Pulmonary ultrasound in COVID-19 and non-COVID-19 pneumonia in South Africa: An observational study

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Background. Pulmonary ultrasound techniques have historically been applied to acute lung diseases to describe lung lesions, particularly in critical care.
Objectives. To explore the role of lung ultrasound (LUS) in hospitalised patients with hypoxaemic pneumonia during the COVID-19 pandemic.
Methods. This was a single-centre prospective, observational study of two groups of adult patients with hypoxaemic pneumonia: those with COVID-19 pneumonia, and those with non-COVID-19 community-acquired pneumonia (CAP). A pulmonologist performed bedside LUS using the Bedside Lung Ultrasound in Emergency (BLUE) protocol, and the findings were verified by an independent study-blinded radiologist.
Results. We enrolled 48 patients with COVID-19 pneumonia and 24 with non-COVID CAP. The COVID-19 patients were significantly older than those with non-COVID CAP (median (interquartile range (IQR)) age 52 (42 - 62.5) years v. 42.5 (36 - 52.5) years, respectively; p=0.007), and had a lower prevalence of HIV infection (25% v. 54%, respectively; p=0.01) and higher prevalences of hypertension (54% v. 7%; p=0.002) and diabetes mellitus (19% v. 8%; p=0.04). In both groups, close to 30% of the patients had severe acute respiratory distress syndrome. A confluent B-line pattern in the right upper lobe was significantly associated with COVID-19 pneumonia compared with the C pattern (relative risk (RR) 3.8; 95% confidence interval (CI) 1.7 - 8.6). Bilateral changes on LUS rather than unilateral or no changes were associated with COVID-19 pneumonia (RR 1.55; 95% CI 1.004 - 2.387). There were no statistically significant differences in median (IQR) lung scores between patients with COVID-19 pneumonia and those with non-COVID CAP (8 (4 - 11.5) v. 7.5 (4.5 - 12.5), respectively). Patients with COVID-19 pneumonia had a higher than predicted mortality. Logistic regression analysis showed a higher Simplified Acute Physiology Score (SAPS II) (RR 1.11; 95% CI 1.02 - 1.21) and a lower total LUS score indicating B lines v. consolidation (RR 0.80; 95% CI 0.65 - 0.99) to be associated with mortality.
Conclusion. Patients with right upper zone consolidation were more likely to have non-COVID CAP than COVID-19 pneumonia. Finding a B pattern as opposed to consolidation was associated with mortality. The admission LUS score was unable to discriminate between COVID-19 and non-COVID CAP, and did not correlate with the ratio of partial pressure of oxygen to fractional inspired oxygen, clinical severity or mortality.

Keywords. COVID-19, lung ultrasound, pneumonia.

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Study synopsis
What the study adds. During the COVID-19 pandemic, in a resource-limited, high-prevalence setting, lung ultrasound (LUS) patterns on admission to hospital were used to distinguish between COVID-19 and other causes in patients with hypoxaemic pneumonia. Patients with right upper zone consolidation were more likely to have non-COVID-19 community-acquired pneumonia (CAP) than COVID-19 pneumonia.
Implications of the findings. The admission LUS score was unable to discriminate between COVID-19 pneumonia and non-COVID CAP, and did not correlate with the ratio of partial pressure of oxygen to fractional inspired oxygen, clinical severity or mortality. The pattern was more valuable than the total LUS score in understanding the disease process.

Lung ultrasound (LUS) has been used successfully for the identification and follow-up of the progression of lung pathology in COVID-19.[1,2] LUS outperforms chest radiography in identifying an alveolar pattern of disease in pneumonia.[3] The benefits of LUS over other radiological modalities in COVID-19 are that it is a bedside test, gives real-time data, can be performed by a single treating physician, thereby limiting hazardous exposure to the patient, is repeatable and low in cost, and has high diagnostic accuracy.[3,4] These factors make LUS particularly attractive as an imaging modality in a resource-constrained environment. Chest radiography and computed tomography (CT) are both limited in the setting of COVID-19, while infection control is better managed through single-machine use and a chlorhexidine-based cleansing protocol.[4]

