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REVIEW

Ultrasound as the New Stethoscope: A Journey From Just Locating Fluid to Assessing Haemodynamics and Venous Congestion

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Abstract

Point-of-care ultrasound (POCUS) has evolved from a simple tool for fluid localization to a comprehensive modality for hemodynamic assessment and real-time clinical decision-making. The Bedside Lung Ultrasound in Emergency (BLUE) protocol enables clinicians to diagnose causes of cardiorespiratory failure more accurately than clinical examination alone. In patients presenting with shock and hypotension, POCUS facilitates rapid identification of the underlying aetiology. This allows for targeted treatment in these critically ill patients. In complex patients presenting with concurrent cardiac failure and renal dysfunction, the venous excess ultrasound (VExUS) score provides a valuable assessment of volume status, guiding fluid management and therapeutic interventions. The increasing availability of handheld ultrasound devices, cloud-based services and artificial intelligence (AI) is driving POCUS beyond the traditional hospital settings into the community. Associated healthcare professionals already perform initial scans in community settings with remote expert review. In future models of care, patients or carers could use AI-assisted handheld devices to enable self-monitoring and early disease management at home. This review examines the expanding role of POCUS in acute and critical care settings, with a focus on key protocols that enhance diagnostic accuracy and guide clinical management, and considers future expansion of POCUS into the community.

Key words: point-of-care; POCUS; ultrasound; shock; hypotension

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Introduction

The stethoscope is a well-recognised and arguably iconic tool of medical practice. For over 200 years, it has been the cornerstone of clinical examination, allowing clinicians to assess heart and lung sounds at the bedside. However, it is limited by the user's skill level and ability to interpret their findings appropriately. With advances in medical technology, the stethoscope can be augmented and even superseded by more advanced diagnostic tools, such as point-of-care ultrasound (POCUS). It has rapidly developed from an instrument for locating fluid, such as a pleural effusion, to a tool that can allow clinicians to comprehensively assess haemodynamics and venous congestion at the bedside. This allows the clinician to make more informed management decisions, such as whether a dyspnoeic patient requires aggressive fluid resuscitation for chest sepsis versus a more cautious approach or possibly even diuresis for pulmonary oedema. The increasing use of

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POCUS reflects the growing recognition that this non-invasive, real-time diagnostic tool can improve diagnostic accuracy in many clinical presentations (Smallwood and Dachsel, 2018).

This review explores how POCUS has evolved from simply detecting fluid to becoming a tool for comprehensive assessment of heart and lung pathologies, haemodynamics, and venous congestion, which then can guide real-time clinical decision-making. It will also consider how POCUS might impact future medical practice by expanding into the community.

Evolution of Ultrasound

The medical applications of ultrasound were first considered during World War II. In 1942, Karl Theodore Dussik was the first to publish his work on ultrasound in detecting brain tumours (Liu et al, 2023). Despite others demonstrating that his findings were mostly due to artefacts, the potential for ultrasound had been recognised. By the 1960s, it had revolutionised obstetric medicine by giving obstetricians the ability to assess gestational age and monitor for conditions such as foetal hydrocephalus. In the 1970s, a further leap forward was made with the development of real-time imaging. Until then, only static, two-dimensional images had been possible. This was ground-breaking for specialties such as cardiology and provided a non-invasive method of assessing valve disease and heart failure, among other applications. In the 1980s, emergency medicine saw the potential of ultrasound and Focused Assessment with Sonography for Trauma (FAST) scanning was developed, providing a rapid bedside assessment for detecting internal bleeding in trauma patients (Scalea et al, 1999). In the last decade, ultrasound has made its way to Internal Medicine, being routinely used by many clinicians to assess for conditions like pulmonary oedema, pneumothorax and deep vein thrombosis (DVT). During the Coronavirus Disease 2019 (COVID-19) pandemic, it proved invaluable at rapidly assessing new and deteriorating patients (Gibbons et al, 2021). The latest advances to emerge are venous excess ultrasound (VExUS), which offers a new, non-invasive bedside approach to the assessment and management of fluid status (Kanitkar et al, 2024).

As ultrasound technology advances, ultrasound machines are becoming more portable whilst maintaining their quality (Leidi et al, 2020). The latest advances have led to mobile ultrasound probes comparable in size to a mobile phone, with ultrasound-on-chip technology that can emulate the traditional piezoelectric crystal system (Baribeau et al, 2020). Their portability and potential to return instant results can prove invaluable in providing urgent assessments of patients.

In the following sections, we will describe the development of different protocols for assessing acutely unwell patients.

Lung Ultrasound

Lung ultrasound was thought to be of little value beyond detecting and assessing pleural thickening and effusions, due to aerated lung tissue reflecting nearly all ultrasound waves. It was not until the 2000s when intensivists Daniel Lichtenstein and Gilbert Mezière developed the Bedside Lung Ultrasound in Emergency (BLUE) protocol that lung ultrasound started to become recognised as a useful imaging modality for patients with respiratory failure (Lichtenstein and Mezière, 2008). The BLUE protocol is a rapid, structured ultrasound assessment of the lungs which can be performed in under three minutes. It was developed to detect common pathologies such as pneumonia, pneumothorax, pulmonary oedema, acute respiratory distress syndrome (ARDS) and pleural effusions in a critical care setting. The key ultrasound signs described in the BLUE protocol have since been integrated into several bedside ultrasound training courses such as Focused Acute Medicine Ultrasound (FAMUS) and Focused Ultrasound in Intensive Care (FUSIC). Their appearance and clinical relevance are outlined below.

Lung Sliding

The pleural surface (termed pleural line, Fig. 1) is seen as a hyperechoic (bright) horizontal line just deep to the ribs. In the normal lung, it represents the interface between the parietal and visceral pleura. The appearance of a pleural line that shimmers with inspiration and expiration indicates that the two pleurae are in contact and sliding over each other whereas absent lung sliding, or a pleural line that appears static, can indicate a pneumothorax (Murali et al, 2023) and was found to be more sensitive than X-ray at detecting pneumothoraces (86% compared to 71% respectively) (Aswin et al, 2023).

