Lung Ultrasound in COVID-19: Clinical Correlates and Comparison With Chest Computed Tomography

Grazia Portale (✉ gportale69@gmail.com)  
Ospedale Generale di Zona Madre Giuseppina Vannini  
https://orcid.org/0000-0002-4940-2858

Federica Ciolina  
Ospedale Generale di Zona Madre Giuseppina Vannini

Luca Arcari  
Ospedale Generale di Zona Madre Giuseppina Vannini

Gianluca Di Lazzaro Giraldi  
Ospedale Generale di Zona Madre Giuseppina Vannini

Massimiliano Danti  
Ospedale Generale di Zona Madre Giuseppina Vannini

Lorenzo Pietropaolo  
Ospedale Generale di Zona Madre Giuseppina Vannini

Giovanni Camastra  
Ospedale Generale di Zona Madre Giuseppina Vannini

Chiara Cordischi  
Ospedale Generale di Zona Madre Giuseppina Vannini

Laura Urbani  
Ospedale Generale di Zona Madre Giuseppina Vannini

Lidia Proietti  
Ospedale Generale di Zona Madre Giuseppina Vannini

Luca Cacciotti  
Ospedale Generale di Zona Madre Giuseppina Vannini

Claudio Santini  
Ospedale Generale di Zona Madre Giuseppina Vannini

Serena Melandri  
Ospedale Generale di Zona Madre Giuseppina Vannini

Gerardo Ansalone  
Ospedale Generale di Zona Madre Giuseppina Vannini

Stefano Sbarbati  
Ospedale Generale di Zona Madre Giuseppina Vannini

Cinzia Sighieri  
Ospedale Generale di Zona Madre Giuseppina Vannini
Abstract

Background: lung ultrasound (LUS) and chest computed tomography (chest-CT) are largely employed to evaluate coronavirus-disease-19 (COVID-19) pneumonia. We investigated semi-quantitative LUS and CT scoring in hospitalized COVID-19 patients.

Methods: LUS and chest-CT were performed within 24 hours upon admission. Both were analyzed according to semi-quantitative scoring systems. Subgroups were identified according to median LUS score.

Results: patients within higher LUS-score group were older (79 vs 60 years, p<0.001), had higher C-reactive protein (CRP) (7.2 vs 1.3 mg/dl, p<0.001) and chest-CT score (10 vs 4, p=0.027) as well as lower PaO2/FiO2 (286 vs 356, p=0.029) as compared to patients within lower scores. We found a significant correlation between scores (r=0.390, p=0.023). Both LUS and CT scores correlated directly with patients age (r=0.586, p<0.001 and r=0.399, p=0.021 respectively) and CRP (r=0.472, p=0.002 and r=0.518, p=0.002 respectively), inversely with PaO2/FiO2 (r=-0.485, p=0.003 and r=-0.440, p=0.017 respectively). LUS-score only showed significant correlation with hs-Troponin T, NT-pro-BNP and creatinine (r=0.433, p=0.019; r=0.411, p=0.027 and r=0.497, p=0.001 respectively).

Conclusions: semi-quantitative bedside LUS related to the severity of COVID-19 pneumonia similarly to chest-CT. Correlation of LUS-score with markers of cardiac and renal injury suggests that LUS might contribute to a more comprehensive evaluation of this heterogeneous population.

Introduction

In late 2019 the outbreak in China of a novel type of betacoronavirus 2019-nCov, later renamed severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), spread to generate a global pandemic of the so-called Coronavirus disease 2019 (COVID-19) [1]. This is a respiratory tract infection that may lead to severe systemic involvement with interstitial pneumonia and respiratory failure often associated with myocardial injury [2, 3], thrombosis [4], multiorgan failure and death [5]. Mainstay of COVID-19 diagnosis is nasopharyngeal swab and subsequent quantitative real-time reverse transcriptase polymerase chain reaction (qRT-PCR) [5], but a central role has been demonstrated for chest computed tomography (chest-CT) too. Indeed, this can provide differential diagnosis and assess complications [6], while the possibility of detecting COVID-19 pneumonia using a chest-CT-only approach has been explored [7]. Lung ultrasound (LUS) is another technique that can be used for lung evaluation in COVID-19 patients, with an expanding role favored by the possibility of performing it bed-side [8]. Aim of the present study was to investigate semi-quantitative assessment of LUS and CT findings in a cohort of patients hospitalized for COVID-19 pneumonia, providing comparison with clinical and laboratory data.

