Original Article

Point-of-care lung ultrasound in the assessment of suspected COVID-19: a retrospective service evaluation with a severity score

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Abstract

Introduction: *Point-of-care lung ultrasound (POCUS) has been advocated as a tool to assess the severity of COVID19 and thereby aid risk stratification.*

Methods: *We conducted a retrospective service evaluation between the 3rd March and the 5th May 2020 to describe and characterise the use of POCUS within an acute care pathway designed specifically for the assessment of suspected or confirmed COVID-19. A novel POCUS severity scale was formulated by assessing pleural and interstitial abnormalities within six anatomical zones (three for each lung). An aggregated score was calculated for each patient and evaluated as a marker of disease severity using standard metrics of discriminatory performance.*

Results: *POCUS was performed in the assessment of 100 patients presenting with suspected COVID-19. POCUS was consistent with COVID-19 infection in 92% (n = 92) of the patients assessed. Severity, as assessed by POCUS, showed good discriminatory performance to predict all-cause inpatient mortality, death or critical care admission, and escalated oxygen requirements (AUC .80, .80, 82). The risk of all-cause mortality in patients with scores in lowest quartile was 2.5% (95%CI 0.12- 12.95) compared with 42.9% (95CI 15.8 – 75.0%) in the highest quartile. POCUS assessed severity correlated with length of stay and duration of supplemental oxygen therapy.*

Conclusion: *A simple aggregated score formed by the summating the degree of pleural and interstitial change within six anatomical lung zones showed good discriminatory performance in predicting a range of adverse outcomes in patients with suspected COVID-19._

Keywords

COVID-19, Point-of-care lung ultrasound, POCUS

Introduction

Coronavirus disease 2019 (COVID-19) is an infection caused by a novel coronavirus, SARS-CoV-2.[1] COVID-19 is primarily a disease of the respiratory system and is heterogenous in terms of disease severity and outcomes.[2,3] Many patients with COVID-19 develop a mild or uncomplicated illness and can be managed safely in the community. When the severity of illness necessitates hospitalisation, approximately 15% of patients require critical care support and estimates of the case fatality rate range from 20% to 30%.[4,5,6] Understanding the risk profile of individual patients and anticipating the most likely trajectory of illness is key to optimising the COVID19 acute care pathway. The use of point of care ultrasound (POCUS) of the lung has the potential to provide valuable information to aid risk stratification leading to better informed clinical decisions making.

The chest radiograph (CXR) is considered the current standard of care in the assessment of undifferentiated breathlessness and/or respiratory failure in the acute setting. Lung ultrasound demonstrates superior diagnostic performance relative to CXR in the detection of a wide range of acute respiratory pathologies.[7,8,9] The use of POCUS in acute care is increasingly common and has been endorsed by professional societies including the Society for Acute Medicine and Intensive Care Society who have developed a protocolised assessments and accredited training programs as a means of ensuring a standardised approach and providing quality assurance.[10,11]

The practical advantages of POCUS have led some to recommend its use as a first line imaging modality in the diagnostic evaluation of suspected COVID-19.[12] Sonographic patterns associated with COVID-19 have been described within small case series[13,14,15] and a narrative review.[16] The typical abnormalities include pleural irregularity and sub-pleural consolidations, with focal, multifocal or confluent B lines indicating varying degrees of interstitial involvement. Pleural effusions are thought to be uncommon.

POCUS has several possible applications within acute models of care adapted to the challenge of

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COVID-19, particularly as a tool to refine risk stratification and determine the most appropriate location of care.[17] POCUS has been utilised within the initial triage process to refine predictions on the likelihood of COVID in order to aid patient cohorting. These practices are currently predicated on the experience of individual practitioners without the benefit of robust empirical evidence. Statistical measures of the performance of POCUS relative to other diagnostic tests have not been established. It is therefore unclear how to incorporate POCUS into existing acute care pathways or how to weigh the information obtained alongside other relevant clinical factors.

We undertook an evaluation of the use of POCUS within a care pathway designed for the assessment and management of confirmed or suspected COVID-19 in the acute medical unit (AMU) at City Hospital Birmingham. The acute medicine department at City Hospital has established expertise in the delivery of POCUS during routine acute care and is known regionally as a centre for training and mentorship. As an area of high prevalence during the early phase of the UK outbreak POCUS was used routinely by the acute medical team and the results recorded in a standardised manner. We retrospectively evaluated the use of POCUS by exploring the relationship between examination findings and the subsequent course and outcome of the hospital admission. This experience was used to evaluate a severity score linking the extent and severity of ultrasound findings to the risk of adverse events.

