Lung ultrasound in a COVID pandemic – Choosing wisely

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Abstract

This is an opinion piece on the role of POCUS in COVID-19, with a focus on lung ultrasound. It is not an instructional essay. Crisis management in medicine has often been likened to crisis management in the aviation industry. The important difference between pilots and clinicians is that the clinician's life was not in imminent danger, should one fail. The clinician did not have the same emotional urgency as the pilot. The COVID-19 pandemic has changed this, and clinicians are now faced with the need to make urgent decisions whilst exposed to some personal risk. Whether to embrace POCUS and lung ultrasound during this pandemic is an important decision. Whilst there are clear advantages, poorly considered overzealous uptake is not without hazard, opportunity cost and potential risk to patient and clinician.

Keywords: COVID-19, lung ultrasound, novel coronavirus, pandemic.

Impact Statement

Lung ultrasound has generated great popular interest in reports from the European front of the COVID pandemic, but it is not the panacea.

This article presents a balanced view of the uses and risks of lung ultrasound, to enable informed choice at the individual coalface.

It concludes with advice on how to adjust scanning for this disease, and a pictorial essay depicting the challenges inherent in a non-specific modality.

At the end of this article, there is general advice on how to perform lung ultrasound for COVID-19. It is at the end of the article because it is probably the least important information, and widely available elsewhere.

Consider first the less glamorous questions of 'why, what, who, and when?' These questions must be answered by each provider, as the answers will differ depending on disease prevalence, user expertise and resourcing within each health service. These questions will help the provider customise lung ultrasound provision because tools are best adapted by users at each coalface.

Within each of these primary questions lies a tangle of values, emotions, purposes, interests and evidences all given extra urgency by the looming disease. The aim of this paper is to make them explicit, to clarify thinking.

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doi: 10.1002/ajum.12213

WHY should lung ultrasound be performed – and why not

Lung ultrasound (LUS) has been recommended by those at the disaster front[1-5] – as a method of triage, of tracking disease progress and informing management decisions. Lung ultrasound has value because it is performed at the bedside, by a clinician. LUS requires fewer people, and there is less equipment to clean and reduced patient movement compared with other imaging. LUS gives similar information – probably better than the relatively insensitive chest X-ray[6] and more convenient than CT. CT may be avoided in vulnerable groups – such as children,[7] pregnant women[8] and unstable ICU patients.[5] The Canadian Internal Medicine Ultrasound recommendations give a balanced and detailed view.[9]

Proponents claim LUS is easy, rapid, reliable, repeatable and low risk in expert hands. Although LUS cannot image below aerated lung, assessing the pleural surface is useful and often representative of deeper or diffuse pathology, particularly those that are peripherally distributed, such as COVID-19. LUS can effectively demonstrate other pleural-based pathology, including pneumothorax, effusion and consolidation.

Those arguing against lung scanning say that it does not add value if it does not replace other imaging (such as chest X-ray) or if management decisions are already being made on clinical signs, symptoms and other investigations. LUS requires patient contact so is an infection risk for the provider. LUS requires extra effort to don, doff and clean the machine.

The training requirement is not insignificant. To teach B-line recognition to novice clinicians requires a minimum of 4 h training and practice,[10,11] and at least A$981 per clinician trained when using external tutors.[11] It will take more time if the novice is to consistently recognise mimics, complications and other lung conditions reported in COVID-19. Acquisition of representative images is not sufficient – these non-specific findings must then be integrated into the individual clinical context.

Each health service must ask, is this the best deployment of this sonologist's time? The answer will change depending on the number of available ultrasound machines, sonographers, sonologists, radiographers, CT machines and alternative tests such as the rapid polymerase chain reaction (PCR) test or serum antibodies.

WHAT is lung ultrasound – and what is it not?

Ultrasound does not penetrate through an air interface. This means that lung ultrasound is the sonographic study of tissues down to and including the visceral pleural surface and the characteristic irregularities of the lung periphery that signal disease. The sonologist analyses the pleural space, the characteristics of lung movement and the reflective properties of the peripheral lung itself. The patterns of reflection create signatures that depend on the nature of lung parenchyma and disease, the density of lung tissue, alveoli and interstitial fluid, and the pulmonary air patterns. The distribution of abnormalities gives an indication of the disease process.

