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ESSENTIAL NOTES

Use of lung ultrasound for COVID-19 in the intensive care unit

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Thoracic imaging is a key component of managing respiratory failure in patients with coronavirus disease 2019 (COVID-19). However, timely access to routine chest X-rays and CT scans can be challenging in a pandemic. Furthermore, resource utilisation is critical, and the safety of the patient and staff must be balanced carefully with the necessity of obtaining images.

Point-of-care lung ultrasound (LUS) is a dynamic technique routinely used in intensive care to answer targeted questions and aid in practical procedures.[1] Whilst LUS has its limitations, and in isolation cannot provide a definitive diagnosis, it can be useful where resources are scarce. In this article we explore the use of LUS specifically in critically ill patients with COVID-19, outlining both essential aspects for new practitioners of LUS and points of high diagnostic yield.

Safety

When using any imaging technology in the face of an infectious disease the equipment itself must not be allowed to become a vector for further spread. Ideally a dedicated ultrasound machine is required for the 'red zone', as was the case during the Ebola virus outbreak in 2014.[2,3] Basic principles of hygiene to minimise contamination include: the removal of organic debris from the probe and machine; disinfection with probe-compatible material; the use of sachets rather than bottled ultrasound gel; and clear documentation of the cleaning process.[4] Portable handheld machines are preferable, being easier both to cover during scanning and to clean.

Suggested approach

There is currently no validated systematic approach for performing LUS in patients with COVID-19 pneumonitis, although the Intensive Care Society has made some recommendations.[5] There are several different techniques and choices of probe, including the Blue protocol.[6] The optimal approach where resources are limited must balance the following:

- The need to answer the clinical question;
- The workload in ICU;
- The risks of disturbing the patient's position, particularly when there is cardiovascular instability.

LUS protocols for ICU assume users have a degree of expertise, time, and appropriate resources. During a pandemic, providers may find themselves in temporary hospital structures with large numbers of critically ill patients. Protocols designed for normal working conditions may not address the context of a strained and overwhelmed system.

We believe the following key points determine the highest yield approach to LUS in patients with COVID-19:

- The changes seen are not homogenous, with normal areas interspaced between areas of abnormality (in contrast to

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bilateral, homogenous changes seen with cardiogenic pulmonary oedema).
- Abnormal lung findings predominate in the posterolateral aspect of the chest.
- Evaluating the heart accurately distinguishes symptoms as primarily pulmonary or cardiac in nature.[1]
- The images obtained should ideally be reproducible, to allow comparison throughout progression of the disease within and between individual patients.

We therefore recommend the following approach for those new to thoracic ultrasound.

- Begin with a 'survey' of the lungs in general using a probe that offers a wide field of view and maximises tissue penetration. The curvilinear (abdominal) probe allows a rapid survey of the lung fields, but shadowing from the ribs can obscure much of the image. The cardiac probe provides superior views between ribs and evaluation of cardiac function, but the narrower field of view prolongs the duration of the scan. Either is suitable, with the aim being to gain a rapid sense of the extent of disease.
- Start at the lung bases as posteriorly as possible, accounting for the patient's position and severity of illness. This allows identification of a dependent pleural effusion and any involvement of the lower lung zones.
- Then move systematically to the apex anteriorly, looking for any abnormalities at the pleural interface suggestive of a large pneumothorax, and reviewing as much of each lung as possible as you scan to gauge the extent of lung involvement. If any abnormalities are detected the higher resolution linear probe (8–12 MHz) should be used to examine these areas in more detail for characteristic findings.
- Ultrasound cannot penetrate aerated lung, thus any pathology such as a hilar mass or an isolated central lung mass not in contact with the pleural surface can be missed. However, CT imaging of patients with COVID-19 pneumonitis suggests that there is frequent pleural involvement.[7] This reduces the risk of missing lung involvement with LUS.

Using this systematic approach should maximise the chances of detecting pleural abnormalities, whilst recognising limitations caused by the position of the patient or inexperience of the practitioner.