Methodology

City Hospital Birmingham is a district general hospital with 304 inpatient beds located within Sandwell and West Birmingham NHS Foundation Trust. During the evaluation period, the assessment and management of suspected or confirmed COVID-19 patients was undertaken via a specific care pathway. Patients were initially assessed by the emergency department (ED) team and patients deemed to meet the threshold for inpatient admission were referred to internal medicine for ongoing care. All POCUS examinations of patients referred with suspected COVID between the 3rd of March 2020 and the 5th of May 2020 were recorded using a standardised report. The evaluation was undertaken during a period of high community prevalence of SARS-CoV-2 infection during which the rates of hospitalisation and deaths attributed to COVID-19 peaked.[18]

Cases in which an alternative diagnosis was strongly suspected by POCUS examination (e.g. pleural effusion) were excluded from analysis using previously described criteria.[19] The number and characteristics of excluded patients are shown in Figure 1.

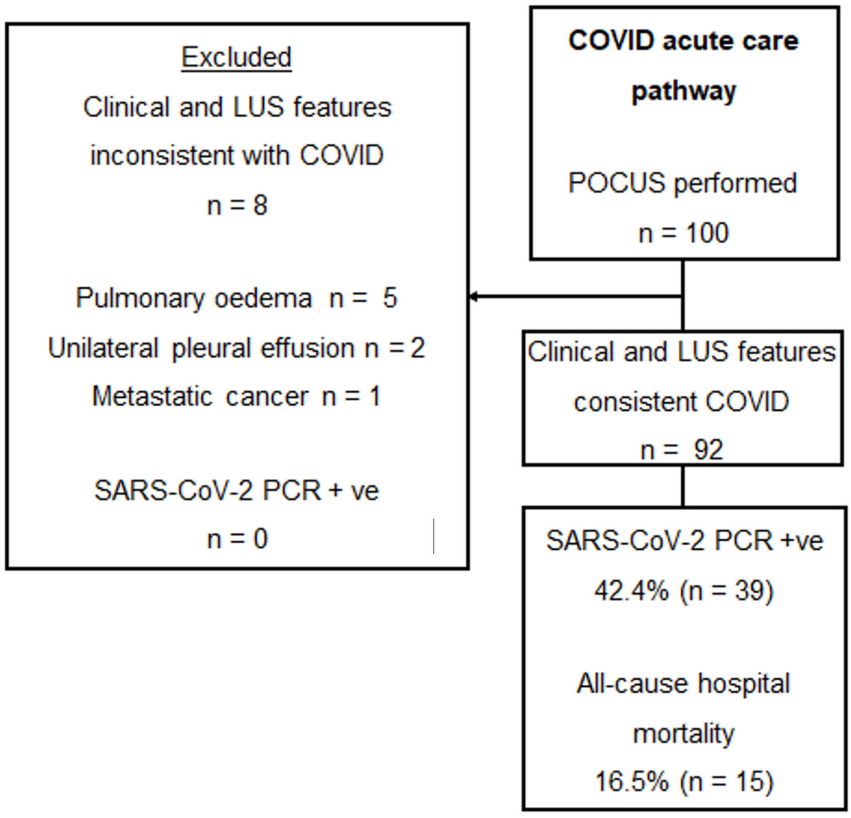


Figure 1. Flow diagram of included patients

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POCUS examinations were undertaken by medically qualified doctors specialising in acute internal medicine. Not all contributing clinicians were held formal accredited in focused bedside ultrasound but bespoke training was provided to ensure competency in acquiring and interpreting images. Given the relative ease of image acquisition and the limited number of associated lung patterns this was felt to be a reasonable and pragmatic approach. All clinicians attended a one-day training course focusing on POCUS in COVID-19. All images provided by clinicians without formal accreditation were reviewed by a British Thoracic Society level 2 ultrasound practitioner prior to inclusion of findings in the evaluation.