Prior to COVID-19, research has shown that using these characteristic irregularities within a specific context ultrasound is far superior to auscultation and better than chest X-ray for diagnosis of peripherally manifest conditions. LUS has demonstrated viral pneumonitis, pulmonary interstitial syndrome and consolidations that touch the pleura.[12-18]

Currently, most descriptions of COVID-19 disease distribution come from CT studies. COVID-19 appears to be a predominantly bilateral, subpleural condition.[1,19-22] The signs described on CT are generally accessible to LUS, and LUS has been shown to correlate with CT findings in small patient cohorts.[2,21,23] Ai *et al*. report that in symptomatic patients with initial negative PCR, 70% had positive CT scan.[20] LUS changes can precede symptoms and may also precede polymerase chain reaction (PCR) positivity. (Personal communication, Yale Tung Chen, 23rd March 2020).

It is important to note that imaging may also be negative in the early stages of the disease. Bernheim noted normal CT scans in 20/36 patients imaged within 2 days of symptoms onset,[21] whilst Wang reported 11/79 normal CT scans in patients imaged within 5 days of symptom onset.[19]

The characteristic CT irregularities reported in COVID-19 are most commonly posterobasal, and bilateral in 83–90% of hospitalised patients.[20-22] The disease seems to progress from asymmetric patches of B lines, to either widespread B-line pattern (interstitial syndrome), and/or areas of pleural line irregularity with or without subpleural consolidations.[19] If large consolidations develop, these may be due to atelectasis or secondary bacterial infection. Pleural effusion is said to be rare (1–7%)[1,19,20] although small localised subpleural effusions have been noted.[23] Resolution is associated with reaeration, regression of B lines, and gradual restitution of the horizontally aligned reverberation pattern associated with smooth pleura.[1,19,21,23]

Findings on LUS, although characteristic, are not specific. In a high prevalence situation such as a pandemic, this is less important as the majority of positive tests will be true positives. However, LUS cannot differentiate early COVID-19 from other viral pneumonitis. It will require close attention to separate cardiogenic pulmonary oedema from COVID-19 confluent B-line pattern. It will take expertise to differentiate atelectasis from bacterial superinfection. Excellent lectures and case studies are available on line.[24,25]

Lung ultrasound in this pandemic assesses the available pleural surface for changes characteristic of COVID-19. The nature and distribution of changes must be described. In addition, other potential causes of dyspnoea or deterioration should be evaluated including but not limited to pneumothorax or pleural effusion. Competent practitioners can extend the examination to include cardiac POCUS as per the ASE guidelines[26]. Assessment of the pericardium and ventricular function is a valuable addition.

WHO should perform LUS – And who not?

In stressful situations, it is recommended that team members are given tasks with which they are already familiar. It is hard to perform a new skill under stress, in full personal protective equipment (PPE). Hence, those who already practise ultrasound are the best candidates to learn LUS. Point-of-care ultrasound is not for everyone, and it requires good psychomotor skills and hand–eye coordination. Practitioners must be comfortable with hands performing different tasks simultaneously.

Learning ultrasound can be likened to learning a musical instrument. Once an expert, incorporating a new technique into a pre-existing repertoire is not difficult. But the first piece of any repertoire requires much effort and practise. True competence requires the assimilation of new knowledge and understanding with technical and motor skills. Learning an entirely new skill in a time of crisis is not wise.

Neither should LUS be performed by the emotionally motivated. The fearful may use LUS as a comfort measure and overmonitor. The evangelist may interpret every dyspnoea as COVID-19 and over-diagnose. Point-of-care ultrasound has long been recognised as 'user dependent'. Those who are emotionally invested in the modality may fail to see its weakness, and hence fail to adapt. As with research, it may be best in the hands of sceptics.

