Combatting COVID-19: Is Ultrasound an Important Piece in the Diagnostic Puzzle?

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ABSTRACT

Lung ultrasound (LUS) has an established role in the diagnosis of acute respiratory failure and has been used during the COVID-19 outbreak in China and Italy as a decision support tool. Chest x-ray (CXR) is a poor diagnostic test for COVID-19, while CT is best used to assess for complications arising from COVID-19 and to rule in or rule out alternative diagnoses. LUS shows characteristic changes in COVID-19, similar to other patterns of viral pneumonitis. It is quick to perform and repeat, may be done at the bedside, and enhances the clinical evaluation of the patient.

The current COVID-19 pandemic is causing significant diagnostic and risk stratification difficulties in Emergency Departments worldwide. The authors believe that LUS can be of use in mitigating uncertainty in undifferentiated patients with respiratory symptoms. The risk of anchoring bias during a pandemic and the need to consider alternative pathologies is emphasised throughout this review. The aim is to provide guidance regarding indications for LUS in patients with acute respiratory illness, to describe the typical sonographic abnormalities seen in patients with COVID-19, and to provide recommendations around the logistics of performing LUS on patients with COVID-19 and managing the infection control risk of the procedure.

We propose that LUS should be available to emergency care providers during the current COVID-19 pandemic as a primary imaging modality within a strict framework that governs education, quality assurance, and proctored scanning protocols.

INTRODUCTION

Coronavirus disease 2019 (COVID-19) is caused by the novel coronavirus SARS-CoV-2, and was first described in Wuhan, China in late 2019. The disease was declared a global pandemic on March 11, 2020. Diagnosis of cases and risk stratification of those with symptoms has been a challenge for healthcare systems worldwide owing to the limited number of available diagnostic tests and/or the poor sensitivity of those tests.

Formal diagnosis of COVID-19 can be obtained via polymerase chain reaction (PCR) testing of respiratory secretion samples.[1] However, the sensitivity of PCR for naso-oropharyngeal swab samples is reported to be as low as 70% at initial presentation, and this figure is reduced if proper specimen collection technique is not adhered to.[2] Chest X-rays (CXR) may suggest COVID-19, but patients can have a range of changes on plain imaging that may result in diagnostic uncertainty . Computed tomography (CT) imaging of the thorax has been suggested as a potential diagnostic modality owing to its increased sensitivity relative to PCR and CXR, and the fact that CT findings can be identified in a more timely manner than PCR testing can be performed.[3] However CT is a suboptimal diagnostic modality as it has many financial costs, and there is a significant radiation exposure for the patient especially in vulnerable groups such as children and pregnant women.[4,5] Due to the time required to perform a CT scan, to interpret the resulting images, and to deep clean the CT scanner, it would not be possible to use CT as a diagnostic test for all patients presenting with symptoms of COVID-19.

Clinicians are therefore frequently left in a degree of uncertainty as to the actual diagnosis in the initial hours and days of treating patients with suspected COVID-19. Lung ultrasound (LUS) has been proposed as an alternative diagnostic aid. LUS is known to be more sensitive for detection of lung pathology compared to plain radiography in the diagnosis of interstitial patterns including pulmonary oedema, consolidation, and effusions.[6] Preliminary studies show that there are characteristic sonographic pleuropathic findings of COVID-19.[7,8] These findings are similar to those reported in other viral pneumonias.[9]

Although LUS is unlikely to replace PCR as a confirmatory test, it has the potential to be faster, repeatable and to contribute additional clinical information. In clinically stable patients with COVID-19 symptoms LUS may help risk stratify and alter management plans, for example discharging with a pulse oximeter and remote monitoring if there is a significant degree of pathology present on LUS. In addition there is a risk of anchoring bias toward a diagnosis of COVID-19 during the current pandemic, and LUS combined with focussed cardiac ultrasound may be useful to identify alternative pathologies resulting in respiratory failure. The management of critically unwell patients with suspected COVID-19 may be altered where features suggestive of pulmonary embolism or superimposed bacterial pneumonia are identified using point-of-care ultrasound.

KEY MESSAGES

- LUS is an established tool in the diagnostic workup of acute respiratory failure.
- LUS shows characteristic but non-specific changes in COVID-19 infection, similar to other patterns of viral pneumonitis. B-line patterns, small localised peripheral consolidations, pleural line irregularities and larger basal consolidations develop as the disease progresses.[7,8,10]
- CXR is a poor diagnostic test for COVID-19 and is significantly out-performed by LUS.[11] Findings in LUS closely mirror the longitudinal changes found in CT. CT is best reserved for more severe and complex cases.[12]
- LUS may be used as a decision support and risk stratification tool in COVID-19. It is quick to perform, may be done at the bedside and adds much to the global clinical evaluation of patients.

CHEST IMAGING FOR COVID-19

Chest imaging is important for diagnostic and prognostic reasons in patients with suspected COVID-19. The ideal test would be quick, reliable, reproducible, deliverable at the bedside, and have a high sensitivity and specificity. Currently the main modalities used are CXR, CT, and in some centres LUS.