The decision to perform POCUS and actions following were made at the discretion of the individual clinician. The acquired images were interpreted and recorded by the performing clinician. POCUS was performed at the bedside using a LOGIQ© E9 machine or a portable Butterfly© IQ device. A structured examination was performed in accordance with the BLUE-protocol, a standardised assessment designed specifically for the bedside assessment of respiratory failure.[20] Focused echocardiography was not routinely performed. The presence of ultra-sonographic artefacts known to be associated with COVID-19 were recorded 6 anatomical zones (3 zones per lung). These included, pleural abnormalities (absent, pleural irregularity and sub-pleural consolidations), the presence and frequency of B-lines (absent, ≤ 2, >2 or coalesced), lung consolidation, and effusions.

Pleural and interstitial abnormalities were graded independently and represented on an ordinal scale from 0 to 3. The pleural and interstitial score from each of the 6 zones was aggregated resulting in a POCUS severity score ranging from 0-36 as shown in Figure 2A. In cases where the findings within a zone had not been recorded the case-wise modal attribute from other areas of the lung was imputed. The score was calculated retrospectively

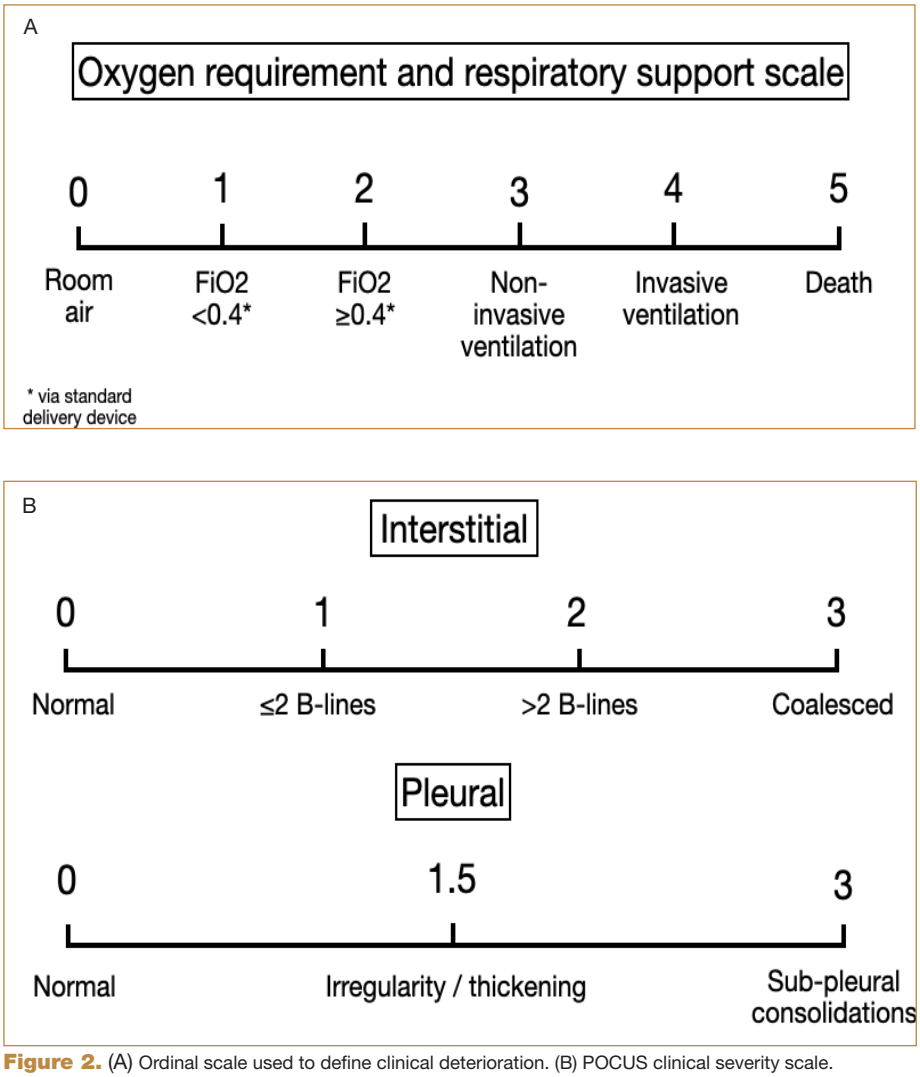


Figure 2. (A) Ordinal scale used to define clinical deterioration. (B) POCUS clinical severity scale.

