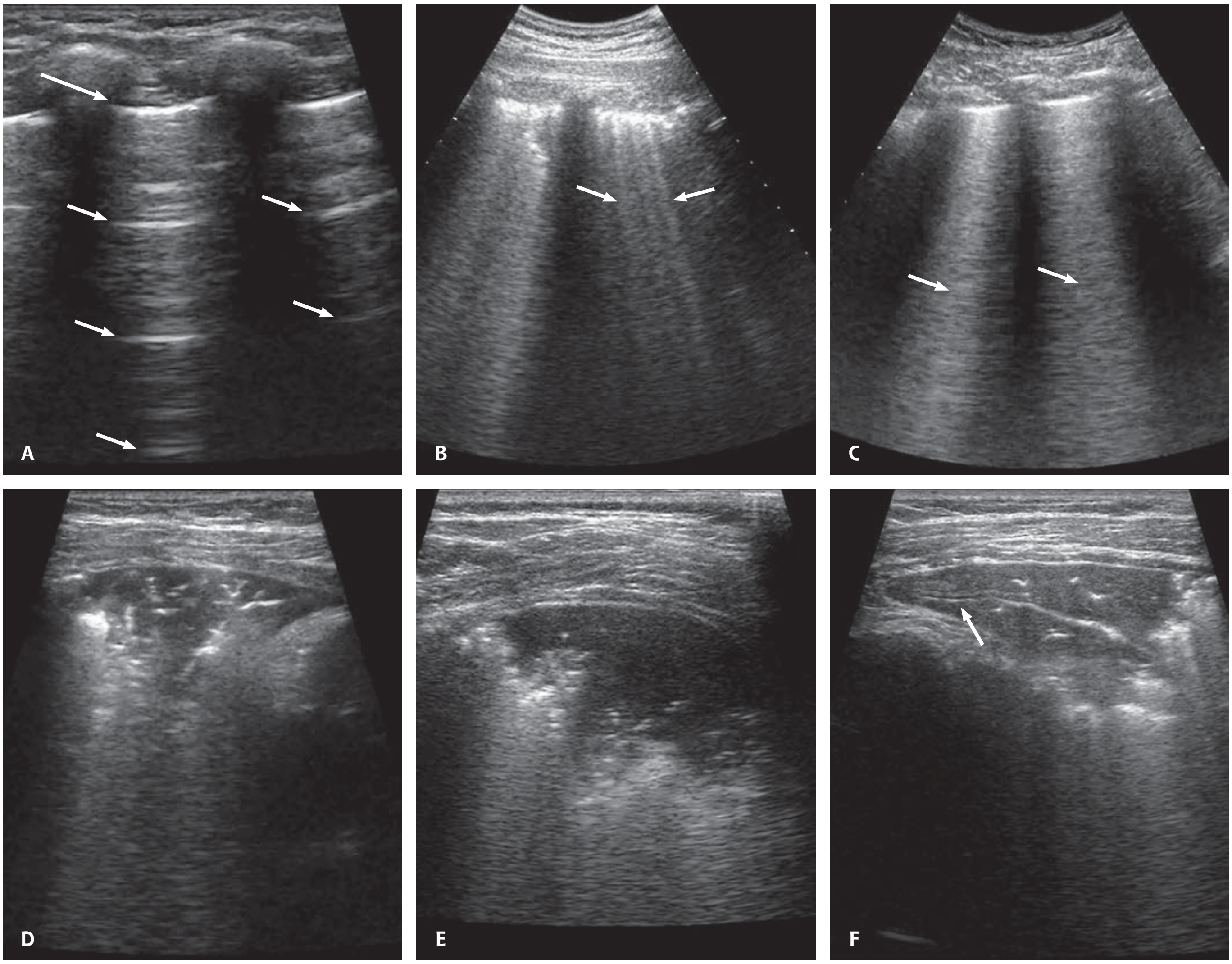
STARD = Standards for Reporting of Diagnostic Accuracy; US = ultrasound.