Almost all patients will receive a chest radiograph, but plain chest radiography has a poor sensitivity as compared with CT and LUS. Plain radiographs may miss up to 40% of confirmed COVID-19 cases.[7,13] The reason for the reported low sensitivity of plain radiography is that virus particles are small and lodge in terminal alveoli close to the pleural interface. These areas are well visualised on CT and LUS, but are more difficult to see on plain imaging.[8]

Thoracic CT imaging has been proposed as a primary screening tool for COVID-19 detection since it performs better than PCR.[2,3,14] Lung abnormalities on CT may precede physical symptoms of COVID-19 thus allowing early detection, isolation, and management of infected patients.[7] However CT is a finite resource and may not be available in some healthcare settings. Decontamination protocols are not well-defined and are time consuming. The practicalities of moving critically ill patients to CT are difficult and thus a risk-benefit approach has been taken by some clinicians, reserving this technology for patients with complications of COVID-19 infection or when other causes of illness such as pulmonary embolism are suspected.[12]

While CT scanning can be practically difficult, LUS offers the opportunity to image larger numbers of patients with suspected COVID-19, with studies indicating a strong correlation between the sensitivity of LUS and thoracic CT for COVID-19 detection.[11,15] LUS has unique sonographic findings [7,8,16] in COVID-19 which should be detectable for those trained and skilled in performing and interpreting LUS. Training novice users in B-line recognition may take up to 4 hours.[17] A comprehensive education programme that includes image review and clinical integration will take more time but this will yield increased long-term benefits.

LUS is a bedside test that is quick to perform and repeat, is low cost and avoids radiation exposure compared with thoracic CT.[7,18] A disadvantage of LUS when compared with thoracic CT is the reduced specificity of LUS findings for COVID-19 diagnosis. This necessitates using LUS in conjunction with other confirmatory tests such as RT-PCR. LUS has been recommended by Italian emergency physicians as an excellent imaging modality for evaluation of suspected COVID-19 infection.[16,19–21] The cited papers discuss the use of portable and inexpensive handheld US devices, ease of use by the treating clinician at the bedside, and reduced movement of patients to the radiology department while minimising exposure of other healthcare workers (HCW) to patients with suspected COVID-19. Physicians working on the frontline in Liberia during the Ebola virus disease epidemic described similar advantages of point-of-care ultrasonography over traditional imaging.[22]

LUS ABNORMALITIES IN COVID-19

Sonoanatomy of the normal lung includes sliding of the pleural line, A-line artefacts, B-line artefacts and a smooth, sharp appearance of the pleural line (figure 1) [23]. A-lines are a type of long-path reverberation artefact found in the lung. These appear as repetitive, horizontal bright lines deep to the reflective pleural line and air within the lungs. B lines are short-path non-fatiguing artefacts formed by reverberation of ultrasound waves within a fluid-filled collection (alveolus) that is surrounded by air. These appear as thin, vertical bright lines starting at the pleural line and extending to the lung far field. B-lines are found in many conditions including pulmonary oedema, viral pneumonitis, ARDS, pulmonary fibrosis, pulmonary contusion and lymphangitis.