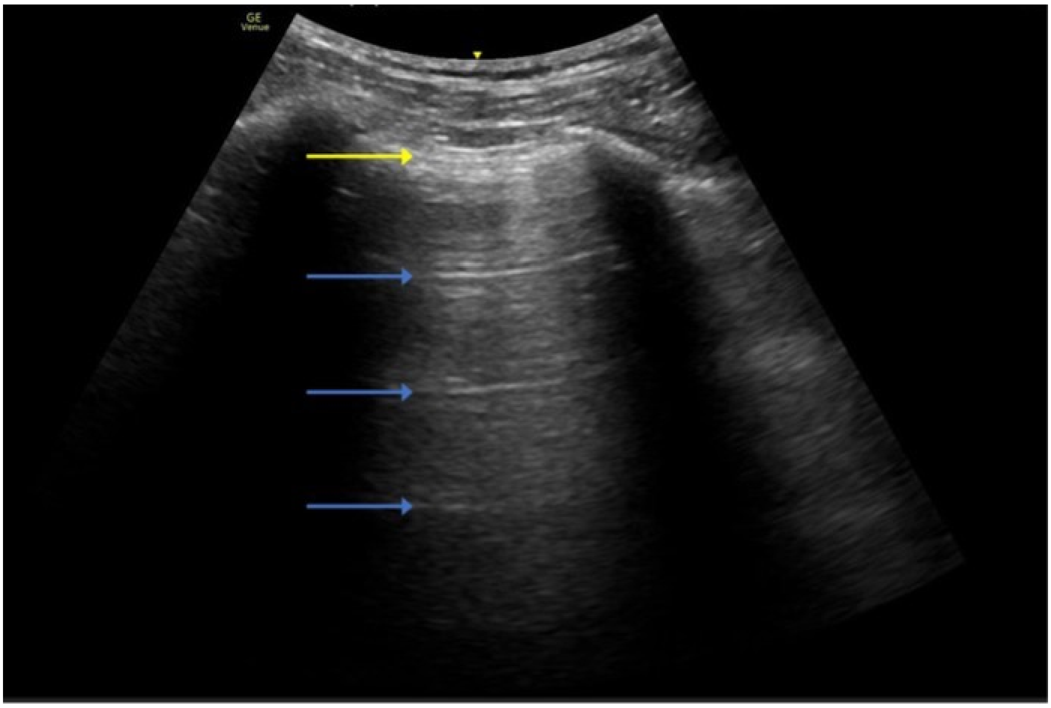

Fig. 1. A-lines. Yellow arrow indicates pleural line. Blue arrows indicate A-lines.

Table 1. The key ultrasound findings and their aetiologies.

Lung sliding	A-lines	B-lines	Pathology
✓	✓	✘	PE COPD Asthma Central pneumonia without reaching the pleura
✘	✓	✘	Pneumothorax One lung intubation
✓	✓	✓	Diffuse B-lines: Pulmonary oedema Focal B-lines: Pneumonia Pulmonary haemorrhage Random mix of A and B lines: ARDS

Abbreviations: PE, pulmonary embolism; COPD, chronic obstructive pulmonary disease; ARDS, acute respiratory distress syndrome.

A-Lines

These recurring horizontal lines denote aerated lung tissue (or when seen with absent lung sliding, they can indicate pneumothorax) (Lichtenstein, 2014). They are an artefact that forms from ultrasound waves being reflected multiple times between the ultrasound probe and the pleural surface. They give the appearance of regularly spaced horizontal lines deep to the pleural line (Table 1; Fig. 1). When a patient has both A-lines and lung sliding, this is termed an A-profile and indicates normal lung tissue (Lichtenstein, 2014). In the dyspnoeic patient, an A-profile would suggest aetiologies affecting the airways or blood vessels; for example, exacerbation of chronic obstructive pulmonary disease (COPD), asthma, or pulmonary embolism (PE) (Lichtenstein and Mezière, 2008; Murali et al, 2023).

B-Lines

These are comet-tail artefacts that arise from the pleural line. They are hyperechoic, well-defined, and erase A-lines (Fig. 2 and Table 1). The presence of three or more per rib space indicates interstitial syndrome (pulmonary oedema, ARDS, or pneumonitis) (Lichtenstein, 2014). Using lung ultrasound to assess for B-lines has been shown to increase the accuracy, specificity and sensitivity of diagnosing pulmonary oedema in patients with heart failure (Muniz et al, 2018). Equally, in patients with a low pre-test probability, the absence of B-lines almost excludes the diagnosis of cardiogenic pulmonary oedema (Al Deeb et al, 2014). This can be game-changing in the initial management of the dyspnoeic wheezy patient, where congestive heart failure often co-exists with airway disease and can be missed (Boella et al, 2022).

Hepatised Lung Tissue

In its early stages, pneumonia can manifest as localised B-lines. As the infection progresses and consolidation becomes more extensive, the fluid content of the lung increases. The appearance of the lung tissue looks macroscopically like

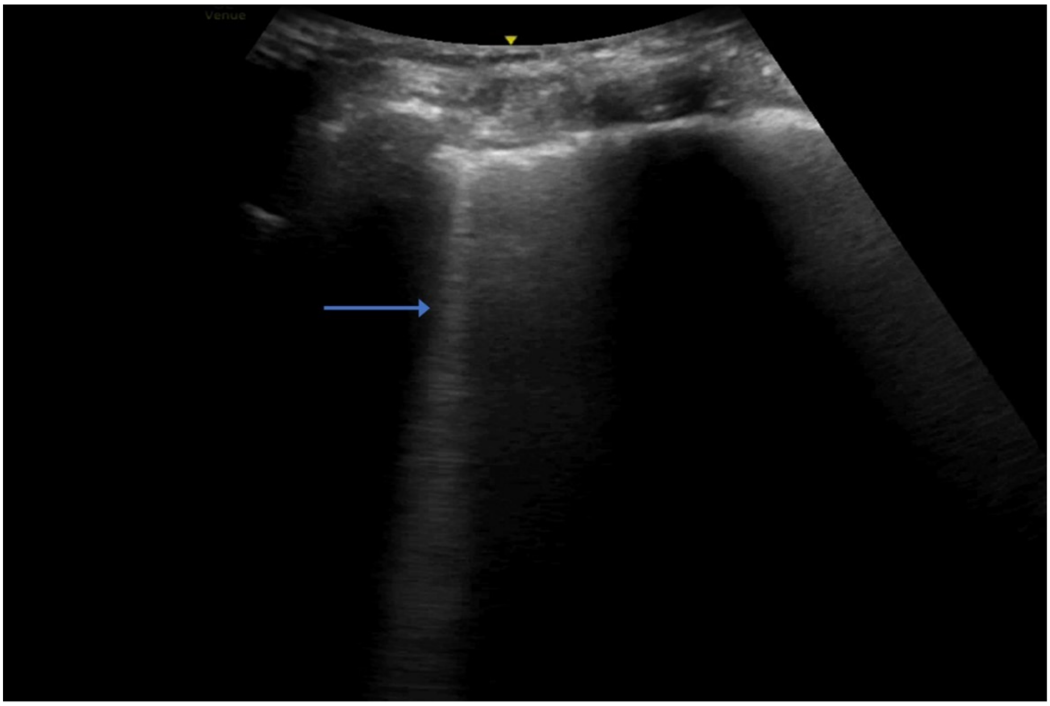

Fig. 2. B-lines. Blue arrow indicates B-line.

liver (red and grey hepatisation). Correspondingly, on ultrasound, it has a similar appearance to liver and hence is described as hepatisation of lung tissue (Fig. 3). Additionally, air bronchograms (small hyperechoic points that move on inspiration and expiration, denoting the movement of trapped air in fluid-filled bronchi) can be seen. Bedside ultrasound is not only capable of detecting pneumonia, but has also been shown to be more sensitive at detecting pneumonia than chest X-rays: A systematic review of lung ultrasound, with a pooled sample size of over 2800 patients, found ultrasound had a sensitivity of 92% whilst chest X-ray had a sensitivity of only 64% (Abid et al, 2024). Not only can it be considered more sensitive than X-ray, but lung ultrasound also has other advantages. In a meta-analysis by Chavez et al (2014), it was found to be superior in terms of time to perform, taking less than 13 minutes. This is an obvious advantage in the acutely unwell patient when compared to computer tomography (CT) and X-ray. It can also be performed at the bedside, making it ideal for emergency and critical care settings. Furthermore, the absence of ionizing radiation increases safety, particularly for certain patient populations, such as pregnant women and children (Chavez et al, 2014).

