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Imaging the Critically Ill

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ICU_Management

Imaging is integral to managing critically ill patients in the ICU as it is a key source of diagnostic information to guide clinical decision-making. In recent years, there has been significant evolution in the field of critical care imaging with an increased focus on improving imaging modalities and methodologies and increasing access to imaging findings. Whether it is critical care ultrasound (including echocardiography), computed tomography, or MRI techniques, diagnostic imaging techniques are essential to guide intensive care and patient management. Moreover, the ability to accurately interpret critical care images has become even more essential, thus highlighting the need for better training and education and providing critical care clinicians with the necessary knowledge and skills to make accurate decisions based on imaging findings.

In this issue, our contributors discuss the different imaging procedures used in the ICU and their practical applications and use within the critical care setting, the role of imaging in diagnosing and treating different types of diseases, the importance of identifying the right patients and the right diagnostic tools, strategies that can optimise the use of imaging and the importance of effective interpretation of images for improved patient outcomes.

Etrusca Brogi, Giuseppe Bozzetti, Matteo Romani and co-authors talk about the importance of critical care ultrasound examination and how it should be considered in specific situations in the ICU. They also highlight the need to master all the possible applications and future innovations of ultrasonography in the critical care setting.

Davide Chiumello, Emilia Tomarchio, and Silvia Coppola discuss computed tomography and how it is an invaluable technique for evaluating lung morphology and response to ventilatory strategy and understanding the pathophysiology of Acute Respiratory Distress Syndrome patients.

Laura Dragoi and Ghislaine Douflé explore the current applications and limitations of critical care echocardiography in the critical care context and its use in guiding the care of critically ill patients. Christopher King, Jonathan Wilkinson, Ashley Miller and Marcus Peck discuss the role of point of care ultrasound in the diagnosis and management of pathology in the critical care setting and as a specific tool to aid in invasive procedures.

Raymundo Flores-Ramírez, Carlos Mendiola-Villalobos, Orlando Pérez-Nieto and co-authors discuss ultrasonographic assessment of the neck vessels in critically ill patients and how it can guide fluid administration. Alberto Gómez-González, Miguel Martínez-Camacho, Robert Jones-Baro and co-authors provide an overview of the main ultrasonographic tools that allow physiotherapists to improve their evaluation of the critical patient. Casey Bryant highlights the ever-expanding footprint of critical care ultrasound in ICUs, pointing out the need to continue demonstrating its impact on patient-oriented outcome measures and defining educational curricula and competency requirements.

Imaging is an essential tool for assessing and managing critically ill patients. The use of advanced imaging procedures plays an increasingly important role in the diagnostic and treatment pathway of patients with critical illness. While there are many tools now available to clinicians, using them at the right time and maximising the diagnostic and therapeutic utility of imaging procedures is essential. At the same time, minimising costs is important within the critical care setting.

As always, if you would like to get in touch, please email JLVincent@icu-management.org.