[a] Defined by the study's inclusion and exclusion criteria (Table 1). All had a history and physical examination performed by the primary care physician.

[b] Study protocol did not require recording of number of potentially eligible patients who were missed (due to patient declining to participate or insufficient time to explain the study).

[c] All chest radiographs were performed the same day at the referral hospital. For this study, the chest radiograph result used for analyses was the one in the report from the hospital's radiology department (interpretation of the radiograph by the primary care physician was not included).

Figure 2. Representative images of various lung ultrasound patterns considered in this study.



Panel A: Normal lung ultrasound showing the A-lines pattern, with a well-defined pleural line (long arrow) and parallel A-lines (short arrows). Panels B and C: Pathological B-lines patterns showing multiple and separated B-lines (arrows in panel B) and coalescent B-lines (arrows in panel C). Panels D, E, and F: Images of consolidations, evident as subpleural hypoechogenic areas with an echogenic air bronchogram. Panel F also shows a hypoechogenic fluid bronchogram (arrow).

The lung US and chest radiograph results were significantly associated (P <.001). In the full cohort, lung US showed sensitivity of 87.8% (95% CI, 74.5%-94.7%), specificity of 58.5% (95% CI, 43.4%-72.2%), a positive predictive value of 67.9% (95% CI, 54.5%-78.9%), a negative predictive value of 82.8% (95% CI, 65.5%-92.4%), a positive likelihood ratio of 2.12 (95% CI, 1.45-3.10), and a negative likelihood ratio of 0.21 (95% CI, 0.09-0.49) (Table 4).

Figures 3A and 3B show concordance of the imaging modalities in each patient with lung US performed by family physicians and by pediatricians, respectively. Nearly one-half of the false results in the former occurred among only 2 family physicians who had some of the most US training and experience, possibly biasing results in these physician subgroups (Table 2). Most of those false results were false-positives, which may have been due to the greater sensitivity of lung US (ie, they could actually have been false-negatives on chest radiography). The few false-negatives had only subtle consolidations on chest radiography.

If lung US had been considered positive with a consolidation only, without any B-lines pattern, specificity would have increased to 82.9% (95% CI, 68.7%-91.5%), but sensitivity would have decreased to 43.9% (95% CI, 29.9%-59.0%); the positive predictive value would have increased slightly to 72.0% (95% CI, 52.4%-85.7%), while the negative predictive value would have decreased more greatly to 59.6% (95% CI, 46.7%-71.4%), with a positive likelihood ratio of 2.57 (95% CI, 1.21-5.49) and a negative likelihood ratio of 0.68 (95% CI, 0.50-0.92). On the other hand, among the 28 patients with a B-lines pattern without any consolidations on lung US, the chest radiograph showed alveolar consolidation in 15 (53.6%) and interstitial pneumonia in 3 (10.7%), and was negative in 10 (35.7%).

These results guided us to propose an algorithm for applying lung US results in clinical practice (Figure 4). According to this algorithm, a normal result would allow conservative management, although clinical follow-up would be needed. Consolidation would allow antibiotic prescribing without chest radiography because of the higher specificity of this finding. Finally, a focal or asymmetrical B-lines pattern without any consolidations would require chest radiography, which would either avoid unnecessary treatment (if negative) or alter treatment choice (if showing interstitial pneumonia).

Subgroup analyses based on patients' age group (pediatric vs adult), physicians' previous US training, and physicians' previous US experience generally produced similar results (Table 4). Lung US appeared to perform somewhat better in pediatric patients (Table 4, Figure 3B), although this finding may have been influenced by the small size of this subgroup.

The time spent performing the lung US scan was 10 minutes or less in 85.4% of patients (median = 10 minutes; interquartile range, 7-10 minutes; range, 3-20 minutes) (Table 3). Scanning time was not significantly associated with patients' age or physicians' previous US training or experience.