Acute Respiratory Distress Syndrome (ARDS)

Perhaps more than at any other time, lung ultrasound really came into its own during the COVID-19 pandemic. The widespread inflammation of the lungs caused by COVID-19 pneumonitis appears as an ARDS picture with a mix of A- and B-lines and pleural abnormalities (Gil-Rodríguez et al, 2022). Lung ultrasound was found to have much greater sensitivity than chest X-ray in detecting COVID-19 pneumonitis, with a sensitivity of 97.6% versus 69.9% (Gibbons et al, 2021). Aside

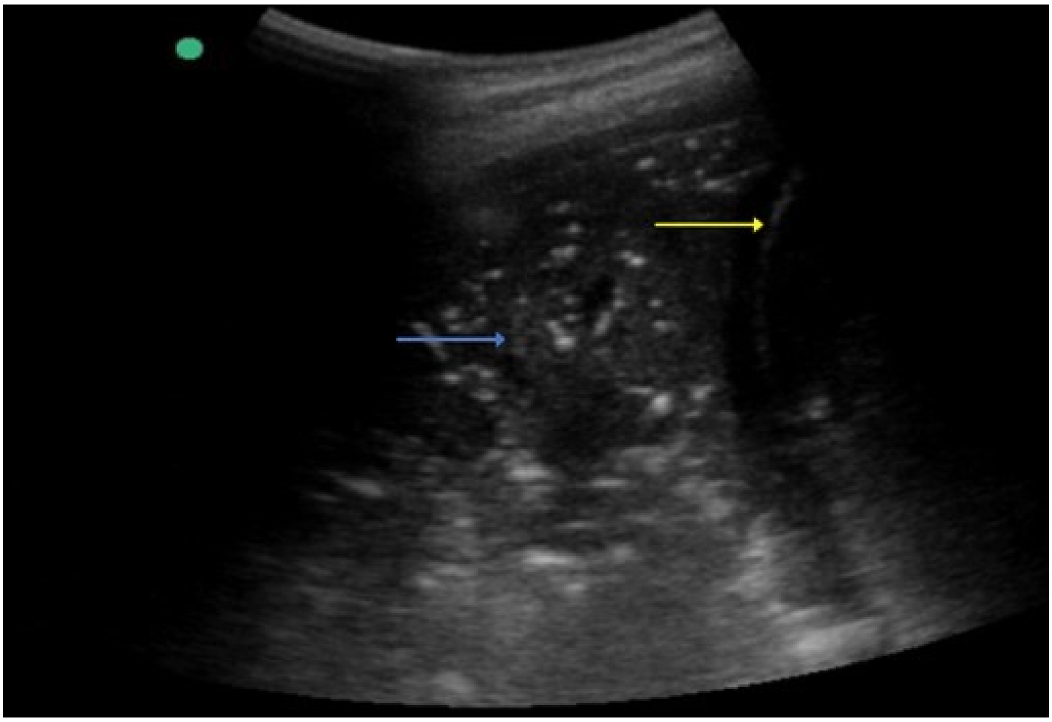

Fig. 3. Hepatisation of lung tissue (indicated by blue arrow). Yellow arrow indicates hemidiaphragm with a small parapneumonic effusion.

from initiating appropriate treatment, this has obvious advantages when patients need to be isolated.

There is no doubt that lung ultrasound is a valuable diagnostic and potential monitoring tool for acutely unwell patients. This was recognised by specialists in Acute Internal Medicine in the UK, and in 2022 it was integrated as a mandatory part of the higher specialty training programme.

Lung ultrasound is a great example of a single-organ system scan. The next chapter explores the development of a multi-system approach for acutely unwell patients.

Ultrasound in Shock and Hypotension

Managing patients with shock or hypotension can be challenging, and one of the priorities is to establish the underlying cause. History (if available) and clinical examination can narrow these down, but they have marked limitations, particularly in differentiating causes of obstructive and cardiogenic shock (Elmer and Noble, 2010). Further modalities are usually needed.

In 2010, Perera et al (2010) published the Rapid Ultrasound for Shock and Hypotension (RUSH) protocol, combining the BLUE protocol with other modalities into a multi-system scan. Performing a RUSH scan includes assessing the pump (heart), the tank (inferior vena cava (IVC), Morrison's pouch, and lungs) and the pipes (aorta and lower extremity DVT). This comprehensive assessment of the patient's circulatory status can be achieved in just under 6 minutes. Findings of the RUSH protocol and how they can guide clinical decisions in emergencies are demonstrated below with clinical scenarios, all of which present commonly to emergency departments.

The first clinical scenario is a 37-year-old lady who collapsed in a gym. She arrived by ambulance with marked hypotension and tachycardia. Using the RUSH protocol, severe right heart strain was seen when assessing the 'pump' (Fig. 4). The 'tank' showed an A-profile (Fig. 1); however, when scanning the 'pipes' an occlusive DVT was seen in the right groin (Fig. 5). Obstructive shock caused by a high-risk PE was rapidly established and the patient received emergency thrombolysis.

