**Abstract**

The COVID-19 global pandemic has overwhelmed health services with large numbers of patients presenting to hospital, requiring immediate triage and diagnosis. Complications include acute respiratory distress syndrome, myocarditis, septic shock, and multiple organ failure. Point of care ultrasound is recommended for critical care triage and monitoring in COVID-19 by specialist critical care societies, however current guidance has mainly been published in webinar format, not a comprehensive review. Important limitations of point of care ultrasound include inter-rater variability and subjectivity in interpretation of imaging findings, as well as infection control concerns. A practical approach to clinical integration of point of care ultrasound findings in COVID-19 patients is presented to enhance consistency in critical care decision making, and relevant infection control guidelines and operator precautions are discussed, based on a narrative review of the literature.

**Keywords:** Acute respiratory distress syndrome, COVID-19, heart failure, point of care ultrasound, shock

**INTRODUCTION**

Coronavirus disease 2019 (COVID-19) infection results in multisystem involvement, with acute respiratory failure, circulatory shock, and acute kidney injury (AKI) accompanied by a global inflammatory response with cytokine storms, endothelial dysfunction and a prothrombotic state.[1–9] Admission to the intensive care unit (ICU) is required in 26%–32% of patients, with a mortality rate of 4.3%–15%.[3,10] Risk factors for increased mortality include severe multiorgan dysfunction[11] and comorbidities.[12] Point of care ultrasound (POCUS) provides real-time bedside imaging that clarifies the findings of physical examination, which may be hindered by personal protective equipment (PPE),[13,14] helps differentiate cardiorespiratory failure[15,16] and reduces the need for formal chest radiography (CXR), chest computed tomography (CT)[17,18] and echocardiography.[19–23] This has significant resource implications on ICU services[24] and requires consistent decision-making.[25] We aim to provide a bedside aide-memoire to standardise POCUS application in COVID-19.

**ACUTE RESPIRATORY FAILURE IN COVID-19**

Patients with COVID-19 develop pneumonia and acute respiratory distress syndrome (ARDS), which must be differentiated from pulmonary oedema due to heart failure. Chest CT findings in a series of 41 patients with COVID-19 pneumonia included bilateral changes in 98% of patients, with ground glass changes in non-ICU patients and multifocal consolidation in patients requiring mechanical ventilation.[3] Severe hypoxaemia in COVID-19 is associated with two ARDS phenotypes,[26,27] which may represent different levels of severity of the same disease.[28–30] These phenotypes may be differentiated using POCUS. The L phenotype is associated with low elastance (high compliance), normal work of breathing, minimal loss of lung aeration and increased risk of infection.

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of pulmonary microvascular thrombosis. These patients are at risk of lung overdistension during mechanical ventilation, and hence, cautious positive end-expiratory pressure (PEEP) settings are recommended. In contrast, the H phenotype is associated with high elastance (low compliance), increased work of breathing, and severe reduction in lung aeration that is more responsive to lung recruitment strategies, thus requiring higher PEEP settings during mechanical ventilation.

**BASIC LUNG ULTRASOUND VIEWS**

A curvilinear or phased array transducer is generally used, with a scanning depth of <5 cm for pleural imaging and 10–20 cm for deeper imaging. More detailed pleural imaging can be achieved with a linear transducer, which gives a better resolution of superficial structures. Standard views are obtained in the upper, middle, and lower zones bilaterally [Figure 1], similar to auscultation in a semi-recumbent or supine patient. However, some authors recommend scanning 6–7 zones per hemi-thorax for semi-quantitative monitoring of lung aeration changes in ARDS.[32,33]

**DIFFERENTIATION OF HYPOXAEAMIA WITH POCUS**

Lung ultrasound features of COVID-19 mirror CT and CXR appearances, allow differentiation of L and H phenotypes, and correlate with severity and mortality in ARDS.[34,35] POCUS reduces the requirement for thoracic CT and CXR, thereby reducing the risk of intra-hospital transfer, radiation and contrast exposure for the patient, and the risk of infection transmission to radiology staff.[17,18] The bedside lung ultrasound in emergency (BLUE) protocol provides rapid and accurate diagnosis in 90.5% of cases of acute respiratory failure.[16] A decision tree is summarised in Figure 2.