Methods
Patients enrollment

This is a partly-retrospective, observational, single center study on hospitalized patients with COVID-19 pneumonia. Diagnostic work-up and clinical management of COVID-19 patients at our institution have been previously described in detail [9]. For the purpose of the present study, we included in the analysis patients (n = 42) who underwent timely LUS within 24 hours upon hospital admission. All patients included in the analysis had established diagnosis of SARS-CoV2 infection (qRT-PCR) with pulmonary involvement (chest CT) and were treated in dedicated “Covid units”. Past clinical history and symptoms were registered by the accepting physician. Within 24 hours upon admission, all patients underwent routine venous and arterial blood gas (ABG) examination as well as 12-lead ECG. On arterial blood gas test, arterial oxygen concentration (PaO2) was normalized to the fractional volume of the inspired oxygen to calculate the PaO2/FIO2 ratio.

Chest computed tomography (CCT)

Two multidetector CT scanners (Philips Brilliance 16 and Brilliance 64) were used for all examinations. Scanning parameters were the same as the manufacturer’s standard recommended pre-setting for a thorax routine. Images were acquired with a 1-mm slice thickness and a reconstruction increment of 0,5 mm in all cases using a soft tissue kernel of B20 and a lung kernel of B60. Coronal and sagittal multiplanar reconstructions (MPR) were also done in all cases.

Infection prevention and control measures were guaranteed in all suspected CT cases (sanitation of CT room and patient’s isolation). Suspicion of SARS-CoV2 pneumonia was established by the presence of three CT patterns: ground glass opacity (GGO), crazy paving and consolidation according to previous publications [10, 11]

The semi-quantitative severity score proposed by Pan was used per each of the 5 lobes considering the degree of anatomical involvement [12]. Specifically, we assigned points:

- 0, no involvement;
- 1, < 5% involvement;
- 2, 5–25% involvement;
- 3, 26–50% involvement;
- 4, 51–75% involvement;
- 5, > 75% involvement.

The resulting global CT score was the sum of each individual lobar score and (0 to 25). Collateral features such as fibrosis, subpleural lines, pleural and pericardial effusion, and lymphadenopathy were also depicted. Distribution of lung abnormalities was also classified as predominantly subpleural, centrolobular, random (without predilection for subpleural or central regions), or diffuse (continuous involvement without respect to lung segments). Blinded independent image analysis was performed by
two radiologists (M.D. and F.C., respectively with > 20 and > 10 years of experience in thoracic radiology) with use of the institutional digital database system (Impax Client, Agfa, version 6.6.0.145, Belgium). Any disagreement was resolved by consensus.

**Lung ultrasound**

Portable ultrasound machines dedicated to exclusive use for patients with COVID-19, both equipped with a 3–6 MHz convex array transducer were used (GE Vividi and Siemens P500). All examinations were performed bedside within 24 hours upon hospital admission. Images were recorded, stored, and analyzed off-line by an experienced operator blinded to patients’ clinical data and CT findings.

All subjects underwent bedside US scanning and were systematically studied as suggested by Soldati et al. in 14 areas: 3 posterior, 2 lateral, and 2 anterior on each chest side [13]. A score was assigned to each segment according to ultrasonographic appearances of chest US as follows: 1) presence of horizontal artifact, A-lines pattern, with continuous and regular pleural line (Score 0); 2) indented pleural with vertical artifacts appearing (Score 1); 3) small-to-large consolidated areas with associated white areas (white lung) (Score 2); 4) dense and largely extended white lung with or without larger consolidations (Score 3). Finally, a total score in each patient was calculated by summation of values recorded in all 14 segments. Groups with low- and high- LUS score respectively were identified according to median value and comparison provided.

**Statistical analysis**

All analysis was performed using SPSS software 25 (SPSS Inc., Chicago, IL). Data are presented as mean ± standard deviation, counts (percentages) or median (interquartile range, IQR), as appropriate. Comparisons between groups were performed using Chi-squared test, Fisher’s exact test, Student t-test for independent samples or Mann–Whitney U test as appropriate. Analysis of relationships was performed using linear regression analysis and bivariate correlation with corresponding Pearson’s or Spearman correlation coefficients as appropriate according to data distribution. Log-transformed values for serum biomarkers (hs-Troponin, NT-pro-BNP, D-dimer, CRP, creatinine) were used to yield approximate normality when performing correlation analysis. All tests were two-tailed, and *p* value of < 0.05 was considered statistically significant. All patients provided informed consent for the use of their record for research purposes, the study complied with the content of the Declaration of Helsinki.