Table 1: Generic process for performance of point-of-care ultrasound during the COVID-19 pandemic

	General	Specific
1. Don PPE	As advised by health service	Second pair of gloves facilitates machine clean
2. Pre-load	Enter patient details, select probes and pre-sets	Children: linear or microconvex Adults: curvilinear or microconvex Obese: phased array
3. Minimise exposed surfaces	As advised by health service	Dedicated COVID machine if available Cover machine if covers available – note ventilation ports Remove electrical cable, extra probes and supplies. Put probes on patient side of machine.
4. Dispense consumables	No consumables to leave room	Consider individual 'grab bags' of disposable items Single-use gel Patient dry wipes Wet wipes to clean machine
5. Patient preparation	Minimalise face-to-face exposure	Patient should be masked. Ask them to sit or face away, remove own gown if able Warn them that the gel is cold
6. Scan	Minimalise time	Scan only to answer clinical questions.
7. Retreat	Minimalise contact	Have patient wipe gel if able Retreat to door or vestibule
8. First clean	Minimum of thorough low level decontamination	Clean machine and remove covers carefully either in patient room or vestibule Ensure gel and debris removed and all exposed surfaces cleaned with an approved detergent and disinfectant wipe Clean or remove outer gloves Adhere to local requirement re machine coverage and presence of aerosolising procedures.
9. Doff PPE	As advised by health service	If area is a dedicated COVID-positive area, complete doff might not be required
10. Second clean	Outside room	If machine is a dedicated COVID-positive machine, a second clean may not be required. If present during an aerosol-generating procedure, thorough reclean is highly recommended. Some services require high-level decontamination of probes

WHEN to perform LUS – and when not

LUS should occur after the history, when a distinct clinical question arises. At present, the highest level of evidence is expert opinion, fuelled by reports from critical regions, CT studies and small case series. Experts have proposed the following.[3,5,27]

1 In a non-critical patient at screening clinic, the question may be 'Do I think this is COVID-19?' The diagnostic accuracy of screening LUS will be dependent on the prevalence of disease in the presenting population. Since PCR test results currently may take several days, LUS has been used to advise the need for further investigations, isolation or monitoring.[3] This use of LUS must be weighed against the time required of the clinician and the availability of PPE.

2 At triage, the question may be 'Do I send to COVID-positive or COVID-negative area?' It is postulated that suboptimal hospital management of the unrecognised COVID-19 patient increases the risk to healthcare workers.[5] A LUS scan is quicker than PCR, and likely to be positive sooner, so an abnormal LUS should direct the patient into the COVID-precaution stream. Conversely, a patient with significant respiratory distress and near normal LUS scan is unlikely to have COVID-19.[3]

3 In a resuscitation area, the question may be 'Why has this patient deteriorated?' A combined lung and cardiac POCUS examination by competent practitioners as per the ASE guidelines[26] will assess for a diverse range of pulmonary and cardiac pathology either directly related to COVID-19, complications of COVID-19, or alternate pathology. It is important to recognise the limitations of these examinations and proceed with other investigations where clinically indicated.

4 Lung scanning can also be performed before, during and after procedures such as central lines or chest drains to exclude complications including pneumo- and haemothorax.

LUS should not be performed de novo. It is a Bayesian exercise that permits re-ordering of simultaneous probabilities. The probabilities should be explicitly stated before the scan.

LUS should not be used without counting the opportunity cost. If sonologists or machines are scarce, they may be better employed to triage the non-COVID complaints so that these vulnerable patients can be sent out of the danger zone.

HOW to perform LUS

It is important to have a defined protocol and communication plan. For LUS to provide value equalling chest X-ray, reports and images must be available for others to see and compare. Without image review capacity, LUS is just another subjective examination technique.

In a crisis, simplicity is vital, so consider diagrammatic reporting tools.[24] Although the nomenclature of lung signs has reached an uneasy consensus, the naming of anatomical regions has not, hence the value of a diagram and descriptive terms.

If LUS is promoted for COVID-19 patient management, practice a standardised hygiene routine superimposed onto the scanning protocol appropriate to the clinical question. Table 1 suggests a generic routine that could be applied to any scanning protocol. For specific scanning protocols, consider the following:

1 Screening scans in low acuity patients should start posteriorly and include as much of the pleura as accessible, as abnormalities may be sparse and localised. In an otherwise well and mobile patient, consider scanning from behind, out of range of cough trajectory.