**Exclusion of pneumothorax**

A horizontal bright pleural line is identified between dark rib shadows in each intercostal space. Air beneath the pleural line reflects the ultrasound beam, generating a reverberation artefact with the appearance of multiple pleural lines at equal distances, termed A-lines [Figure 3a]. Pleural movement seen during respiration (pleural sliding) or cardiac activity (pleural pulsation) signifies that the lung is in contact with the chest wall, excluding a pneumothorax. Pleural movement appears as the ‘seashore sign’ on time-motion (M)-mode, where structures deep to the moving pleural line appear grainy, and superficial static structures appear as horizontal lines, like waves approaching a sandy beach [Figure 3b]. Pneumothorax is also excluded by any type of tissue pattern (B-lines, consolidation or pleural fluid, see below).[16] Absent pleural sliding and pulsation may signify a pneumothorax; however, specificity is increased if a ‘lung point’ is identified where intermittent movement of the lung edge is seen in a partial pneumothorax. Pneumothorax is associated with the M-mode ‘barcode’ sign of multiple horizontal lines, as all structures deep and superficial

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**Figure 1:** Lung ultrasound views. (a) Upper zone; (b) middle zone; (c) Lower zone; (d) Three imaging zones per hemithorax; (e) Six imaging zones per hemithorax.
to the pleural line are static [Figure 3c]. A false positive barcode sign may occur with bullae or severe bronchospasm.\cite{36,37}

**Differentiation of unilateral chest movement and confirmation of endotracheal tube placement**

Bilateral pleural sliding and chest rise confirms endotracheal tube placement in emergencies. However, widespread pleural pulsation with absent sliding and unilaterally reduced chest movement implies a total lung collapse without pneumothorax, allowing the identification of endobronchial intubation or obstruction.\cite{38} POCUS can also differentiate unilaterally reduced chest movement due to extensive consolidation or pleural effusion (see below). Of note, pleural pulsation is normally visualised at the parasternal borders bilaterally,\cite{39} and localised regions of pleural pulsation may occur in ARDS.

**Differentiation of crepitations: ARDS vs. cardiogenic pulmonary oedema**

The ultrasound beam is conducted by fluid in the interstitial and alveolar spaces in ARDS and pulmonary oedema, giving rise to vertical bright lines, termed B-lines, with $\geq 3$ B-lines per intercostal space considered pathological [Figure 3d]. Occasional B-lines may be normal at the lung bases, and false positive B-lines may occur with interlobular septal thickening in inflammatory, fibrotic or infiltrative conditions.\cite{40,41}

Pulmonary oedema due to heart failure or volume overload.
is associated with a homogeneous B-line distribution pattern with bilateral pleural effusions, preserved pleural sliding, and absence of pleural line abnormalities or consolidation. Increasing severity of pulmonary oedema is associated with thicker and more confluent B-lines. In contrast, a heterogeneous B-line distribution pattern with spared areas, localised regions of pleural pulsation with reduced sliding, pleural line abnormalities (thickening, indentation or a broken pleural line), consolidation (subpleural, multifocal or basal) and minimal effusions is more suggestive of COVID-19 ARDS and pneumonia. Increased severity of ARDS is associated with subpleural or basal consolidation, and increasing B-line density.

**Differentiation of wheeze: cardiogenic pulmonary oedema vs bronchospasm**

POCUS allows differentiation of a cardiac wheeze from bronchospasm in patients with coexisting asthma or chronic obstructive pulmonary disease. Bilateral A-lines with wheeze on auscultation suggests bronchospasm, whereas B-lines suggest pulmonary oedema.

**Differentiation of reduced breath sounds at the lung bases: consolidation vs. pleural effusions**

Consolidation gives the appearance of hepatised lung tissue, similar in appearance to liver, interspersed with multiple bright, irregular air-fluid bronchograms due to inflammatory fluid within the peripheral air spaces [Figure 3e]. This gives the appearance of a shredded border between hepatised lung and air-fluid bronchograms, termed the ‘shred sign’ in ultrasound imaging.

Pleural effusions appear as a hypoechoic (dark) fluid collection with underlying collapsed lung floating within the effusion [Figure 3f]. Transudates are usually bilateral and uniformly hypoechoic, whereas exudates are usually unilateral with visible strands or loculations within them. A separation of 3–5 cm between parietal and visceral pleura at the lung bases generally signifies a pleural effusion volume of >500 mL; however, multiple views are recommended to assess the cephalad extension of the effusion and to avoid overestimation of pleural effusion size at the lung bases.