**Results**

**Baseline characteristics**

Baseline clinical and demographic characteristics in our sample are summarized in Table 1. Mean age was 70 years and 48% were male. Comorbidities were largely prevalent within the study population, where more than half of the patients had known hypertension, approximately one third had pre-existing CVD and 57% were taking an ace-inhibitor or angiotensin II receptor blocker before hospital admission. Median CRP and D-dimer were increased (4.6 and 892 fibrinogen equivalent unit respectively). Blood gas analysis
showed mean PaO2 of 73 ± 16 mmHg and mean PaO2/FIO2 of 318 ± 95. Median LUS score was 6 (3, 10), median CT score was 7 (3, 11).
Table 1
Baseline demographic and clinical characteristics of the study population overall and stratified by median LUS score value. LUS (lung ultrasound), CVD (cardiovascular disease) CRP (C-reactive protein), FEU (fibrinogen equivalent unit), CKD (chronic kidney disease), COPD (chronic obstructive pulmonary disease), WBC (white blood cells), NLR (neutrophil to lymphocyte ratio), CT (computed tomography).

| Variable                  | Overall (n = 42) | Low LUS score (n = 21) | High LUS score (n = 21) | P     |
|---------------------------|------------------|------------------------|-------------------------|-------|
| Age (years)               | 70 ± 18          | 60 ± 19                | 79 ± 11                 | < 0.001 |
| Sex (male)                | 20 (48%)         | 11 (55%)               | 9 (45%)                 | 0.537 |
| Signs and symptoms at presentation |                   |                        |                         |       |
| Cough                     | 20 (48%)         | 10 (48%)               | 10 (48%)                | 0.591 |
| Dyspnea                   | 15 (36%)         | 5 (25%)                | 10 (48%)                | 0.204 |
| Fever                     | 28 (66%)         | 13 (60%)               | 15 (71%)                | >0.99 |
| Coexistent Conditions     |                   |                        |                         |       |
| Hypertension              | 29 (%)           | 11 (55%)               | 18 (82%)                | 0.145 |
| Dyslipidemia              | 8 (19%)          | 2 (10%)                | 6 (27%)                 | 0.258 |
| Diabetes                  | 4 (9%)           | 1 (4%)                 | 3 (15%)                 | 0.613 |
| Previous CVD              | 14 (33%)         | 5 (25%)                | 9 (41%)                 | 0.275 |
| - Atrial Fibrillation     | 8 (19%)          | 3 (15%)                | 5 (23%)                 | 0.709 |
| - Coronary Artery Disease | 3 (7%)           | 3 (15%)                | 0 (0%)                  | 0.083 |
| - Heart failure           | 9 (22%)          | 3 (15%)                | 6 (28%)                 | 0.476 |
| - Stroke                  | 3 (7%)           | 1 (4%)                 | 2 (10%)                 | >0.99 |
| CKD                       | 3 (7%)           | 0 (0%)                 | 3 (15%)                 | 0.238 |
| COPD                      | 11 (26%)         | 7 (35%)                | 4 (18%)                 | 0.173 |
| Cancer                    | 4 (9%)           | 3 (15%)                | 1 (4%)                  | 0.333 |
| Ace-inhibitor therapy     | 24 (57%)         | 13 (60%)               | 11 (55%)                | 0.743 |
| Laboratory Tests          |                   |                        |                         |       |
| Hb (g/dl)                 | 12.4 ± 2.5       | 12.9 ± 2.6             | 12 ± 2.4                | 0.289 |
| WBC (per µL)              | 7.1 (5, 9.4)     | 6 (4.3, 9.3)           | 7.5 (5.3, 10.2)         | 0.411 |
| Neutrophil (per µL)       | 4.7 (3.2, 7.2)   | 4.2 (3.1, 7.4)         | 5.9 (3.5, 7.3)          | 0.240 |
| Lymphocyte (per µL)       | 1.1 (0.9, 1.6)   | 1.2 (0.99, 1.7)        | 1 (0.8, 1.5)            | 0.299 |
| Variable                   | Overall (n = 42) | Low LUS score (n = 21) | High LUS score (n = 21) | P     |
|----------------------------|------------------|------------------------|-------------------------|-------|
| NLR                        | 4.2 (2.3, 7.1)   | 3.4 (2, 6)             | 5 (2.6, 8)              | 0.147 |
| Creatinine (mg/dl)         | 0.8 (0.6, 1.14)  | 0.72 (0.56, 0.94)      | 1 (0.64, 1.6)           | 0.014 |
| CRP (mg/dl)                | 4.6 (1, 7.7)     | 1.3 (0.3, 5)           | 7.2 (4.3, 13)           | < 0.001 |
| D-dimer (FEU)              | 892 (548, 1376)  | 701 (276, 2168)        | 971 (745, 1216)         | 0.647 |
| Hs-Troponin T (pg/ml)      | 17 (7, 43)       | 10 (6, 23)             | 24 (9, 62)              | 0.123 |
| NT-pro-BNP (pg/ml)         | 436 (85, 4171)   | 187 (42, 610)          | 1068 (199, 1216)        | 0.057 |
| Blood Gas Analysis         |                  |                        |                         |       |
| pH                        | 7.48 ± 0.08      | 7.5 ± 0.1              | 7.46 ± 0.05             | 0.170 |
| pO2 (mmHg)                | 73 ± 16          | 79 ± 13                | 69 ± 16                 | 0.04  |
| pCO2 (mmHg)               | 35 ± 7           | 35 ± 6                 | 34 ± 7                  | 0.771 |
| PaO2/FiO2                 | 318 ± 95         | 356 ± 97               | 286 ± 83                | 0.029 |
| Chest CT                  |                  |                        |                         |       |
| CT score (available in 34/42) | 7 (3, 11)    | 4 (2,8)                | 10 (7, 13)              | 0.027 |
| LUS                       |                  |                        |                         | < 0.001 |
| LUS score                 | 6 (3, 10)        | 3 (1, 5)               | 10 (6, 14)              |       |