Table 2. Characteristics of Patients (N = 82) and Primary Care Physicians (N = 28)

Characteristic	Value
Patients	
Sex, female, No. (%)	42 (51.2)
Age, median (IQR), y	47 (22-60)
Age by age-group[a]	
Pediatric, mean (SD), y	8.9 (2.3)
Adult, mean (SD), y	51.3 (16.8)
Temperature ≥38°C, No. (%)	58 (70.7)
Signs and symptoms, No. (%)	
Cough	80 (97.6)
Expectoration	58 (70.7)
Hemoptysis	3 (3.7)
Pleuritic pain	22 (26.8)
Dyspnea (subjective)	27 (32.9)
Signs of respiratory distress	9 (11.0)
Auscultatory findings, No. (%)[b]	
Normal	16 (19.5)
Crackles	49 (59.8)
Hypoventilation	16 (19.5)
Rhonchi	7 (8.5)
Wheezing	6 (7.3)
SpO_2, median (IQR), %	97 (95-98)
Primary care physicians	
Specialty, No. (%)	
Family physician	21 (75)
Pediatrician	7 (25)
Previous accredited US training, median (IQR), h	85 (49-244)
Previous US experience, median (IQR), y	4.5 (2-6.75)
Number of patients recruited per physician, median (IQR) [range]	2 (1-3.8) [1-8]

IQR = interquartile range; SpO_2 = peripheral oxygen saturation; US = ultrasound.

[a] There were 15 patients in the pediatric age-group (aged 5-14 years) and 67 patients in the adult age-group (aged ≥14 years).

[b] More than 1 finding possible.

DISCUSSION

Evidence of the usefulness of lung US in primary care for CAP diagnosis is still lacking, as almost all previous studies were conducted in hospital settings (emergency departments or intensive care units). In primary care, most patients' symptoms are not severe enough to warrant a hospital visit, so the clinical scenario differs. Our research tries to provide evidence in this regard.

Several previous studies compared lung US with a CT scan as the gold standard, or with combined results of a CT scan and chest radiograph,[13-15,24,25] although a few compared lung US with the radiologist's report on chest radiograph.[26,27] We chose the latter option (while bearing in mind that the chest radiograph is not a perfect reference standard) as patients' symptoms were generally mild or moderate, the study was conducted in primary care, and chest radiography is the imaging test performed in usual practice.

In patients with suspected pneumonia, previous studies sufficiently demonstrated that the presence of a consolidation measuring greater than 1 cm on lung US is quite specific for consolidation found on chest radiography,[10,11,16,20,24,28-30] and our results agree. Most studies (largely performed with patients likely to be sicker) did not consider the B-lines

Table 3. Results of Lung US and Chest Radiography

Imaging Test and Result	Patients, No. (%)
Lung US[a]	
Negative (A-lines pattern)	29 (35.4)
Positive	53 (64.6)
≥1 consolidation measuring >1 cm[b]	25 (30.5)
B-lines pattern without any consolidation measuring >1 cm	28 (34.1)
Chest radiography	
Negative	41 (50.0)
Normal	36 (43.9)
Peribronchial thickening	5 (6.1)
Positive	41 (50.0)
Alveolar consolidation	35 (42.7)
Interstitial pneumonia	4 (4.9)
Both alveolar and interstitial findings	2 (2.4)

IQR = interquartile range; US = ultrasound.

[a] Median (IQR) time spent on the scan was 10 min (7-10 min).

[b] Mean (SD) consolidation depth diameter was 2.73 cm (0.86 cm).

pattern to be a positive lung US finding in the context of clinically suspected pneumonia. In our experience in primary care, however, we noticed that many patients with nonsevere symptoms having a B-lines pattern on lung US had alveolar consolidations on their chest radiograph. International recommendations[23] have noted that when pneumonia is clinically suspected, a focal or asymmetric B-lines pattern could indicate its presence, given that consolidations still small in size (as occur in the first stages of CAP) and not directly contacting the pleura could produce just a B-lines pattern if there is only perilesional edema contacting the pleura.[31,32] We aimed to investigate this possibility and therefore considered presence of a B-lines pattern to be a positive lung US result.