**ACUTE CIRCULATORY FAILURE IN COVID-19**

Circulatory failure requiring vasopressors may coexist with respiratory failure in 71% of mechanically ventilated patients with COVID-19. Direct myocardial involvement results in myopericarditis, myocardial dysfunction and elevated cardiac troponin levels in 20% of patients, mimicking septic cardiomyopathy due to cytokine storms. This must be differentiated from an acute coronary syndrome in view of the prothrombotic state or cardiac tamponade due to a pericardial effusion, both of which require urgent cardiac intervention. In addition, right ventricular dysfunction may develop secondary to ARDS, pulmonary microvascular thrombosis or pulmonary embolism (PE), requiring cautious PEEP titration and a limited trial of a pulmonary vasodilator. Careful intravenous (IV) fluid titration is recommended, as capillary leak may worsen ARDS severity and systemic venous congestion may increase the risk of AKI.

**BASIC VENOUS AND ECHOCARDIOGRAPHIC VIEWS**

**Internal jugular vein and inferior vena cava views**

Increasing central venous pressure results in venous distension, with an increase in anteroposterior diameter and reduced respiratory variation of the internal jugular vein (IJV) and inferior vena cava (IVC). Transverse and longitudinal views are obtained of the IJV in the neck with a linear transducer. Cephalad movement of the transducer from the level of the cricoid cartilage allows identification of the level at which the jugular vein collapses, which correlates with the height of the jugular venous column. Transverse and longitudinal views of the IVC are obtained in the epigastrium or right flank with a curvilinear linear phased array transducer. Visualisation of the IVC also allows for guidance of cannula positioning for venovenous extracorporeal membrane oxygenation, if required, for severe refractory hypoxaemia.

**Basic echocardiographic views**

Four basic cardiac views are obtained with a phased array transducer. The parasternal long axis view of the left heart structures is obtained at the lower left sternal edge with the transducer marker dot pointing towards the patient’s right shoulder, allowing assessment of left ventricular systolic function, left ventricular hypertrophy (LVH), left atrial

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**Figure 4:** Inferior vena cava. (a) Subcostal long axis view; (b) Right flank long axis view.
Dilatation, left ventricular outflow tract obstruction and mitral and aortic valves [Figure 5a]. Rotating the transducer 90° so the marker dot faces the patient’s left shoulder yields the parasternal short axis view, allowing evaluation of both ventricles and the interventricular septum in cross section, for identifying regional wall motion abnormalities (RWMAs) with coronary lesions or paradoxical septal motion in right ventricular dysfunction [Figure 5b]. The relative sizes of both atria and ventricles, and the position and motion of the interventricular and interatrial septae are best visualised in the apical 4 chamber (A4C) view at the cardiac apex [Figure 5c], or the subcostal 4 chamber (S4C) view in the epigastrium [Figure 5d].

Left and right ventricular systolic function, ejection fraction and RWMAs are estimated visually. Left ventricular dilatation is suggested by a change from a bullet shape [Figure 6a] to a more globular appearance [Figure 6b]. Right ventricular dilatation is identified when the right ventricular end-diastolic area is equal to or greater than the left ventricular end-diastolic area, with paradoxical shift of the interventricular septum from right to left [Figure 6c and d]. Elevated left atrial pressure is indicated by a fixed curvature of the inter-atrial septum from left to right throughout the cardiac cycle, associated with a risk of pulmonary oedema and post-capillary pulmonary hypertension. Pericardial effusions [Figure 6e] are best seen in the A4C and S4C views, and right atrial collapse signifies cardiac tamponade.[22,23,72,73]

**Figure 5:** Basic echocardiographic views. (a) Parasternal long axis (PLAX) view; (b) Parasternal short axis (PSAX) view; (c) Apical 4 chamber (A4C) view; (d) Subcostal 4 chamber (S4C) view. AoR: aortic root, DTA: descending thoracic aorta, IAS: interatrial septum, IVS: interventricular septum, LA: left atrium, LV: left ventricle, LVOT: left ventricular outflow tract, RA: right atrium, RV: right ventricle, RVOT: right ventricular outflow tract

**Figure 6:** Common cardiac pathological appearances. (a) Left ventricle (LV) and right ventricle (RV) not dilated; (b) Isolated LV dilatation; (c) LV and RV (biventricular) dilatation; (d) Isolated RV dilatation; (e) Tamponade.