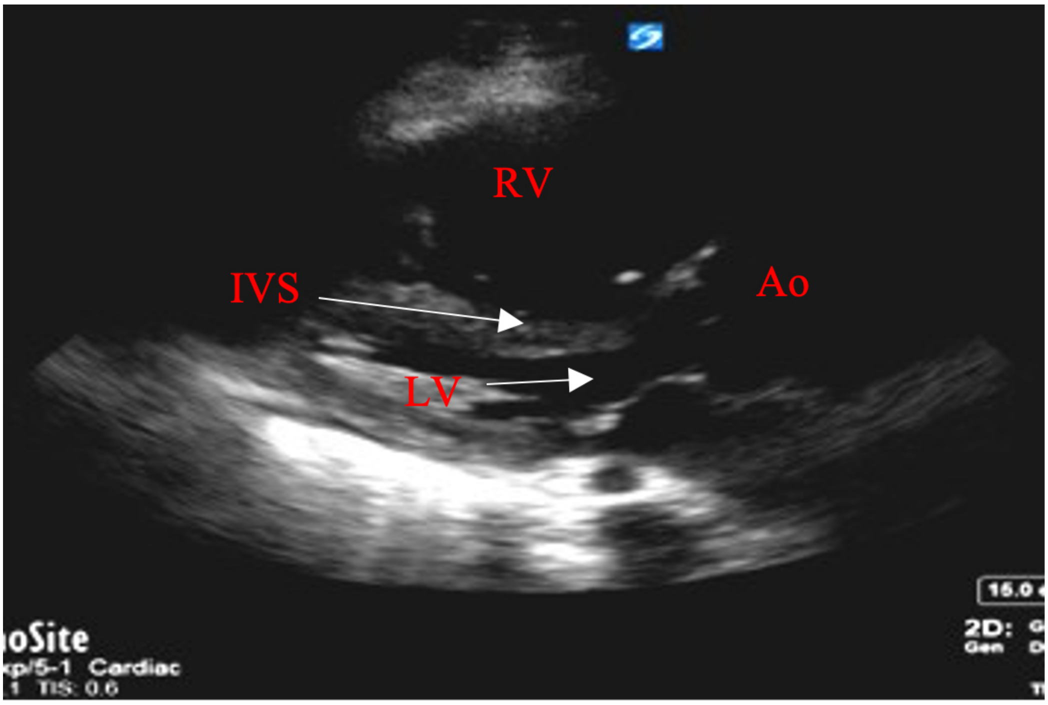

Fig. 4. Parasternal long axis (PLAX) view. A severely dilated right ventricle (RV) is seen. Left ventricle (LV), inter-ventricular septum (IVS), and aorta (Ao) are highlighted. Arrows are to aid labelling of structures.

The second scenario is a 54-year-old lady admitted with severe hypotension and tachycardia. Ultrasound of the 'pump' showed a marked pericardial effusion causing tamponade (Fig. 6). Ultrasound of the 'tank' and 'pipes' was unremarkable. An emergency pericardial drain was inserted. While also an obstructive shock, the RUSH protocol quickly determines a different diagnosis and treatment requirement.

The third scenario is a 62-year-old gentleman who arrived in the emergency department with hypoxia, tachycardia and hypotension. On assessment of his 'pump', the left ventricle was dilated (Fig. 7), while both lungs (the 'tank') showed increased lung water (B-lines, Fig. 8) and sizable pleural effusions (Fig. 9). 'Pipes' were unremarkable. In this scenario, the RUSH protocol identified that the patient was in cardiogenic shock. Urgent diuresis was required, with the addition of inotropes.

In the final scenario, a 74-year-old gentleman, with confusion and multiple comorbidities, arrived severely hypotensive in the emergency department. His RUSH

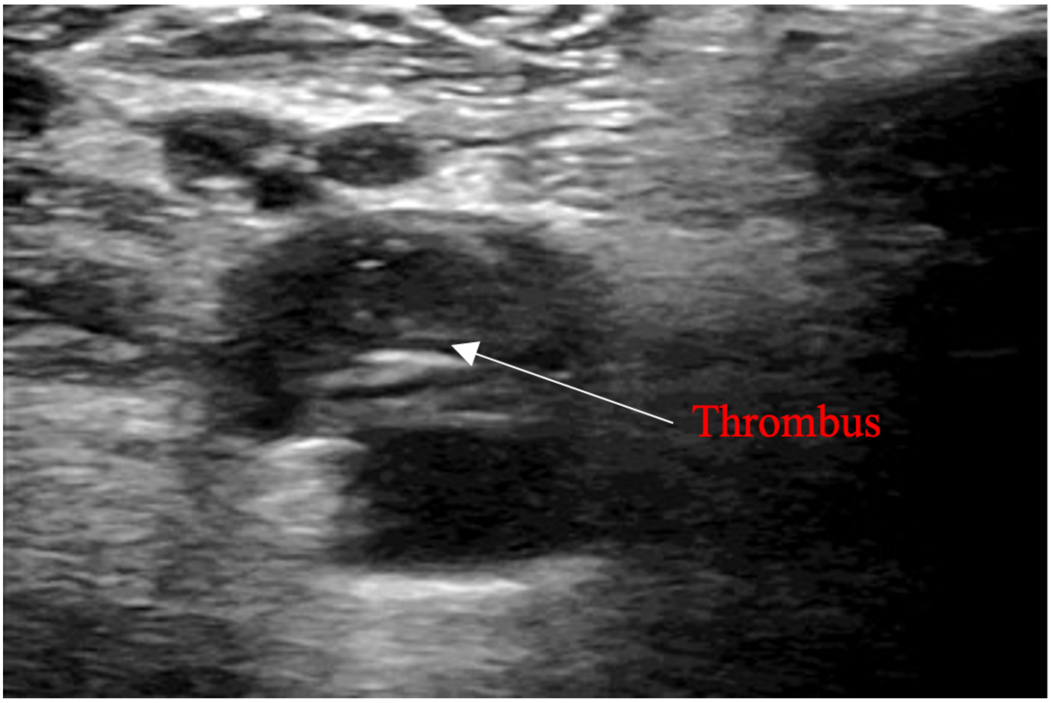

Fig. 5. Deep vein thrombosis (labelled thrombus) in Femoral Vein. Arrow is to aid labelling of structures.

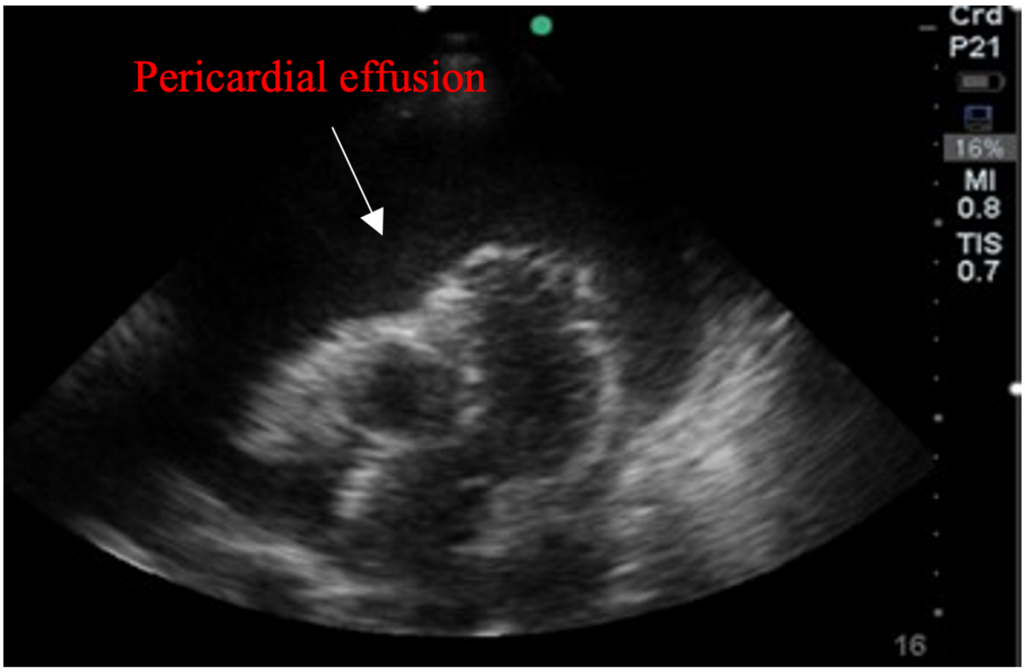

Fig. 6. Apical 4-chamber view, large pericardial effusion. Arrow is to aid labelling of structures.