Our findings show good sensitivity of lung US, comparable to that in previous studies.[12-15,20,26-28,33,34] Conversely, the lower specificity we observed could be at least partly explained by the proven higher sensitivity of lung US relative to chest radiography, when compared with CT scan.[16,35-37]

Table 4. Diagnostic Performance of Lung US Compared With Chest Radiography, in Full Cohort and in Subgroups

	Chest Radiography Result				
Lung US Result	**Positive, No. (%)**	**Negative, No. (%)**	**Total, No. (%)**	**OR (95% CI) [*P* Value]**	**Diagnostic Performance of Lung US, Value (95% CI)**
Full cohort					
Positive lung US	36 (87.8)	17 (41.5)	53 (64.6)	10.2 (3.3-31.2)	Sensitivity: 0.88 (0.75-0.95); specificity: 0.59 (0.43-0.72); PPV: 0.68 (0.55-0.79); NPV: 0.83 (0.66-0.92); positive LR: 2.12 (1.45-3.10); negative LR: 0.21 (0.09-0.49)
Negative lung US	5 (12.2)	24 (58.5)	29 (35.4)	[<.001]	
Total	41 (100)	41 (100)	82 (100)		
Patients' age group					
Pediatric					
Positive lung US	8 (100)	1 (14.3)	9 (60.0)	96[a] (2.7-3,362)	Sensitivity: 1 (0.68-1); specificity: 0.86 (0.49-0.97); PPV: 0.89 (0.57-0.98); NPV: 1 (0.61-1); positive LR: 6.99 (1.14-42.97); negative LR: not calculable
Negative lung US	0 (0)	6 (85.7)	6 (40.0)	[.001]	
Total	8 (100)	7 (100)	15 (100)		
Adult					
Positive lung US	28 (84.8)	16 (47.1)	44 (65.7)	6.3 (2.0-20.2)	Sensitivity: 0.85 (0.69-0.93); specificity: 0.53 (0.37-0.69); PPV: 0.64 (0.49-0.76); NPV: 0.78 (0.58-0.90); positive LR: 1.80 (1.23-2.65); negative LR: 0.29 (0.12-0.68)
Negative lung US	5 (15.2)	18 (52.9)	23 (34.3)	[.001]	
Total	33 (100)	34 (100)	67 (100)		
Physicians' accredited US training time					
<100 hours					
Positive lung US	18 (90.0)	6 (35.3)	24 (64.9)	16.5 (2.8-96.7)	Sensitivity: 0.90 (0.70-0.97); specificity: 0.65 (0.41-0.83); PPV: 0.75 (0.55-0.88); NPV: 0.85 (0.58-0.96); positive LR: 2.55 (1.32-4.93); negative LR: 0.16 (0.04-0.60)
Negative lung US	2 (10.0)	11 (64.7)	13 (35.1)	[.001]	
Total	20 (100)	17 (100)	37 (100)		
≥100 hours					
Positive lung US	18 (85.7)	11 (45.8)	29 (64.4)	7.1 (1.6-30.6)	Sensitivity: 0.86 (0.65-0.95); specificity: 0.54 (0.35-0.72); PPV: 0.32 (0.44-0.77); NPV: 0.81 (0.57-0.93); positive LR: 1.87 (1.17-2.99); negative LR: 0.26 (0.09-0.80)
Negative lung US	3 (14.3)	13 (54.2)	16 (35.6)	[.005]	
Total	21 (100)	24 (100)	45 (100)		
Physicians' experience using US					
<3 years					
Positive lung US	7 (100)	3 (37.5)	10 (66.7)	23.3[a] (1.0-576.1)	Sensitivity: 1 (0.65-1); specificity: 0.63 (0.31-0.86); PPV: 0.70 (0.40-0.89); NPV: 1 (0.57-1); positive LR: 2.67 (1.09-6.52); negative LR: not calculable
Negative lung US	0 (0)	5 (62.5)	5 (33.3)	[.03]	
Total	7 (100)	8 (100)	15 (100)		
3-6 years					
Positive lung US	20 (83.3)	5 (35.7)	25 (65.8)	9 (1.9-41.7)	Sensitivity: 0.83 (0.64-0.93); specificity: 0.64 (0.39-0.84); PPV: 0.80 (0.61-0.91); NPV: 0.69 (0.42-0.87); positive LR: 2.33 (1.13-4.82); negative LR: 0.26 (0.10-0.69)
Negative lung US	4 (16.7)	9 (64.3)	13 (34.2)	[.005]	
Total	24 (100)	14 (100)	38 (100)		
>6 years					
Positive lung US	9 (90)	9 (47.4)	18 (62.1)	10 (1.1-95.2)	Sensitivity: 0.90 (0.60-0.98); specificity: 0.53 (0.32-0.73); PPV: 0.50 (0.29-0.71); NPV: 0.91 (0.62-0.98); positive LR: 1.90 (1.13-3.19); negative LR: 0.19 (0.03-1.28)
Negative lung US	1 (10)	10 (52.6)	11 (37.9)	[.04]	
Total	10 (100)	19 (100)	29 (100)		

