

## Ultrasound findings in acute respiratory disease

Luis Campos Caubet<sup>1</sup>, Ricardo Campo Linares<sup>2</sup>, Manuel Ferreiro Gómez<sup>3</sup>, Joaquín Antonio Álvarez Gregori<sup>4</sup>, Iván García Suárez<sup>5</sup>, Juan José Zafra Sánchez<sup>6</sup>, Ramón Nogué Bou<sup>7</sup>, Jaldún Chenayeb<sup>8</sup>

**OBJECTIVES.** To assess the value of emergency department use of lung ultrasound imaging to predict prognosis in COVID-19 diagnosed by rapid antigen or polymerase chain reaction testing in relation to predicting changes in clinical variables reflecting severity: intensive care unit (ICU) admission, need for invasive mechanical ventilation (MV), or noninvasive MV, death, or hospital stay of more than 14 days.

**MATERIAL AND METHODS.** Prospective observational multicenter study recruiting patients during 3 months in 2020 (April 1 to July 1).

**RESULTS.** Data for 400 patients were analyzed; 226 were men (56.5%, the mean age was 62.3 years (95% CI, 60.1-64.4 years, and 263 patients (70.8%; 95% CI, 66.1%-75%) had positive test results for COVID-19. The clinical course of 93 of these patients (32.9%; 95% CI, 27.7%-38.5%) resulted in serious illness (ICU admission, invasive or noninvasive MV, death, or hospital stay over 14 days). Abnormal lung ultrasound findings correlated with severity. A noteworthy ultrasound finding was of anterior confluent B-lines, which increased the probability of disease progression 9-fold (odds ratio, 9.41; 95% CI, 4.71-18.78), as well as the likelihood of seeing the clinical outcomes studied. Six of the clinical outcome associations were significant.

**CONCLUSIONS.** A lung ultrasound score is a good predictor of severity, but it should be used in conjunction with clinical variables and physical examination. In lung disease in the context of COVID-19, the ultrasound score correlates significantly with clinical variables whose complex associations we were able to simplify in a QR (quick response) code for use in emergency departments.

**Keywords:** Ultrasonography, lung. Prognosis. COVID-19. QR score coding.

## Estudio de Patología Respiratoria Aguda con Ultrasonidos (EPRAUS)

**OBJETIVO.** Valorar la utilidad de la ecografía pulmonar en los servicios de urgencias hospitalarios (SUH) para la estratificación pronóstica de pacientes diagnosticados de COVID-19 por PCR o antígeno rápido, asociada a parámetros clínicos que permitan prever su evolución grave [ingreso en unidad de cuidados intensivos (UCI), necesidad de ventilación mecánica invasiva (VMI) o ventilación mecánica no invasiva (VMNI), fallecimiento, o ingreso mayor de 14 días].

**MATERIAL Y MÉTODOS.** Estudio observacional prospectivo, multicéntrico, de reclutamiento por oportunidad con una duración de 3 meses (1/04/2020-01/07/2020).

**RESULTADOS.** Se estudiaron 400 pacientes, 226 varones (56,5%) con una edad media de 62,3 años (IC 95%: 60,1-64,4). Doscientos ochenta y tres tuvieron prueba diagnóstica para COVID-19 positiva (70,8% IC 95%: 66,1-75); de estos pacientes 93 (32,9%, IC 95%: 27,7-38,5) sufrieron una evolución grave (UCI/VM/VMNI/fallecimientos/> 14 días de ingreso). Existió una relación entre la presencia de los artefactos ecográficos pulmonares y gravedad, destacando por encima de los demás las líneas B confluyentes anteriores, las cuales multiplicaron por 9 la probabilidad de evolución a gravedad (OR 9,41, IC 95%: 4,71-18,78).

**CONCLUSIÓN.** El score ecográfico pulmonar por sí solo es un buen predictor de gravedad, pero debe ser usado en sintonía con la clínica y la exploración física. En el caso de la afectación pulmonar por COVID-19, se puede asociar el score ecográfico con las variables clínicas significativas, cuya compleja fórmula simplificamos a través de un código QR para facilitar su uso en los SUH.