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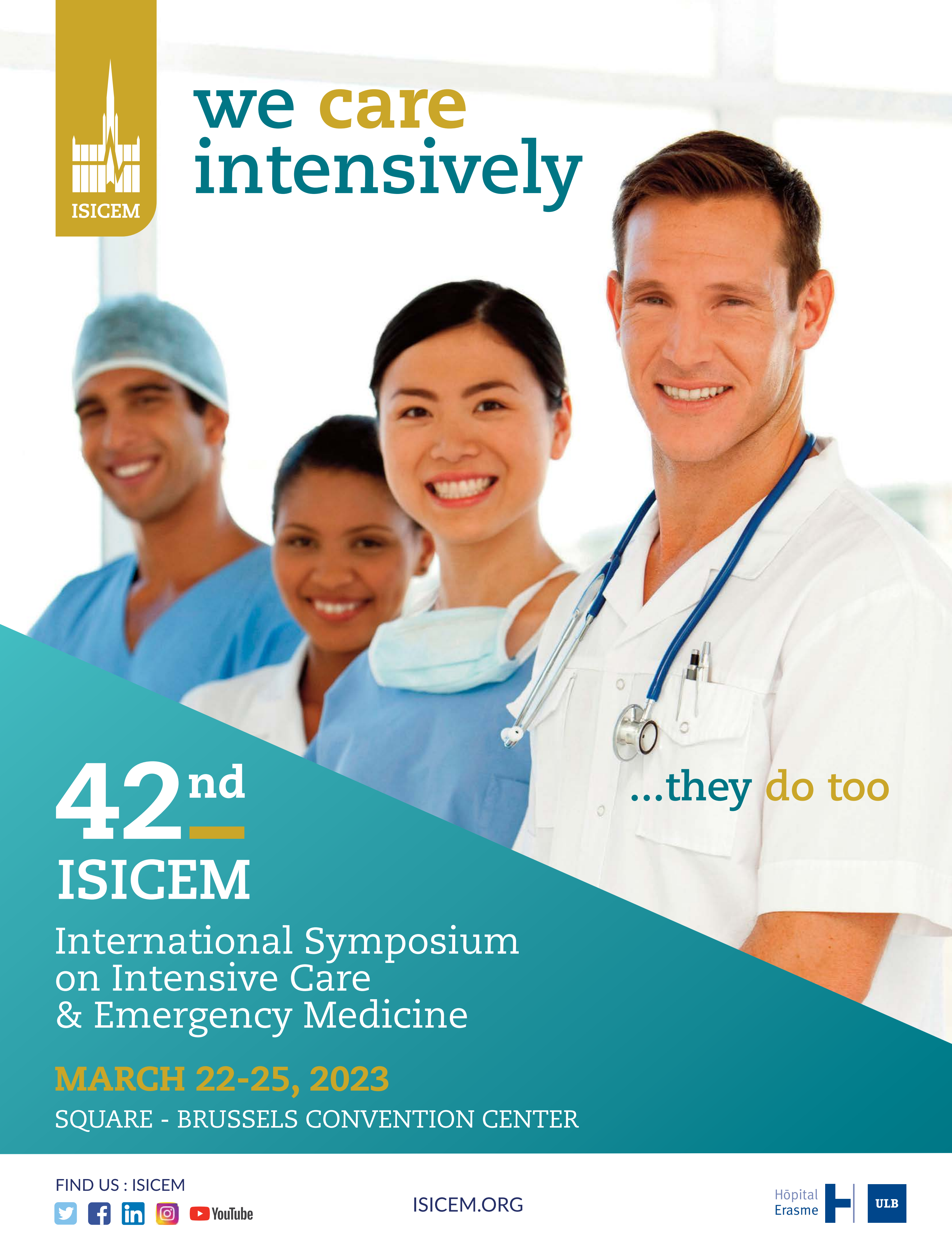
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The Use of Critical Care Ultrasound


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Critical care ultrasound examination should be considered in specific situations in the intensive care unit. It has become increasingly important to understand and master all the possible application and future innovation of ultrasonography in the critical care setting.

Point of care application of ultrasound has been widely validated as an essential imaging technique in the management of critical care patients (Lou and See 2022). Bedside ultrasonography consents real-time evaluation of the anatomy and function of several organs, allowing a rapid recognition and diagnosis of the major cause of haemodynamic instability in intensive care patients (i.e., hypovolaemia, acute cardiac tamponade, pneumothorax, cardiogenic shock, haemoperitoneum). Even more, as part of acute management of critically ill patients, critical care ultrasound examination should be considered for the study of specific situations encountered in intensive care unit; heart and lung interaction, the effects of mechanical ventilation on central haemodynamic, multiorgan consequences of septic shock, severe multisystem trauma, and intensive care unit-acquired weakness (Guevarra and Greenstein 2020; Vieillard-Baron et al. 2008; Soliman-Aboumarie et al. 2021; Mongodi et al. 2021). In addition to clinical examination, ultrasound can provide intensivists with useful information for quick decision-making and set or change therapeutic strategy, allowing a direct evaluation of the response of a specific treatment. Beside its diagnostic potential, ultrasonography also represents a real-time guidance for several invasive procedures (e.g., tracheostomy, central line insertion, local anaesthesia, intercostal drain insertion) (Saugel et al. 2017; Wong et al. 2020). Consequently, it is essential for intensivists to gain specific training and competence in ultrasonography, following internationally validated curricula (Wong et al. 2020; Expert Round Table on Echocardiography in ICU 2014). An overview of possible indications of ultrasonography in ICU is provided in **Figure 1.**