LR = likelihood ratio; NPV = negative predictive value; OR = odds ratio; PPV = positive predictive value; US = ultrasound.

[a] In the 2 cases where a cell contained a 0 value, the OR was calculated by imputing 0.5 for that cell.

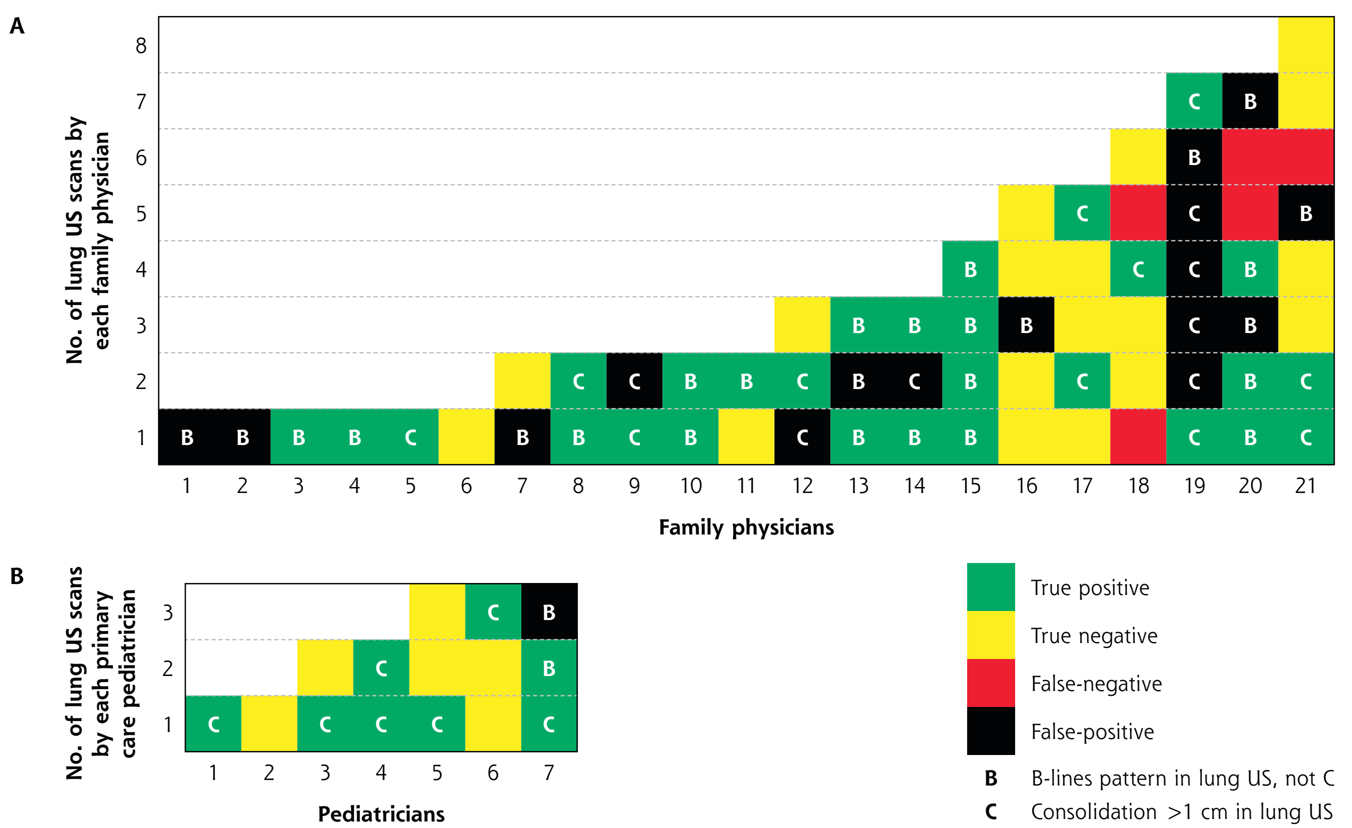
Several lung US false-positives thus could actually have been chest radiograph false-negatives, especially if a consolidation measuring greater than 1 cm was found on lung US.[28,33,38] The specificity found in this study is consistent with that in previous studies having a similar design.[25-27,33] Nevertheless, our results support certain practices outlined in our proposed algorithm: (1) the higher specificity of consolidation measuring greater than 1 cm on lung US would allow primary care physicians to directly prescribe antibiotics without performing chest radiography, and (2) normal lung US would initially allow physicians to rule out pneumonia, avoiding chest radiography and antibiotic prescription, although subsequent follow-up would be recommended to detect worsening in the few patients possibly having false-negative lung US results. Lung US also allows serial imaging controls if needed.