Lung findings on histological examination and CT in COVID-19 are predominantly bilateral ground-glass opacification (GGO), peripheral consolidation, or a mixture of GGO and consolidation, with occasional crazy paving (10%) and wedge-shaped lesions.[5,6] The preponderance of peripheral lesions enhances the suitability of imaging by LUS. The common LUS findings described in COVID-19 pneumonia include bilateral B lines (separate or confluent) and subpleural consolidation,[4,6] although these findings are less accurate in the presence of interstitial lung disease and pulmonary oedema.[7] In the acute phase of the illness, there is typical sparing of areas between the various forms of B lines found, resulting in bilateral patchy areas of infiltrates.[6] It has been suggested that during a peak of the pandemic, a normal LUS in a patient with respiratory symptoms and no comorbid lung disease can be used to rapidly exclude the requirement for a SARS-CoV-2 swab or further testing for COVID-19 pneumonia.[6,7] Pleural effusion is also uncommon in the early phase of the disease, and its absence should prompt consideration of an alternative diagnosis.[4] However, LUS findings are time dependent, and evolve, resulting in consolidation and pleural effusion later during the course of the disease.[8]

LUS has also been shown to predict mortality, with scores of >18 (in a 12-point LUS examination) associated with reduced survival.[2] Szekely *et al.*[9] showed that LUS within the first 24 hours of admission improved prediction of the need for ventilation.

It was with the above in mind that the present study was performed to compare LUS findings in patients with COVID-19 and non-COVID-19 pneumonia, and to determine associations with disease severity and survival, in the South African (SA) setting.

Methods

Study design and site

This was a prospective, observational study of two cohorts of adult patients with hypoxaemic pneumonia (those with COVID-19 pneumonia and those with non-COVID-19 community-acquired pneumonia (CAP)) in a South African hospital. Right heart echocardiography findings in the same cohorts of patients have been reported previously.[10] Both articles form part of the first author (SAvB)'s PhD.

Study population

During working hours of weekdays, we screened all consecutive adult patients who were under investigation for SARS-CoV-2 virus infection and were admitted between 20 October 2020 and 11 March 2021. Patients were included if they had hypoxaemic pneumonia, diagnosed by a physician or with a chest radiograph, and met the criteria for severe or critical illness. Severe illness was defined as oxygen saturation (SpO_2) ≤92% with a respiratory rate ≥25 breaths per minute requiring supplemental oxygen support without the need for invasive or non-invasive ventilation. Critical illness was defined as hypoxaemia and the need for additional ventilatory support, in the form of non-invasive or invasive ventilation. Patients were excluded if they were pregnant or had known chronic lung disease, chronic cardiac disease, or a history of pulmonary or cardiac surgery.

Study procedure

Patient demographic, clinical, laboratory and hospital survival data were extracted from clinical notes. The Simplified Acute Physiology Score (SAPS II)[11] and Sequential Organ Failure Assessment (SOFA) score[12] were calculated from the clinical information at the time of admission, and admission biomarkers were recorded. LUS was performed as described below, and all patients were followed up for survival at hospital discharge.

LUS was performed using a GE HealthCare Mindray M7 ultrasound diagnostic system (GE Medical, China), with the patient in a supine or semi-recumbent position. Lesion locations were divided into six zones, corresponding with lobes, according to the Bedside Lung Ultrasound in Emergency (BLUE) protocol (upper, middle and lower on the right and left), and corresponded to the semi-quantitative LUS evaluation using standardised points described in the BLUE protocol.[1] If both hands are placed horizontally on the anterior chest, with the fifth finger below and along the clavicle, and other hand next to it with one thumb over the other, the standardised points are as follows: upper BLUE point at the middle of the upper hand and lower BLUE point at the middle of the lower palm, while the lower point is defined by the intersection of a horizontal line at the level of the lower BLUE point and a vertical line at the posterior axillary line. A low-frequency, curvilinear probe and a high-frequency linear probe were used. All studies were performed by one pulmonologist trained in the BLUE protocol, and images were stored. A study-blinded radiologist with a special interest in LUS reviewed the images, and any discrepancies were settled via consensus between the pulmonologist and the radiologist. All reventive measures for respiratory, droplet and contact isolation were adhered to. At the end of each procedure, the ultrasound machine was cleaned with chlorhexidine soap and water. A point scoring system was employed by region and ultrasound pattern, with an LUS of 0 being normal, and 18 being the worst LUS score. Lung lesions were graded in the following categories: normal pattern (A lines, non-significant B lines (<3)) = 0 points; B lines (≥3) = 1 point; BC (≥3 B lines, and very small consolidations) = 2 points; ultrasound signs of consolidation, e.g. hepatisation, shred sign (C pattern) = 3 points.