**DIFFERENTIATION OF CIRCULATORY SHOCK AND HEART FAILURE WITH POCUS**

POCUS can help exclude a significant cardiac lesion that requires specialist imaging or intervention,[19-23] potentially reducing the need for referral and risk of infection transmission to cardiology staff. A decision tree is summarised in Figure 7.

**Classification of circulatory shock**

Shock is classified according to the presence or absence of systemic venous congestion on POCUS, and clinical features of hypoperfusion and preload responsiveness. Venous diameter and respiratory variation is related to central venous pressure, which is determined by the balance between intravascular volume, vasodilatory state, patient position, intrathoracic pressure and right ventricular end-diastolic pressure. Hence, flat, visibly collapsed veins indicate hypovolaemia, while intermediate vein size with visible respiratory variation and no collapse indicates euvoalaemia or distributive shock, and distended veins with minimal respiratory variation suggest intravascular volume overload, or cardiogenic or obstructive shock. True intravascular hypovolaemia is associated with relatively collapsed veins and small hypercontractile ventricles with end-systolic collapse. Ventricular function is generally preserved in distributive shock; however, late impairment may occur with the development of septic cardiomyopathy. Obstructive shock...
Figure 7: Flowchart shows proposed point of care ultrasound decision tree for evaluation of venous thromboembolism. ARDS: acute respiratory distress syndrome, HFpEF: heart failure with preserved ejection fraction, HFrEF: heart failure with reduced ejection fraction, IV: intravenous, IVC: inferior vena cava, LV: left ventricle, LVEF: left ventricular ejection fraction, MI: myocardial infarction, PE: pulmonary embolism, RV: right ventricle, RWMA: regional wall motion abnormalities.

Classification of heart failure
Heart failure is classified according to clinical features of hypoperfusion and pulmonary oedema. POCUS can identify ventricular dilatation, impaired cardiac systolic function, RWMA, pulmonary oedema (B-lines), pleural effusions and venous congestion, allowing differentiation of heart failure with preserved or reduced ejection fraction. Resolution of pulmonary oedema and jugular venous distension are therapeutic end-points for diuretic therapy.

Differentiation of causes of cardiac arrest
POCUS can confirm endotracheal tube placement and identify hypovolaemia, pneumothorax, tamponade, right heart strain and left ventricular dilatation in cardiac arrest, complementing clinical assessment and arterial blood gases in differentiating reversible causes. Care must be taken not to interfere with the effectiveness of chest compressions, and aerosol precautions must be followed in COVID-19, as cardiopulmonary resuscitation (CPR) is an aerosol-generating procedure.

Fluid stewardship
Intravenous fluid therapy may adversely affect the severity of ARDS in COVID-19; hence, a cautious fluid strategy is recommended, with objective assessment of preload responsiveness and early de-escalation when appropriate. POCUS allows rapid exclusion of false-positive preload responses due to distributive shock, obstructive shock or right ventricular failure. POCUS also helps to monitor the distribution of fluid between the intravascular compartment (venous distension) and extravascular compartment (B-lines, pleural effusions) during fluid therapy, diuresis and evaluation of dysnatraemias.

Identifying acute cor pulmonale
The development of right ventricular dilatation in COVID-19 patients with ARDS is associated with pulmonary hypertension and increased mortality. Differentials include acute cor pulmonale due to ARDS, pulmonary microvascular thrombosis or pulmonary embolism (see below), requiring further diagnostic workup, careful ventilator recruitment strategies and possibly, a trial of pulmonary vasodilator therapy.

Differentiating myopericarditis, septic cardiomyopathy and acute coronary syndromes
Echocardiographic features of COVID-19 include biventricular dilatation with impaired systolic function, myocardial thickening (oedema) with a bright echogenic appearance, dilated IVC and pericardial effusion, with similar features observed in severe acute respiratory syndrome (SARS) and Middle East respiratory syndrome. The inflammatory response may result in septic cardiomyopathy, with elevations...
in cardiac troponin and n-terminal pro-brain natriuretic peptide levels, biventricular dilatation and impaired systolic function. This must be differentiated from an acute coronary syndrome, which requires coronary intervention, suggested by RWMAs in a distinct coronary territory together with a strong clinical suspicion.