**Characteristics of population according to LUS findings**

On subgroups analysis, patients who had higher LUS score were older (79 vs 60 years, p < 0.001) with similar prevalence of CVD (41% vs 25%, p = 0.275) and other comorbidities, whereas blood examinations showed higher CRP and creatinine (7.2 vs 1.3, p > 0.001 and 1 vs 0.72, p = 0.014 respectively) and lower PaO2/FiO2 (286 vs 356, p = 0.029) as compared with patients with lower LUS score (Fig. 1). On CT examination, significantly higher scores were measured in patients with higher LUS score (10 vs 4, p = 0.027); Fig. 2 depicts LUS and CT findings in a representative patient. Rate of ace-inhibitor or angiotensin receptor blocker intake before hospital admission was similar between LUS subgroups.

**Analysis of relationships**

Analysis of relationships results are summarized in Table 2 and Fig. 3. We observed a significant correlation between LUS and CT scores (r = 0.390, p = 0.023). Both LUS and CT scores correlated directly
with patients age ($r = 0.586, p < 0.001$ and $r = 0.399, p = 0.021$ respectively) as well as CRP ($r = 0.472, p = 0.002$ and $r = 0.518, p = 0.002$ respectively), and inversely with PaO2/FiO2 ($r = -0.485, p = 0.003$ and $r = -0.440, p = 0.017$ respectively). On the other hand, only LUS score had significant correlation with hs-Troponin T, Nt-pro-BNP and creatinine ($r = 0.433, p = 0.019$; $r = 0.411, p = 0.027$ and $r = 0.497, p = 0.001$ respectively), whereas CT score had none (all $p > 0.05$).

Table 2

| Variable                                      | LUS score (n = 42) | CT score (n = 34) |
|-----------------------------------------------|-------------------|------------------|
|                                               | R     | P     | R     | P     |
| Age                                           | 0.586 | < 0.001 | 0.399 | 0.021 |
| Sex (male)                                    | -0.171 | 0.280 | -0.040 | 0.822 |
| Previous CVD                                  | 0.215 | 0.171 | 0.111 | 0.533 |
| Ace-inhibitor therapy                         | 0.045 | 0.819 | 0.146 | 0.496 |
| WBC                                           | 0.153 | 0.347 | 0.140 | 0.436 |
| Neutrophil                                    | 0.208 | 0.198 | 0.029 | 0.873 |
| Lymphocyte                                    | -0.175 | 0.279 | 0.219 | 0.221 |
| NLR                                           | 0.241 | 0.135 | -0.113 | 0.531 |
| Creatinine                                    | 0.497 | 0.001 | 0.302 | 0.087 |
| CRP (Log10)                                   | 0.472 | 0.002 | 0.518 | 0.002 |
| D-dimer (Log10)                               | 0.182 | 0.418 | 0.097 | 0.685 |
| Hs-Troponin T (Log10)                         | 0.433 | 0.019 | 0.131 | 0.541 |
| NT-pro-BNP (Log10)                            | 0.411 | 0.027 | 0.163 | 0.437 |
| PaO2/FiO2                                      | -0.485 | 0.003 | -0.440 | 0.017 |
| CT score                                      | 0.390 | 0.023 | NA    | NA    |
| LUS score                                     | NA    | NA    | 0.390 | 0.023 |

