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Lung Ultrasound Compared to Chest Computed Tomography (CT) Imaging, In Predicting the Clinical Course and Outcomes in COVID-19 Patients

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ABSTRACT

Background: Chest computed tomography (CT) is highly recommended for evaluating and monitoring suspected COVID-19 cases, serving as a standard diagnostic tool for pneumonia. It is effective in identifying typical radiographic features of COVID-19, such as ground-glass opacification, consolidation, and pleural effusion, which are commonly seen in affected patients. Compared to chest radiography, lung ultrasonography (LUS) offers higher diagnostic accuracy for interstitial lung disease and alveolar consolidation. LUS results align well with the clinical course, similar to high-resolution CT findings across various patient groups. **Aim of the work:** This study aimed to describe the results of the LUS examination and their association with the clinical course and outcome in hospitalized patients with COVID-19 infection, to assess risk, predict outcomes, and potentially replace chest CT with ultrasound as a more accessible and cost-effective method.

Patients and methods: This was a comparative study involved 50 cases presenting with acute dyspnea ($SpO_2 < 94\%$ and/or shortness of breath) accompanied by a positive PCR test in a nasopharyngeal specimen, requiring admission to the COVID-19 isolation department of the Suez Canal University Hospital, during the period from March 2021 to September 2023. Complete LUS was done on admission along with Chest CT and follow-up LUS was done on discharge, then follow-up by LUS & CT chest that is 24 h apart from LUS scan was done 6-8 weeks later. **Results:** This study showed that LUS score on admission was found to have a significant correlation with oxygen saturation on admission (negative correlation) and degree of pulmonary infiltration on pulmonary CT (positive correlation). It was found that the LUS score is an important predictor of ICU admission, prolonged hospital stays duration of more than 2 weeks, and incidence of post-COVID fibrosis 8 weeks after discharge. Over time, there was a statistically significant decrease in Lung ultrasound scores.

Conclusions: Our study demonstrated that the LUS modality had a better overall diagnostic performance if added to CT scans in COVID-19 patients, particularly concerning consolidation and ground-glass opacities (GGO). It is recommended as an effective bedside tool for assessing severity and monitoring COVID-19 patients, especially for vulnerable groups like children, pregnant women, and critically ill patients who cannot be moved.

Keywords: Chest computed tomography, Lung ultrasound, COVID-19.

INTRODUCTION

The COVID-19 pandemic, first identified in Wuhan in late 2019, has disseminated worldwide [(1)]. The main presentation is viral pneumonia, which may advance to severe acute respiratory distress syndrome (ARDS) [(2-3)]. Severe cases need critical care and extended mechanical breathing, frequently leading to consequences that impact many organ systems, including hemodynamic instability, cardiac damage, renal failure, and coagulopathy [(4)]. Chest computed tomography (CT) is highly recommended for evaluating and monitoring suspected COVID-19 cases, serving as a standard diagnostic tool for pneumonia. It is effective in identifying typical radiographic features of COVID-19 [(5)], such as ground-glass opacification, consolidation, and pleural effusion, which are commonly seen in affected patients [(6-8)]. Compared to chest radiography, lung ultrasonography (LUS) offers higher diagnostic accuracy for interstitial lung disease and alveolar consolidation [(9-10)]. LUS is recommended for diagnosing and managing pneumonia [(11)], including during past viral pandemics [(12)]. Lung ultrasound (LUS) can decrease intrahospital transfers, limit healthcare professionals' exposure, and reduce the risk of contaminating medical devices [(13)]. It is widely used as a diagnostic tool for critically ill patients, assessing treatment response and follow-up care [(14-20)]. Furthermore, LUS has been recommended as a standard of care [(21)] and its results align well with the clinical course, similar to high-resolution CT findings [(22-23)] across various patient groups.

Despite the fact that the COVID-19 outbreak began months ago, comprehensive lung ultrasound (LUS) examinations for risk assessment and management have not been routinely performed, likely due to concerns about virus transmission. In response, we carried out detailed LUS examinations on hospitalized COVID-19 patients.