**Palabras clave:** Ecografía pulmonar. Pronóstico. COVID-19. Score pulmonar.

**Author Affiliations:** <sup>1</sup>Servicio de Urgencias, Hospital Comarcal Sierrallana, Torrelavega, Cantabria, Spain. <sup>2</sup>Servicio de Urgencias, Hospital Santa Bárbara, Soria, Spain. <sup>3</sup>Servicio de Urgencias, Hospital de A Coruña, La Coruña, Spain. <sup>4</sup>Servicio de Urgencias, Hospital General Universitario Nuestra Señora del Prado, Talavera de la Reina, Toledo, Spain. <sup>5</sup>Servicio de Urgencias, Hospital San Agustín, Avilés, Spain. <sup>6</sup>Servicio de Urgencias, Hospital San Eloy, Bilbao, Spain. <sup>7</sup>Servicio de Urgencias, Hospital Santa María, Spain. <sup>8</sup>Servicio de Urgencias Hospital Clínico de Valladolid, Valladolid, Spain.

**Corresponding Author:** Luis Campos Caubet. Servicio de Urgencias. Hospital Comarcal Sierrallana. Bo. Ganzo s/n. Torrelavega. Cantabria, Spain.

**E-mail:** luiscamposcaubet@yahoo.es

**Article Information:** Received: 1-3-2023. Accepted: 14-3-2023. Online: 14-4-2023.

**Editor in Charge:** Guillermo Burillo Putze.

## Introduction

EPRAUS (Study of Acute Respiratory Pathology with Ultrasound) is a project aimed at studying patients with dyspnea whose diagnostic orientation shifted with the sudden emergence of COVID-19. The course of the disease is mild or moderate in 80% of cases, but 20% of patients require hospitalization,<sup>1</sup> and 5% of the total develop a severe form of acute respiratory distress syndrome (ARDS), requiring admission to an intensive care unit.<sup>2</sup>

Lung ultrasound (LUS) has demonstrated its usefulness in diagnosing respiratory conditions such as pneumothorax, pleural effusion, various etiologies of interstitial syndrome (ARDS, heart failure, pulmonary fibrosis), and pneumonias.<sup>3,4</sup> It is a proven tool in the differential diagnosis of patients with dyspnea at the point of care.<sup>5-7</sup> However, chest X-ray has been the reference test during this pandemic, although it lacks sufficient sensitivity to be considered definitive.<sup>8</sup> Although the axial chest computed tomography (CT) may be regarded as the standard imaging modality,<sup>9</sup> it requires patient transport, involves radiation, and increases health care workers' exposure to the virus.<sup>10</sup>

Therefore, since the emergence of SARS-CoV-2, LUS has been used in different clinical settings. It is more sensitive than plain radiography for diagnosing COVID-19 pneumonia.<sup>11</sup> Hank and, primarily, Volpicelli<sup>12</sup> have shown that ultrasound is a reliable tool for diagnosing pulmonary involvement in COVID-19, also allowing detection of alternative diagnoses,<sup>13</sup> though it is not highly specific; thus, clinical context remains essential. It enables rapid and accurate suspicion of viral lung involvement in situations of high disease prevalence.<sup>14</sup> The extent of lung disease detected by ultrasound correlates with findings on CT and provides a real-time picture of the degree of pulmonary involvement.<sup>15,16</sup>

The sonographic findings of COVID-19 pneumonia<sup>17-19</sup> typically describe a predominantly bilateral, irregular, patchy distribution with spared areas, mainly affecting the posterior basal segments. Pleural surface involvement manifests as an irregular pleural line, while interstitial involvement is evidenced by the appearance of B-lines in variable number and density (B-lines/confluent B-lines).<sup>20,21</sup>

The classical lung examination is the one recommended by the 2012 consensus conference.<sup>22</sup> With the development of the pandemic and due to its similarity with ARDS, adapted protocols such as those developed by Bouhemad *et al.*<sup>23</sup> included examination of the posterior areas of both lungs, assessing a total of 12 segments. Each segment was assigned a score based on sonographic findings (0: Normal; 1: > 3 B-lines; 2: Confluent B-lines; 3: Consolidations).

Subsequently, other COVID-19-oriented protocols appeared, such as that of Soldati *et al.*,<sup>24</sup> who proposed examining 14 pulmonary zones—7 per hemithorax (2 anterior, 2 lateral, and 3 posterior)—with a scoring system similar to Bouhemad's. Gargani and Volpicelli<sup>25</sup> adopted a 12-zone protocol, similar in design, with minor modifications specific to this disease.

The endpoints of our study are:

1. To determine the sensitivity and specificity of LUS in

prognostic stratification of COVID-19 pneumonia in symptomatic patients diagnosed by PCR or antigen nasal swab test.