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for the purposes of evaluation and not utilised within contemporaneous decision making.

POCUS was assessed using all-cause mortality to hospital discharge, critical care admission, requirement for escalation in respiratory support, duration of oxygen therapy and length of hospital admission as outcome measures. Escalation in oxygen requirement was defined using an ordinal scale shown in Figure 2B. An increase in one-point on the scale was classified as deterioration. Patient demographic and clinical details were obtained from the electronic health record. Frailty was assessed using the electronic Frailty Index (eFI) calculated using the hospital electronic record and frailty was defined as eFI of ≥ 0.12.[21]

Analysis was performed using the R statistical software. Normally distributed data is described using mean and standard deviation. Non-normally distributed data is described using median value and interquartile range. The discriminatory performance and calibration of the derived score was assessed using receiver operating characteristic curves and reported by calculating the area under the curve (AUC). Standard statistics of diagnostic performance were obtained from a 2 by 2 contingency table using the optimal threshold defined by maximisation of the Youden index. Calibration of the severity score was assessed by demonstrating estimates of mortality, a composite outcome of clinical deterioration, median duration of hospital stay (days) and median of oxygen therapy (days) within risk score quartiles. Sensitivity analysis to ascertain the impact of different methods of imputation of missing data was undertaken. The results of modal imputation are presented as the primary analysis.

This service evaluation to improve accuracy of detection of high risk patients with COVID19 was approved by the clinical effectiveness team. Formal ethical review was not required. This study is supported by the National Institute for Health Research (NIHR) Applied Research Collaboration (ARC) West Midlands and by the NIHR Community Healthcare MedTech and In Vitro Diagnostic Coop-erative (MIC) hosted by Oxford Health NHS Foundation Trust. The views expressed are those of the authors and not necessarily those of the NIHR or the Department of Health and Social Care.

Results

POCUS was performed in the assessment of 100 individual patients during the evaluation period.

The clinical features and ultrasound examination were deemed to be consistent with COVID-19 in 92 patients. A flow diagram of included patients is shown in Figure 1. Of the excluded patients, five had clinical and ultra-sonographic features of pulmonary oedema. All were managed with intravenous diuretics. Large unilateral pleural effusions were identified in two patients, without accompanying evidence of pleural or interstitial abnormalities suggestive of COVID-19. One patient presented with complications of metastatic oesophageal cancer without respiratory symptoms. POCUS was undertaken to assess for occult COVID-19 to aid cohorting of care. No POCUS abnormalities were detected and the likelihood of COVID-19 was deemed to be low. Nasopharyngeal swabs for SARS-CoV-2 PCR were negative in all 8 excluded cases. Description of the pleural and interstitial ultrasound findings were recorded for all 6 anatomical locations in 88·0% (n = 81) of cases. In 6.5% (n = 6) of cases data was missing from a single anatomical zone and in 5.4% (n = 5) cases data was missing from two separate anatomical zones.

The median interval between admission and ultrasound examination was 1 day (range 0 - 6 days). POCUS was performed by a Consultant physician in 44·5% (n = 41) of cases and by a middle grade physician in all other cases. Quality of image acquisition was rated as good in 55·4% (n = 51), average in 41·3% (n = 38), and poor in 3·3%(n = 3). The mean age of the cohort was 60·3 years (SD 17·7) and 71.7% (n = 66) were male. SARS-CoV2 nasopharangeal swab results were positive in 42·4% of cases (n = 39). Details regarding ethnicity were recorded in 78.2% (n = 72) of cases. The majority of patients included were Black, Asian or from Ethnic Minority groups.

The demographic, clinical and radiological characteristics of the cohort stratified by severity score are demonstrated in Table 1. The median duration of symptoms prior to presentation was 7 days (IQR 3 - 10).

The median NEWS2 was 3 (IQR 0-7). At the time POCUS was undertaken, 50·0% (n = 46) of patients had peripheral oxygen saturations of greater than ≥94% on room air. In those receiving oxygen therapy, the fraction of inspired oxygen (FiO2) delivered was ≤ 0.4 in 35·9% (n = 33) and FiO2 > 0.4 in 14·2% (n = 13). The observed all-cause mortality to hospital discharge was16·3% (n = 15, 95%CI 13·9-19·1). Advanced respiratory support was required in 9·8% of cases (n = 9, 95%CI 5·3.-17·6), 2 patients required continuous positive airway pressure (CPAP) and 7 patients required intubation and ventilation. The median length of stay was 5 days (IQR 2 - 8) and the median duration of oxygen therapy was 2 days (IQR 0-5).