scan showed a normal 'pump' with a normal-sized and functioning left ventricle (Fig. 10). The 'tank' showed a small IVC diameter (Fig. 11) with full collapse on inspiration. A-lines were present on lung ultrasound (Fig. 1), apart from the right lower lobe where a lobar pneumonia was found (Fig. 3). RUSH protocol identified

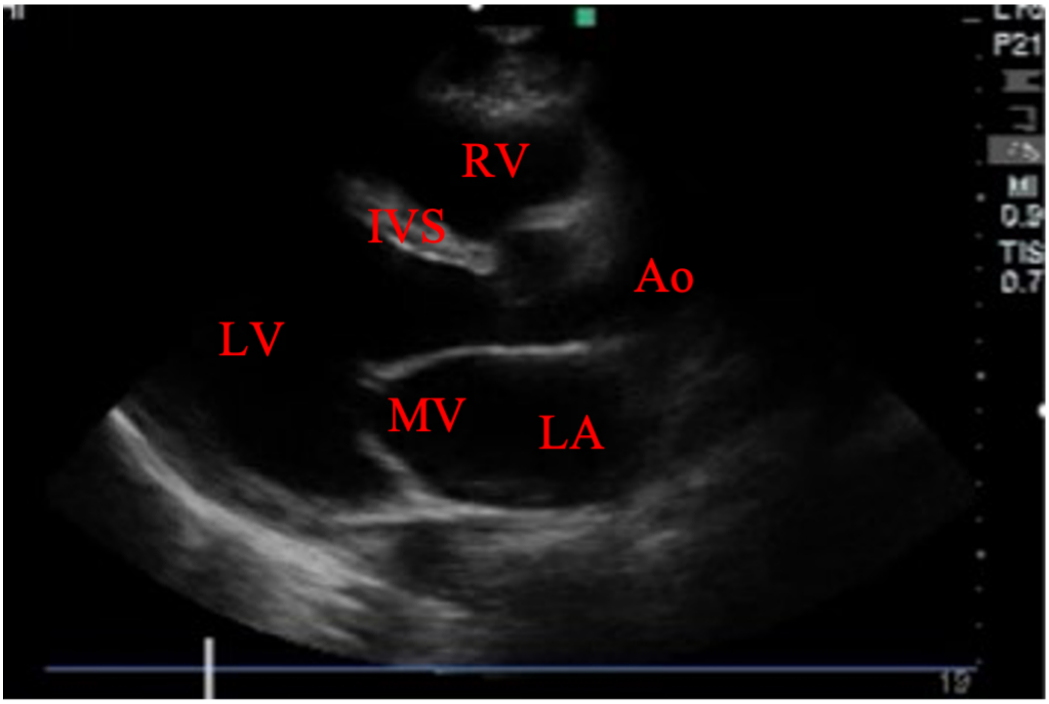

Fig. 7. PLAX view. Dilated left ventricle (LV), with right ventricle (RV), inter-ventricular septum (IVS), mitral valve (MV), left atrium (LA), and aorta (Ao).

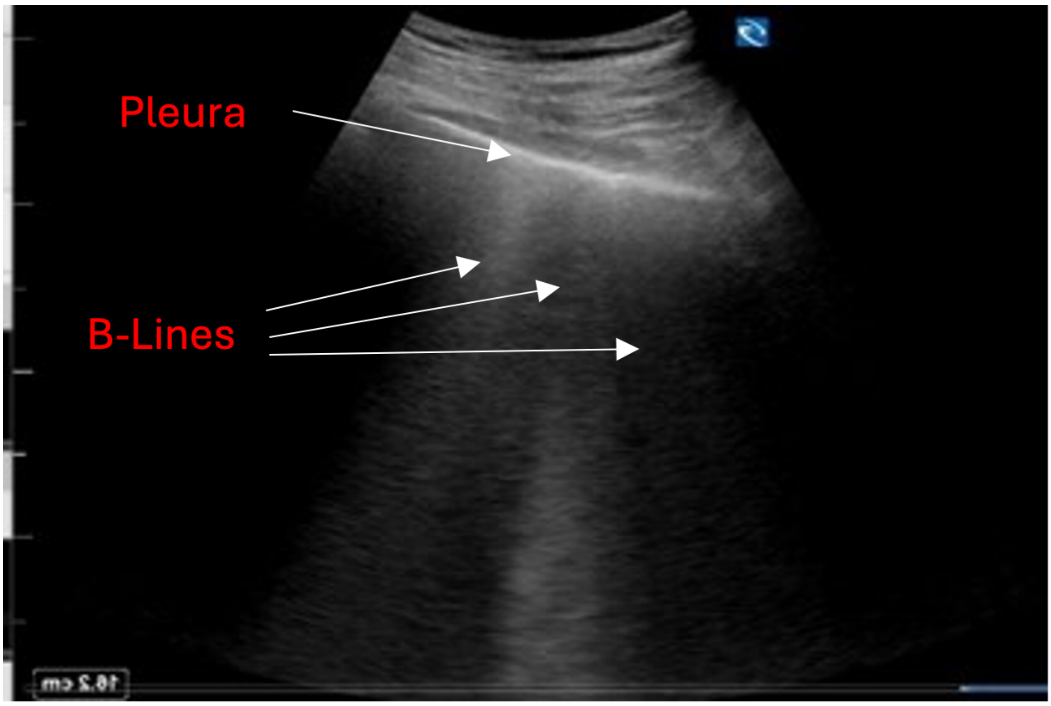

Fig. 8. Widespread B-lines indicating high lung water content. Arrows are to aid labelling of structures.

the patient was in septic shock secondary to lobar pneumonia. The patient was urgently fluid resuscitated with intravenous fluids, and he received antibiotics.