   If the LUS is normal despite 3–5 days of symptoms, then COVID is very unlikely (but not ruled out.) If the LUS has more than one area of pleural line abnormality, and the absence of a more likely cause, COVID is postulated and management is decided based on severity of symptoms.

2 Triage scanning of patients with respiratory compromise may be limited by patient mobility. Posterior views are hard to obtain in the ventilated patient and may be limited to the posterior axillary line. Posterior consolidation will be missed from the posterior axillary line only if it is limited to the para-midline region. If the spine is visible at the base of the screen, there is lobar consolidation, atelectasis or pleural effusion.

   Look for signs of advancing disease such as global B lines, extensive pleural line abnormalities, small subpleural consolidations and large consolidation with air bronchograms. Bacterial superinfection is suggested by increased vascularity of consolidations and effusion.[3] A single area of consolidation or large pleural effusion directs attention to other causes of dyspnoea. Sonologists scanning in Europe say that prognostication based on lung changes is not reliable;[3,5] however, papers from CT studies in China report a waxing and waning pattern of abnormalities.[1,19,21]

3 LUS during acute deterioration can exclude significant pneumothorax by demonstrating lung sliding. A small anterior

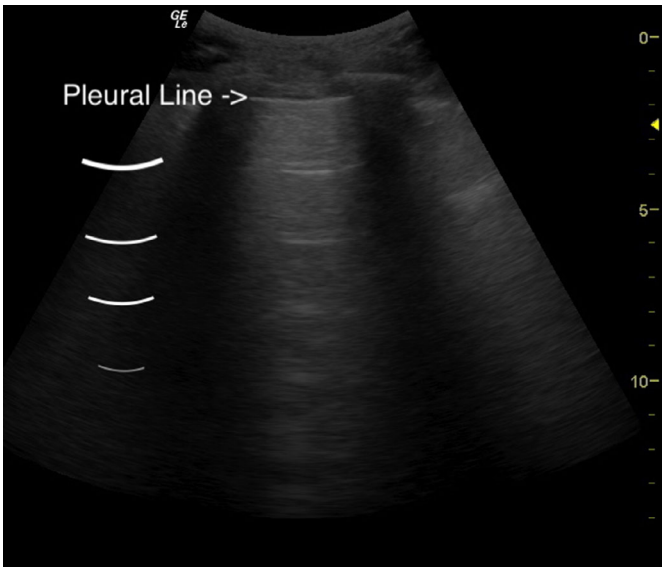

Figure 1: Typical view of healthy dry pleura, seen with a curvilinear probe and a high focus. There are multiple horizontal reflection artefacts equally spaced and fatiguing with depth. This pattern may also be seen in asthma, chronic airways disease, or pneumothorax, with decreasing degrees of movement at the pleural surface. [Colour figure can be viewed at wileyonlinelibrary.com]

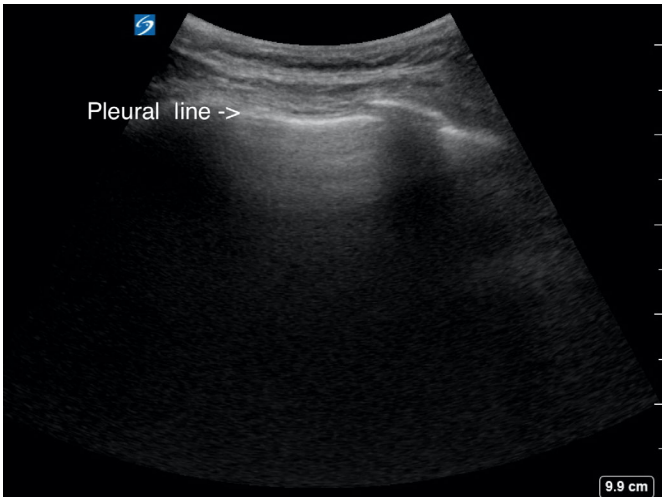

Figure 2: Another potentially healthy lung imaged with less gain and wider focal zone. Some settings attenuate the horizontal artefacts rapidly such that the base of the screen is uniformly dark. Certain machines give a softer image due to increased smoothing' settings. The differential diagnosis is the same as Figure 1. [Colour figure can be viewed at wileyonlinelibrary.com]