Among the patients with a B-lines pattern without consolidation on lung US, more than 50% were indeed found to have alveolar consolidation on chest radiography. This finding, consistent with that in other studies,[30] supports the potential relevance of B-lines patterns in this population; however, 10.7% had interstitial pneumonia and 35.7% had a normal chest radiograph—clinical situations that need distinctly different management. We therefore propose in our algorithm that a finding of only a B-lines pattern without consolidations should be followed by a chest radiograph to refine treatment and follow-up.

Despite the small number of pediatric patients recruited, lung US sensitivity and specificity in the age group 5 to 14 years were especially good. This finding agrees with that of previous meta-analyses.[10-12,39,40] It suggests that radiation-free lung US could be particularly useful in the pediatric population, reducing antibiotic prescriptions in primary care when compared with the approach of treating solely based on clinical suspicion of CAP.[5,6] In our study sample, our proposed algorithm would have correctly avoided 40% of pediatric antibiotic prescriptions.

Time spent on procedures is very relevant in primary care. It would not be efficient or ethical to propose lengthy tests when physicians could better use the time for other important clinical tasks. Here, the large majority of lung US scans took

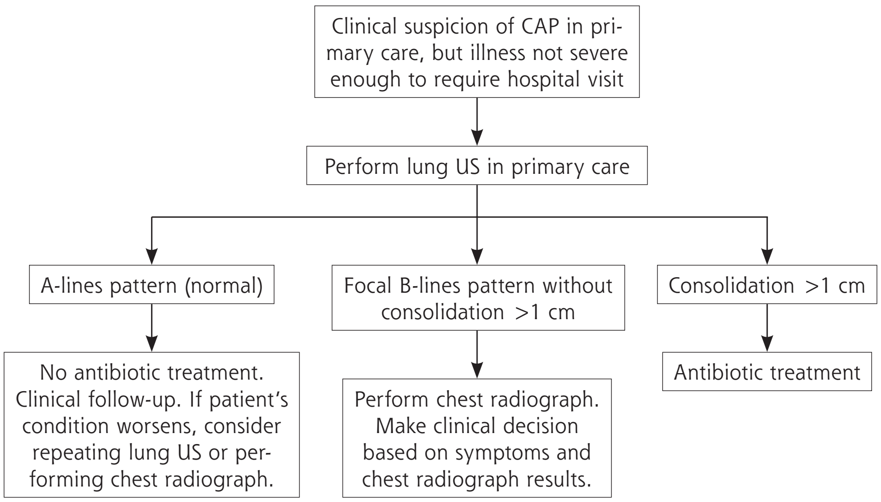
Figure 3. Concordance of lung US and chest radiography results for individual patients, according to type of primary care physician performing US.