Appearance on imaging

LUS does not rely primarily on visualising actual pathology but instead uses artefacts generated by density changes at air/water or air/tissue interfaces.[8] Terminology and definitions are important. B-line patterns are frequently referred to in patients with COVID-19. By definition, B-lines must arise from the pleura and erase A-lines.[9] However, in COVID-19 the vertical lines often originate from subpleural consolidations and not from the pleura itself. Whilst similar, these are not strictly B-lines but instead C-lines, which are defined as originating below the pleura from consolidations or defects on the pleural surface (Fig. 1; Supplementary Videos 1 and 2).[9] The 'light-beam artefact' that has also been described may be a confluence of C-lines leading to a different appearance than that seen in pulmonary oedema or bacterial pneumonia.[10] The key difference between C-lines and B-lines is that C-lines are artefacts caused by viral-induced irregularities of the pleural surface and not caused by alveolar oedema, which gives rise to B-lines. This is similar to the ring-down pattern in tuberculosis, which affects the pleural interface causing defects and artefacts that arise from the pleura itself (Fig. 2; Supplementary Videos 3 and 4).[11] However, the clinical implications of the differences between B-lines and alveolar oedema, and between C-lines and pleural-based defects, are still unclear with regard to diagnosis and treatment. True B-lines potentially suggest iatrogenic fluid overload or other pathology secondary to the viral pneumonitis. Where serial LUS shows improvement in the C-line pattern with increasing B-lines at the lung bases, this might suggest a need for treatment with diuretics in a patient whose cardiac function is decompensating.

LUS and management strategies

Work continues to identify the similarities and differences of pathological changes in COVID-19 pneumonitis compared with acute respiratory distress syndrome. Gattinoni and colleagues recently proposed that patients with COVID-19 are classified into L and H phenotypes and speculated that different LUS patterns in each may help identify the severity of disease and facilitate management.[12] However, it is likely that there is a vast spectrum of presentations between the two phenotypes.[13] Therefore, the strategy for artificial ventilation should not be based on LUS findings. Regular scanning combined with monitoring other clinical variables may allow clinicians to track disease progression; for instance, LUS may reveal changes in type and number of B-lines and pleural irregularities. Pleural effusion, lung consolidation, air bronchograms, and hepatisation of the lung may be visible in advanced disease or can be associated with superimposed bacterial infections.

Other lung pathologies, such as pneumothorax and endobronchial intubation during prone positioning, may also be identified by LUS. Both pathologies will abolish lung sliding, although in endobronchial intubation a lung pulse will remain. Pulmonary embolism (PE) is a frequent complication in COVID-19; LUS in conjunction with laboratory and clinical information can help in detection of PE.[14,15] However, the diagnostic accuracy of LUS in PE is poor, and echocardiography is not recommended in patients at low risk who are haemodynamically stable. Features suggestive of an acute PE include acute right ventricular dysfunction (McConnell's sign, impaired tricuspid annulus plane systolic excursion [TAPSE], dilated right ventricle, distended inferior vena cava with no respiratory variation, and flow reversal in the hepatic vasculature). Infrequently, thrombus may be seen in the right ventricle and main pulmonary artery.[15] As the majority of PEs originate from a deep venous thrombosis, diagnostic accuracy can be increased by incorporating compressive venous ultrasonography of the femoral and popliteal viens.[15]

Quality assurance

LUS is operator-dependent and technical expertise is required to acquire and interpret images; reproducibility of images is crucial to allow monitoring of disease progression. Supervised practice during the early stages of learning may not be possible during a pandemic setting. During the Ebola pandemic, physicians were trained to obtain images which were reviewed remotely by an expert for detailed analysis and quality assurance. This 'telemedicine' approach is used extensively in providing ultrasound training to front-line