Discussion

We reported LUS and CT findings in a cohort of patients affected by COVID-19. We observed a significant correlation between scores assessed by LUS and CT respectively. Higher scores by either technique
correlated directly with age and CRP, and inversely with PaO2/FiO2; however, LUS score only showed significant direct correlation with hs-troponin T, NT-pro-BNP and creatinine.

Previous studies in COVID-19 showed that LUS semi-quantitative evaluation provided useful diagnostic [14] and prognostic [15, 16] information, while it correlated well with worsening respiratory insufficiency [14]. In our sample we reported similar results, however, in comparison to others [14, 15] we observed lower values of LUS scores and higher PaO2/FiO2, possibly partly explained by the non-critical care setting of our population [9]. Of note, COVID-19 is featured by quite heterogeneous clinical behavior, ranging from asymptomatic cases to different degrees of flu-like symptomatology and bilateral pneumonia complicated by respiratory failure [5, 11]. Taken together these data suggest that LUS scoring could be a reliable index of disease severity across all the COVID-19 spectrum.

In the majority of the study population, we were able to provide comparison of LUS with chest CT results evaluated by a scoring system described in literature [12]. As already reported by others [17, 18], we observed significant agreement between techniques, indicating that both could be informative regarding lung and systemic involvement in these patients. Indeed, in our sample both correlated with markers of worsening respiratory insufficiency such as PaO2/FiO2 and inflammation (CRP and D-dimer). Of note, LUS score only showed significant association with markers of cardiac and renal injury. Patients with COVID-19, especially those with older age included in our cohort [9], are characterized by high comorbidity burden including cardiovascular and renal diseases [19–21], which in turn can relate to pulmonary congestion through volume overload.

Previous studies showed that LUS can be more effective than conventional chest X-ray for diagnosis of acute heart failure [22], while it can identify lung congestion in the context of volume overload driven by acute kidney injury [23, 24]. Both conditions at LUS evaluation are characterized by diffuse B-lines. Accordingly, volume overload and lung congestion might at least partly explain why degree of cardiac and renal injury were related to LUS but not CT findings in our cohort. If on one hand this result reiterates the high specificity of a semi-quantitative chest-CT scoring system in evaluating COVID-19 lung pneumonia, on the other it suggests that LUS might potentially provide added value in these highly comorbid patients, in which pneumonia might not be the sole cause of dyspnea and respiratory insufficiency.

Our findings might carry potential clinical implications. COVID-19 is a highly contagious disease [25], for which dedicated multidisciplinary "COVID units" have been created for the safety management of affected patients [26]. Imaging testing constitutes a potential risk for healthcare personnel and its use should be accurately weighted to reduce the number of unnecessary examinations [27]. Our study showed that LUS could be used for pneumonia severity evaluation in COVID-19 providing results comparable to chest-CT in the assessment of lung and systemic inflammatory involvement, with the added advantage of being effectively executable bedside.

**Limitations**
Our study should be read in light of several limitations, such as partly retrospective nature, limited sample size and non-critical care setting which can reduce generalizability of our findings. Associations we observed between imaging scoring and systemic COVID-19 involvement must be cautiously interpreted as hypothesis generating only, not allowing to draw patterns of existing cause-effect relationships. Larger prospective studies are needed to fully assess whether LUS could be reliably used as possible alternative to chest CT scan for the diagnosis COVID-19 and in-hospital monitor of disease evolution.

