Evolution of Lung Abnormalities on Lung Ultrasound in Recovery From COVID-19 Disease—A Prospective, Longitudinal Observational Cohort Study

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Objectives—SARS-CoV-2 can cause respiratory diseases with various manifestations. However, little is known about its potential for lung recovery. Lung ultrasound has shown characteristic changes during COVID-19 and has proven to be useful for triage, diagnosis, and therapy. This study investigated how the recovery process from COVID-19 respiratory disease can be monitored using 12-zone lung ultrasound.

Methods—This prospective observational cohort study was conducted in a busy urban emergency department in London, United Kingdom, over a 20-week period between April and October 2020. We followed 24 patients recovering from COVID-19 with varying disease severity using 12-zone lung ultrasound at 2-week intervals and monitored the changes in the prevalence of lung abnormalities previously described in COVID-19 infection (irregular pleura, subpleural consolidation, B-lines, and small localized effusions).

Results—Lung ultrasound showed that the lung recovers significantly over 20 weeks postdisease. Individual lung abnormalities also resolved at different rates. The entire rib space occupied by confluent B-lines wane after the acute phase, whereas irregular pleura and subpleural consolidations resolved more gradually. Separate wide B-lines moving with the pleura during respiration may represent more stable features, indicating residual fibrotic changes. Small, localized effusions appear transiently after the initial acute phase of the disease, peaking at approximately 10 weeks after infection. The measured lung abnormalities were strong predictors of perceived shortness of breath during ambulation.

Conclusion—Lung ultrasound can be a useful tool for long-term monitoring of COVID-19 lung disease, avoiding repeated exposure to ionizing radiation, and may distinguish between acute and past infections.

Key Words—acute respiratory distress syndrome; COVID-19; lung ultrasound; pneumonia; SARS-CoV-2

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Abbreviations
LUS, lung ultrasound; OR, odds ratio; RT-PCR, reverse transcription-polymerase chain reaction; SOB, shortness of breath

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shown to be comparable to that of CT and far superior to chest X-ray.\textsuperscript{1,2}

Normal appearances on LUS include the visualization of a regular pleural line and A-lines (a reverberation artifact) throughout the lung zones. In contrast, abnormalities seen on LUS in COVID-19 include pleural irregularities and subpleural consolidations accompanied by an interstitial pattern of B-lines (ring-down artifacts) of various morphologies, ranging from thin and sparse B-lines to wide, broad vertical bands emanating from the pleura that can span the entire intercostal space.\textsuperscript{3} These can be found in all lung zones, and areas of abnormal lungs are typically interspersed with normal lungs. Small localized pleural effusions have also been reported.\textsuperscript{4,5} Lung abnormalities have been shown to correlate with disease severity.\textsuperscript{6,7}

B-lines are vertical artifacts that move with pleural sliding and indicate interstitial disease, which includes fibrotic changes and interstitial fluid syndromes. It has been suggested that their presence correlates with disease severity in COVID-19 lung disease, as previously observed in acute respiratory distress syndrome and pulmonary edema. Previous studies have concluded that up to two separate B-lines in gravity-dependent lung areas do not constitute a disease process but that more than two B-lines in any rib space indicate an interstitial disease pattern. In COVID-19 infections, B-lines have been demonstrated to have particular distributions and morphologies. Wide, broad B-lines are seen in a patchy distribution throughout all lung zones and can coalesce to a level where the entire rib spaces are occupied by a white lung appearance. In the literature, these phenomena have been termed the “light beam” and “waterfall” signs. Furthermore, LUS abnormalities correlate well to findings seen on CT scans of patients with COVID-19 pneumonia: characteristic predilection for peripheral changes that include patchy ground-glass opacification, “crazy-paving” patterns, and a very low occurrence of large consolidations and basal effusions.\textsuperscript{8-10}

The literature published on the potential use of LUS in COVID-19 has mostly focused on its use in triage and diagnosis. With the continuing evolution of the COVID-19 pandemic and an increasing number of people affected by the disease, including reports of long-term sequelae, such as long COVID syndrome, questions regarding lung recovery become pertinent. As patients begin to present with symptoms consistent with COVID-19 respiratory disease, it is important to understand whether changes on LUS are due to residual changes from previous infection or new infection with SARS-CoV-2.