Outcome measures

The primary outcome was describing the LUS findings in COVID-19 pneumonia and non-COVID CAP with regard to type and extent of lung lesions. Secondary outcomes included correlating the type and extent of lung lesions with the ratio of partial pressure of oxygen to fractional inspired oxygen (FiO_2) (P/F ratio or Horowitz index), investigating the relationship between LUS and inflammation, and describing survival in the two pneumonia groups.

Statistical analysis

Study data were collected and managed using the REDCap (Research Electronic Data Capture) online database manager[13,14] hosted at the University of the Witwatersrand, Johannesburg. Statistical analyses were performed using Statistica version 13.3 (TIBCO Software Inc., USA). Continuous variables were expressed as medians with interquartile ranges (IQRs), and proportions/percentages were used for categorical variables. Continuous data were compared using the Mann-Whitney *U*-test, while proportions were compared using the χ^2 test. A *p*-value <0.05 was considered statistically significant. The relationships between LUS lesions and clinical parameters (severity scores) and oxygenation were investigated using Spearman's rank correlation (Rho).

Ethical considerations

Approval was received from the University Human Research Ethics Committee (Medical) (ref. no. M200728) (National Health Research Database GP_202008_140). Written informed consent from the patient or patient surrogate was obtained as per local ethics committee guidelines.

Results

Patient characteristics

We enrolled 72 patients, of whom 48 had COVID-19 pneumonia and 24 non-COVID CAP. The COVID-19 patients were significantly older than the non-COVID group (median (IQR) 52 (42 - 62.5) years v. 42.5 (36 - 52.5) years, respectively; *p*=0.007) and had a lower prevalence of HIV infection (25% v. 54%; *p*=0.01), a higher frequency of both hypertension (54% v. 17%; *p*=0.002) and diabetes mellitus (19% v. 8%; *p*=0.04), and a trend towards a lower admission severity of illness score (SAPS II) (median (IQR) 18 (13 - 31.5) v. 29 (17 - 36.5); *p*=0.15). The demographics and comorbidities of the cohort are set out in Table 1.

Characterisation of LUS patterns, B lines v. C pattern

The overall frequency of LUS signs in both the right and left lungs is shown in Figs 1 and 2. The B-line profile dominated over the C profile of consolidation in both the right and left lungs. A dominant B-line profile was more strongly associated with COVID-19 pneumonia than with non-COVID CAP (relative risk (RR) 1.87; 95% confidence interval (CI) 1.36 - 2.59 for the right lung and RR 1.36; 95% CI 1.03 - 1.78 for the left lung).

Bilateral changes on LUS rather than unilateral or no changes were strongly associated with COVID-19 pneumonia (RR 1.55; 95% CI 1.004 - 2.387). A confluent B-line pattern (ground-glass appearance) in the right upper lobe was significantly associated with COVID-19 pneumonia compared with the C pattern (consolidation) (RR 3.8; 95% CI 1.7 - 8.6).

Ultrasound lung score

There were no statistically significant differences in median lung scores between COVID-19 pneumonia and non-COVID CAP (median (IQR) 8 (4 - 11.5) v. 7.5 (4.5 - 12.5), respectively).

LUS and P/F ratio

There were 20 patients with severe hypoxaemia, defined as a P/F ratio <100. Thirteen were COVID-19 positive and 7 had non-COVID CAP. For patients with a P/F ratio <100, there was a trend to a lower LUS score (≤10) in the COVID-19 group compared with the non-COVID CAP group (χ^2 = 3.52; *p*=0.06).

LUS and inflammation

We entered LUS scores for each of the six zones and the total LUS into a linear regression model to predict inflammation based on the C-reactive protein (CRP) level. In the final model that included five variables (right upper zone (RUZ), right middle zone (RMZ), left middle zone (LMZ), left upper zone (LUZ) and total LUS score), higher LUS scores (reflective of greater changes) in the RUZ (*p*=0.04; 95% CI 0.008 - 0.65) and LMZ (*p*=0.03; CI 0.03 - 0.94) were significantly associated with greater CRP values.

Mortality

There was a trend towards lower severity of illness (SAPS II) scores in the COVID-19 group compared with the non-COVID CAP group (18 v. 29, respectively; *p*=0.15). The standardised mortality ratio (SMR) was 1.3 (95% CI 0.8 - 3.4) for non-COVID CAP, with an actual mortality of 12.5% and a predicted mortality based on the SAPS II of 9.7% (95% CI 3.7 - 15.7). The SMR was 9.3 (95% CI 5.1 - 54.2) for COVID-19 pneumonia, with an actual mortality of 27.1% and a predicted mortality based on the SAPS II of 2.9% (95% CI 0.5 - 5.3).