US = ultrasound.

Notes: Figure shows result of lung US performed by primary care physicians (index test) compared with result of chest radiograph as interpreted by a radiologist (reference test). Each block represents a lung US scan and is color coded to show the test result. Blocks are arranged vertically in chronological order, with the first scan at the bottom. Panel A: Adult patients (aged >14 years) with lung US performed by family physicians. Almost one-half of all false results were accounted for by physicians 19 and 20, who had among the most US training and experience. Panel B: Pediatric patients (aged 5-14 years) with lung US performed by primary care pediatricians. Note that despite the initial clinical suspicion of pneumonia, patients with true-negative results (40% of pediatric results) would not have received antibiotics according to the algorithm shown in Figure 4.

Figure 4. Proposed clinical algorithm to guide decision making when using lung US in patients with suspected CAP in primary care.



CAP = community-acquired pneumonia; US = ultrasound.

10 minutes or less, which could be an efficient use of time in routine clinical practice. A meta-analysis found that lung US scanning required less than 13 minutes.[29]

Although the different levels of previous training in and experience with US among participating physicians could be considered a study limitation, we found similar results between subgroups. None of the physicians were absolutely new to US use, but we conducted a training session in lung US taking just 5 hours. Our results suggest that this training was enough for most of the inexperienced primary care physicians to acquire sufficient competency. There is no consensus on the level of training needed to perform lung US for CAP diagnosis, and there are several different lung US training models[41]; therefore, results may differ in settings other than primary care. Our findings suggest that implementing a short lung US training for primary care physicians could be useful. A recent study performed in a poor-resource setting had a similar conclusion.[42]

Strengths and Limitations

This is, to our knowledge, the first study performed specifically in primary care in a high-resource setting to analyze feasibility and utility of lung US in patients with suspected CAP. Participation of physicians from multiple health centers allowed us to better analyze real conditions of clinical practice, showing positive results after short training even among physicians with little prior experience. The results let us propose a practical algorithm to guide decision making, which will need to be prospectively tested to ensure its usefulness.

The small sample size is a study limitation. We planned to continue patient recruitment longer, but the COVID-19 pandemic interrupted it abruptly, sooner than expected. Nevertheless, the study's results are significant even with this sample size, although larger samples would have probably reduced confidence intervals and clarified potential differences in subgroup analyses. As previously mentioned, chest radiograph is not a perfect reference, as lung US could be even more sensitive. We chose it because it is the most commonly performed imaging test in this clinical scenario, and the large majority of patients had mild or moderate illness (so performing a CT scan would have been unethical because of its radiation). Comparison with an expert sonographer, which could have been a good reference and would have allowed us to assess interobserver accuracy in lung US, was not possible because of logistic issues related to the small size and dispersion of the participating centers. Although each chest radiograph was evaluated by only 1 radiologist, several radiologists from different hospitals participated, which could decrease potential bias. We did not consider clinical follow-up to establish final diagnosis or illness severity because our purpose was to analyze whether lung US imaging was comparable to chest radiography in the described clinical scenario. Further randomized trials analyzing outcomes such as clinical evolution or antibiotic prescription by imaging modality are needed. Exclusion of patients with respiratory diseases (and children younger than 5 years) could also be considered a limitation, as many of those patients could have a higher probability of experiencing CAP. Considering the scarce evidence in primary care, however, we preferred to conduct this initial study in a population without a high possibility of confounding lung US findings that could have been misinterpreted as CAP. Further studies in the excluded populations are needed and will be the focus of our group's next research. In our primary care setting, consultations and diagnostic tests are free of charge for patients, and availability of US devices in each center is common; our conclusions about feasibility could differ in other primary care settings.