2. To identify sonographic findings in COVID-19 pneumonia—regarding distribution, extent, location, or score—that may help predict the course of the disease: which cases may progress unfavorably and which may follow a mild or moderate course and thus be managed at home.

3. To develop a prognostic scale incorporating clinical and imaging parameters (LUS) to predict disease severity outcomes [ICU admission, need for invasive mechanical ventilation (IMV) or noninvasive mechanical ventilation (NIMV), death, or hospital stays > 15 days].

## Method

### Study design

We conducted a prospective, multicenter, observational, opportunity-based study across the following hospital emergency departments: Hospital Comarcal Sierrallana (Torrelavega, Cantabria), Hospital San Eloy (Barakaldo, Bizkaia), Hospital Universitario San Agustín (Avilés), Hospital Santa María (Lleida), Hospital Clínico Universitario de Valladolid, Hospital de Santa Bárbara (Puertollano, Ciudad Real), Hospital General Nuestra Señora del Prado (Talavera de la Reina, Toledo), and Hospital Universitario de A Coruña (A Coruña). The study duration was 3 months (April 1<sup>st</sup> – July 1<sup>st</sup>, 2020).

The investigators were emergency physicians with at least an intermediate level of ultrasound training according to ECOSEMES (Ultrasound Working Group of the Spanish Society of Emergency Medicine), who had used ultrasound in clinical practice for at least 10 years and had at least 5 years of teaching experience in clinical ultrasound for emergency and critical care.

Following approval by the ethics committees of the participating hospitals, data collection sheets, patient information documents, and informed consent forms were developed.

Ultrasound examinations were performed with patients in a 45-degree semi-supine position, using a low-frequency convex probe (1–6 MHz), with a lung preset and standard disinfection/isolation procedures according to the protocol of each hospital, following AIUM (American Institute of Ultrasound in Medicine) and WHO guidelines.

Each lung was divided into 6 scanning zones delimited by the sternum, anterior axillary line, posterior axillary line, and spine—12 zones per patient (2 anterosuperior, 2 anteroinferior, 2 lateral superior, 2 lateral inferior, 2 posterosuperior, and 2 posteroinferior)—labeled as right (D1–D6) and left (L1–L6), similar to former studies.<sup>24,25</sup>

A scoring system ("LUS score") was used to quantify severity based on ultrasound findings:

- Score 0: A-lines.
- Score 1: B-lines (LB).
- Score 2: Confluent or coalescent B-lines (LBC).
- Score 3: Subpleural consolidation (CSP)/consolidation.

A total score ranging from 0 to 36 (0–18 per lung) was obtained. To predict severe progression, a 5-point cut-off value was selected, yielding 92% sensitivity and 40% specificity (Youden index = 0.32), given the severity of the disease, rapidly progressive, and potentially fatal course.

Non-invasive variables (respiratory rate, temperature, blood pressure, pulse oximetry) and the past medical history (age, sex, chronic conditions such as obesity, diabetes, renal failure, ischemic heart disease, COPD, or active neoplasm) were analyzed for their prognostic value alone and in combination with ultrasound findings.

Severe disease outcomes were defined as ICU admission, NIMV, IMV, hospital stay > 14 days, or death.

### Inclusion criteria

– Adults presenting to the emergency department with respiratory infection symptoms (cough, fever, and/or dyspnea) and pulse oximetry or arterial oxygen saturation  $\leq$  94% without supplemental oxygen.

– Patients with radiographic findings of pneumonia regardless of oxygen saturation.

### Exclusion criteria

– Terminal patients with an estimated life expectancy < 6 months.

– Patients who did not consent to participate.

### Statistical analysis

A sample size of 400 subjects was estimated, assuming a maximum 25% loss. Quantitative variables were expressed as mean, standard deviation, median, range, interquartile range, and 95% confidence interval (CI) and the qualitative ones as frequency and percentage with 95% CI.

Means between 2 groups were compared using Student's t-test or Mann-Whitney U test, as appropriate. For > 2 groups, ANOVA or Kruskal-Wallis tests were used. Normality was verified with the Kolmogorov-Smirnov test. Associations between qualitative variables were analyzed using the chi-square or Fisher's exact test, as applicable.

To identify variables influencing severity, multivariate binary logistic regression models were used. ROC (Receiver Operating Characteristic) curves and corresponding AUC (Area Under the Curve) values were calculated.