We performed logistic regression analysis using six variables: a ix-zone LUS, oxygenation (P/F ratio), severity of illness (SAPS II), lactate, ventilation (partial pressure of carbon dioxide ($PaCO_2$)), and COVID-19 status. A higher SAPS II (RR 1.11; 95% CI 1.02 - 1.21) and a lower total LUS score indicating B lines v. consolidation (RR 0.80; 95% CI 0.65 - 0.99) were associated with mortality.

Discussion

The main finding of this study was that the BLUE protocol was useful in describing COVID-19 pneumonia. The type of LUS profile (B lines with and without subpleural consolidations), the widespread distribution (bilateral changes), and the specific regional ultrasound fingerprint (ground-glass confluent/coalescent B lines in the RUZ) were all important in characterising COVID-19 pneumonia and differentiating it from non-COVID CAP. Our findings of bilateral interstitial syndrome are consistent with existing literature on LUS presentation in COVID-19, as first recognised at the beginning of the pandemic and in more recent data.[4,15-21]

Compared with COVID-19 pneumonia patients, non-COVID CAP patients were significantly younger, with a higher HIV-positivity rate and lower prevalences of hypertension and diabetes, in keeping with established risk factors for severe COVID-19 pneumonia.[22] There was a clinically significant trend towards higher severity of illness scores (SAPS II) in the non-COVID CAP group, as well as higher D-dimer levels, indicating that these patients presented on admission with more organ dysfunction than the COVID-19 group. Severe acute respiratory distress syndrome was present in ~30% of both groups, indicating similar admission respiratory compromise.

Use of the LUS score in differentiating COVID-19 from non-COVID pneumonia has been described as having high sensitivity and varying specificity,[16,23-26] the latter probably dependent on the background prevalence of COVID-19 at the time of the studies. LUS scores vary according to the number of

Table 1. Patient characteristics

Variable	Total (*N*=72), *n* (%)†	Non-COVID-19 pneumonia (*n*=24), *n* (%)†	COVID-19 pneumonia (*n*=48), *n* (%)†	*p*-value
Age (years), median (IQR)	48.5 (40 - 58)	42.5 (36 - 52.5)	52 (42 - 62.5)	0.007*
Male	32/72 (44)	12/24 (50)	20/48 (42)	0.5
Comorbidities				
HIV	25/72 (35)	13/24 (54)	12/48 (25)	0.01*
Hypertension	30/72 (42)	4/24 (17)	26/48 (54)	0.002*
Diabetes mellitus	11/70 (16)	2/24 (8)	9/48 (19)	0.04*
Smoker	15/72 (21)	7/24 (29)	8/48 (17)	0.21
SAPS II, median (IQR)	21 (14 - 34)	29 (17 - 36.5)	18 (13 - 31.5)	0.15
SOFA score, median (IQR)	2 (2 - 4)	2.5 (2 - 4)	2 (2 - 4)	0.36
Lactate (mmol/L), median (IQR)	1.8 (1.2 - 2.4)	2.2 (1.7 - 3.2)	1.6 (1.1 - 2.4)	0.03*
PaO_2 (mmHg), median (IQR)	45 (31 - 62)	43 (29 - 57)	46 (32 - 63)	0.47
$PaCO_2$ (mmHg), mean (SD)	37 (7.4)	36 (9.4)	37 (8.5)	0.83
P/F ratio				
Median (IQR)	132 (93 - 192)	143 (96 - 218)	126 (81 - 183)	0.62
≤100%	20/72 (28)	7/24 (29)	13/48 (27)	0.85
101 - 200%	34/72 (47)	10/24 (42)	24/48 (50)	0.5
201 - 300%	15/72 (21)	6/24 (25)	9/48 (19)	0.54
>300%	3/72 (4)	1/24 (4)	2/48 (4)	1
CRP (mg/L), median (IQR)	128 (60.5 - 211)	106 (63 - 225)	132.5 (56 - 192)	0.92
D-dimers (mg/L), median (IQR)	1.15 (0.38 - 3.56)	2.08 (1.08 - 3.84)	0.82 (0.35 - 3.18)	0.02*
Total LUS score, median (IQR)	8 (4 - 12)	7.5 (4.5 - 12.5)	8 (4 - 11.5)	0.56