Preliminary studies using sequential CT scanning of COVID-19 patients for up to 26 days following infection have shown a degree of initial lung recovery. Gradual absorption of “crazy paving” pattern, which is shown as patchy peripheral ground-glass opacities with ill-defined margins and inter- and intralobular septal thickening, decreased from being noted in 91% of patients at the peak stage (9–13 days) to 19% at 20 weeks. The remaining changes noted were a significant degree of ground-glass opacification, subpleural consolidation, and cord-like high-density shadows indicative of fibrosis.\textsuperscript{11,12}

In this prospective observational cohort study, we used 12-zone LUS at 2-week intervals in patients diagnosed with SARS-CoV-2 infection to monitor dynamic lung changes during their recovery from the COVID-19 respiratory disease.

Patients and Methods

Ethics Approval

Ethics approval for this study was granted by the Health Research Authority through the integrated research application system (reference number IRAS286015). Ethical approval was obtained from the Research Ethics Committee (REC reference 20/SC/0270). The patients received a written patient information leaflet and were required to provide written consent.

Study Design, Setting, and Participants

We conducted a single-center prospective observational cohort study at a busy urban hospital in the United Kingdom. Patients who presented to the emergency department between April and May 2020 with symptoms consistent with COVID-19 and had an LUS as part of their clinical investigation on presentation were identified. Patients’ notes were then cross-referenced to identify patients who had been diagnosed as SARS-CoV-2-positive by reverse transcription-polymerase chain reaction (RT-PCR). Patients with known preexisting fibrotic lung disease...
or heart failure were excluded from this study because they may exhibit ultrasound features similar to those analyzed in this study. Eligible patients were also contacted through telephone. Patients who agreed to participate in the study were invited to outpatient appointments. A patient information leaflet was provided and written informed consent was obtained from all patients. Patients were then scheduled for appointments at 2-week intervals, and a 12-zone ultrasound was performed, as well as pulse oximetry when static and after ambulation of 40 steps. Patients were also interviewed regarding their functional status, particularly their perception of shortness of breath (SOB) at rest and on exertion. In total, six follow-up appointments were scheduled for each patient at set times after initial presentation to the emergency department, spanning a total time frame of 20 weeks (follow-up [FU]1, 8–10 weeks; FU2, 10–12 weeks; FU3, 12–14 weeks; FU4, 14–16 weeks; FU5, 16–18 weeks; FU6, 18–20 weeks). The first follow-up was set at 8 weeks because of pandemic pressures but also to allow for patients’ recovery to be able to attend outpatient appointments.

Patients were grouped into severity categories based on the oxygenation deficit at initial presentation, as measured by SpO2/FiO2 ratios. Categories for these severity groups were based on the BERLIN criteria for acute respiratory distress syndrome.\(^{13}\) PiO2/FiO2 ratios were equated to SpO2/FiO2 ratios using a mathematical equation, as suggested by Rice et al.\(^{14}\)

There was no incentive or payment provided to the study participants.

**Ultrasound**

Twelve-zone ultrasound scans were performed by one of the three doctors trained in LUS. One of the doctors had formal training in ultrasound as well as over 5 years of experience in performing and teaching ultrasound; the others had completed a formal ultrasound fellowship and received targeted training in LUS during 10 to 50 supervised scans.

Two ultrasound machines were used in the department: a GE Venue (GE Healthcare, Chicago, IL) using a lung preset and a SonoSite X-porte (FUJIFILM SonoSite Inc, Bothell, WA). To emulate the lung preset, which is not available on Sonosite, an abdominal preset was used with tissue harmonic imaging and compound imaging turned off, as well as a reduced dynamic range.

In preparation for the study, images from both ultrasound machines with the chosen machine settings taken on the same patients were compared in terms of B-line count, pleural appearance, and subpleural consolidation appearance to ensure equivalence. The intercostal spaces were scanned in the sagittal plane at a depth of 13 to 16 cm. The focal zone is defined as the pleural line. Images and clips of each zone were saved for analysis.

Lung zones were identified as follows: each hemithorax was divided into anterior and posterior axillary lines in the anterior, lateral, and posterior areas, which were further subdivided into superior and inferior zones, resulting in six scanning zones per hemithorax. Labeling was set according to the laterality of the hemithorax (R [right], L [left]), and zones were numbered as one and two for anterior zones, three and four for lateral zones, and five and six for posterior zones (Figure 1).