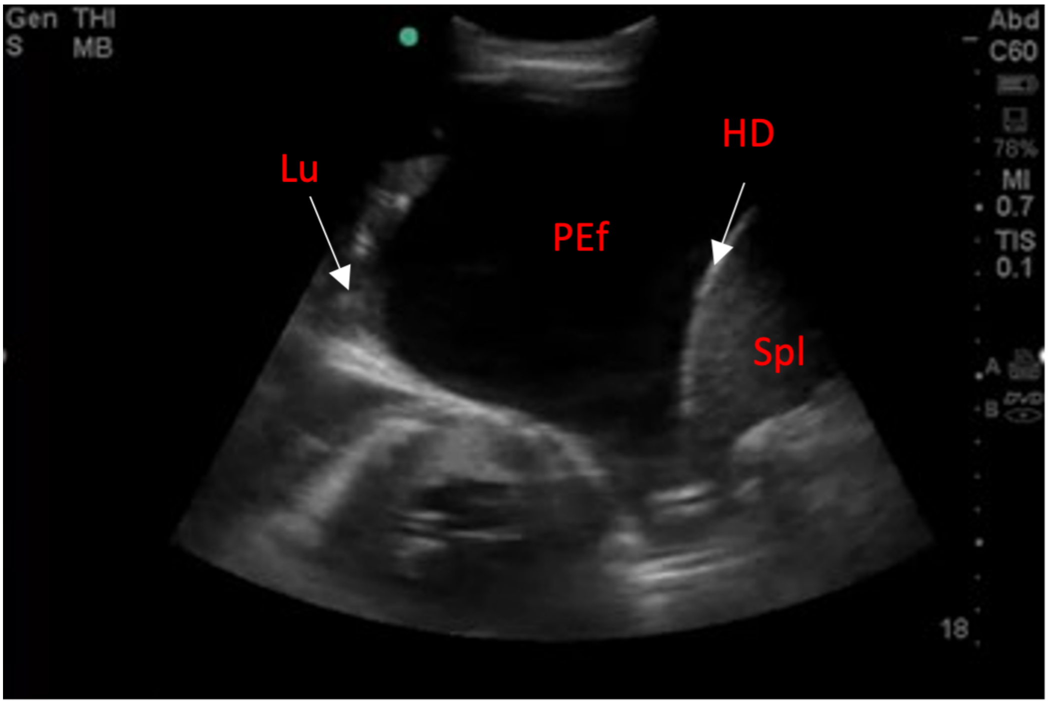

Fig. 9. Marked left-sided pleural effusion (PEf), with collapsed lung (Lu), hemidiaphragm (HD) and spleen (Spl) highlighted. Arrows are to aid labelling of structures.

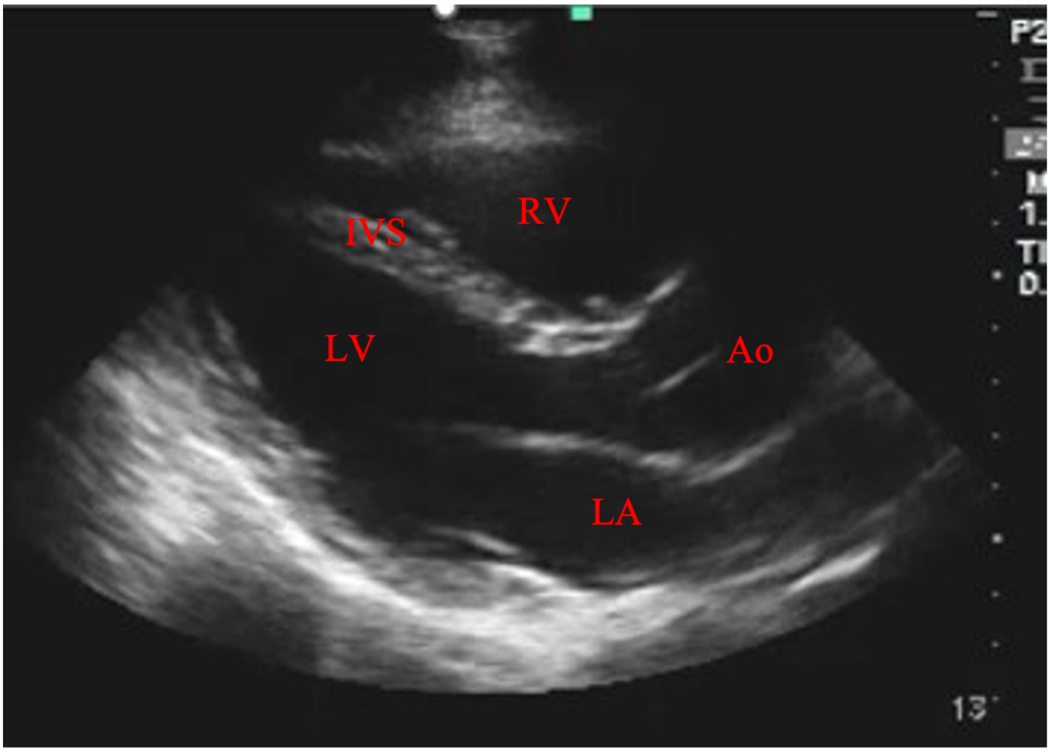

Fig. 10. Parasternal long axis view (PLAX), normal biventricular size.

The impact of the RUSH protocol was assessed in a meta-analysis by Stickles et al (2019). They found positive likelihood ratios of 40 for obstructive shock, 24 for cardiogenic shock, 18 for distributive shock and 8 for hypovolaemic shock.

Negative likelihood ratios were not quite as impressive, ranging from 0.13 to 0.24 for each of the shock types. They concluded that the RUSH exam performed better when used to confirm suspected causes of shock rather than to exclude specific aetiologies.

Therapeutic Guidance

Ultrasound can serve as a therapeutic guide in managing these complex patients. In the past, the concept of "fluid responsiveness" using IVC size and collapsibility, together with cardiac measurements, was thought to be useful for fluid resuscitation. However, Long et al (2017) and Orso et al (2020) performed systematic reviews and meta-analyses looking at the usefulness of IVC size and collapsibility and concluded that neither the IVC size nor collapsibility was reliable in predicting "fluid responsiveness".

There has been a shift towards emphasising the concept of "fluid tolerance" rather than "fluid responsiveness" (Kattan et al, 2022). Nair and Sauthoff (2020) and Lau et al (2024) describe lung ultrasound as a dynamic method for assessing "fluid tolerance" and as a great tool to avoid an increase in extravascular lung water (EVLW), which has been shown to increase inpatient mortality (Gavelli et al, 2022). Marini et al (2020) described the use of lung ultrasound in addition to physical examination to guide fluid therapy in heart failure. They showed that compared to physical examination alone, lung ultrasound can significantly reduce hospital admissions and prevent decompensation.

Consider a 77-year-old severely hypotensive male admitted with a 4-day history of diarrhoea and vomiting, with a past medical history of severe left ventricular dysfunction (known ejection fraction (EF) of $<15\%$). On ultrasound assessment of his pump, there was no pericardial effusion, and the EF was poor. There were no abnormalities found on assessment of his pipes. Most importantly, his tank was empty, with a small IVC and no B-lines or pleural effusions at the lung bases. He received fluid boluses of 250 mL, with lung ultrasound performed after each fluid bolus. A total of 1.75 litres of intravenous crystalloids were infused, which resulted in the resolution of the hypotension, with no signs of pulmonary oedema.

Ultrasound in a Patient With Congestive Cardiac Failure (CCF) and Acute Kidney Injury (AKI)—The Venous Excess Ultrasound (VExUS Scan)

Patients with both congestive cardiac failure (CCF) and acute kidney injury (AKI) represent a clinical conundrum. Consider an elderly woman admitted with increasing confusion. She has a past medical history of congestive cardiac failure, and her bloods show an acute kidney injury. The clinician must ascertain the patient's fluid status and then decide if treatment with fluids or diuretics would be appropriate.

Rola et al (2021) explain that "volume status" is a rather vague concept that remains a challenge for clinicians due to the limitations of physical examination.

For example, looking at the jugular venous pressure (JVP) in an overweight patient is difficult, with a large inter-observer difference, but ultrasound can improve this markedly (Newman et al, 2018). Wang et al (2021) also found a high specificity for elevated right atrial pressure (RAP) with ultrasound assessment of JVP. However, even with an accurate clinical assessment of the JVP, there is no clear evidence that this indicates either organ congestion or fluid responsiveness.