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Table 1. Patient and clinical characteristics stratified by severity score

	All patients n = 92	Severity score <7.5 n = 38	Severity score ≥7.5-<15 n = 26	Severity score ≥15<22.5 n = 21	Severity score ≥22.5 n = 7
Mean Age	60·3 (SD 17·7)	60·5 (SD 20·7)	60·8 (SD 15·4)	63·0 SD(17·9)	60·9 (SD10·7)
Gender Male (%)	71·7 % (n = 66)	63·2% (n = 24)	76·9 % (n = 20)	76·2 % (n = 16)	85·7 % (n = 6)
Ethnicity: Asian	25·0% (n=23)	21·1% (n =8)	30·8% (n =8)	28·5% (n =6)	14·3% (n =1)
Ethnicity: Black	19·6% (n =18)	7·9% (n =3)	26·9% (n =7)	23·8% (n =5)	42·8% (n =3)
Ethnicity: White	29·3% (n= 27)	36·8% (n =14)	26·9% (n =7)	19·0% (n =4)	28·5% (n =2)
Ethnicity: Other	4·3% (n = 4)	5·2% (n =2)	3·8% (n = 1)	4·7% (n =1)	0% (n = 0)
Ethnicity:Not stated/ unknown	21·7% (n = 20)	28·9% (n =11)	11·5% (n =3)	9·5% (n =2)	14·3% (n =1)
Charlson comorbidity index (Median/IQR)	4 (2-7)	5 (3-7)	3 (0-6)	5 (2-8)	5 (4-6)
Chronic respiratory disease	31·5% (n = 29)	28·9% (n =11)	46·2 (n =12)	19·0% (n =4)	28·6% (n = 2)
Type 2 diabetes	35·9% (n = 33)	28·9% (n =11)	46·2 (n =12)	33·3% (n =7)	42·9% (n =3)
Frailty (eFrailty index ≥0.12)	34·8% (n = 32)	39·5% (n= 15)	34·6% (n = 9)	28·6% (n = 6)	28·6% (n = 2)
SARS-CoV-2 PCR +ve	42·4% (n = 39)	28·9% (n = 11)	57.7% (n = 15)	42·9% (n = 9)	57·1% (n = 4)
Duration of illness (days) Median (IQR)	7 (3 -10)	8 (6-9)	9 (4 -14)	7 (3-13)	8 (6-9)
NEWS2 Median (IQR)	3 (0 - 7)	2 (1- 4)	3 (1 - 5)	3 (2 - 5)	5 (3 - 8)
Lymohopaenia (lymphocyte count <1)	46·2% (n = 42)	44·7% (n = 17)	32·0% (n = 8)	52·4% (n = 11)	85·7% (n = 6)
CRP Median (IQR)	79 (13 -162)	22 (4-88)	80 (26-136)	153 (84- 211)	114 (98 211)
CXR:Probable COVID	n = 41	23·7% n = 9	48·0% n =12	71·4% n =15	71·4% n =5
CXR:Indeterminate	n = 18	16·8% n = 6	28.0% n =7	19·0% n =4	19·0% n =1
CXR: Alternate diagnosis	n = 5	10·5% n = 4	0% n = 0	4·8% n = 1	0% n = 0
CXR: Normal	n = 25	47·4% n = 18	24·0% n =6	4.8% n = 1	0% n = 0
Not performed	n = 2	2.6% n = 1	0% n = 0	0% n = 0	4.8% n = 1