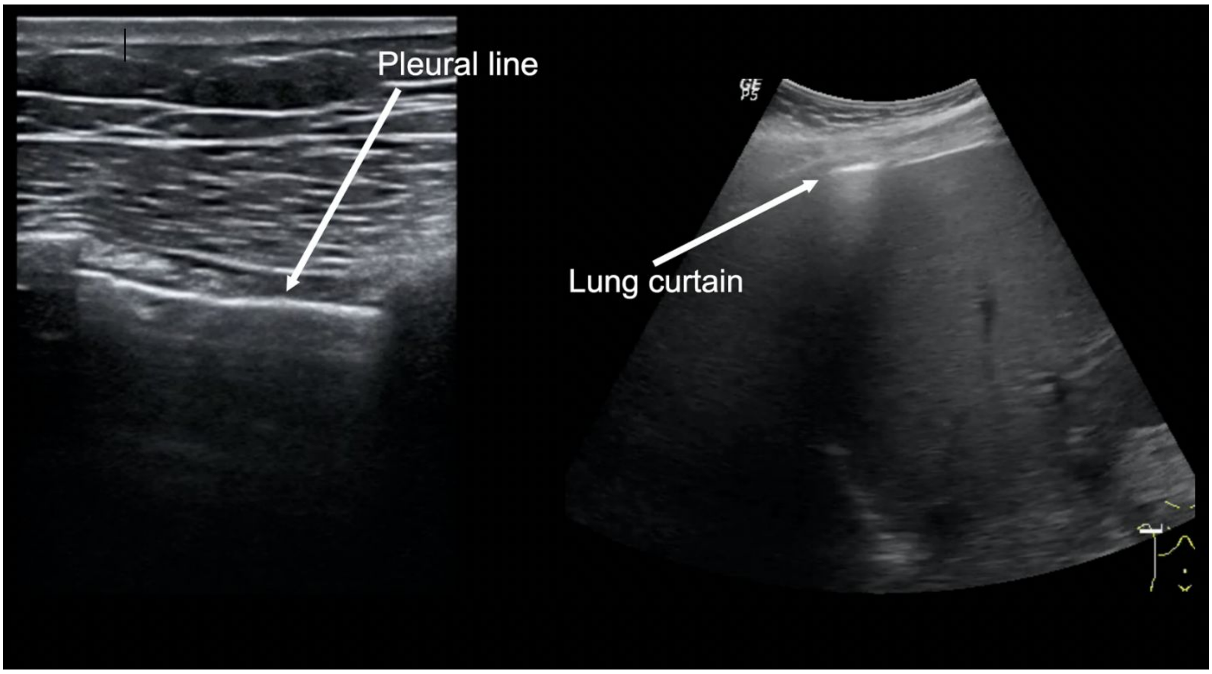

Figure 1: The left-hand image shows normal anterior lung. Pleural line is thin, sharp, smooth, and lies inferior to and bordered on each side by dark rib shadows. A-lines appear as horizontal bright lines inferior to the pleural line and equidistant from the transducer.

The right-hand image shows normal posterior lung. Lung curtain moves with respiration across at the liver/ spleen-diaphragm interface.

Abnormal LUS findings in COVID-19 pneumonitis:[7,8,10]

- B-lines appear in focal, multifocal, and confluent patterns. They can initially be seen at the postero-lateral lung bases. As disease severity increases, B-lines increase in number and occur closer together (confluent pattern) at sites distant from the lung bases (figure 2).
- Small peripheral consolidations (less than 1.5cm) appear as dark areas immediately inferior to the pleural line (figure 3).
- A pleuropathy develops as the pleural line appears coarse, irregular and fragmented (figure 3). Similar changes may also be seen in chronic lung conditions such as idiopathic pulmonary fibrosis. Skip lesions may appear as normal pleura lies alongside thickened pleura (patchy areas). As increasing amounts of inflammatory fluid fills the alveoli, areas of consolidated lung appear (hepatization) especially at the lung bases (figure 4). Residual air may be trapped in the bronchi - this is known as a sonographic air bronchogram.
- Large volume pleural effusions are uncommon; if these are seen, other lung pathology should be considered.

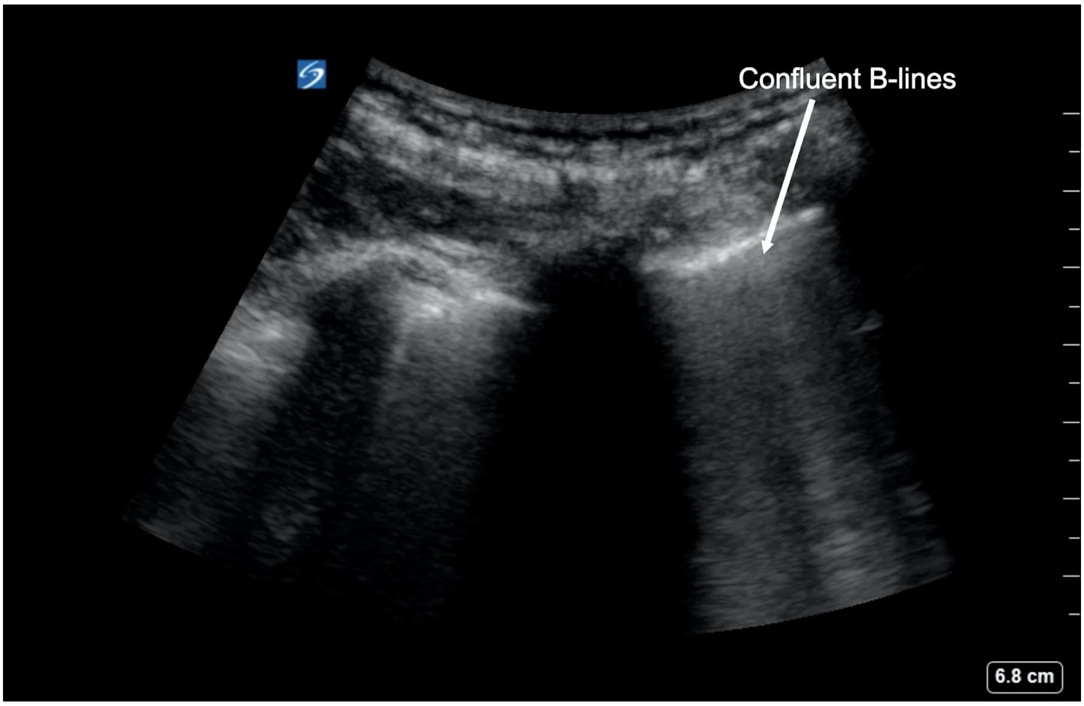

Figure 2: confluent B lines, as can be seen in COVID-19 pneumonitis.