PATIENTS AND METHODS

This was a comparative study included 50 cases presenting with acute dyspnea ($SpO_2<94\%$ and/or shortness of breath) accompanied by a positive PCR test in a nasopharyngeal specimen, requiring admission to the COVID-19 isolation department of the Suez Canal University Hospital, during the period from March 2021 to September 2023. For whom complete LUS was done on admission along with chest CT and follow-up LUS was

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done on discharge, then follow-up by LUS & CT chest that is 24 h apart from LUS scan was done 6-8 weeks later.

Exclusion criteria: Patients with a negative nasopharyngeal swab polymerase chain reaction (PCR) test and a normal chest computed tomography (CT) scan.

All patients were diagnosed with COVID-19, verified by a positive PCR test for SARS-CoV-2 in a respiratory material. Patients were classified as mild, moderate, or severe according to saturation levels and chest CT findings [24].

• Mild: If saturation is ≥ 94% and CT chest lesions are < 30% of total lung and this is for home isolation.
• Moderate: If saturation is > 94% and the CT chest lesions are between 30% and 50% of total lung and this is for inpatient admission.
• Severe: If saturation is < 94% and the CT chest is more than 50% of total lung and this is for ICU admission.

The clinical data were combined with the computed tomography (CT) findings and compared to the lung ultrasound results. A score system was applied to each location using the lung ultrasound:
The usual pleural line reverberation artifacts, or A-lines, which show adequate lung aeration in conjunction with lung sliding, were equal to zero points.
- Reverberation artifacts caused by edematous interlobular septa or alveoli can be identified as B-lines, which are hyperechoic lines that run vertically to the pleura line and disappear when the A-lines are no longer visible. These lines can be further classified into:
B1, which stands for moderate loss of pulmonary aeration and is shown by divided B-lines, was 1 point. The B2 score, which represents coalescent B-lines that indicate a significant decrease in lung aeration, was 2 points. Lung consolidation was equal to 3 points. Thus, an LUS score of 0 is normal, and 36 is worst.

Ethical approval: After thoroughly explaining the study's risks and advantages, all participants or their legal representatives were asked to provide written consents. Patients had the right to refuse participation without affecting the medical care they would receive. Confidentiality of all data and test results of the entire study population was maintained. The Ethical Committee of Faculty of Medicine, Suez Canal University approved the study. The study adhered to the Helsinki Declaration throughout its execution.

Statistical analysis

After data collection, Microsoft Excel 2016 was used to enter the information into spreadsheets. Data were processed using Stat version 12 (Stata Corp LP, TX, USA). Unpaired T-test, Pearson correlation coefficient, and ROC curve were used. A P-value of less than 0.05 (5%) was considered statistically significant. Descriptive statistics using Mean ± Standard Deviation (SD), and range for numerical parametrical data. Frequency and percentage for non-numerical data.

RESULTS

Regarding baseline demographics and patient characteristics of the studied patients (n=50), showed that 54% of the studied patients were females. The mean age was 56.4 years ranging from 23 – 84 years. 46% of the studied patients were smokers or ex-smokers. The most common chronic medical disease was hypertension followed by chronic pulmonary disease, which was reported among 38% and 30% respectively (Table 1).

Table (1): Baseline demographic and patient characteristics of the studied patients (n=50)

Characteristics		Number	Percentage
Sex	Male	23	46%
	Female	27	54%
Age	Mean ± SD	56.4 ± 16.14	
	Range	23 – 84	
Residence	Rural	19	38%
	Urban	31	62%
Smoking	Non-smoker	27	54%
	Smoker/ex-smoker	23	46%
Chronic diseases	DM	13	26%
	Hypertension	19	38%
	IHD	4	8%
	CLD	3	6%
	CKD	3	6%
	Chronic pulmonary disease	15	30%

Table (2) summarizes the laboratory findings among the studied patients on admission. Mean oxygen saturation was 86.1% with range from 70% to 93% on room air.