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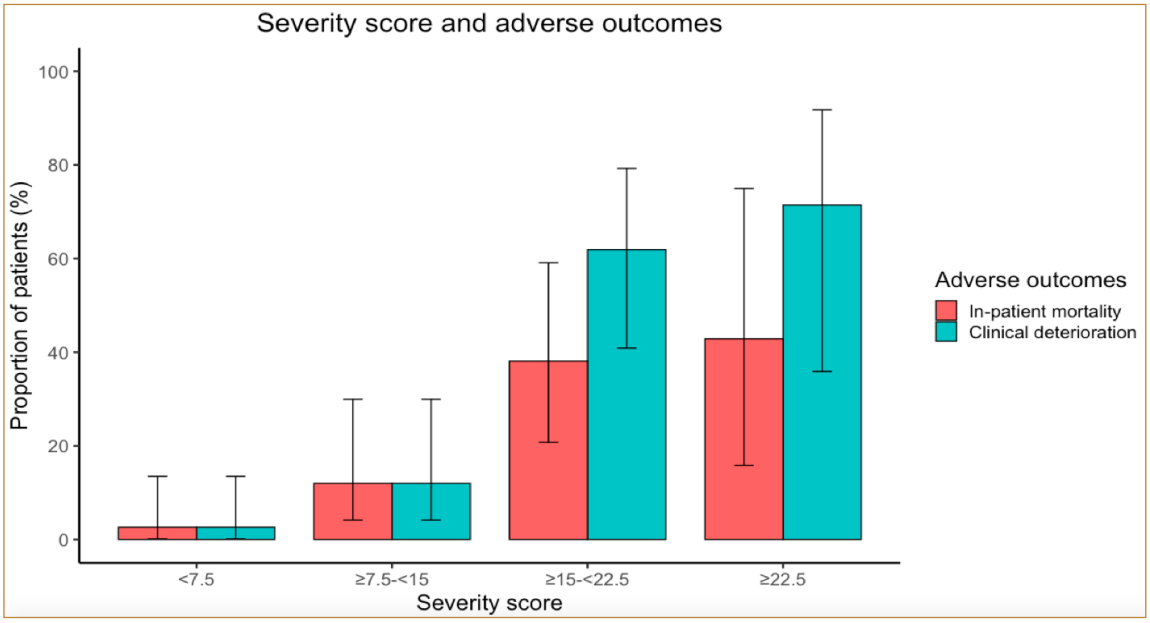


Figure 3. Severity score and adverse outcomes

The observed severity scores were non-normally distributed with significant skew towards lower values. The median score of the entire patient cohort was 11·0 (IQR 3·5 - 16·0). The median score in patients not requiring oxygen therapy was 4·5 (IQR 1·0 - 12.4), in patients receiving oxygen at an Fi02 < 0·4, 14·0 (IQR 6·4 - 17·3), and 17·0 (IQR 12·5-17·5) in patients receiving oxygen at an FiO2 of ≥ 0·4.

The discriminatory performance of the severity score was assessed using ROC curves. The model AUC in relation to inpatient all-cause hospital mortality was .80 (Optimal threshold >15. sensitivity 73·3%, specificity 77·9%). The performance of the score to predict the composite outcome of death or intensive care admission was 0.81 (optimal threshold >15 sensitivity 75·0%, specificity 79·0%) and to predict the composite outcome of increased oxygen requirement or death was 0.82 (optimal threshold 15, sensitivity 75·0%, specificity 85·3%).

The relationship between elevated severity score was assessed against a range of clinically relevant outcomes. Estimates of inpatient mortality increased incrementally with increasing scores as shown in Figure 3. One patient with a severity score less than 7.5 died 18 days after POCUS examination. In this case the initial swab result and subsequent clinical course were consistent with nosocomial infection. The estimated in-patient mortality in patients with scores in the highest quartile (> 22·5) was 42·9% (95%CI 15·8 - 75·0). Elevated scores were associated with increased median duration of hospital stay and mean duration of oxygen therapy as shown in Figure 4. The effect was more pronounced in relation to duration of oxygen therapy. Frailty as assessed by the eFI appeared to influence length of stay and duration of oxygen therapy (Figure 4). Patients with features of frailty tended to have longer lengths of stay at lower risk scores but duration of oxygen therapy increased incrementally with the severity of ultrasound findings.