**Review Process**

All images and video clips were captured, anonymized, and reported in real time by one of the three emergency department clinicians with postgraduate training in ultrasound, by using an ultrasound probe that was specifically developed for the assessment of COVID-19 LUS in the department (supplemental Figure 1). Clip and still images of the examinations were also independently scored by one of the other emergency department clinicians taking part in the study. Reports were compared for agreement and categorized as “agree” or “disagree.” The reports were then categorically compared, and...
inter-rater reliability was assessed. In cases of disagreement, a third emergency department doctor with formal ultrasound training was consulted, and the consensus result was used for the analysis. Inter-rater reliability was assessed using Cohen’s kappa. The sonographic clips or images, captured with the curvilinear probe at a depth of 13 to 16 cm with the focal zone set to the pleural line, were scored for the presence (positive or negative) of the following ultrasound appearances: A-line pattern (A), pleural irregularity (P), small peripheral consolidation (<1 cm) (C), B-lines: ≤2 isolated (B1), >2 B-lines or wide band-like B-lines with a thickness occupying >25% of the pleura at origin (B2), confluent B-lines occupying the entire intercostal space resulting in a full intercostal “white-out” (B3), and small. Localized pleural effusion (<1 cm) (E) (Figure 2).

Statistical Analysis
The prevalence (%) of each LUS feature and 95% confidence intervals were calculated for the entire cohort of patients for the initial scans, as well as for each follow-up scan, and were compared to elicit lung changes over time. To circumvent convergence problems in a multivariable model, we used a multilevel generalized linear model with a normal distribution and an identity link with a robust variance estimator to obtain valid standard errors and confidence intervals. This model provides the difference in the prevalence of LUS features between the time points. Moreover, we conducted separate analyses for each of the seven LUS features. Fixed effects were included for time point (1–7), side of the body (right/left), scan order (1–6), age, sex, and disease severity, with a random intercept by patient to account for the hierarchical structure of the data with repeated scans nested within patients. Predicted probabilities (point prevalence) at each time point were also derived, along with differences in prevalence at each time point versus the initial presentation. All analyses were conducted using the Stata software (Stata Statistical Software: Release 16; College Station, TX, StataCorp LLC). Binary logistic regression analysis between lung features and SOB on ambulation (SOB amb) was performed using SPSS software (SPSS Statistics for Macintosh, version 28.0; Armonk, NY: IBM Corp).

Results
Thirty eligible patients, who had been diagnosed as SARS-CoV-2-positive by RT-PCR and who also underwent LUS as part of their initial investigations in the emergency department were identified. Twenty-four patients agreed to participate in the study and provided written consent. Of the 24 patients, 17 were male, 7 were over 60 years old, and 11 had reported prior cardiovascular comorbidities (Table 1). According to SpO2/FiO2 ratios, 11 patients were in the mild group, 7 patients were in the moderate group, and 6 patients were in the severe group.

During the study, one patient from the severe group was admitted to the intensive therapy unit after the first follow-up appointment (8–10 weeks after initial infection), and one patient from the moderate severity group dropped out due to difficulty with travel arrangements during the pandemic after the second follow-up appointment (10–12 weeks after initial infection) (Figure 3).

Changes in Ultrasound Findings in Sequential LUS Scans
Table 2 shows the estimated point prevalence at each time point for each lung finding measured in this study. Overall, there was a marked decline in all
abnormal findings over the 20-week study period and a simultaneous increase in the prevalence of normal lungs (Figures 4 and 5). Lung abnormalities were observed to change at different rates.

The prevalence of normal-appearing lung zones (A-lines) continued to increase throughout the study from an initial prevalence of 31.8% to over 80%, with the largest incremental improvement seen at 10 to
12 weeks. Only one patient in the study had a completely normal LUS at the initial presentation. This patient was in the “mild” severity group, with normal oxygen saturation throughout the study.

The irregular pleura (P) and small peripheral consolidations (C) decreased substantially over the 20-week follow-up period. The largest incremental change was seen at 10 to 12 weeks for P and 8 to 10 weeks for C, after which the improvements occurred at a slower rate with 11 to 16% of lung zones still affected by these features after 20 weeks.