Table (2): Clinical and laboratory characteristics of the studied patients on admission (n=50)

Characteristics		Mean ± SD	Range
Oxygen saturation on admission (%)		86.1 ± 5.7	70 – 93
Lab	TLC	6.1 ± 5.2	2 – 23
	Lymphocytes count	755.4 ± 193.3	293 – 990
	LDH	350 ± 52.4	289 – 489
	CRP	119.26 ± 44.6	69 – 250
	D Dimer	1463.7 ± 814.4	700 – 4100
	Ferritin	727.3 ± 261.7	300 – 1478

Consolidation and GGO were the main CT findings on admission and were reported among 68% and 54% of the studied patients respectively. The mean percentage of lung infiltration on CT on admission was found to be 50.8% with a range from 40 to 85% involvement of lung parenchyma (Table 3).

Table (3): CT findings at the time of admission among the studied patients (n=50)

Characteristics		Number	Percentage
CT infiltration %	Mean ± SD	50.8 ± 11.97	
	Range	40 – 85	
CT findings	Consolidation	34	68%
	GGO	27	54%

The mean lung ultrasound score was 8.9 with a range from 2 to 26 among the studied patients on admission (Table 4).

Table (4): Lung Ultrasound score at the time of admission among the studied patients (n=50)

	Mean ± SD	Range
Lung US score at the time of admission	8.9 ± 5.1	2 – 26

Lung ultrasound score on admission was found to have a significant correlation with oxygen saturation on admission (negative correlation), lymphocyte count (negative correlation) CRP, D-Dimer, and ferritin (positive correlation) as well as degree of pulmonary infiltration on pulmonary CT (positive correlation) (Table 5).

Table (5): Correlation between Lung Ultrasound score at the time of admission among the studied patients with clinical, laboratory, and CT infiltration on admission (n=50)

	r	p-value
Oxygen saturation on admission (%)	-0.3	0.001*
TLC	-0.05	0.7 (NS)
Lymphocytes count	-0.6	0.001*
LDH	0.2	0.08 (NS)
CRP	0.5	0.003*
D Dimer	0.5	0.001*
Ferritin	0.4	0.002*
CT infiltration %	0.7	0.001*

Table (6) showed that 20% of the studied patients showed the need for domiciliary oxygen at discharge. The mean duration of hospital stay was 10.86 days with a range from 5 to 30 days. 18% of the studied patients required ICU admission. The mortality rate was 6% among the studied patients.

Table (6): In-hospital and at discharge patients' outcome (n=50)

		Number	Percentage
Hospital stays (days)	Mean ± SD	10.86 ± 5.6	
	Range	5 – 30	
ICU admission	No	41	82%
	Yes	9	18%
Need for domiciliary oxygen at discharge	No	40	80%
	Yes	10	20%
In hospital mortality	No	47	94%
	Yes	3	6%

Patients with the need for ICU admission have significantly higher lung ultrasound scores versus patients not requiring ICU admission. There was a significant positive correlation between lung ultrasound score on admission and hospital stay duration (Table 7).

Table (7): correlation between LUS score on admission with different outcomes; in hospital and at discharge (n=50)

			LUS on admission	p-value
Need for domiciliary oxygen at discharge	No	Mean ± SD	9.1 ± 5.5	0.5 (NS)
	Yes	Mean ± SD	8.2 ± 2.9	
ICU admission	No	Mean ± SD	7.9 ± 4.4	0.02*
	Yes	Mean ± SD	13.2 ± 5.7	
In hospital mortality	No	Mean ± SD	8.3 ± 4.4	0.1 (NS)
	Yes	Mean ± SD	18.3 ± 6.6	
Hospital stay duration	r		0.6	
	p-value		0.002	

Table (8) showed that over time there was a statistically significant reduction in lung ultrasound score.