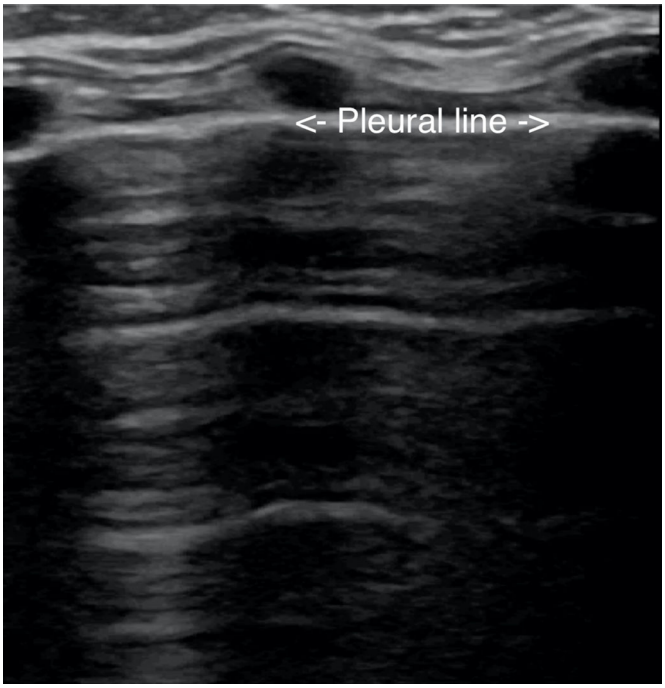

Figure 3: Pristine pleura imaged with a linear probe, showing multiple horizontal reflection artefacts. The pleural line is not broken by rib shadows in this instance as the scan is taken through the cartilaginous portion of the rib. Despite a very different image, the differential diagnosis is the same as Figures 1 and 2. [Colour figure can be viewed at wileyonlinelibrary.com]

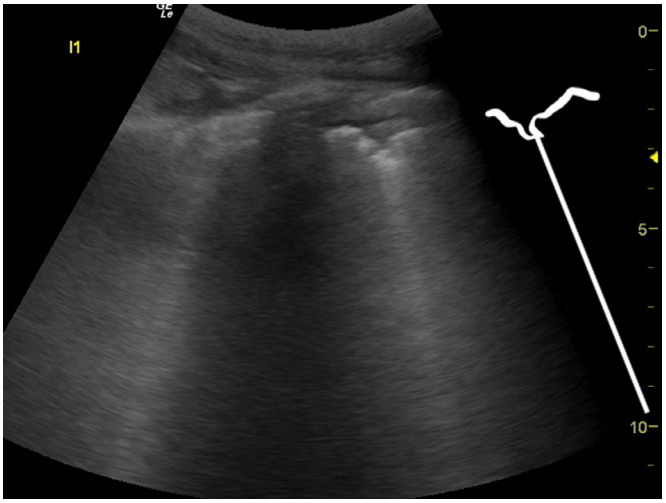

Figure 4: Centre of image shows rib and rib shadow. To the right, an area of irregular pleura is highlighted by the single vertical B-line artefact dropping almost to the base of the screen. This might be seen in any acute pneumonitis (including COVID), or fibrosing conditions. [Colour figure can be viewed at wileyonlinelibrary.com]

pneumothorax can be identified when LUS demonstrates new loss of lung sliding, loss of pleural line irregularities and B lines, and replacement by prominent A lines, or a lung