The robustness of results to different methods of imputation was assessed. Imputing the minimum and maximum possible scores for all missing values produced models with AUC 0.83 to predict all-cause hospital mortality in both instances. Minimum and maximal imputation yielded models AUCs of .84 and .85 to predict clinical deterioration

Discussion

We evaluated the use of POCUS within a patient population with suspected COVID-19 referred for inpatient assessment by the ED. We used a simple pragmatic scale to grade the severity of ultrasound findings by categorising pleural and parenchymal abnormalities in six anatomical locations and aggregating the values to generate a summary score. The resulting severity score demonstrated good predictive performance against a range of adverse outcomes. Estimates of all-cause mortality and the risk of clinically relevant deterioration in oxygen requirements increased incrementally with elevated severity scores suggesting appropriate calibration to risk. The severity of ultrasound findings correlated with both length of and duration of oxygen therapy. In the patient group classified as frail by the eFI, the median duration of oxygen therapy mirrored the severity score more closely than duration of stay. This suggests factors other than the severity of lung

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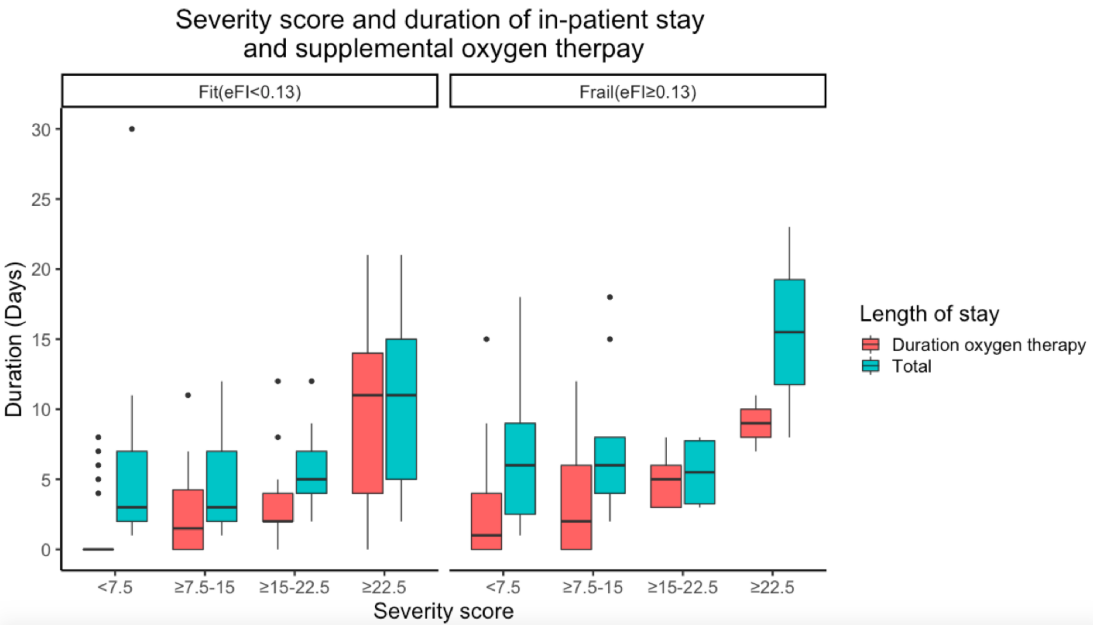


Figure 4. Severity score, length of stay and duration of oxygen therapy stratified by presence of frailty

injury, such as frailty, are key determinants of length of stay in this patient group. It appears a significant proportion of patients require an extended period of hospital care after the need for oxygen therapy has passed which may impair the predictive performance of POCUS assessed against length of stay in isolation.

Higher severity scores were associated with other clinical features known to confer elevated risk of mortality in COVID-19. The proportion of patients with lymphopaenia and the mean serum CRP was higher in patients within high risk severity scores. The median NEWS2 increased in line with increasing severity score. Patients from Black, Asian and Minority Ethnic groups appeared to be over-represented in the higher risk severity score quartiles. Disparity in outcomes in relation to ethnicity is well recognised.[22]