Table (8): Change of Lung US score over time (admission, at discharge, and 8 weeks after discharge) (n=50)

	Mean ± SD	Range
Lung US score at the time of admission	8.9 ± 5.1[a]	2 – 26
Lung US score at the time of discharge	3.24 ± 2.1[b]	0 – 10
Lung US score 8 weeks after discharge	0.9 ± 1.7[c]	0 – 5
p-value	0.001*	

26% of the studied patients have evidence of lung fibrosis on pulmonary CT 8 weeks post discharge (Table 9).

Table (9): Incidence of post-COVID fibrosis finding on CT chest 8 weeks after discharge (n=50)

Post COVID fibrosis	Number	Percentage
No	37	74%
Yes	13	26%

Patients found to have post-COVID fibrosis have higher lung ultrasound scores compared to patients without post-COVID fibrosis 8 weeks after discharge (Table 10).

Table (10): Relation between lung US score on admission with post-COVID fibrosis on CT 8 weeks after discharge (n=50):

			LUS on admission	p-value
Post-COVID fibrosis	No	Mean ± SD	7.6 ± 4.9	0.001*
	Yes	Mean ± SD	18.5 ± 3.8	

Table (11) showed that after receiver operating characteristic curve analysis, it was found that lung ultrasound score was a significant predictor of ICU admission, prolonged hospital stays duration of more than 2 weeks, and incidence of post-COVID fibrosis 8 weeks after discharge with cutoff values of more than 10, 15 and 12 respectively.

Table (11): Predictive characteristics of LUS on admission for prediction of in-hospital, at discharge, 8 weeks post-discharge outcome (n=50)

Outcome	Lung US on admission					p-value
	Cutoff point	Sensitivity	Specificity	PPV	NPV	
ICU admission	> 10	71%	55%	68%	50%	0.01*
Prolonged hospital stay > 14 days	> 15	91%	85%	88%	80%	0.001*
Post-COVID fibrosis 8 weeks post-discharge	> 12	85%	73%	80%	65%	0.001*

Case (1): A 67-year-old male patient was known to be diabetic, hypertensive & heavy smoker. Presented with dyspnea, fever, and cough, his PaO_2 was 80 %, and the PCR result confirmed COVID-19 infection. He was admitted to the isolation ward.