Lung Ultrasonography

Lung Ultrasonography (LUS) is a radiation-free, low-cost, rapid, and portable imaging technique, that allows real-time examination of pulmonary structures. LUS is a key component of critical care; it can be used to evaluate patients with acute respiratory failure, titrate mechanical ventilation, guide interventional procedures, and monitor outcomes (Corradi et al. 2014; Luecke et al. 2012; Schmidt et al. 2019; Corradi et al. 2022a; Vezzani et al. 2017). LUS has also played an important role in the management of patients with COVID-19-associated lung injury through the study of the lung parenchyma and the diaphragm (Hussain et al. 2020; Volpicelli et al. 2021; Corradi et al. 2021a; Corradi et al. 2021b).

LUS has recently gained consideration as a useful tool for the assessment of lung pathophysiology. Compared with chest radiography, LUS has shown higher sensitivity and similar specificity for the detection of pleural effusion, pneumonia, pneumothorax, and pulmonary oedema (Vezzani et al. 2014). However, although recognition of B-lines and differentiation between A- and B-pattern are simple tasks also for beginners, the quantification of B-lines and their distance can be challenging (Corradi et al. 2022b). Thus, automatic methods for the detection and quantification of B-lines have been recently proposed to have an objective, operator-independent, automated, and

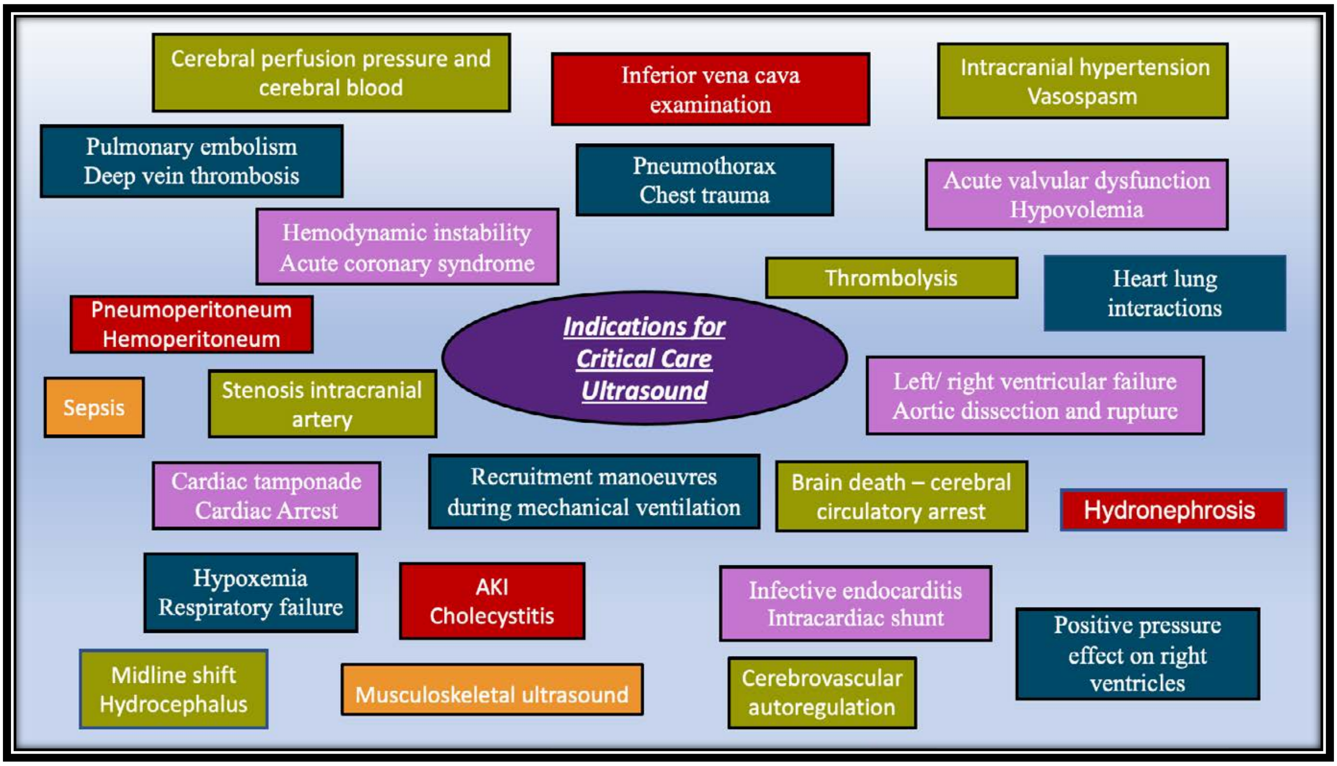

Figure 1. Overview of the major indications for critical care ultrasonography

quantitative classification of the severity of pulmonary interstitial syndrome (Weitzel et al. 2015; Brattain et al. 2013; Anantrasirichai et al. 2017).