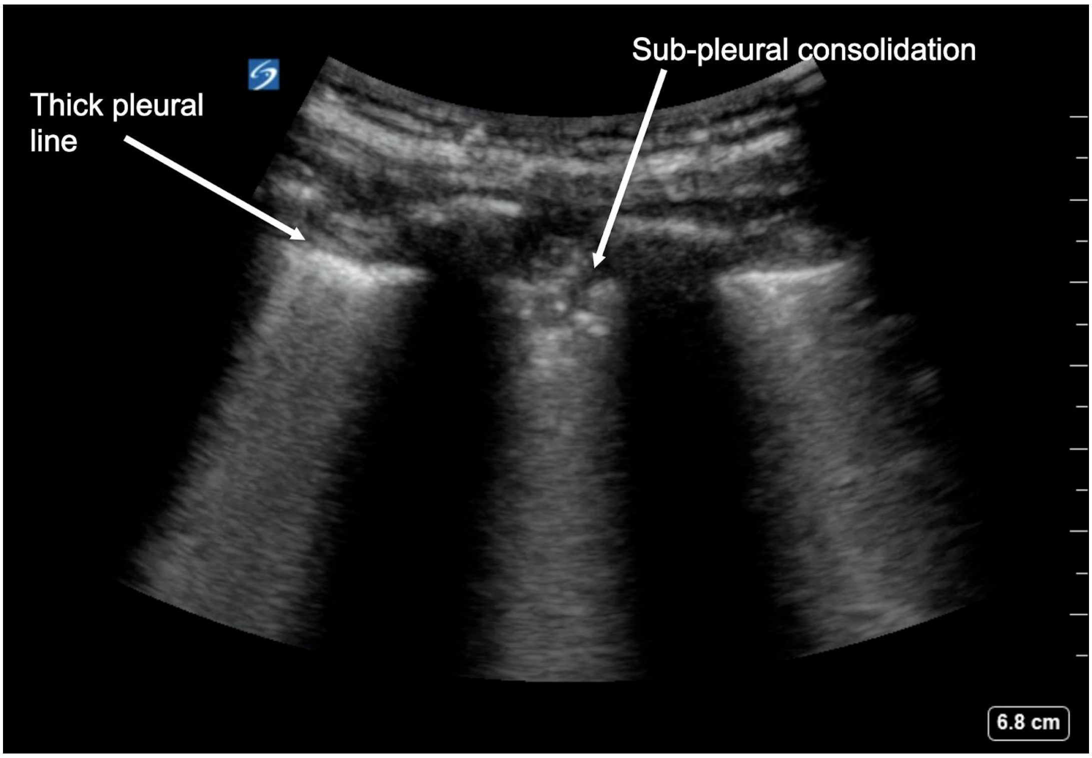

Figure 3: small, peripheral localised consolidation and irregular appearance of the pleural line.