IQR = interquartile range; SAPS II = Simplified Acute Physiology Score; SOFA = Sequential Organ Failure Assessment; PaO_2 = partial pressure of oxygen; $PaCO_2$ = partial pressure of carbon dioxide; P/F ratio = ratio of PaO_2 to fractional inspired oxygen (Horowitz index); CRP = C-reactive protein; LUS = lung ultrasound.
*Statistically significant ($p<0.05$).
†Except where otherwise indicated.

zones scanned and protocols applied, but in confirmed COVID-19, higher LUS scores are associated with increasing severity. Studies conducted in the pre-vaccine period have compared the LUS scores and characterisation of COVID-19 compared with non-COVID pneumonia[1,4,16,18,23-34] in varying detail, with most studies favouring more descriptive terms in addition to the LUS score, to show a better picture of the lung pathology.[4,16,18,23,27,29-31,33] Our findings demonstrate a predominance of B lines with and without subpleural consolidations in COVID-19. Furthermore, we found a discriminating finding between the two types of pneumonia: RUZ confluent B lines predicted COVID-19 as the cause of the pneumonia, compared with finding consolidation in the same zone (RUZ), which predicted non-COVID pneumonia, assisting in rapid clinical discrimination on admission in high COVID-19 prevalence settings. There was a trend towards significance in the finding that the absence of ultrasound findings in the left chest conferred an increased RR for COVID-19 pneumonia. An SA study looking at severe COVID-19 pneumonia chest radiographs consistently found sparing of the LUZ.[35] Postulated reasons include the slight hypoperfusion of the left lung compared with the right lung, and considering that COVID-19 causes endothelial and pulmonary microvascular injury, this could translate to more significant pathology in areas that are better perfused,[35] with upper zones relatively less perfused than lower zones. Furthermore, Buckley *et al.*[35] suggest that differences in the lymphatic drainage between the right and left upper lobes could contribute to the sparing of the LUZ.[35] The present study did not find large pleural effusions in any COVID-19 patients, in keeping with other studies showing absence or rarity of pleural effusions in early stages of COVID-19 pneumonia,[2,4,8] suggesting that the presence of a large pleural effusion on admission should prompt the clinician to consider an alternative diagnosis.

The relationship between total LUS score and oxygenation (P/F ratio) was interesting. In comparison with the non-COVID CAP group, there was a trend to lower LUS scores in the COVID-19 pneumonia group. This finding is likely to be a result of the weighting of B-line changes as opposed to consolidation, with the latter given a higher score. Rather than a lesser degree of ultrasound findings in more hypoxaemic patients, it is likely to reflect a relationship between a B-line profile and hypoxaemia compared with consolidation in this early admission period. There are few studies looking at LUS scores and oxygen requirements in both COVID-19 and non-COVID pneumonia, with one having normal oxygenation in both groups (but COVID-19 lower than non-COVID) and the other showing an inverse relationship between the P/F ratio and finding of subpleural consolidations, although specific lung zones were not reported.[5,24] There are studies supporting the inverse relationship between LUS score and oxygenation, but there is heterogeneity with regard to how oxygenation was assessed and described.[2,4,8,16,21,24,36-44] Some studies found that patients with COVID-19 pneumonia had a lower SpO_2 than those with non-COVID pneumonia, but this was not clinically significant, as both groups had normal oxygenation,[24,45] whereas