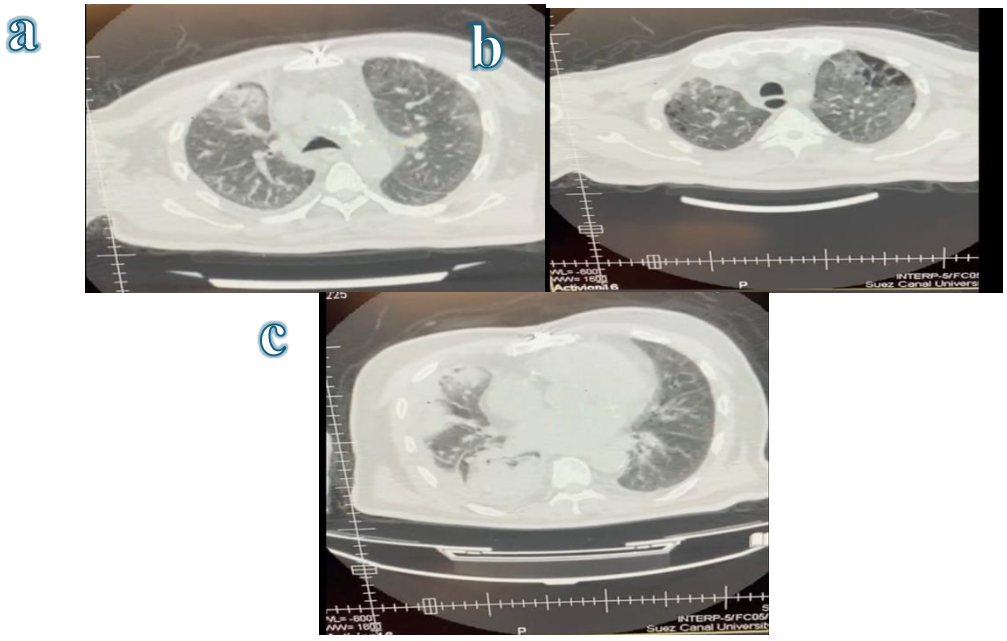

Figure 1: CT chest showed (a) Bilateral emphysematous changes and few GGOs, (b) There was a patch of consolidation on the upper lobe of the right lung, (c) There was mild to moderate pleural effusion with underlying consolidation vs collapse on the right side lower lobe. The total degree of tissue involvement in CT was approximately 70%.