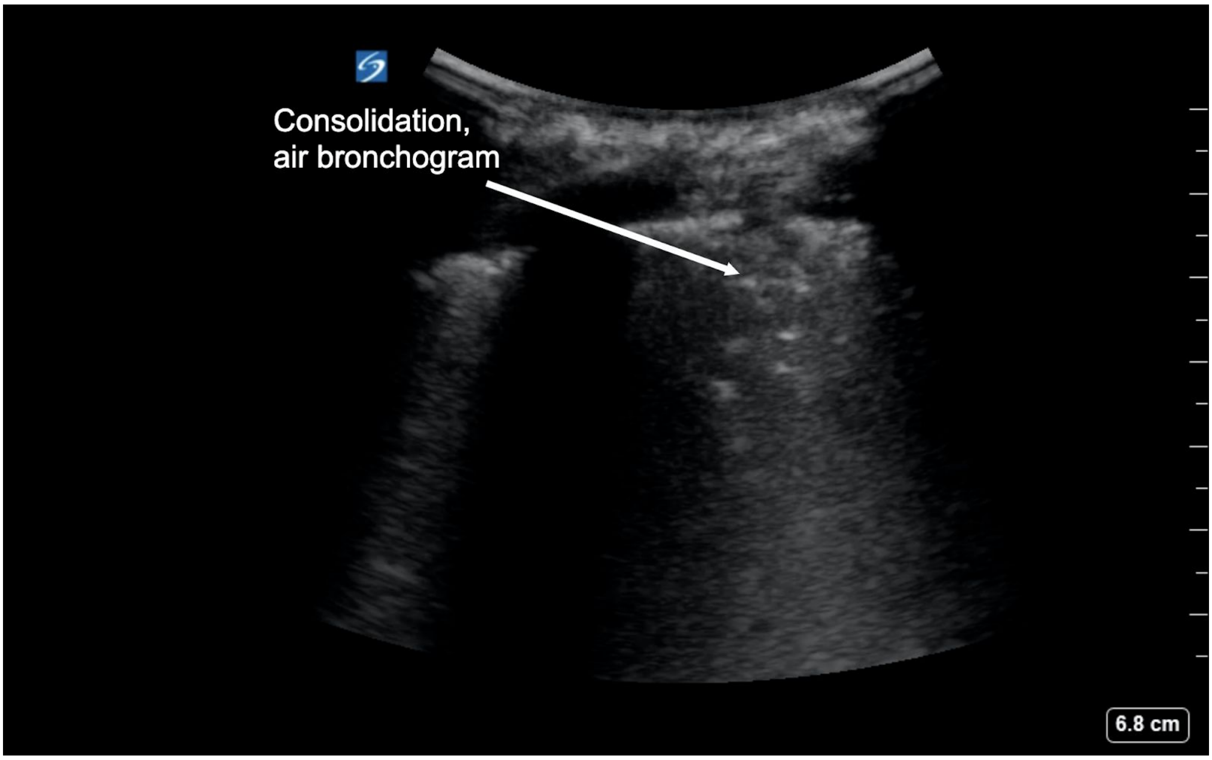

Figure 4: larger consolidation stippled with air bronchogram, typical of more advanced lung changes seen in COVID-19.

COVID-19 Risk Stratification

LUS may be useful to categorise the degree of lung involvement in COVID-19 infection:[8]

- Significant lung involvement is unlikely if an A-line pattern is noted.
- In early or mild COVID-19 B-lines predominate, and small consolidations and pleural thickening may occur.
- As disease progresses B-lines increase in number and occur closer together as well at sites distant to the lung base. The disease tends to involve multiple lobes on both sides. Severe COVID-19 will manifest as lung consolidation posteriorly and at the lung bases (figure 4).
- Bacterial superinfection is suggested by basal consolidations with dynamic air bronchograms, reduced pleural sliding and the presence of pleural effusions. This ultrasound finding may guide the decision to initiate antibiotics.[24]

The role of LUS during the COVID-19 pandemic is to identify characteristic sonographic abnormalities as well as to support clinical decision-making. The diagnostic accuracy of screening LUS will be dependent on the prevalence of disease in the presenting population.

It may be useful in the following situations:

- Patients who are clinically well and fit for discharge are unlikely to benefit from LUS, as they will be managed based on clinical appearance. In these patients, a completely normal LUS likely excludes further imaging at that time and thus facilitates safe and early discharge. Abnormal LUS findings may identify a patient cohort that would benefit from closer observation such as a home pulse oximeter and remote monitoring.
- Critically-ill patients should be resuscitated without delay, and LUS is not useful for the primary diagnosis of COVID-19. Ultrasound is useful to exclude other causes of undifferentiated shock, for example pulmonary embolism, tamponade, or hypovolaemia, thus avoiding anchoring bias in the midst of a pandemic.
- Goal-directed focussed cardiac ultrasound may help identify left ventricular and right ventricular size and function in the case of COVID-19 heart-lung complications.[25,26]

- Ultrasound can also be used to assess volume status and guide fluid resuscitation.[27]
- Ultrasound may be used to assist with emergency central or peripheral venous access and with the diagnosis of venous thromboembolism.

LUS SCANNING TECHNIQUE

In general, principles and techniques of LUS are the same for patients with suspected COVID-19 as they were in the pre-COVID era. Some modifications necessary for patients with suspected COVID-19 will also be outlined.

Transducer selection & settings [28]

- Linear transducers are better for visualising superficial structures. This may be used to view pleural line thickening, small superficial effusions, skip lesions, and B-lines.
- Curvilinear transducers may be better for posterior pathology such as consolidation, hepatization, and bronchograms.
- Optimize the depth of field-of-view so that the pleural line is in the middle of the screen.
- Adjust the transducer focal zone to the level of the pleural line for increased spatial resolution.
- Turn off smoothing algorithms such as compounding and tissue harmonic imaging filters to allow visualisation of lung artefacts. Most lung presets will default to this mode.
- Record cine loop clips rather than still images to visualise subtle pleural changes that may not appear on a single frame.

Transducer hold

Hold the transducer close to the crystal matrix, between the tips of the index finger and the thumb of the insonating hand. Fingers of the insonating hand should be spread out to stabilise the transducer and hand position. Brace the insonating hand against the surface being scanned. These techniques will facilitate small adjustments of the transducer and will allow for greater probe stability and better-quality images to be shown on the screen.

Scanning protocol

Traditional lung scanning protocols suggest evaluation of several anterior, lateral and posterior lung zones.