Several methods of performing POCUS of the lung have been described, the main differentiating variable is the number of anatomical zones within the lung that should be assessed. We made the pragmatic decision to record abnormalities within six anatomical zones. Others have advocated more extensive scanning in acknowledgement of the frequency of patchy lung involvement.[23] The decision to perform more limited scanning was based on the assumption that it would yield similar information while minimising close contact time limiting the risk of infection. The inclusion of more granular information on ultrasonographic severity might be expected to outperform the method described by providing a more detailed representation of the relationship between the extent of abnormalities and outcome. In this sense the use of limited scanning may underrepresent the true predictive capability of POCUS. It is also possible that the addition of further information may impair the predictive performance of the test. The methodology employed within our study was not designed to define the optimal approach. The evaluation was undertaken in a patient group with suspected COVID-19 deemed to meet the threshold for inpatient admission by the referring clinician. The risk profile of patients in this group is different from other clinical settings and the decision making required contextually specific. The observed hospital mortality and rates of critical care admission were lower in comparison with other observational studies of hospitalised patients.[4] The overall prevalence of SARS-CoV-2 PCR positivity in our patient group was 42.9%. This, in part, may reflect the variable diagnostic performance of the PCR test, but is also reflective of the difficulty in streaming care based on the clinical probability of COVID-19. The case definition used to govern entry into the COVID care pathway priorities sensitivity, therefore, a proportion of patients initially suspected to have COVID-19 will ultimately be determined to have symptoms attributable to an alternate diagnosis. The evaluation was undertaken during a period of high community prevalence which increases the pre-test probability of COVID-19, but it remains likely that many streamed to the COVID-19 care pathway had other infectious or non-infectious pathology. Our cohort is therefore likely to contain patients without COVID-19, the size of this group cannot be defined accurately. The emergence of dexamethasone as a treatment for COVID-19 places

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greater importance on accurate diagnosis. However, as the use of dexamethasone is currently limited to those with severe disease requiring oxygen, the ability of the severity score to predict the need for oxygen therapy maintains the clinical relevance of the score despite this change in treatment strategy.

While restricting the analysis to patients with PCR confirmed COVID-19 would allow a cleaner interpretation of the score and its specific prognostic relationship with COVID-19, this approach would not provide a realistic representation of POCUS within acute care delivery. There is often diagnostic uncertainty at the point of admission and the PCR result is not typically available within a time-frame which allows influence on front door decision making. POCUS appears to provide prognostic information which could help clinicians tailor responses, such as the intensity of monitoring to the degree of risk. This of particular importance when the clinical decision involves de-escalation of care to the community where the ability to respond to occult deterioration is significantly diminished. Although the lower rates of death and decreased oxygen requirement in those with lower severity scores suggests POCUS could provide valuable information to guide decision making, the appreciable rate of adverse events in those with scores <15 is important to recognise. This reinforces the notion that POCUS is one component of a multi-faceted assessment and is not a replacement for clinical judgement.

Limitations

We employed service evaluation methodology to assess the use of point of care ultrasound in the context of COVID-19 within a single-centre with considerable experience and expertise in the delivery of the technique in acute care. The service evaluation methodology employed places strict limits on the generalisability of inference. The evaluation should therefore be viewed as hypothesis generating in relation to the potential applications of POCUS in acute care.

Our sample size compares favourably with other currently published investigations on the role of POCUS in COVID-19, however, it represents a relatively small proportion of the total number of patients assessed via the COVID-19 care pathway in our hospital. 13.1% of included cases had missing values related to one or more anatomical lung zones. The statistical relationships described were robust to a range of imputation methods for missing values providing greater confidence in our findings.

POCUS was performed on an ad-hoc basis rather than as a complete consecutive case series. Whilst this provides insight into real-world application there are likely to be systematic differences between the population scanned and not scanned which cannot be established or described from available data. The distribution of scores was skewed towards the lower end of the risk spectrum, as a result, estimates of the adverse event rate at higher risk scores are associated relatively wide confidence intervals. The characterisation of ultrasonographic abnormalities required subjective assessment of the acquired images by the performing clinician. Prior knowledge of additional prognostic factors available at the time of scanning may have influenced assessment leading to systematic over- or under-representation of findings.

An unanswered question in the evaluation of POCUS is how the results should be integrated with other factors and ultimately whether the information obtained justifies the effort. Ideally the information provided by POCUS should not be redundant when placed in the context of other clinical findings. It is not possible to ascertain the value of POCUS in relation to these other factors empirically from our evaluation. Patients with higher severity scores also tended to have additional adverse prognostic factors, including higher NEWS2, higher CRP and higher prevalence of lymphopaenia. Strategies which combine POCUS with clinical and laboratory data may improve the predictive power of current models. This derivation and validation of risk scores incorporating all these elements should be the focus of future research.

Conclusion

A simple aggregated score formed by the summating the degree of pleural and interstitial change within six anatomical lung zones showed good discriminatory performance in predicting a range of adverse outcomes in patients with suspected COVID-19.

Conflict of interests

The Authors declare that there is no conflict of interest.

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