All three B-line morphologies decreased substantially over the study period, of which confluent B-lines (B3) were the fastest to resolve after the acute phase, from an initial prevalence of 10.6% to near zero after 14 weeks. Wide B-lines (B2) halved in prevalence to approximately 1-in-10 within 16 weeks, after which a plateau was reached with no further

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**Table 1. Patient Characteristics**

| Characteristics                  | All Patients | Mild (S/F > 315) | Moderate (S/F 148–315) | Severe (S/F < 148) |
|----------------------------------|--------------|-----------------|------------------------|-------------------|
| No of patients                   | 24           | 11              | 7                      | 6                 |
| Sex                              |              |                 |                        |                   |
| M                                | 17           | 7               | 6                      | 4                 |
| F                                | 7            | 4               | 1                      | 2                 |
| Age Mean (SD) (range)            | 52.9 (14.3) (27–73) |
| Cardiovascular comorbidities     | 11           | 4               | 5                      | 2                 |
| Day of illness                   |              |                 |                        |                   |
| ≤4                               | 2            | 1               | 1                      | 0                 |
| 4–9                              | 8            | 4               | 2                      | 2                 |
| 10–15                            | 9            | 3               | 3                      | 3                 |
| >15                              | 4            | 2               | 1                      | 1                 |
| Dyspnoea                         | 24           | 11              | 7                      | 6                 |
| CXR reported as COVID+           | 21           | 8               | 7                      | 6                 |
| Clinical course                  |              |                 |                        |                   |
| Discharged from A&E              | 10           | 10              | 0                      | 0                 |
| O2                               | 5            | 1               | 4                      | 0                 |
| NIV                              | 6            | 0               | 3                      | 3                 |
| Invasive Ventilation             | 3            | 0               | 0                      | 3                 |

S/F, SpO2/FiO2 ratio thresholds for disease severity.

**Figure 3.** Flow diagram showing eligibility, enrolment, and completion of study participants.
Table 2. Estimated Point Prevalence at Each Time Point and Differences from the Initial Presentation for Each of the Lung Features Analyzed