Chinese authors have described COVID-19 scanning using a 12-zone protocol (figure 5).[8] Soldati et al have proposed a 9-zone protocol and associated scoring system to quantify pulmonary involvement.[28] It is possible to perform a focussed study (6 chest zones) in less than 2 minutes [29] and a rapid LUS protocol is one potential approach. The Intensive Care Society have endorsed this approach as part of the FUSIC lung accreditation module (figure 5).[30]

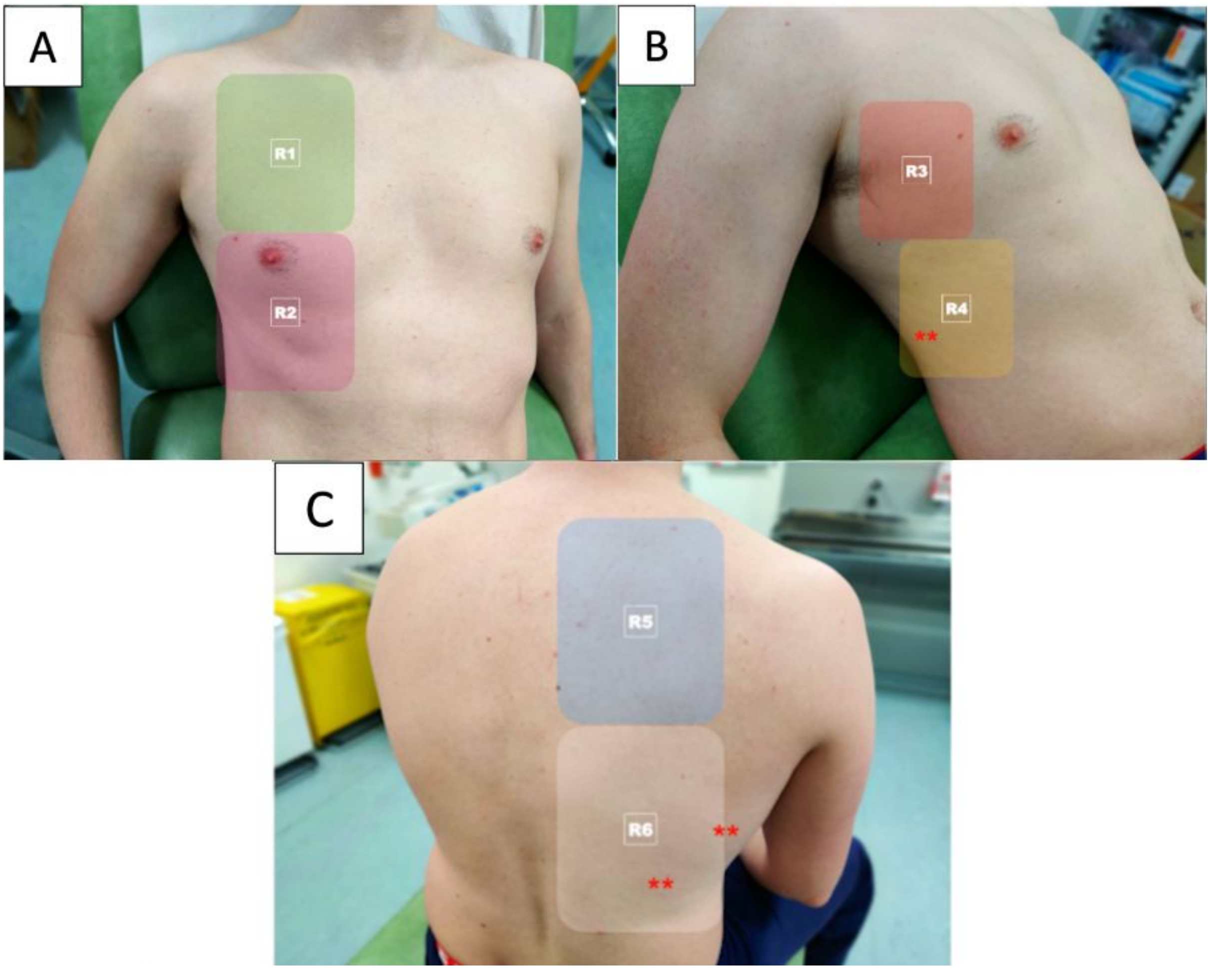

Figure 5: 12-zone technique for LUS in suspected COVID-19. A – right anterior zones, B – right lateral zones, C – right posterior zones. Early pathology tends to occur at the postero-basal lung zones, and these should be areas for particular scrutiny (marked with asterisks).

In comparison, the FUSIC protocol utilises three zones on each side of the chest – two anterior zones (R1 + R2) and one posterolateral zone (R4).[23]

Modifications to further minimise exposure risk

COVID-19 changes are often found in postero-basal zones.[8,28] It may be quicker and safer for the point-of-care US provider to:

- Scan with the patient facing away from the operator to minimize HCW exposure to droplets (figure 6). The US machine may also become less contaminated if placed behind the patient.

- Start by scanning the patient's back using the linear transducer in vertical orientation.
- Start medial to the scapula sliding inferior to the lower rib border and moving laterally towards the posterior axillary line.
- Evaluate each rib space first with the transducer in a vertical (crossing the ribs) orientation (figure 6) then evaluate each rib space again with the transducer in a horizontal orientation (between the ribs) especially if any abnormalities are seen.
- Finish by scanning lateral zones of the lung in the mid-axillary line. Using the curvilinear probe here may be helpful (figure 6).