Conclusions

In patients with COVID-19 pneumonia admitted to non-critical-care wards, semi-quantitative bedside LUS evaluation identified the subgroup of patients with worse respiratory failure and systemic inflammation with results comparable to chest-CT evaluation. Correlation of LUS score with markers of cardiac and renal injury suggests that LUS might contribute to a more comprehensive evaluation, potentially aiding detection of non-pneumonia related causes of respiratory insufficiency within this heterogeneous and highly comorbid population.

Declarations

Funding: none

Conflicts of interest/Competing interests: none declared

Ethics approval: institutional review board approved the study

Consent to participate: the patients provided written informed consent to the used of data for research purpose

Consent for publication: the patients consented to the publication of anonymized data

Availability of data and material: data will be made available upon request

Code availability: not applicable

Authors’ contributions: performed imaging tests (GP, FC, MD, SM), involved in the care of the patients (all authors), literature search (GP, FC, LA), wrote the draft of the manuscript (GP, FC, LA, MD) provided critical revision and approved the final version of the manuscript (all authors).

References

1. Zhu N, Zhang D, Wang W, et al (2020) A novel coronavirus from patients with pneumonia in China, 2019. N Engl J Med 382:727–733. https://doi.org/10.1056/NEJMoa2001017
2. Puntmann VO, Carerj ML, Wieters I, et al (2020) Outcomes of Cardiovascular Magnetic Resonance Imaging in Patients Recently Recovered from Coronavirus Disease 2019 (COVID-19). JAMA Cardiol.
3. Camasta G, Ciolina F, Arcari L, et al (2021) OUP accepted manuscript. Eur Hear J - Cardiovasc Imaging. https://doi.org/10.1093/ehjci/jeea414
4. Choudry FA, Hamshere SM, Rathod KS, et al (2020) High Thrombus Burden in Patients With COVID-19 Presenting With ST-Segment Elevation Myocardial Infarction. J Am Coll Cardiol 76:1168–1176. https://doi.org/10.1016/j.jacc.2020.07.022
5. Huang C, Wang Y, Li X, et al (2020) Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. Lancet 395:497–506. https://doi.org/10.1016/S0140-6736(20)30183-5
6. Larici AR, Cicchetti G, Marano R, et al (2020) Multimodality imaging of COVID-19 pneumonia: from diagnosis to follow-up. A comprehensive review. Eur. J. Radiol. 131:109217
7. Harmon SA, Sanford TH, Xu S, et al (2020) Artificial intelligence for the detection of COVID-19 pneumonia on chest CT using multinational datasets. Nat Commun 11:1–7. https://doi.org/10.1038/s41467-020-17971-2
8. Sultan LR, Sehgal CM (2020) A Review of Early Experience in Lung Ultrasound in the Diagnosis and Management of COVID-19. Ultrasound Med Biol 46:2530–2545. https://doi.org/10.1016/j.ultrasmedbio.2020.05.012
9. Arcari L, Luciani M, Cacciotti L, et al (2020) Incidence and determinants of high-sensitivity troponin and natriuretic peptides elevation at admission in hospitalized COVID-19 pneumonia patients. Intern Emerg Med. https://doi.org/10.1007/s11739-020-02498-7
10. Salehi S, Abedi A, Balakrishnan S, Gholamrezanezhad A (2020) Coronavirus disease 2019 (COVID-19): A systematic review of imaging findings in 919 patients. Am. J. Roentgenol. 215:87–93
11. Ye Z, Zhang Y, Wang Y, et al (2020) Chest CT manifestations of new coronavirus disease 2019 (COVID-19): a pictorial review. Eur Radiol 30:4381–4389. https://doi.org/10.1007/s00330-020-06801-0
12. Pan F, Ye T, Sun P, et al (2020) Time course of lung changes at chest CT during recovery from Coronavirus disease 2019 (COVID-19). Radiology 295:715–721. https://doi.org/10.1148/radiol.2020200370
13. Soldati G, Smargiassi A, Inchingolo R, et al (2020) Proposal for international standardization of the use of lung ultrasound for COVID-19 patients; a simple, quantitative, reproducible method. J Ultrasound Med. https://doi.org/10.1002/jum.15285