| Lung Feature* | Time Point        | Prevalence (%; 95% CI) | Difference to Initial Presentation (Percentage Points; 95% CI) |
|---------------|-------------------|------------------------|---------------------------------------------------------------|
| A-lines (A)   | Initial presentation | 31.8 (23.3–40.3)      | -                                                              |
|               | 8–10 weeks        | 39.4 (29.5–49.5)       | 7.6 (–0.16 to 15.4)                                           |
|               | 10–12 weeks       | 53.8 (44.1–63.5)       | 22.0 (12.9–31.0)                                              |
|               | 12–14 weeks       | 67.0 (56.2–77.8)       | 35.2 (23.5–46.8)                                              |
|               | 14–16 weeks       | 70.4 (60.2–80.6)       | 38.6 (27.3–49.9)                                              |
|               | 16–18 weeks       | 77.2 (66.4–88.0)       | 45.4 (32.5–58.2)                                              |
|               | 18–20 weeks       | 81.7 (70.6–92.9)       | 49.9 (37.1–62.7)                                              |
| Abnormal pleura (P) | Initial presentation | 61.3 (52.7–70.0)      | -                                                              |
|               | 8–10 weeks        | 51.6 (41.7–61.4)       | –9.7 (–19.1 to –0.36)                                         |
|               | 10–12 weeks       | 35.4 (24.1–46.8)       | –25.9 (–36.8 to –14.9)                                        |
|               | 12–14 weeks       | 27.2 (17.0–37.4)       | –34.1 (–44.7 to –23.5)                                        |
|               | 14–16 weeks       | 25.7 (15.6–35.8)       | –35.6 (–46.9 to –24.3)                                        |
|               | 16–18 weeks       | 20.8 (10.3–31.3)       | –40.5 (–52.8 to –28.2)                                        |
|               | 18–20 weeks       | 16.2 (5.5–27.0)        | –45.1 (–57.8 to –32.3)                                        |
| Subpleural consolidation (C) | Initial presentation | 52.7 (42.5–62.9)      | -                                                              |
|               | 8–10 weeks        | 37.8 (27.4–48.2)       | –14.9 (–27.1 to –2.7)                                         |
|               | 10–12 weeks       | 24.6 (13.8–35.4)       | –28.1 (–39.4 to –16.8)                                        |
|               | 12–14 weeks       | 17.2 (7.4–27.0)        | –35.5 (–46.8 to –24.2)                                        |
|               | 14–16 weeks       | 16.4 (7.3–25.6)        | –36.3 (–47.3 to –25.2)                                        |
|               | 16–18 weeks       | 14.9 (5.0–24.9)        | –37.8 (–49.6 to –26.0)                                        |
|               | 18–20 weeks       | 10.8 (0.23–21.4)       | –41.9 (–54.7 to –29.1)                                        |
| B1            | Initial presentation | 16.3 (10.2–22.5)      | -                                                              |
|               | 8–10 weeks        | 20.8 (13.6–28.1)       | –4.5 (–2.8 to 11.9)                                           |
|               | 10–12 weeks       | 10.7 (6.5–14.9)        | –5.6 (–12.2 to 0.9)                                           |
|               | 12–14 weeks       | 8.4 (4.3–12.6)         | –7.9 (–15.4 to –0.3)                                          |
|               | 14–16 weeks       | 8.4 (4.3–12.6)         | –7.9 (–15.2 to –0.6)                                          |
|               | 16–18 weeks       | 5.4 (2.4–8.4)          | –10.9 (–17.2 to –4.6)                                         |
|               | 18–20 weeks       | 4.3 (1.8–6.8)          | –12.0 (–18.1 to –6.0)                                         |
| B2            | Initial presentation | 21.8 (11.7–31.9)      | -                                                              |
|               | 8–10 weeks        | 19.4 (10.8–28.0)       | –2.4 (–11.4 to 6.6)                                           |
|               | 10–12 weeks       | 14.2 (6.1–22.4)        | –7.6 (–15.0 to 0.14)                                          |
|               | 12–14 weeks       | 8.9 (0.81–17.0)        | –12.9 (–20.7 to –5.1)                                         |
|               | 14–16 weeks       | 9.5 (1.3–17.8)         | –12.3 (–20.3 to –4.3)                                         |
|               | 16–18 weeks       | 9.9 (0.57–19.3)        | –11.9 (–20.9 to –3.2)                                         |
|               | 18–20 weeks       | 9.5 (0.14–19.0)        | –12.3 (–21.1 to –3.4)                                         |
| B3            | Initial presentation | 10.6 (4.5–16.7)       | -                                                              |
|               | 8–10 weeks        | 2.3 (0.35–4.2)         | –8.3 (–14.8 to –1.9)                                          |
|               | 10–12 weeks       | 2.3 (0–5.2)            | –8.3 (–15.4 to –1.2)                                          |
|               | 12–14 weeks       | 1.4 (0–3.2)            | –9.2 (–15.7 to –2.8)                                          |
|               | 14–16 weeks       | 0.25 (0–16.2)          | –10.4 (–16.8 to –3.9)                                         |
|               | 16–18 weeks       | 0.25 (0–16.2)          | –10.4 (–16.8 to –3.9)                                         |
|               | 18–20 weeks       | 0.25 (0–16.2)          | –10.4 (–16.8 to –3.9)                                         |
| E             | Initial presentation | 5.0 (1.5–8.6)         | -                                                              |
|               | 8–10 weeks        | 14.1 (6.9–21.3)        | 9.0 (0.5–17.6)                                                |
|               | 10–12 weeks       | 11.0 (5.3–16.8)        | 6.0 (–1.5 to 13.4)                                            |
|               | 12–14 weeks       | 4.8 (2.2–7.5)          | 0.24 (–5.3 to 4.8)                                            |
|               | 14–16 weeks       | 4.0 (0.13–8.0)         | –1.0 (–6.2 to 4.2)                                            |
|               | 16–18 weeks       | 1.0 (0–3.3)            | –4.0 (–7.4 to –0.7)                                           |
|               | 18–20 weeks       | 1.0 (0–3.0)            | –4.0 (–7.2 to –0.86)                                          |

*refers to the explanation of the different lung features.
A, A-line pattern; P, pleural irregularity; C, small peripheral consolidation (<1 cm); B1, ≤2 isolated B-lines; B2, >2 B-lines or B-lines with a thickness occupying >25% of the pleura at origin; B3, confluent B-lines occupying the entire intercostal space; E, small localized pleural effusions (<1 cm).
The prevalence of single separated B-lines (B1) continued to decrease throughout the observation period, from 16.3% to approximately 4%.