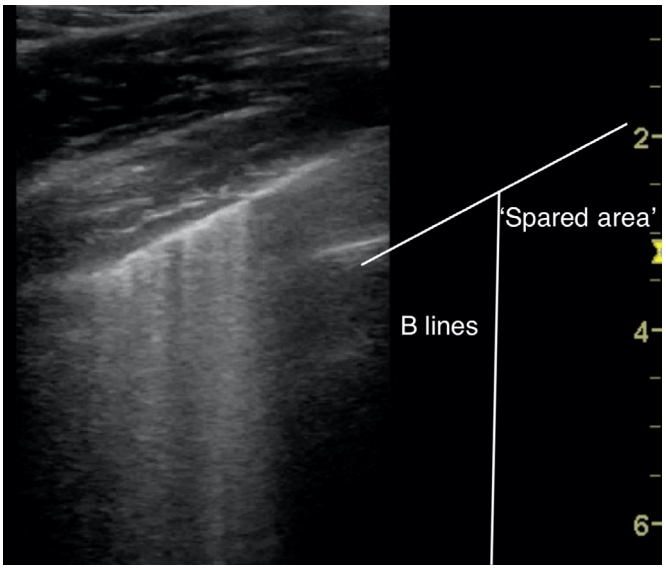

Figure 5: This linear probe view shows a straight pleura sharply divided into a curtain of hyperechoic B lines on the left and a 'spared area' to the right. This patchy distribution is seen both in viral pneumonias and ARDS-like conditions. [Colour figure can be viewed at wileyonlinelibrary.com]

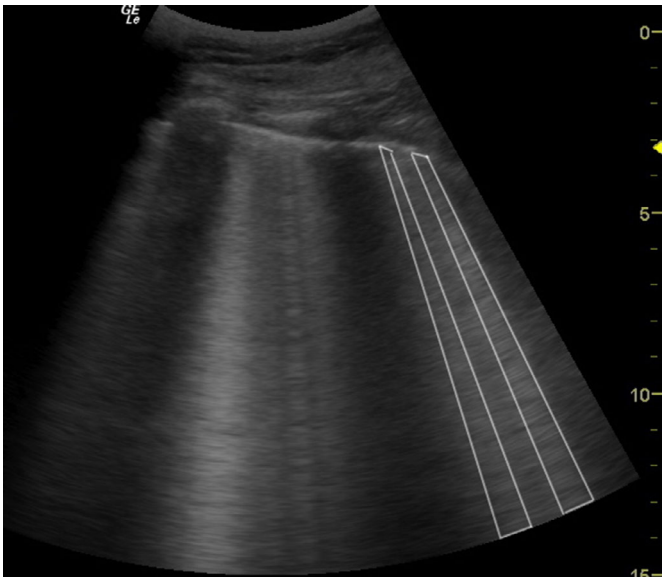

Figure 6: This curved probe with high focus shows a straight pleural line with multiple vertical B lines, two are outlined on the right. This is highly correlated with ground glass opacity' reported on CT scanning but is also seen in cardiogenic and non-cardiogenic pulmonary oedema, and fibrosing conditions with minimal pleural retraction. [Colour figure can be viewed at wileyonlinelibrary.com]

point. LUS can identify a small anterior pneumothorax with more accuracy than a supine chest X-ray.[16,17] Unilateral loss of sliding may also suggest endotracheal tube displacement – loss of sliding is a sensitive but non-specific sign

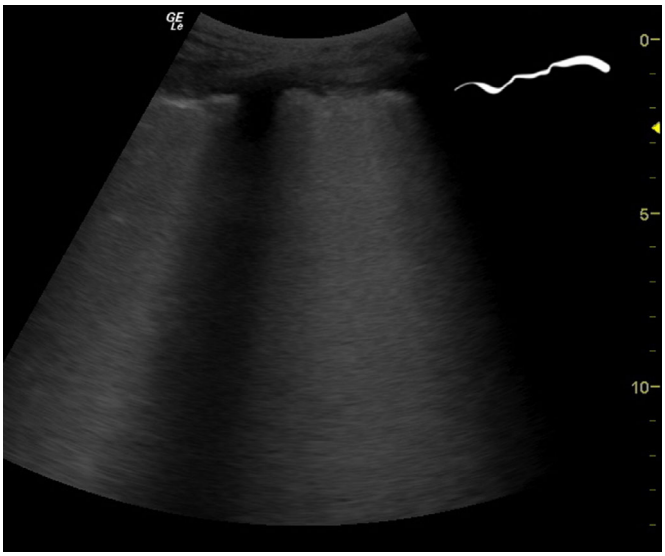

Figure 7: This view shows an irregular pleural line and confluent B lines reaching to the base of screen. This image might be seen in COVID or ARDS, but in this case is from a stable fibrosing lung condition. [Colour figure can be viewed at wileyonlinelibrary.com]