The Youden index was used to evaluate cut-off points; for the chosen cut-off, sensitivity and specificity values with 95% CI were computed.

Analyses were performed using IBM SPSS Statistics 26.0 and R 4.0.2 (The R Foundation for Statistical Computing, <https://www.R-project.org/>).

### Results

A total of 400 patients were studied, 226 men (56.5%), with a mean age of 62.3 years (95% CI, 60.1–64.4). Of these, 283 had positive diagnostic tests for COVID-19 (70.8%, 95% CI, 66.1–75.0); among them, 93 (32.9%, 95% CI, 27.7–38.5) experienced severe disease progression (ICU/IMV/NIMV/death/hospitalization > 14 days).

Table 1 illustrates the descriptive data of the sample.

Using logistic regression, the variables most strongly associated with severe progression in clinically and analytically confirmed COVID-19 patients were identified.

Table 2 shows that the probability of severe progression was nearly 5 times higher in patients with chronic kidney disease (OR, 4.78; 95% CI, 1.22–18.73), and the risk increased 12% for each additional LUS score point (OR, 1.128; 95% CI, 1.071–1.118), while oxygen saturation acted as a protective factor (each 1-point increase reduced risk by ~10%; OR, 0.909; 95% CI, 0.837–0.987).

Using this logistic regression, a ROC analysis was performed for diagnostic probability, comparing the fractions of true positives (TPR) and false positives (FPR), obtaining a value of 0.901, which can be interpreted as a "very good" test for screening patients affected by COVID-19. This would allow calculating the percentage probability of severe progression in each subject, considering as severe those cases requiring ICU admission, NIMV, IMV, or resulting in death (Figure 1).

### Ultrasound findings

Ultrasound findings were analyzed according to laterality and location. The most frequent finding was B-lines, observed in 191 patients, with 91.2% showing at least one ultrasound abnormality.

In turn, the possibility of severe progression was analyzed according to the type and location of the lesion, revealing a 25-fold higher probability of severe evolution in patients with anterior subpleural consolidations (OR, 25.75; 95% CI, 5.87–112.96), an 8-fold increase in those with confluent B-lines in the upper-lateral regions (OR, 8.27; 95% CI, 4.72–14.49), a 7-fold increase in those with confluent B-lines in the lower-anterior regions (OR, 7.07; 95% CI, 3.92–12.75), and nearly a 6-fold increase in those with confluent B-lines in the upper-anterior regions (OR, 5.78; 95% CI, 3.32–10.06) (Figure 2).

Considering the relationship between the lung ultrasound score and the clinical variables that showed statistical significance for severe disease progression, a formula was developed integrating all these parameters to allow individualized estimation of each patient's probability of severe progression at the time of emergency department assessment.

$$p(G) = \frac{1}{1 + \exp(20.286 - 0.039 * \text{Edad} - 1.565 * \text{ERC} - 0.858 * \text{Obes} - 0.635 * \text{Temp} - 0.055 * \text{FR} + 0.95 * \text{SatO}_2 - 0.120 * \text{Score})}$$

### Discussion

Our findings show a correlation between the clinical severity of COVID-19 pneumonia and the application of the LUS score, suggesting that it could be used for risk stratification in patients with COVID-19 respiratory disease and to support clinical decision-making.

We know that LUS is a highly sensitive technique for detecting pulmonary disease, though it lacks specificity. To increase this specificity, we analyzed which clinical and laboratory variables could be incorporated into a risk score associated with imaging findings.