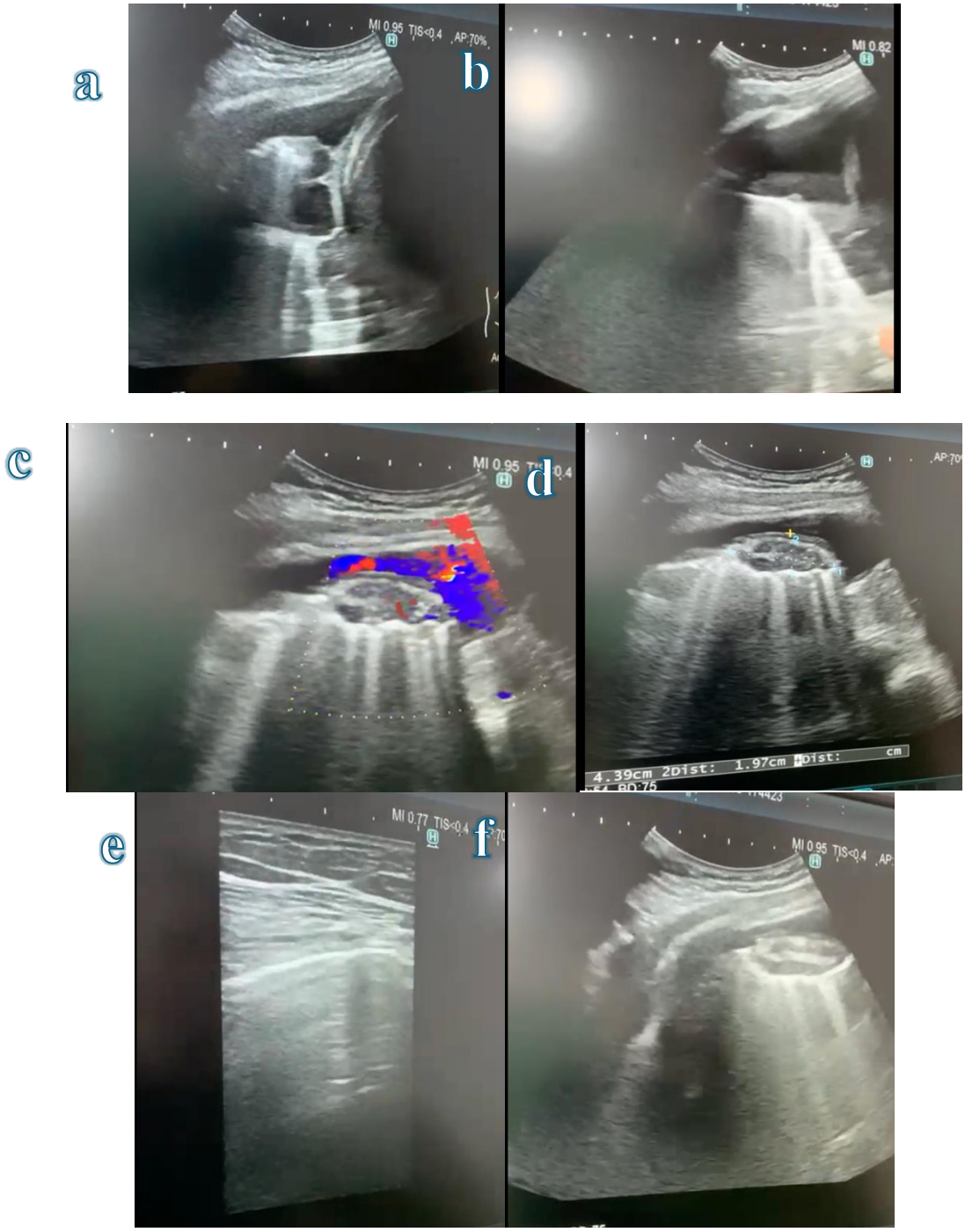

Figure (2): Lung ultrasound showed different patterns of lung affection: (a & b): Moderate pleural effusion with septations and collapse of lower lobe (Severity Score = 0), (c & d): consolidation patch with air-bronchogram measuring 4.39x1.97 cm (Severity Score = 3), (e): Excessive B lines more than 3 (Severity Score = 2), (f): A-lines (Severity Score = 0). The total LUS score was 10/ 36.

DISCUSSION

Severe acute respiratory syndrome SARS-CoV-2 can be detected through chest CT scan, which reveal ground-glass opacification, consolidation, and thickening of interlobular septa. These CT scans can help predict patient prognosis but carry risks, including adverse events and increased resource utilization. Compared to chest radiography, lung ultrasonography (LUS) offers improved diagnostic accuracy for interstitial lung disease and alveolar consolidation [25].

Since COVID-19 pulmonary infiltrates are peripherally distributed, LUS is a reliable imaging study that can reduce the need for CT scans, thereby minimizing risks related to infection transmission and radiation, and it can be easily performed at the bedside, addressing challenges in transporting critically ill patients [26].

This comparative study was conducted on 50 COVID-19 patients to evaluate lung ultrasound results and their correlation with clinical outcomes in hospitalized individuals. The goal was to assess risk, predict outcomes, and potentially replace chest CT with ultrasound as a more accessible and cost-effective method. The study was conducted on patients admitted to the medical department of Suez Canal University Hospital and Outpatient Clinics. The endpoints were all-cause mortality and the composite endpoint of death or new need for invasive mechanical ventilation. All patients underwent both chest imaging (including CT of the chest & Lung ultrasound) and laboratory tests.

Regarding CT findings & LUS score at the time of admission, consolidation and GGO were the main CT findings on admission and were reported among 68% and 54% of the studied patients respectively. The mean percentage of lung infiltration on CT on admission was found to be 50.8% with a range from 40 to 85% involvement of lung parenchyma. The mean lung ultrasound score was 8.9 with a range from 2 to 26. This comes in agreement with **Zhanna *et al.*** [27].

Regarding the correlation between LUS scores at the time of admission among the studied patients with clinical, laboratory, and CT infiltration on admission, LUS score on admission was found to have a significant correlation with oxygen saturation on admission (negative correlation), lymphocyte count (negative correlation) CRP, D-Dimer and ferritin (positive correlation) as well as the degree of pulmonary infiltration on pulmonary CT (positive correlation). This comes in agreement with **Zhanna *et al.*** [27].

Zhanna Davidovna *et al.* [27] conducted an observational research including 62 patients with bilateral lung involvement as demonstrated by chest CT scans. The predominant lesions identified were GGO and consolidations, with most patients exhibiting lung lesions aligned with CT-2 and CT-3 severity classifications. CT-2 (GGO in 26 to 50% of the lung parenchyma) and CT-3 (GGS and consolidations in 51 to 75% of the lung parenchyma). The average LUS severity score was 26.4 ± 6.7, demonstrating a robust association with CT severity classifications. LUS severity scores had a stronger correlation with disease severity, C-reactive protein, and D-dimer levels than with total CT severity scores. A significant negative connection was identified between overall LUS severity ratings and admission blood oxygen saturation levels. According to a separate report by **Nouvenne *et al.*** [28], LUS identified bilateral anomalies in all patients, with a mean score of 15 ± 5. A notable positive association existed between the LUS score and the CT visual score, while a negative correlation was observed with admission oxygen saturation.