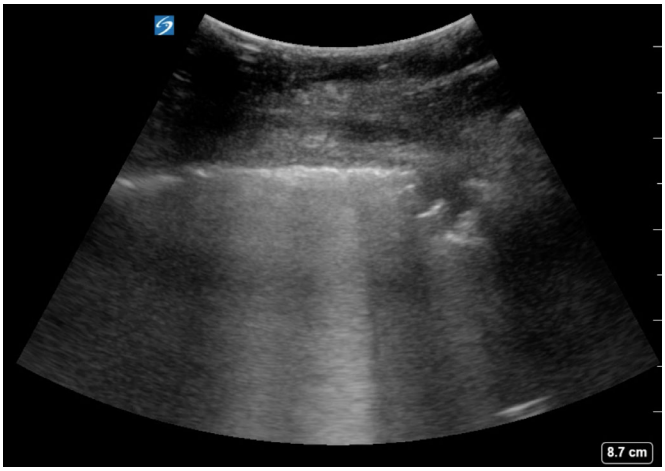

Figure 8: The probe is oriented in the intercostal space, and with less depth, demonstrating a subpleural consolidation on the right and several broad B lines. This could be seen in any viral pneumonitis, reticulonodular lung conditions or small pulmonary infarction. [Colour figure can be viewed at wileyonlinelibrary.com]

A global anterior B-line pattern suggests that increased positive end-expiratory pressure may be useful and that echocardiography is indicated to look for causes of poor left ventricular function. Relatively clear lungs steer the diagnosis towards asthma, hypovolaemia or pulmonary embolism.

Scan available rib spaces, and as far posteriorly as able and if consolidation or atelectasis is seen, consider recruitment manoeuvres. In intensive care, and now also in the emergency situation proning is considered if there are larger areas of posterior atelectasis.[3,5]

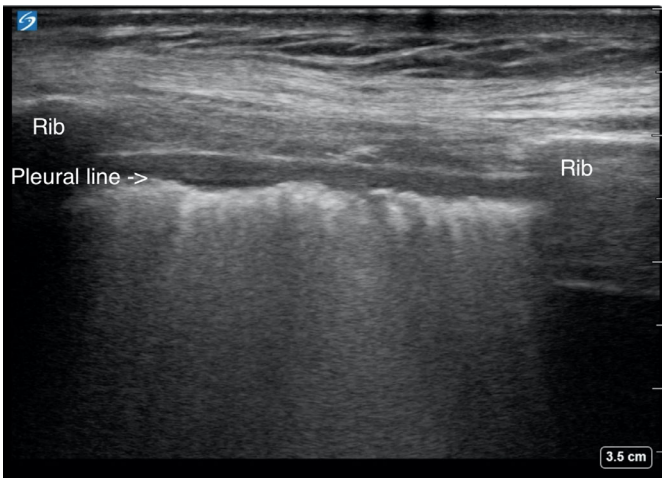

Figure 9: A close-up view of pleura with a linear probe shows a small subpleural effusion immediately above an irregular pleura. B lines may be less distinct when imaged with a linear probe, but are more obvious in a moving clip. A pleural plaque gives a similar appearance. [Colour figure can be viewed at wileyonlinelibrary.com]

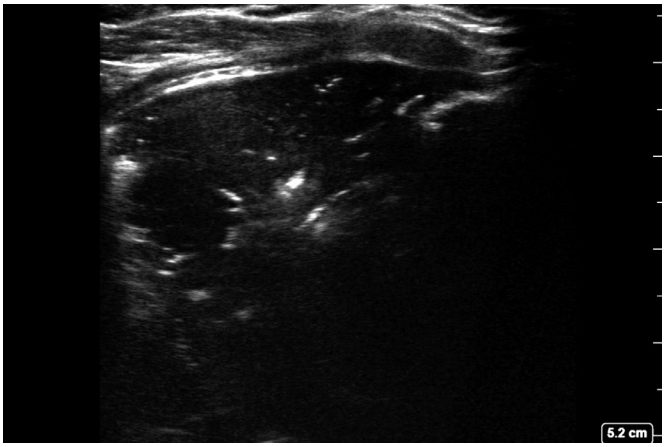

Figure 10: Consolidation as seen with a linear probe shows a hypoechoic, liver-like texture usually broken by bright white air bronchograms' which may be linear or round, static or dynamic. Pure atelectasis tends to retract, infiltration less so.