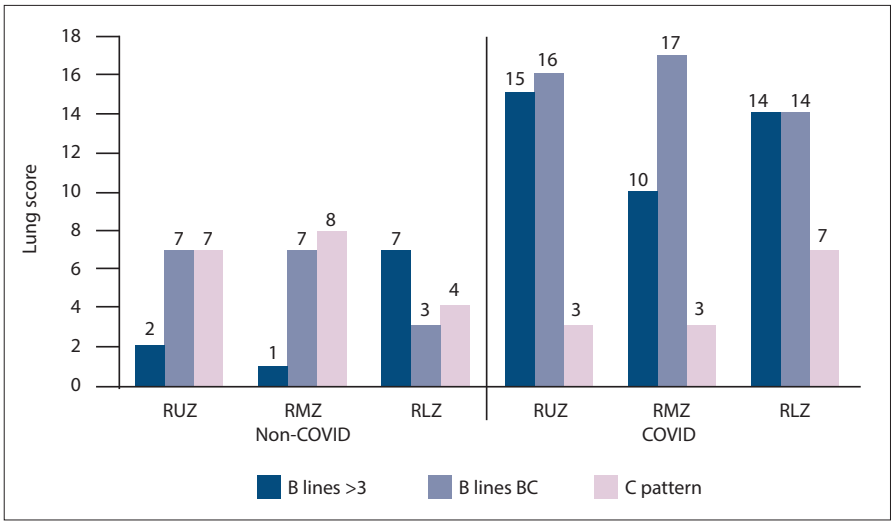

Fig. 1. Right lung ultrasound findings. (R = right; U = upper; Z = zone; M = middle; L = lower; BC = ≥3 B lines, and very small consolidations.)

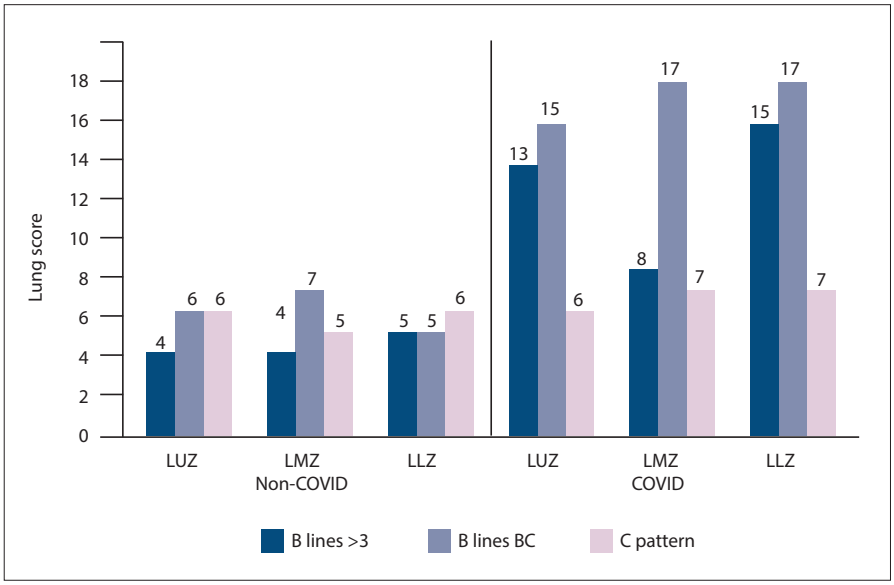

Fig. 2. Left lung ultrasound findings. (L = left; U = upper; Z = zone; M = middle; L = lower; BC = ≥3 B lines, and very small consolidations.)

other studies described a higher LUS score as being associated with a lower SpO_2 or SpO_2/FiO_2 ratio.[2,40,44] When the P/F ratio is used, or a measurement including the P/F ratio, generally the higher the LUS score, the lower the P/F ratio,[8,19,41] with one study showing no correlation with P/F and LUS score.[8] This study did, however, describe an association between the BLUE protocol and the P/F ratio.[8] Studies have also described a higher LUS score as being associated with severe/critical illness (criteria including hypoxaemia of some degree, but also other factors, including shock, or need for organ support or intensive care).[37,38,42] Our study demonstrated an inverse relationship between the P/F ratio and the B-line pattern in the LMZ for the COVID-19 group, suggesting that once the middle zone has developed alveolar-interstitial syndrome in COVID-19 pneumonia, the patient is likely to be hypoxaemic with diffuse disease involvement. If specific LUS findings associated with hypoxaemia in COVID-19 pneumonia are to be considered, these would include B lines[31,40] and subpleural consolidations,[4] but there are few data exploring the changes in different lung areas associated with severity of hypoxaemia in COVID-19 pneumonia.

We found a relationship between LUS and inflammation. More specifically, regional changes (RUZ and LMZ) and ultrasound scores were directly associated with CRP levels, indicating greater inflammation. Pare *et al.*[24] found a non-significant increased CRP level in COVID-19 patients compared with non-COVID, but this finding was not related to the LUS score or to a specific LUS finding. In COVID-19 patients, a higher LUS score has been associated with increased CRP[2,21,46] and interleukin 6 levels.[43] Specific LUS findings associated with higher CRP in patients with COVID-19 pneumonia include consolidation as opposed to B lines,[16] which could suggest a more severe form of disease, or a later presentation with complications.