Regarding the relation between LUS score on admission as well as at discharge and in-hospital outcome, patients with the need for ICU admission have significantly higher LUS scores versus patients not requiring ICU admission. There was a significant positive correlation between lung ultrasound score on admission and hospital stay duration. This comes in agreement with **Zieleskiewicz *et al.*** [25] who conducted a multicenter observational study with 100 patients, finding that LUS score correlated significantly with pneumonia severity as determined by chest CT and clinical features. A higher LUS score was linked to the necessity for mechanical ventilation. Mechanically ventilated patients had a considerably higher LUS score compared to those not ventilated (28 ± 5 vs. 14 ± 8; $p < 0.0001$). All the mechanically ventilated patients had LUS score above 19.

Lightowler *et al.* [29] conducted a single-center prospective research including physicians conducting lung ultrasound on adult patients with confirmed COVID-19 pneumonia, categorizing severe lung damage based on a SpO_2/FiO_2 ratio of less than 315. The LUS score varied from 0 to 36 according to the aeration patterns. A total of 248 participants participated in the trial. An entrance LUS score of 17 or above signifies an elevated risk of in-hospital mortality, ICU admission, and the necessity for both invasive and non-invasive mechanical ventilation.

Regarding the change in LUS score over time (admission, at discharge, and 8 weeks after discharge), over time there was a statistically significant reduction in LUS score. This comes in agreement with **Lightowler *et al.*** [29] who conducted 657 LUS examinations, reporting a median score of 11 (IQR: 7–15) for the initial LUS examination and a median score of 10 (IQR: 7–14) for the second LUS examination.

Regarding Predictive characteristics of LUS on admission for prediction of in-hospital, at discharge, 8 weeks post-discharge outcome, after receiver operating characteristic curve analysis. It was found that lung ultrasound score is a significant predictor of ICU admission, prolonged hospital stay duration more than 2 weeks and incidence of post COVID fibrosis 8 weeks

after discharge with cutoff values of more than 10, 15 and 12 respectively. This comes in agreement with **Lichter *et al.*** [26] who reported that, hospitalized COVID-19 patients, at all clinical grades, exhibited pathological LUS findings. The baseline LUS is closely linked to the need for invasive mechanical ventilation and serves as a significant predictor of mortality. Patients assigned LUS scores ranging from 0 (best) to 36 (worst), with 67% having scores between 0 and 18, and 33% between 19 and 36. The median total lung score was 15. Findings such as pleural thickening and subpleural consolidations increased with higher LUS scores and disease severity. Additionally, LUS findings were compared with clinical data. Clinical deterioration correlated with higher follow-up LUS scores, mainly due to decreased aeration in the anterior lung segments.

Increased mortality was significantly linked to the presence of pleural effusion, pleural thickness, and a high total LUS score at baseline. The optimal LUS score cutoff for predicting 30-day mortality, identified through ROC analysis, was 18. A baseline LUS score greater than 18 was associated with higher mortality and a greater need for invasive mechanical ventilation. Specifically, a total LUS score above 18 corresponded to a lower survival rate (66±20% vs. 88±11% for 30-day survival; p=0.01) [26].

CONCLUSION

Our study demonstrated that the LUS modality had a better overall diagnostic performance if added to CT scans in COVID-19 patients, particularly concerning consolidation and ground-glass opacities. There is a positive correlation between LUS score & degree of lung infiltration on CT, and a negative correlation between LUS score & oxygen saturation. It was found that LUS score helps predict ICU admission, prolonged hospital stays over two weeks, and post-COVID fibrosis eight weeks after discharge. It is recommended as an effective bedside tool for assessing severity and monitoring COVID-19 patients, especially for vulnerable groups like children, pregnant women, and critically ill patients who cannot be moved.

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