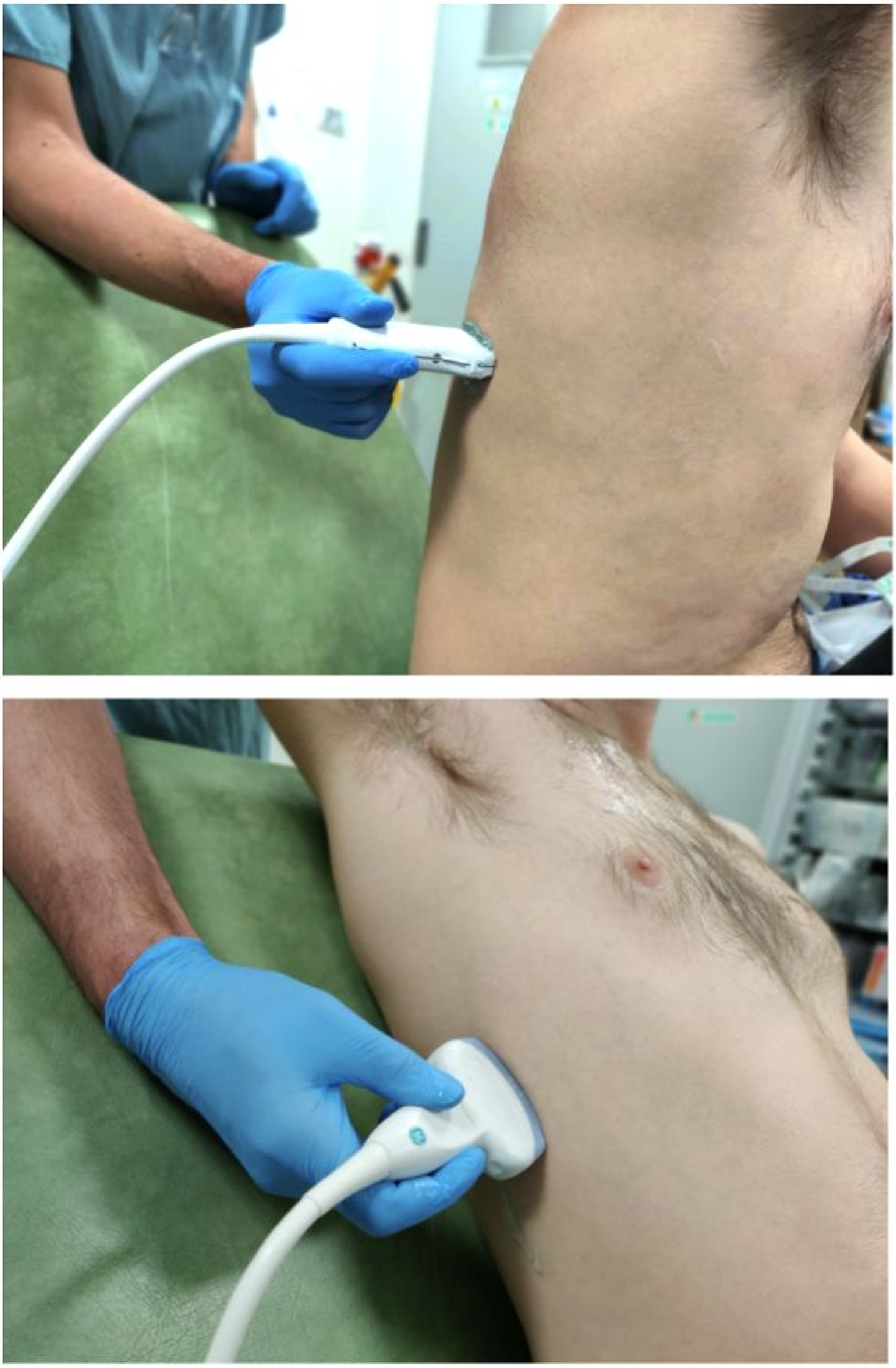

Figure 6: transverse orientation with linear transducer between ribs in the intercostal space (top). Sagittal/longitudinal orientation with curvilinear transducer across ribs in the intercostal space (bottom).

CLEANING & DISINFECTION PROTOCOLS

Strict adherence to decontamination strategies are vital to prevent patient-to-patient COVID-19 transmission as well as patient-to-HCW transmission. What follows are summary points drawn from a number of international best practice standards [31,32] and should be considered when using ultrasound with suspected COVID-19 patients:

- Place a dedicated ultrasound machine in the COVID-19 "hot zone" of the Emergency Department (ED).
- Wear standard PPE when performing LUS and wear gloves when moving the machine from cubicle to cubicle.
- Strip away ECG leads, gel bottles, extra buckets and straps from the machine.
- Use a barcode scanner to enter patient details to avoid further contact with the machine.
- Use the machine in battery mode - pre-charge at all times to avoid use of cables.
- Use a touchscreen device rather than a keyboard, cart-based system.
- Consider using a handheld device, e.g. Lumify or Butterfly systems, with the advantage that the whole device can be placed within a probe cover and images are uploaded to the cloud for remote reviewing.
- Consider use of a transparent, disposable drape to cover the screen, cradle, and cart of the ultrasound machine.
- Use chlorhexidine/alcohol or soap-based wipes to clean transducer heads, as well as the entire length of probe cables, screen and cart after scanning.[33]
- Wait for up to 3 minutes 'dry time' after using disinfectant wipes before using the machine again.
- Use a transducer sheath/probe cover for all high-risk patients.
- Use single-use gel packets rather than gel bottles.