14. Bosso G, Allegorico E, Pagano A, et al (2020) Lung ultrasound as diagnostic tool for SARS-CoV-2 infection. Intern Emerg Med. https://doi.org/10.1007/s11739-020-02512-y
15. Lichter Y, Topilsky Y, Taieb P, et al (2020) Lung ultrasound predicts clinical course and outcomes in COVID-19 patients. Intensive Care Med 46:1873–1883. https://doi.org/10.1007/s00134-020-06212-1
16. Rojatti M, Regli IB, Zanforlin A, et al (2020) Lung Ultrasound and Respiratory Pathophysiology in Mechanically Ventilated COVID-19 Patients—an Observational Trial. SN Compr Clin Med 2:1970–1977. https://doi.org/10.1007/s42399-020-00536-1
17. Tung-Chen Y, Martí de Gracia M, Díez-Tascón A, et al (2020) Correlation between Chest Computed Tomography and Lung Ultrasonography in Patients with Coronavirus Disease 2019 (COVID-19). Ultrasound Med Biol 46:2918–2926. https://doi.org/10.1016/j.ultrasmedbio.2020.07.003
18. Marggrander DT, Borgans F, Jacobi V, et al (2020) Lung Ultrasound Findings in Patients with COVID-19. SN Compr Clin Med 2:2151–2157. https://doi.org/10.1007/s42399-020-00553-0
19. Núñez-Gil IJJ, Fernández-Ortiz A, Maroud Eid C, et al (2020) Underlying heart diseases and acute COVID-19 outcomes. Cardiol J 28:. https://doi.org/10.5603/cj.a2020.0183
20. Liu Y-F, Zhang Z, Pan X-L, et al (2021) The chronic kidney disease and acute kidney injury involvement in COVID-19 pandemic: A systematic review and meta-analysis. PLoS One 16:e0244779. https://doi.org/10.1371/journal.pone.0244779
21. Uribarri A, Núñez-Gil IJ, Aparisi A, et al (2020) Impact of renal function on admission in COVID-19 patients: an analysis of the international HOPE COVID-19 (Health Outcome Predictive Evaluation for COVID 19) Registry. J Nephrol 33:737–745. https://doi.org/10.1007/s40620-020-00790-5
22. Rinaldi L, Milione S, Fascione MC, et al (2020) Relevance of lung ultrasound in the diagnostic algorithm of respiratory diseases in a real-life setting: A multicentre prospective study. Respirology 25:535–542. https://doi.org/10.1111/resp.13659
23. Ciumanghel A, Siriopol I, Blaj M, et al (2018) B-lines score on lung ultrasound as a direct measure of respiratory dysfunction in ICU patients with acute kidney injury. Int Urol Nephrol 50:113–119. https://doi.org/10.1007/s11255-017-1730-8
24. Panuccio V, Tripepi R, Parlongo G, et al (2020) Lung ultrasound to detect and monitor pulmonary congestion in patients with acute kidney injury in nephrology wards: a pilot study. J Nephrol 33:335–341. https://doi.org/10.1007/s40620-019-00666-3
25. Li Q, Guan X, Wu P, et al (2020) Early Transmission Dynamics in Wuhan, China, of Novel Coronavirus–Infected Pneumonia. N Engl J Med 382:1199–1207. https://doi.org/10.1056/NEJMoa2001316
26. Pennica A, Conforti G, Falangone F, et al (2020) Clinical Management of Adult Coronavirus Infection Disease 2019 (COVID-19) Positive in the Setting of Low and Medium Intensity of Care: a Short Practical Review. SN Compr Clin Med 1–6. https://doi.org/10.1007/s42399-020-00333-w
27. Skulstad H, Cosyns B, Popescu BA, et al COVID-19 pandemic and cardiac imaging: EACVI recommendations on precautions, indications, prioritization, and protection for patients and healthcare personnel. https://doi.org/10.1093/ehjci/jeaa072

Figures
Figure 1

Boxplot shows significantly higher CRP (A) and lower PaO2/FIO2 (B) in patient with high median LUS score.

A. CRP (log10) vs. LUS score

B. PaO2/FIO2 vs. LUS score

C. CT score vs. LUS score

D. Hs-Troponin (log10) vs. LUS score
Figure 2

Images from a 60-year-old man hospitalized for COVID-19 pneumonia. High resolution chest computed tomography revealed focal consolidation and ground-glass pleural opacities in both inferior lobes (red arrows in panel 2.a). Lung ultrasound confirmed the presence of consolidation areas in both posterior lung lobes (red asterisk in panel 2.b and 2.c).

![Figure 2](image)

Figure 3

Scatter plots showing correlations between LUS score and CRP (A), PaO2/FIO2 (B), CT score (C) and hs-Troponin (D), all p<0.05.