The mortality rate for COVID-19 pneumonia in the present study was high (27%) compared with non-COVID CAP (12%), and the SMR indicates that the actual mortality was higher than predicted for COVID-19 pneumonia but not for non-COVID CAP, despite the two groups being similar in terms of oxygenation, and the COVID-19 group having a clinically significantly lower SAPS II.

We included clinically meaningful parameters (LUS score, oxygenation (P/F ratio), severity of illness (SAPS II), lactate, ventilation ($PaCO_2$), and COVID-19 status) to build a logistic regression, and found a higher SAPS II and a LUS score in keeping with B lines rather than consolidation to be predictive of poor outcome.

This study suggests that B lines in the RUZ are associated with a higher mortality rate than the presence of consolidation in the RUZ. We attribute this finding to disease progression and expansion of the pathology over time, with the presence of B lines in the RUZ possibly representing more advanced COVID-19 disease. Some pre-vaccine studies showed that expansive lung involvement was associated with a worse prognosis,[38,47] with more demonstrating that a higher baseline LUS score is associated with higher mortality.[2,38,39,43,48] Literature describing LUS patterns is similar to our findings, where a coalescent B pattern was associated with a poorer prognosis,[17] and in a study that did not compare COVID-19 with non-COVID pneumonia, the presence of consolidation in COVID-19 pneumonia was associated with mortality.[16]

Study limitations

This was a single-centre prospective, observational study with a relatively small

sample size. Despite being unable to control for biases, we did have a control group to compare against, which is lacking in many observational studies on this topic. While LUS only examines the peripheral pulmonary parenchyma, and as such no conclusions regarding the central parenchyma can be made, no comparisons were made with other imaging modalities. LUS is operator dependent. We did mitigate against this by having a single clinician perform all the imaging. Furthermore, a study-blinded radiologist with a special interest in LUS also interpreted the images, with any differences being resolved by consensus. LUS was performed in hypoxaemic patients, either under investigation for or positive for COVID-19, which could be a source of bias for the interpretation of pathology findings, as it could decrease the specificity of the LUS in COVID-19 in a non-pandemic scenario.

Conclusions

Admission LUS scores were unable to discriminate between COVID-19 and non-COVID pneumonia, and did not correlate with the P/F ratio, clinical severity or mortality. Survival is reduced in COVID-19 pneumonia compared with non-COVID CAP. LUS patterns could discriminate between COVID-19 and non-COVID, in that patients with RUZ consolidation are more likely to have non-COVID than COVID-19 pneumonia. Finding a B pattern as opposed to consolidation was associated with mortality.

Data availability. The datasets generated and analysed during the present study are available from the corresponding author (SAvB) on reasonable request. Any restrictions or additional information regarding data access can be discussed with the corresponding author.

Declaration. The research for this study was done in partial fulfilment of the requirements for SAvB's PhD degree at the University of the Witwatersrand.

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Author contributions. SAvB: conception, design of the work, data collection and sample collection, interpretation of data, drafted the article, substantively revised it and approved the submitted version, and agrees both to be personally accountable for the author's own contributions and to ensure that questions related to the accuracy or integrity of any part of the work, even ones in which the author was not personally involved, are appropriately investigated, resolved, and the resolution documented in the literature. CM: conception, design of the work, substantively revised the article and approved the submitted version, and agrees both to be personally accountable for the author's own contributions and to ensure that questions related to the accuracy or integrity of any part of the work, even ones in which the author was not personally involved, are appropriately investigated, resolved, and the resolution documented in the literature. BFJ: conception, substantively revised the article and approved the submitted version, and agrees both to be personally accountable for the author's own contributions and to ensure that questions related to the accuracy or integrity of any part of the work, even ones in which the author was not personally involved, are appropriately investigated, resolved, and the resolution documented in the literature. SO: conception, design of the work, analysis and interpretation of data, substantively revised the article and approved the submitted version, and agrees both to be personally accountable for the author's own contributions and to ensure that questions related to the accuracy or integrity of any part of the work, even ones in which the author was not personally involved, are appropriately investigated, resolved, and the resolution documented in the literature. TN: interpretation of data, substantively revised the article and approved the submitted version, and agrees both to be personally accountable for the author's own contributions and to ensure that questions related to the accuracy or integrity of any part of the work, even ones in which the author was not personally involved, are appropriately investigated, resolved, and the resolution documented in the literature.

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