Finally, there was a marked increase in the appearance of small, localized peripleural effusions (E) at 8 to 10 weeks compared with the initial presentation from 5 to 14%, after which it declined to a final prevalence of just 1%.

The inter-rater reliability agreement between the performing clinician and the second reporting clinician was 91%.

Focusing on clinical parameters, the reported resting SOB as well as static and ambulatory SpO₂/FiO₂ ratios fell to near zero by the first follow-up appointment, whereas SOB amb demonstrated a more gradual decline in prevalence and was still experienced by 25% of all patients by 20 weeks (Table 3 and Figure 6). This suggests that SOB amb is the most likely functional clinical parameter with a potential correlation with the prevalence of lung abnormalities.

Binary logistic regression analysis between each lung feature and the presence or absence of ambulatory SOB showed that all lung abnormalities, apart from small, localized effusions, were strong predictors of SOB on ambulation (Table 4). B3, in particular, showed a strong relationship to SOB amb with each stepwise increase in the number of affected lung zones, increasing the odds of reported SOB by a factor of 4.1 ($b = 1.4, \ P < .01, \ odds \ ratio \ [OR] \ 4.1$). Conversely, the increase in the amount of normal lung zones proved to be a negative predictor for perceived SOB amb ($b = -0.3, \ P < .001, \ OR \ 0.7$). A visual representation of the relationship between the prevalence of lung features over time and the amount of reported ambulatory SOB is shown in Figure 5, which shows that the rate of improvement differs depending on initial disease severity.

Discussion

In this study, we followed 24 patients over a 20-week period at 2-week intervals, from 8 weeks postinitial attendance, using LUS to ascertain the evolution of ultrasound features associated with COVID-19 respiratory disease. Our analysis shows that there is significant lung recovery over the 20 weeks after initial presentation and that LUS is a useful tool to demonstrate this. The prevalence of normal lung features increased by approximately 50% after 20 weeks.
For each severity group, there was a noticeable plateau phase for recovery, which appeared to occur after 14 weeks in the mild disease group, with a lag of up to 4 weeks in moderate and severe diseases. It could be that recovery time is related to disease severity, as determined by oxygen deficiency at presentation; however, further research with larger sample size is required to determine this association.

The analysis of individual lung abnormalities showed differences in resolution rates. While the B3 pattern (rib space fully occupied by coalesced B-lines) displayed a steep decrease by 10 weeks postdisease with a barely detectable presence after 14 weeks, irregular pleura and subpleural consolidations showed a slower and much more gradual decline. The wide B-lines (B2) appeared to follow a different time
course, reaching a plateau of approximately 10% 14 weeks postinfection. Then, the appearance of these wide bands appears fixed in width, with the overall appearance as broad wide bands moving with the pleura on inspiration. Importantly, none of the patients in the mild disease severity group displayed wide B-lines at the end of this study, indicating that residual fibrotic disease may be a feature observed mostly in patients affected by moderate and severe disease. It is conceivable that these bands may represent a more permanent fibrotic transformation of some lung areas as a long-term sequela of COVID-19 lung disease, whereas the B3 feature is confined to the acute disease process and immediate recovery. Meanwhile, irregular pleura and small subpleural consolidations seem to improve gradually and continually, and it remains to be seen whether they do so after the 20-week endpoint of our study. A prominent feature in the follow-up process was the amount of small localized peripleural effusions (E), which increased in the postinfection phase, reaching a peak prevalence of 14% at 8 to 10 weeks postinfection and steadily declining thereafter. The mechanism of this observation is unclear, but it is conceivable that it represents a postinflammatory process.

It is interesting to note the correlation between the improvement in the prevalence of functional clinical parameters, particularly the perceived ambulatory SOB, and the observed changes in lung findings. While the ability of the lungs to maintain normal oxygenation returned to normal by 8 weeks in all patients, the perceived SOB on ambulation persisted for longer with a more gradual improvement. In some patients, ambulatory SOB persisted until the end of the study period. It is conceivable that this may represent features of “long COVID.”