The most important principle in every LUS is to look for the distribution of the abnormalities. Lung artefacts are non-specific, but COVID-19 appears to manifest in distinctive distributions with a gradient of worsening disease. Early disease is patchy, so scanning must include as much of the lung surface as possible and plot the distribution of abnormalities. Figures 1–12 comprise a pictorial essay of the typical abnormalities depicted with different probes, but it also highlights the non-specific nature of lung scanning and the need for experience when integrating these signs into the individual case. Video 1 contains a series of still images and clips for further practice at recognising pathology.

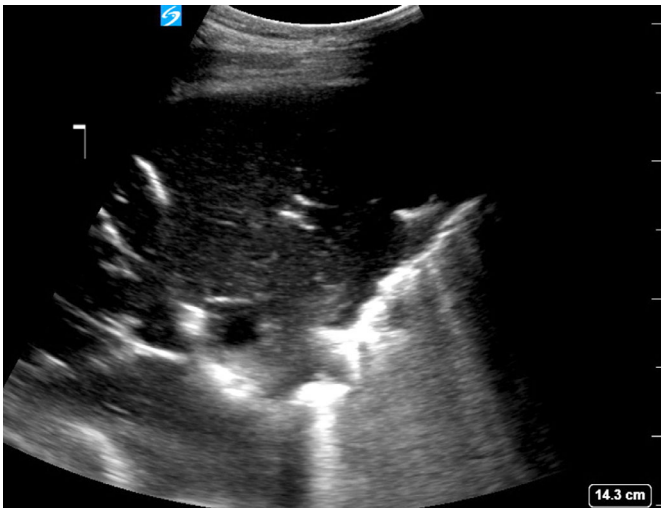

Figure 11: Lobar consolidation as seen with a curved probe. The uneven hyperechoic white margin on the lower right of screen is aerated lung abutting the consolidation. Use colour Doppler to look for hyperaemia or relative ischaemia. [Colour figure can be viewed at wileyonlinelibrary.com]

Figure 12: This longitudinal coronal view of the right lung base shows a large hypoechoic effusion abutting the diaphragm. Effusions such as this are not common in COVID and should prompt investigation for other causes of breathlessness. [Colour figure can be viewed at wileyonlinelibrary.com]

Conclusion

Lung ultrasound can be a useful tool in COVID-19 management, when implemented mindfully.

Take into account all risks and resources including personnel, consumables and time. Implement point-of-care ultrasound to match your specific capabilities. Our recommendations, based purely on prior learning, are as follows:

- If you are experienced at ultrasound, then adding lung ultrasound to your repertoire is simple and a good idea. Learning an entirely new skill during a pandemic is not recommended.
- Before any scan, consider risk vs. benefit. What is the clinical question(s)? Will this change management? Who is the best person to perform the scan? What is the opportunity cost?
- Lung ultrasound has limitations, understand these and integrate clinical findings, other investigations, risks and stakes into the sonographic pattern.
- Know the sonographic patterns of COVID-19 and other pathologies that manifest the same changes. These may be possible to differentiate clinically or sonographically.
- Consider multisystem scanning – cardiac, IVC, DVT and vascular access as clinically indicated and where credentialled.
- Standardise practice – archive images and write reports.
- Practice meticulous infection control. Do not endanger yourself, your colleagues or other patients.

Acknowledgements

The authors express deepest thanks to those at the leading edge of this pandemic who have taken time despite overwhelming workload, to share their findings and help prepare those of us still waiting.

Funding

No funding information is provided.

Conflict of Interest

Kylie Baker teaches ultrasound at the Australian Institute of Ultrasound.

Author Contributions

Kylie Baker: Conceptualization (lead); Resources (equal); Visualization (equal); Writing-original draft (lead); Writing-review & editing (equal). **James Rippey:** Resources (supporting); Supervision (lead); Writing-original draft (supporting); Writing-review & editing (lead).

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