Marik et al (2008) demonstrated a very poor relationship between central venous pressure (CVP) and response to a fluid bolus and concluded that CVP measurement should not be used to make clinical decisions regarding fluid management. In the past, invasive monitoring was needed to identify the presence of venous congestion and the associated potential end-organ dysfunction (Rola et al, 2021).

In 2020, however, a new protocol for detecting venous congestion was introduced by Beaubien-Souligny et al (2020); the VExUS. They combined flow measurements (using pulse wave doppler) and IVC size to determine a venous excess grading score. This was highly predictive in post-operative cardiac patients for the development of AKI with a hazard ratio of 3.69 (95% confidence interval (CI): 1.65–8.24, $p = 0.001$).

The first step of VExUS is to assess the IVC. The intrahepatic portion is measured in a subcostal approach just distal from the hepatic vein confluence. In Fig. 11, a small IVC can be seen, while Fig. 12 shows a dilated IVC.

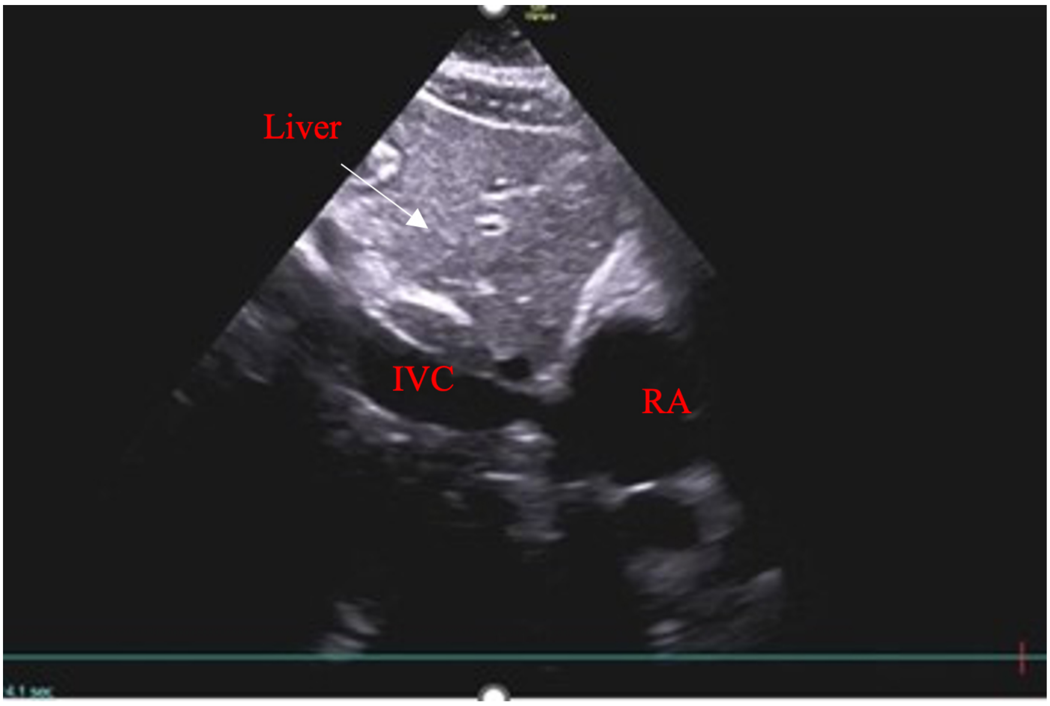

Fig. 11. Normal inferior vena cava (IVC), liver and right atrium (RA). Arrow is to aid labelling of structures.

If the IVC is smaller than or equal to 2 cm, venous congestion is unlikely, and the scan can be terminated at this stage. If, however, the IVC is larger than 2 cm, then the hepatic, portal, and renal veins are assessed for specific flow patterns,

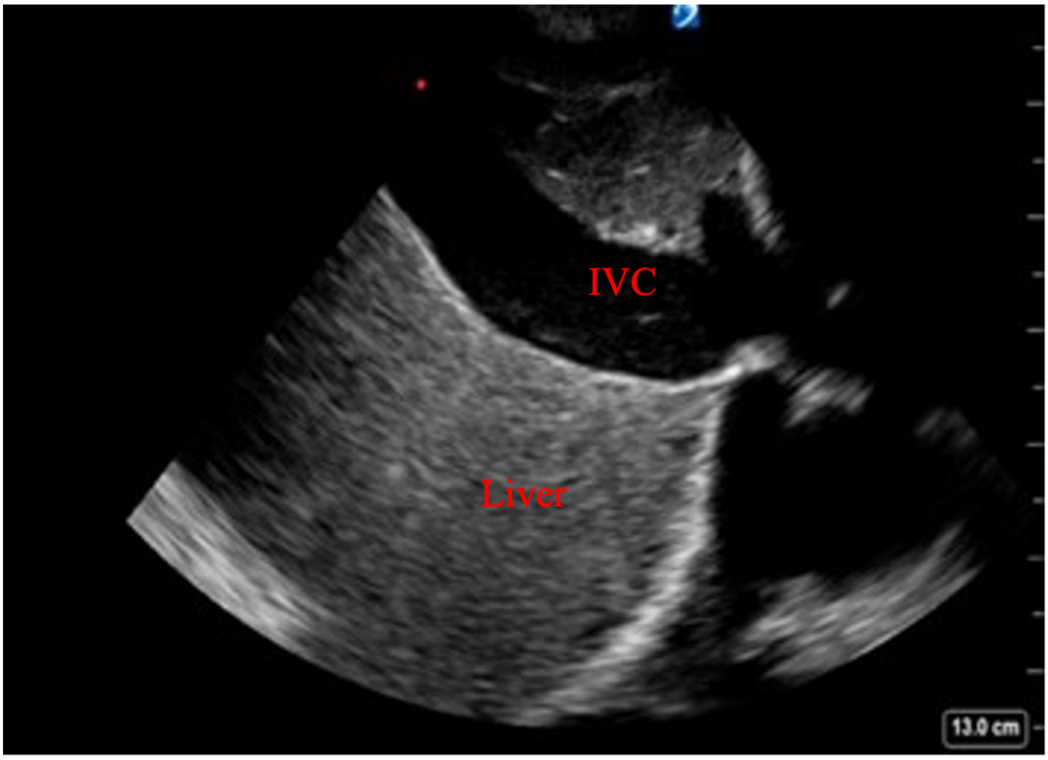

Fig. 12. Large inferior vena cava (IVC) diameter more than 2 cm.

which could indicate organ congestion (Figs. 13,14). A grading system is used to assess the degree of congestion.