Understanding the evolution of LUS findings post-COVID-19 will help inform frontline clinicians as they encounter patients both in various phases of recovery, as well as during the assessment of patients who have ongoing symptoms or patients who present back to the emergency department with possible new infection.

The main limitation of this study is the relatively small sample size, which was a result of the logistical obstacles involved in following up patients over a significant period of time, requiring repeated hospital visits during an ongoing pandemic, with some
patients still limited by respiratory symptoms. Therefore, we view our results as descriptive/exploratory. In addition, although patients with preexisting pathology who may also exhibit ultrasound features analyzed in this study, such as fibrotic lung disease or heart failure, were excluded from this study, we cannot be certain that some of the LUS features evaluated in the study were not present before the patient contracted COVID-19. This limitation also reflects the relatively poor specificity of LUS for changes

Figure 6. A. Bar graph showing the perceived SOB by patients at each time interval, at static and on ambulation of 40 steps for each severity group and for all patients. B. Bar graph of average oxygenation measured by pulse oximetry and shown as SpO2/FiO2 ratio for each severity group and for all patients. Note that ambulatory oxygen saturations were not tested on admission in breathless patients.
observed in COVID-19. Future research should determine whether the residual changes found in our study resolve in the long term. Finally, 70% of the study cohort were men. While this reflects the general emerging evidence suggestive of a gender gap in SARS-CoV-2 related morbidity and mortality, it could also result in gender bias in our results. Future studies with larger sample sizes will help reduce this bias.

An important remaining question is whether LUS remains useful for the assessment of COVID-19 in the emergency department, as suggested in the initial wave of the pandemic. Irregular pleura, subpleural consolidations, and thick B-lines remain at a higher prevalence until at least 20 weeks postinfection and might not be as useful in the assessment of new COVID infections. However, very confluent B-lines in the presence of relevant clinical symptoms indicate new and florid disease activity and are also associated with more severe disease. Hence, while LUS might not retain the same value for triage of COVID-19, it will still remain relevant in the diagnosis of new infections and more consistently useful in assessing disease severity. Therefore, lung ultrasonography remains a useful tool for identifying active diseases and likely disease progression in the emergency department.

In this study, we demonstrated that there is a significant amount of lung recovery over a 20-week period after presenting with COVID-19 respiratory disease. We demonstrated that certain lung abnormalities appeared to resolve at different rates. Some lung abnormalities resolved after the acute phase (B3), whereas others gradually resolved (such as P and C). Small, localized effusions appear transiently after the initial acute phase of the disease, peaking at approximately 10 weeks after infection. Broad, wide B-lines that move with the pleura during respiration appear to have a more stable appearance over the study period and may represent residual fibrotic changes.

Our study suggests that LUS could be used in conjunction with clinical features at targeted time intervals with prognostic value, as well as providing information regarding disease resolution, and may also be employed to distinguish between acute and past infections. These results indicate that LUS can be a useful tool for the long-term monitoring of COVID-19 lung disease, avoiding repeated exposure to ionizing radiation.

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### Table 4. Binomial Logistic Regression Analysis Illustrating the Relationship Between the Prevalence of Each Lung Feature and Ambulatory SOB. “b” Represents the Unstandardized Regression Coefficient with its Standard Error Values (SE.) Noted in the Adjacent Column. Statistical Significance at \( P < .05 \)

| Lung Feature | \( b \) | SE | \( P \) | OR | Lower | Upper |
|--------------|-------|----|-------|----|-------|-------|
| A            | −0.3  | 0.0 | <.001*| 0.7| 0.7   | 0.8   |
| P            | 0.4   | 0.1 | <.001*| 1.4| 1.3   | 1.6   |
| C            | 0.5   | 0.1 | <.001*| 1.6| 1.4   | 1.8   |
| B1           | 0.5   | 0.1 | <.001*| 1.7| 1.3   | 2.1   |
| B2           | 0.7   | 0.1 | <.001*| 1.9| 1.5   | 2.5   |
| B3           | 1.4   | 0.5 | .0*   | 4.1| 1.5   | 11.7  |
| E            | 0.2   | 0.1 | .1    | 1.2| 0.9   | 1.6   |

OR, odds ratios; 95% CI for OR, 95% confidence intervals.
*Indicate statistical significance.
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