**Table 1.** Descriptive data of the sample

Category	N	%	95%CI
<b>Sex</b>			
Female	174	43.5%	38.7%-48.4%
Male	226	56.5%	51.6%-61.3%
<b>EPOC</b>			
No	339	84.8%	80.9%-87.9%
Yes	61	15.3%	12.1%-19.1%
<b>Diabetes mellitus</b>			
No	341	85.3%	81.4%-88.4%
Yes	59	14.8%	11.6%-18.6%
<b>Hypertension</b>			
No	231	57.8%	52.9%-62.5%
Yes	169	42.3%	37.5%-47.1%
<b>Ischemic heart disease</b>			
No	356	89.0%	85.6%-91.7%
Yes	44	11.0%	8.3%-14.4%
<b>Chronic kidney disease</b>			
No	364	91.0%	87.8%-93.4%
Yes	36	9.0%	6.6%-12.2%
<b>Cancer</b>			
No	372	93.0%	90.1%-95.1%
Yes	28	7.0%	4.9%-9.9%
<b>Obesity</b>			
No	340	85.0%	81.2%-88.2%
Yes	60	15.0%	11.8%-18.8%
<b>Influenza A</b>			
Positive	0	0.0%	0.0%-1.1%
Negative	40	100.0%	98.9%-100.0%
<b>Influenza B</b>			
Positive	1	2.4%	0.4%-12.3%
Negative	41	97.6%	87.7%-99.6%
<b>Respiratory syncytial virus</b>			
Positive	0	0.0%	0.0%-1.1%
Negative	33	100.0%	98.9%-100.0%
<b>Pneumococcal antigen (urine)</b>			
Positive	6	7.8%	3.6%-16.0%
Negative	71	92.2%	84.0%-96.4%
<b>Legionella antigen (urine)</b>			
Positive	0	0.0%	0.0%-1.7%
Negative	80	100.0%	98.3%-100.0%
<b>COVID-19</b>			
Positive	283	70.8%	66.1%-75.0%
Negative	117	29.3%	25.0%-33.9%
<b>Computed tomography</b>			
No	329	82.3%	78.2%-85.7%
Yes	71	17.8%	14.3%-21.8%
<b>Ward admission</b>			
No	97	24.3%	20.3%-28.7%
Yes	303	75.8%	71.3%-79.7%
<b>ICU admission</b>			
No	359	89.8%	86.4%-92.4%
Yes	41	10.3%	7.6%-13.6%
<b>Mechanical ventilation</b>			
No	373	93.3%	90.4%-95.3%
Yes	27	6.8%	4.7%-9.6%
<b>Noninvasive ventilation</b>			
No	368	92.0%	88.9%-94.3%
Yes	32	8.0%	5.7%-11.1%
<b>Death</b>			
No	354	88.7%	85.2%-91.5%
Yes	45	11.3%	8.5%-14.8%
<b>Severe (ICU/IMV/NIV/death/&gt; 14 days)</b>			
No	288	72.2%	67.6%-76.3%
Yes	111	27.8%	23.7%-32.4%

<sup>1</sup>95% confidence interval: Wilson score.

COPD: chronic obstructive pulmonary disease; ICU: intensive care unit.

**Table 2.** Logistic regression model for risk of severe progression of COVID-19 infection

Variables	B	Standard Error	Sig.	Exp (B) (OR)	95% CI for EXP(B)	
					Lower	Upper
Age	0.039	0.011	0.000	1.040	1.018	1.063
Chronic kidney disease (Ref: No)	1.565	0.696	0.025	4.784	1.222	18.730
Obesity (Ref: No)	0.858	0.463	0.064	2.357	0.951	5.847
Temperature	0.635	0.207	0.002	1.887	1.259	2.828
Respiratory rate	0.055	0.031	0.078	1.056	0.994	1.122
SatO <sub>2</sub>	-0.095	0.042	0.024	0.909	0.837	0.987
Score	0.120	0.026	0.000	1.128	1.071	1.188
Constant	-20.826	9.143	0.023	0.000	—	—

OR: Odds Ratio.

Of the variables analyzed, only 6 showed statistical significance (age, chronic kidney disease, obesity, temperature, respiratory rate, and oxygen saturation).

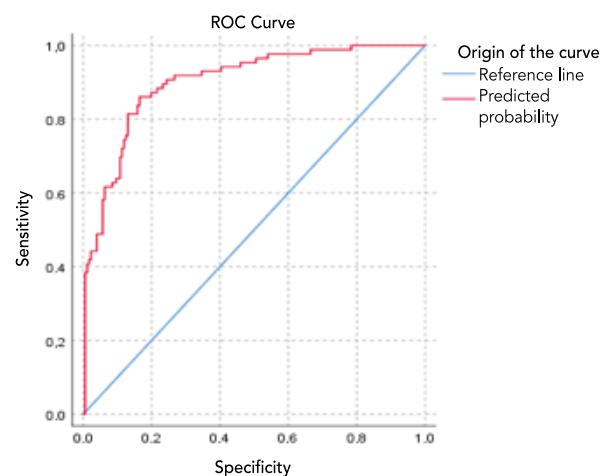
These parameters, when added to the LUS score—which is by itself a good predictor of severity—further improved sensitivity and specificity.