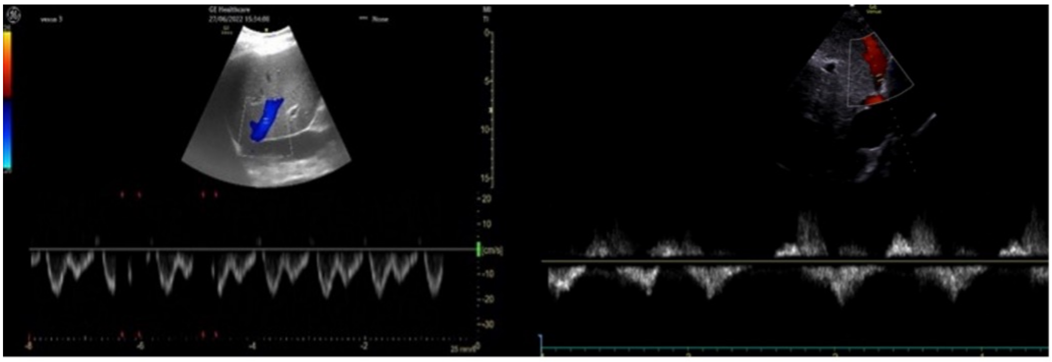

Fig. 13. Normal (left) and severely abnormal flow pattern (right) in hepatic vein.

Returning to the case of the elderly woman with both AKI and CCF, the patient was found to have an IVC of more than 2 cm and severe abnormal flow patterns in hepatic, portal and renal veins. She was treated with diuretics, with improvement of clinical status and kidney injury.

VExUS scanning is currently part of the Focused Ultrasound in Intensive Care Haemodynamics (FUSIC HD) curriculum in the UK.

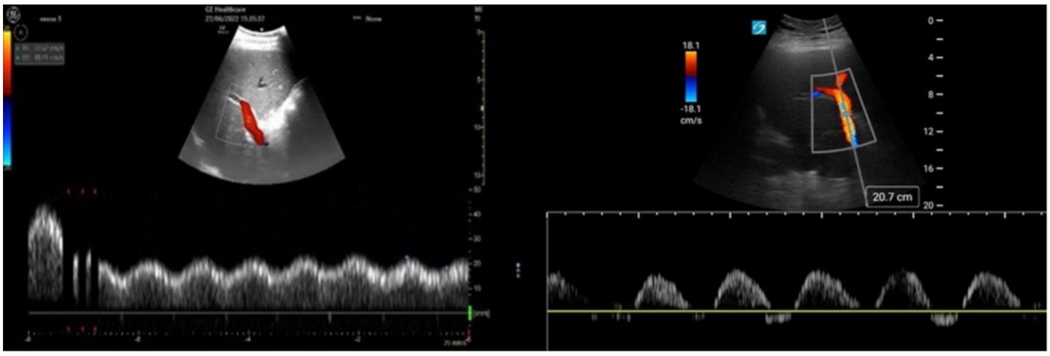

Fig. 14. Mildly abnormal (left) and severely abnormal flow patterns in portal vein.

Expanding the Scope of Ultrasound

Ultrasound in the assessment of acutely unwell patients is mainly used in Intensive Care, Emergency Medicine and Acute Medicine. Other specialties use single organ ultrasound (e.g., Cardiology uses echocardiography, Respiratory uses pleural ultrasound).

Expanding access to ultrasound training across various specialties, including General Internal Medicine, Geriatrics Medicine, and General Practice, may be a worthwhile exercise, particularly with the rise of handheld ultrasound devices (HUD) and hospital-at-home services. Kato et al (2024) report a case where a heart failure nurse reviewed a dyspnoeic patient with multiple co-morbidities (including COPD) at home. The heart failure nurse performed a POCUS exam and was able to determine that the patient was experiencing decompensated heart failure rather than a COPD exacerbation. His diuretics were immediately increased, and he avoided a hospital admission.

With the development of artificial intelligence (AI) functions, the potential for ultrasound is expanding. Modern ultrasound devices already use software with an AI function. Papadopoulou et al (2022) used an AI-enabled HUD and compared AI-measured with manually derived ejection fractions. Detection of abnormal LV function (EF $<$50%) by automated algorithms was feasible, with a sensitivity of 90%, a specificity of 87%, and a total diagnostic accuracy of 88%. Additionally, the HUD in the study could guide the user to achieve the best possible ultrasound images, reducing operator variability.

Another AI feature of current POCUS devices is the automatic detection of B-lines on lung ultrasound. Gottlieb et al (2023) showed that both the physician and AI software were highly sensitive (96.7% vs. 95.6%) in detecting these, though the specificity of the physician was greater compared to the AI software (79.1% vs. 64.1%).

Patients are beginning to be able to use ultrasound themselves. Resnikoff et al (2021) described patient-delivered ultrasound during the COVID pandemic. Patients used the easily accessible antero-apical position, and it was demonstrated that particularly younger patients less than 80 years of age, who used the internet daily, could obtain diagnostic lung images with minimal instructions.

Ultrasound devices are becoming ever smaller and more affordable, while AI is becoming more advanced. Smartwatches already detect atrial fibrillation and falls at home. In the opinion of the authors, it is feasible that in the next ten years, patients may be given or purchase their own HUDs and be able to monitor and manage their conditions at home. The patient with COPD and CCF could be using an AI-enabled HUD to perform a self-assessment and initiate the appropriate rescue pack. The HUD will send the images into the patient's electronic patient record for future reference.

Conclusion

Ultrasound has become an indispensable tool, from diagnosing respiratory failure to managing shock and guiding fluid resuscitation. The portability, availability, and speed with which an ultrasound assessment can be done at the bedside have made it an essential tool to assess critically ill patients. Its ever-increasing integration into clinical practice and medical curricula through programmes like FAMUS or FUSIC further demonstrates its value. With ongoing developments in ultrasound education, its role is set to expand, making it an essential skill for clinicians across multiple specialties.

With further evolution of ultrasound technology and AI, it has the potential for patient self-management, resulting in more involved patients who can be treated at home, with the potential to avoid hospital admissions.

The future certainly does look (echo) bright!

Key Points

- Ultrasound technology can be used by general physicians as a non-invasive point-of-care imaging device to aid clinical assessment and decision-making.
- The BLUE protocol provides a comprehensive framework to aid clinicians in making diagnoses of patients with respiratory failure.
- Other imaging protocols, such as RUSH, provide a framework to ascertain the aetiology of shock and initialise treatments.
- VExUS can help assess venous congestion in patients with heart failure and kidney injury and guide treatment.
- Ultrasound has the potential to be used much more extensively in the community to enable healthcare professionals to assess fluid status better, amend medication, and keep patients out of hospital.
- Advances in size and affordability of probes and artificial intelligence (AI) may soon allow patients to assess themselves in a community setting.

Availability of Data and Materials

All data included in this study are available from the corresponding author upon reasonable request.

Author Contributions

LB, AZ, and MD designed the work. LB, AZ, and MD contributed to the writing of the manuscript. All authors contributed to the important editorial changes of the important content in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

Ethics approval was not required for this review. Images used are from our practice and as per GMC guidelines no patient consent was needed as no patient-identifying information was used.

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Conflict of Interest

Authors LB and AZ have no conflict of interest. Author MD is part of the FAMUS working group in an unpaid role.

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