Conclusion

Point-of-care lung US in primary care for patients with non-severe symptoms having suspected CAP seems to be useful and feasible, and our results let us propose an algorithm to guide decision making. This approach could possibly avoid radiation exposure (and unnecessary referrals if chest radiography is not available in the primary care clinic, as is usually the case in our setting) if lung US is normal or a consolidation greater than 1 cm in diameter is found (2 situations that accounted for approximately two-thirds of our patients). Furthermore, it can improve the diagnostic capacity of primary care physicians at the point of care, and allows serial imaging controls should patients' clinical condition worsen. A focal or asymmetrical B-lines pattern could indicate CAP if it is clinically suspected, but it should probably be followed by a chest radiograph to better inform clinical decisions; future research in patients with nonsevere symptoms should consider the B-lines pattern as a potential indicator of early or mild CAP. Lung US for suspected CAP does not seem to require lengthy training or extensive experience, and the technique usually can be performed in 10 minutes or less. Although we compared lung US with chest radiography (which could be considered a suboptimal reference), and larger and longer studies are needed to reproduce the findings, our study suggests that implementing training programs and using lung US for suspected CAP could be useful and feasible for family physicians and pediatricians working at primary care.

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Key words: ultrasonography; thoracic radiography; pneumonia; diagnosis; primary health care; lung; sensitivity and specificity; point of care systems; practice-based research

Submitted April 19, 2021; submitted, revised, August 25, 2021; accepted November 11, 2021.

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Acknowledgments: We are very grateful to all the investigators who actively collaborated with this research: Dr Pilar Soladana-Blanco (family physician, Centro de Salud Galapagar); Dr Juan Antonio García-Sánchez (primary care pediatrician, Centro de Salud San Carlos, San Lorenzo de El Escorial); Dr Marta Imaz-Rubalcaba (family physician, Centro de Salud Torrelodones); Mª Teresa Gijón-Conde (family physician, Centro de Salud Cerro del Aire, Majadahonda); Dr Nieves Marina Puente-García (family physician, Centro de Salud Galapagar); Dr Pilar García-Guzmán (primary care pediatrician, Centro de Salud San Juan de la Cruz, Pozuelo); Dr María del Carmen Antón-Sanz (family physician, Centro de Salud Collado Villalba Estación); Dr Nuria González-Alonso (family physician, Centro de Salud Collado Villalba Estación); Dr Olga Vicente-López (family physician, Centro de Salud La Marazuela, Las Rozas); Dr Silvia Membrado-Gómez (family physician, Centro de Salud Galapagar); Dr Ana María Carrasco-Torres (primary care pediatrician, Centro de Salud Galapagar); Dr María Luisa Sanz-Calvo (primary care pediatrician, Centro de Salud Palma Norte); Dr Cristina Ciria-de Pablo (family physician, Centro de Salud Torrelodones); Dr Alexandra Bonevic-Miletic (family physician, Centro de Salud Collado Villalba Estación); Dr Lourdes del Río-Martín (family physician, Centro de Salud Isla de Oza); Dr Esther Minguela (family physician, Centro de Salud Valle de la Oliva, Majadahonda); Dr María Teresa González-Cantueso (family physician, Centro de Salud Collado Villalba Estación). Thanks to Luisa María Cabello-Ballesteros for her contribution in the design of the study and to Carmen Ruiz-Tuñón for her help in organizing the initial US training for the primary care physicians. And thanks to Victor Gillanders for his kind revision of the English version of the manuscript.

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