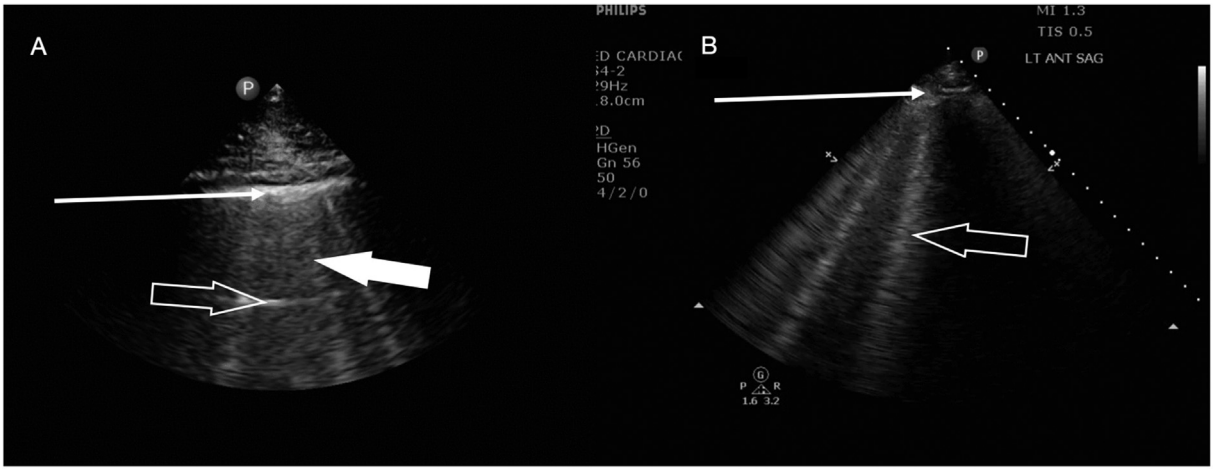

Fig 1 Both images are taken with the same ultrasound machine using a phased array probe with similar settings. The probe in both cases is positioned in the mid axillary line at the base of the lung in the lower lung zone just above the diaphragm. (A) From a patient with known COVID-19 pulmonary disease. Ring-down artefacts are seen as C-lines (solid arrow) originating from a thickened pleura (thin arrow) and do not erase the underlying A-lines (hollow arrow). (B) Demonstrates true B-lines (hollow arrow) in a patient with pulmonary oedema originating from a thin pleural line (thin arrow) and erasing the A-lines below which are absent in the image. (Videos 1 and 2 in the Supplementary material demonstrate differences dynamically).

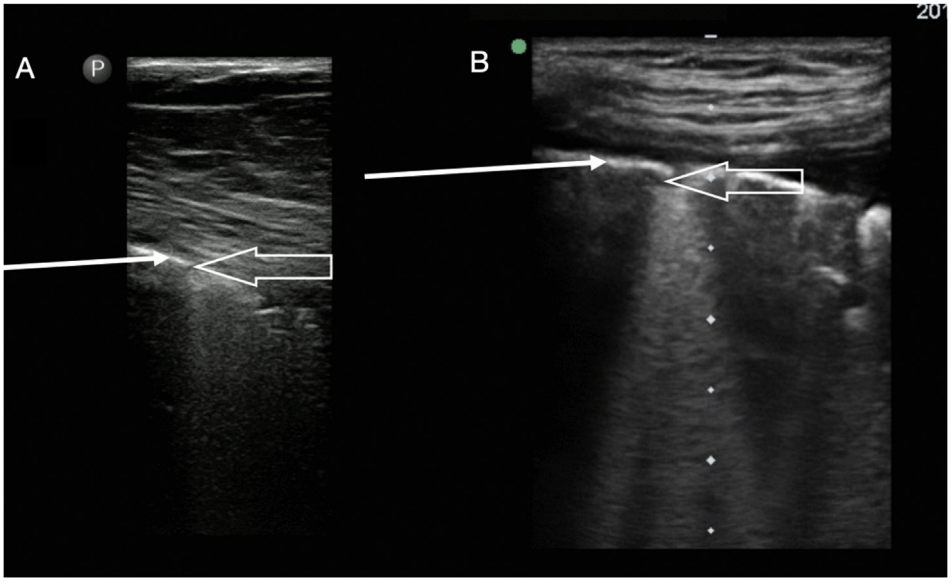

Fig 2 This figure demonstrates the similarity between the subpleural findings in COVID-19 and pulmonary tuberculosis. (A) Shows a linear probe positioned at the lung base in the midaxillary line and demonstrates pleural-based abnormalities (hollow arrow) in a COVID-19 patient just below the pleura (thin arrow). (B) Taken from a linear probe positioned at the lung apex in the midclavicular line and demonstrates similar findings of subpleural consolidations (hollow arrow) in a patient with tuberculosis. Note subpleural consolidations in both and dense ring-down artefacts originating below the pleura (Videos 3 and 4 in the Supplementary material).

providers throughout the world and could also be used for patients with COVID-19.

Conclusions

LUS is simple, easy to learn, and reproducible if a systematic approach is used. Ultrasound could potentially have a major role in the management of patients with COVID-19 in ICU where resources are scarce and access to definitive imaging limited. It can help clinicians in quickly investigating alternative causes of hypoxia. As knowledge about COVID-19 continues to evolve, LUS may allow providers to individualise patients' care in a highly variable disease.

Declaration of interests

RA is a trainee and podcast editor and editorial board member of *BJA Education*. DK declares that he has no conflicts of interest.

Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bjae.2020.09.001.

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