In COVID-19 patients, interstitial patterns and consolidations were found in proportions similar to the loss of aeration, suggesting that the severity of respiratory failure is related more to the overall proportion of affected lung tissue than to the specific pattern observed. In our study, we found a relationship between the presence of LUS artifacts and disease severity, with confluent B-lines being particularly notable, increasing the probability of severe progression 9-fold (OR, 9.41; 95% CI, 4.71–18.78).

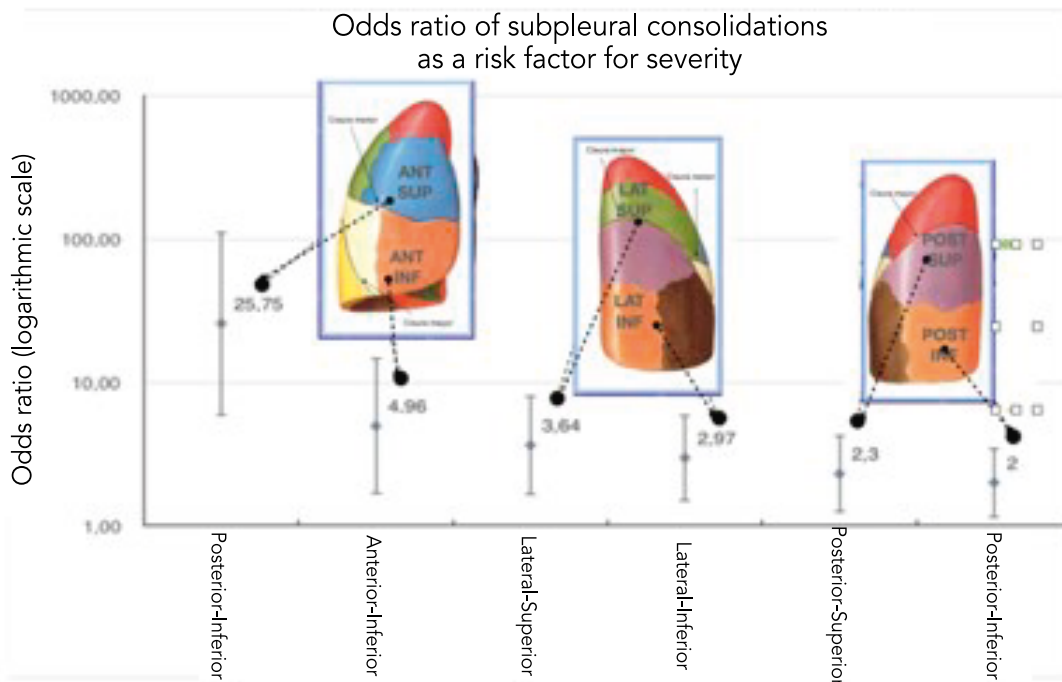
Furthermore, we found an association between the presence of subpleural consolidations and LBC in upper and anterior lung fields and worse prognosis in these patients.

As described by Volpicelli and Villén,<sup>21</sup> there are high-probability patterns, others suggesting alternative diagnoses, and low-probability patterns, in which significant pulmonary involvement can be ruled out even if COVID-19 infection is subsequently confirmed.

We hypothesized that the LUS score at the time of emergency department admission could predict the final evolution of COVID-19 patients.



**Figure 1.** ROC analysis for diagnostic probability.



**Figure 2.** Odds ratio of subpleural consolidations as a risk factor for severity.

In our study, LUS effectively discriminated patients who met criteria for severe disease progression. An increase in the LUS score was associated with poorer outcomes, consistent with Lichter's findings,<sup>26</sup> in which patients with severe progression had higher ultrasound scores, particularly when anterior lung fields were involved.

In our results, low scores ( $\leq 5$ ) predicted favorable outcomes with a sensitivity of 93%. Conversely, high scores ( $> 25$ ) met the criterion for severe progression, with a specificity of 98%, considering the maximum possible score was 36.

Our mean LUS score in relation to severity was 16.5, close to that observed by García Alencar,<sup>27</sup> whose mean score was  $18.7 \pm 6.8$ . The mean score for patients who did not meet severity criteria was 8.

The highest Youden index corresponded to a cut-off score of 12.5, yielding a sensitivity of 67.7% and a specificity of 78.9%. In contrast, in the study by Lichter conducted in an internal medicine ward, a higher cut-off of 18 was established, with 62% sensitivity and 74% specificity.