VENOUS THROMBOEMBOLISM IN COVID-19

COVID-19 is associated with a prothrombotic state, with prophylactic or therapeutic anticoagulation recommended to prevent or treat deep vein thrombosis (DVT), PE or pulmonary microvascular thrombosis. The diagnostic workup is similar to that for non-COVID-19 patients and centres on pre-test probability based on Wells or Vienna score, elevated D-dimers, tachycardia, right ventricular failure, sudden onset of hypoxaemia that is out of proportion to the degree of lung aeration changes and clinical features of DVT. POCUS may reduce the need for transfer of a COVID-19 patient for a CT pulmonary angiogram and the risk of contrast nephropathy and infection transmission to radiology staff.

POCUS EVALUATION OF VENOUS THROMBOEMBOLISM

Indirect sonographic features

Severe hypoxaemia with POCUS features of right ventricular dilatation and minimal loss of lung aeration can add to the pre-test probability of a clinically significant DVT or PE. Alternative diagnoses for refractory hypoxaemia and right ventricular dilatation must also be considered [Figures 2 and 7].

Three-point venous compression ultrasound

POCUS using three-point compression of the popliteal and femoral veins, and saphenofemoral junctions bilaterally, can accurately exclude a proximal lower limb DVT. 2D imaging of the veins is performed in the transverse and longitudinal views to identify hyperechoic (bright, organised) or hypoechoic (dark, acute) thrombus. Gentle pressure is applied with the transducer in the transverse view to compress the vein without significantly compressing the artery [Figure 8a] to compress the vein without significantly compressing the artery [Figure 8b]. A compressible vein with a patent lumen excludes a DVT. Colour Doppler imaging demonstrates flow within the vein [Figure 8c], and colour flow augmentation during gentle calf compression [Figure 8d] may further improve specificity and negative predictive value.

LIMITATIONS OF POCUS

Infection control considerations in COVID-19

Operator considerations for COVID-19 include routine contact and droplet precautions, with escalation to airborne precautions during aerosol-generating procedures, including airway instrumentation or CPR [Figure 9]. A flat screen tablet or phone-based device with a single transducer should be used to allow easy cleaning before and after use, and for coverage during scanning. Sterile, single-use gel sachets are recommended rather than multi-use bottles. Coronaviruses remain viable on inanimate objects as fomites for 96 hours to 9 days, and are inactivated with low-level disinfectants within one minute, particularly 70% isopropyl alcohol and 0.1% sodium hypochlorite. The transducer must be cleaned to remove macroscopic contamination and disinfected with low-level disinfectant wipes before and after use for non-critical applications (surface scanning on intact skin). Some guidelines recommend high-level disinfection with chlorine dioxide, hydrogen peroxide or peroxyacetic acid based wipes for semi-critical or critical applications (contact with non-intact skin, mucous membranes, blood, body fluids, or ultrasound-guided invasive procedures), together with the use of a sterile transducer sheath and sterile gel.

Inter-rater variability in clinical application: Occam’s razor vs. Hickam’s dictum, and cognitive biases

The clinical decision support tool presented gives the most likely diagnoses based on clinical and ultrasound features, following Occam’s razor. However, in reality, the clinical picture may evolve over time, particularly after treatment effects, resulting in a mixed picture where multiple diagnoses may co-exist (Hickam’s dictum). In particular, respiratory failure due to pneumonia may be complicated by a PE at any time, and heart failure may be associated with collapsed veins following over-diuresis. Hence, clinical integration of POCUS findings depends on the clinical context and index of suspicion, which may be confounded by experience and cognitive biases.
CONCLUSION

POCUS has several applications in COVID-19, including exclusion of life-threatening pathologies, and monitoring respiratory, fluid and haemodynamic management. In addition, POCUS helps identify patients that require specialist imaging or intervention, such as thoracic CT or diagnostic echocardiography. This paper presented a POCUS clinical decision support tool to enhance consistent decision-making during the COVID-19 pandemic.

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Conflicts of interest
There are no conflicts of interest.

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