In 2013, Corradi and co-workers first studied isolated bovine lung to test the hypothesis that extravascular lung water (EVLW) could be reliably quantified by a first order computer-assisted grey-scale LUS analysis, using gravitometry as a gold standard (Corradi et al. 2013). The results showed that quantitative LUS by video grey-scale analysis was more accurate in the estimation of EVLW than visual scoring or quantitative chest Computed Tomography (CT). Most importantly, the study provided further insight into the relationship between B-lines and EVLW, underlining differences between quantitative LUS and quantitative CT as diagnostic tools. The authors observed that mean LUS intensity was strongly correlated with EVLW but weakly with physical density; CT analysis showed opposite results. These data suggest that comparison of quantitative LUS and quantitative CT has the potential to distinguish increased water content from increased tissue content in lung disorders where pulmonary oedema and parenchymal abnormalities may co-exist. Moreover, quantitative LUS was clearly superior to visual scoring in detecting the presence of EVLW; even in case of amounts as small as 16% of initial lung weight. Furthermore, multi-frame video-based was superior to single-frame method, due to the fact that single-frame methods are not sufficient to evaluate the total respiratory cycle.

In patients mechanically ventilated after cardiac surgery (Corradi et al. 2016), the same group of authors also showed that mean echo-intensities were significantly better correlated with the degree of EVLW content than the 28-region-based aeration score. This study also showed that quantitative LUS was superior to visual scoring in the assessment of EVLW with moderate-to-high positive end-expiratory pressure. Indeed, visual scores (progression or regression of abnormal patterns, spaced B-lines, coalescent B-lines, and consolidation) seemed effective in determining large changes in lung aeration (i.e., >600 ml), as those caused by positive end-expiratory pressure used for recruitment manoeuvres in ARDS; however, the accuracy diminished dramatically with milder changes of lung aeration (Bouhemad et al. 2011).