Because of the strong correlation of our results, we developed a tool that we believe can help clinicians assess the severity of confirmed COVID-19 patients with pulmonary involvement. We presented it in the form of a formula implemented via a QR code to facilitate its use (Figure 3).

Of note, the composite endpoint included death, ICU admission, IMV, NIMV, or hospitalization  $> 14$  days; thus, values should be interpreted accordingly.

We believe that LUS alone should not be used to decide discharge in such patients, as significant comorbidities must be taken into consideration. Rapid decision-making

regarding patient disposition (home, hospital ward, or ICU) by emergency physicians and proper allocation of therapeutic resources can be vital in resource-limited situations such as the early stages of the pandemic. The LUS score alone is a good predictor of clinical evolution, but it should be used in conjunction with clinical assessment and physical examination.

This study has several limitations. First, as a multi-center study, there was considerable variability in COVID-19 prevalence. Second, inter-operator variability, which was minimized by standardizing the examination and including only physicians experienced in clinical ultrasound. Third, the possibility of false positives or negatives during the early pandemic period due to the initial performance of PCR tests. Despite these limitations, we conclude that scales integrating LUS with clinical or laboratory data may be useful to predict and anticipate which patients are likely



**Figure 3.** Clinical tool for stratifying severity in patients with pulmonary involvement due to COVID-19.

to have an unfavorable outcome. This could help guide clinical management strategies and ensure appropriate resource allocation.

In the context of COVID-19 pulmonary involvement, we believe that the formula integrating the ultrasound

score and clinical variables—implemented through a QR code—improves the precision of patient assessment, allowing anticipation of disease progression and better resource management in emergency departments, particularly during pandemic situations.

## ARTICLE INFORMATION

**Conflict of Interest Disclosures:** None reported.

**Funding:** The authors declare the non-existence of funding in relation to this article

**Ethical Responsibilities:** The authors have confirmed the maintenance of confidentiality and respect for the patient rights, agreement of publication, and transfer of rights to Revista Española de Urgencias y Emergencias.

**Article not commissioned by the Editorial Board and with external peer review.**

**Note of the editors:** This is a BOWMAN-generated English translation of the officially indexed Spanish-language article, which should be cited as *Rev Esp Urg Emerg*. 2023;2:78-84. In this translated version, the editors have supervised the process; however, it cannot be ruled out that some errors resulting from the artificial intelligence translation process may have gone unnoticed.