Much of this material has been 'crowdsourced' or extrapolated from shared knowledge of global expert user groups. There are many practical and innovative approaches to US machine decontamination available on social media, collated under the hashtag

#POCUSforCOVID or on specialist point-of-care ultrasound websites.[34,35] Traditional literature sources may struggle to keep pace with this material in a pandemic situation.

DISCUSSION

We argue that the evidence presented demonstrates a potential role for lung and focussed cardiac ultrasound in the risk stratification and management of patients with suspected COVID-19. However, there are limitations to the evidence and our experience.

LUS in the ED offers a rapid, repeatable bedside test and provides a dynamic data point in the clinical assessment of patients with suspected COVID-19 infection. There are characteristic but non-specific peripheral sonographic signs that suggest viral pneumonitis and correlate well with thoracic CT findings. Recent studies have shown that the specificity of LUS ranges from 78.6% to 100% in ED patients.[11,15] In a high-prevalence situation such as a pandemic, the majority of positive tests will represent true positives and this is less important. However LUS is unable to distinguish early COVID-19 from other viral pneumonitis such as RSV, H1N1 [36] or H7N9.[37]

When interpreting LUS findings, the operator should bear in mind that:

- LUS should be performed after the medical history is taken, when a specific clinical question arises, and with a pre-test probability of COVID-19 diagnosis already in mind.
- Characteristic sonographic patterns on LUS may help categorise patients into groups with low probability, moderate probability, high probability and a further group with alternate pathology other than COVID-19.[10] Accurate interpretation may present a challenge to novice sonologists since there is a degree of subjectivity involved in these classifications.
- LUS findings are best interpreted in close correlation with the patient’s clinical presentation. It is not uncommon to encounter patients with few respiratory symptoms that have severe abnormalities on LUS. The converse is not usually true - few patients with severe respiratory failure will have a normal LUS.
- LUS findings seem to peak in severity 2 weeks after the onset of symptoms and regress gradually afterwards.[38]

In the coming months if the pendulum swings away from COVID-19 and towards alternate causes of respiratory failure, a re-think of the diagnostic approach of COVID-19 using LUS will be necessary.

In addition, LUS requires a degree of operator skill which may not be available in all departments, and at all times. Although LUS is a relatively easy skill to learn, it does need practice and supervision to develop core competencies. In the first instance, we see LUS in COVID-19 to be adopted by those already familiar with ultrasound techniques and with prior experience of using LUS for the detection of pathologies such as pneumothorax, cardiac failure, infection and effusion. However, we would be concerned if LUS were to be used without adequate training, supervision and governance. We suggest that local US champions should plan now to enable and upskill current users in COVID-19 pathological features using the resources linked in this article and available online.

CONCLUSION

LUS appears promising as a first-line and comprehensive diagnostic imaging modality in clinically suspected or diagnosed COVID-19, when implemented mindfully and in conjunction with other diagnostic modalities. LUS findings should be interpreted alongside a careful history, physical examination, and bearing in mind the pre-test probability for this disease. Point-of-care ultrasound may help to identify the need for further investigations or may guide the physician toward an alternative diagnosis.

Further research is needed to clarify the diagnostic and prognostic role of LUS in COVID-19. Investigators at the University of Pennsylvania are currently undertaking the CLUSCO study to examine the potential role of LUS in predicting outcomes of patients with COVID-19 [39]. Such studies are needed to provide an evidence base for incorporation of LUS into practice during the current pandemic.

Incorporating ultrasound into the evaluation of COVID-19 patients will depend upon available resources, expertise of personnel, and logistic configurations unique to each situation. If LUS is adopted it will require governance systems to oversee decontamination, training and clinical oversight.

Contributors

All authors have contributed to the design of the paper, the writing of the manuscript and have seen and approved the final manuscript; they all meet the definition of an author as stated by the International Committee of Medical Journal Editors.

Declaration of interests

Authors declare no competing interests. The authors have no conflicting financial interests.

Supplementary video material

Video 1 - R5 B-lines

Video 2 - L6 small pleural consolidation

Video 3 - Confluent B-lines*

Video 4 - R3 patchy B-line distribution

Video 5 - L2 coarse, irregular pleural line with small pleural consolidation

(*courtesy of Dr Justin Kirk Bayley, Consultant Anaesthetist and Intensivist, Royal Surrey County Hospital, Guildford, UK)

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