## REFERENCES

- Berlin DA, Gulick RM, Martinez FJ. Severe COVID-19. *N Engl J Med*. 2020;383:2451-60.
- ARDS Definition Task Force, Ranieri VM, Rubenfeld GD, Thompson BT, Ferguson ND, Caldwell E, Fan E, et al. Acute respiratory distress syndrome: the Berlin Definition. *JAMA*. 2012;307:2526-33.
- Reissig A, Copetti R, Mathis G. Lung ultrasound in the diagnosis and follow-up of community-acquired pneumonia: a prospective, multicenter, diagnostic accuracy study. *Chest*. 2012;142:965-72.
- Liteplo AS, Marill KA, Villen T. Emergency thoracic ultrasound in the differentiation of the etiology of shortness of breath (ETUDES): sonographic B-lines and N-terminal pro-brain-type natriuretic peptide in diagnosing congestive heart failure. *Acad Emerg Med*. 2009;16:201-10.
- Wimalasena Y, Kocierz L, Strong D, Watterson J, Burns B. Lung ultrasound: a useful tool in the assessment of the dyspnoeic patient in the emergency department. Fact or fiction? *Emerg Med J*. 2018;35:258-66.
- Lichtenstein DA, Meziere GA. Relevance of lung ultrasound in the diagnosis of acute respiratory failure: the BLUE protocol. *Chest*. 2008;134:117-25.
- Mantuani D, Frazee BW, Fahimi J, Nagdev A. Point-of-Care Multi-Organ Ultrasound Improves Diagnostic Accuracy in Adults Presenting to the Emergency Department with Acute Dyspnea. *West J Emerg Med*. 2016;17:46-53.
- Winkler MH, Touw HR, van de Ven PM. Diagnostic accuracy of chest radiograph, and when concomitantly studied lung ultrasound, in critically ill patients with respiratory symptoms: a systematic review and meta-analysis. *Crit Care Med*. 2018;46:e707-e714.
- Fang Y, Zhang H, Xie J. Sensitivity of chest CT for COVID-19: comparison to RT-PCR. *Radiology*. 2020;296:e115-e117.
- Mayo JR, Aldrich J, Müller NL. Fleischner Society. Radiation exposure at chest CT: a statement of the Fleischner society. *Radiology*. 2003;228:15-21.
- Gibbons RC, Magee M, Goett H, Murrett J, Genninger J, Mendez K, et al. Lung Ultrasound vs. Chest X-Ray Study for the Radiographic Diagnosis of COVID-19 Pneumonia in a High-Prevalence Population. *J Emerg Med*. 2021;60:615-25.
- Volpicelli G, Gargani L, Perlini S, Spinelli S, Barbieri G, Lanotte A, et al. Lung ultrasound for the early diagnosis of COVID-19 pneumonia: an international multicenter study. *Intensive Care Med*. 2021;47:444-54.
- Tsung JW, Kessler DO, Shah VP. Prospective application of clinician-performed lung ultrasonography during the 2009 H1N1 influenza A pandemic: distinguishing viral from bacterial pneumonia. *Crit Ultrasound J*. 2012;4:1-10.
- Pivetta E, Goffi A, Tizzani M, Locatelli SM. Molinette MedUrg Group on lung ultrasound. Lung Ultrasonography for the Diagnosis of SARS-CoV-2 Pneumonia in the Emergency Department. *Ann Emerg Med*. 2021;77:385-94.
- Zielaskiewicz L, Markarian T, Lopez A, Taguet C, Mohammedi N, Boucekine M, et al. Comparative study of lung ultrasound and chest computed tomography scan in the assessment of severity of confirmed COVID-19 pneumonia. *Intensive Care Med*. 2020;46:1707-13.
- Li K, Wu J, Wu F, Guo D, Chen L, Fang Z, et al. The clinical and chest CT features associated with severe and critical COVID-19 pneumonia. *Invest Radiol*. 2020;55:327-31.
- Huang C, Wang Y, Li X. Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. *Lancet*. 2020;395:497-506.
- Peng QY, Wang XT, Zhang LN. Chinese Critical Care Ultrasound Study Group. Findings of lung ultrasonography of novel corona virus pneumonia during the 2019-2020 epidemic. *Int Care Med*. 2020;46:849-50.
- Poggiali E, Dacrema A, Bastoni D. Can lung US help critical care clinicians in the early diagnosis of novel coronavirus (COVID-19) pneumonia? *Radiology*. 2020;295:e6.
- Volpicelli G, Gargani L. Sonographic signs and patterns of COVID-19 pneumonia. *Ultrasound J*. 2020;12:22.
- Volpicelli G, Lamorte A, Villén T. What's new in lung ultrasound during the COVID-19 pandemic. *Intensive Care Med*. 2020;46:1445-8.
- Volpicelli G, Elbarbary M, Blaivas M, Lichtenstein DA, Mathis G, Kirkpatrick AW, et al. International evidence-based recommendations for point-of-care lung ultrasound. *Intensive Care Med*. 2012;38:577-91.
- Bouhemad B, Brisson H, Le-Guen M, Arbelot C, Lu Q, Rouby JJ. Bedside ultrasound assessment of positive end-expiratory pressure-induced lung recruitment. *Am J Respir Crit Care Med*. 2011;183:341-7.
- Soldati G, Smargiassi A, Inchingolo R. Proposal for international standardization of the use of lung ultrasound for COVID-19 patients; a simple, quantitative, reproducible method. *J Ultrasound Med*. 2020;39:1413-9.
- Gargani L, Soliman-Aboumarie H, Volpicelli G, Corradi F, Pastore MC, Cameli M. Why, when, and how to use lung ultrasound during the COVID-19 pandemic: enthusiasm and caution. *Eur Heart J Cardiovasc Imaging*. 2020;21:941-8.
- Lichter Y, Topilsky Y, Taieb P, Banai A, Hochstadt A, Merdler I, et al. Lung ultrasound predicts clinical course and outcomes in COVID-19 patients. *Intensive Care Med*. 2020;46:1873-83.
- de Alencar JCG, Marchini JFM, Marino LO, da Costa Ribeiro SC, Bueno CG, da Cunha VP, et al. Lung ultrasound score predicts outcomes in COVID-19 patients admitted to the emergency department. *Ann Intensive Care*. 2021;11:6.