In adults, computer-assisted LUS has been used in a wide array of pulmonary diagnoses. Raso et al. (2015) graded pulmonary fibrosis and lung oedema by computer analysis in two sets of preselected patients. Corradi et al. (2015) found that the mean grey-scale intensity, determined by computer-aided grey-scale analysis, was considerably more accurate than either chest x-ray or visual LUS in the diagnosis of community-acquired pneumonia confirmed by CT. This was independent of size and distance from pleural line, presumably owing to more hyper-echogenic images resulting from hypo-aerated lung parenchyma around consolidations. In children, quantitative LUS was used to assess the severity of neonatal respiratory distress, to evaluate foetal lungs for predicting neonatal respiratory morbidity, and to detect pneumonia (Raimondi et al. 2018; Cisneros-Velarde et al. 2016; Bonet-Carne et al. 2015). Finally, an algorithmic approach allowed to clinically validate the most valuable semiquantitative ultrasound score by demonstrating that only the calculation of the percentage of the pleural line, inferred by a transversal approach within the intercostal spaces, correlates with EVLW (Brusasco et al. 2019).

There are still technical advancements that are necessary to make quantitative LUS widely applicable in clinical practice: the inclusion of radio frequency signal data in addition to B-mode image data to provide more detailed ultrasound information and the validation of second order statistics, based on a set of textural features extracted from the grey-level co-occurrence matrix, to make results independent of ultrasound device, parameters, and settings (Brusasco et al. 2022).

Furthermore, there is emerging evidence that local lung strain can be estimated by LUS, thus possibly providing a method for assessing local lung ventilation. Although lung sliding is affected by a variety of lung pathologies, the magnitude of this change was never quantified. It has been suggested that speckle-tracking technology applied in the lung will be able to provide speckle displacement during inspiration and expiration (Dori and Jakobson 2016). This would represent the final step towards the development of an ultrasound protocol suitable as a global ventilatory monitoring tool, also allowing the quantification of pulmonary over-distension.

Critical Care Echocardiography

Critical care echocardiography (CCE) has to be considered something parallel to conventional echocardiography performed by cardiologists, requiring specific knowledge of critical care medicine peculiarities. Ultrasonography in critical care setting requires to be quickly available on 24h basis and to respond to specific clinical questions, not only addressing the heart and great vessel anatomy and physiopathology but also evaluating the tight interaction between heart and lung, the potential consequences of mechanical ventilation on right heart and the possible causes of haemodynamic instability (Soliman-Aboumorie et al. 2021). Consequently, critical care echocardiography demands specific training and competence, following internationally validated curricula (Expert Round Table on Echocardiography in ICU 2014).

Bedside echocardiography allows the assessment of global left ventricular (LV) size and function, the identification of regional wall motions abnormalities, the evaluation of right ventricular (RV) size and function, the estimation of pulmonary pressure, the presence of pericardial effusion, the study of valvular dysfunction and to evaluate hypovolaemic status with dynamics parameter (Longobardo et al. 2018). Consequently, several usual disorders encountered in ICU can be quickly diagnosed and treated. Critical care echocardiography is a fundamental tool for the primary evaluation and differential diagnosis in case of circulatory and respiratory failure, especially when combined with LUS evaluation, and to identify life-threatening causes of shock and cardiac arrest (Long et al. 2018; Price et al. 2010; Chou et al. 2020). Noteworthy, ultrasonography may help in the differential diagnosis of the cause of shock in haemodynamic unstable patients, detecting pericardial tamponade, aortic dissection, hypovolaemia, and regional or global LV dysfunction (Yamamoto 2014). Even more, echography findings of right ventricles overload and dysfunction may be also looked at carefully in this setting. Indeed, right ventricular dysfunction can be due to a concomitant cardiac or respiratory disease. However, the findings of right heart overload or dysfunction in a haemodynamic unstable patient always raises suspicions of possible pulmonary embolism (Daley et al. 2019). In this group of patients, CT angiography is generally not feasible, consequently, ultrasound can provide important diagnostic information in order to carry out the diagnosis. The combination of several echography findings such as the 60/60 sign and the McConnell's sign in addition to right ventricle dilatation/dysfunction, septal flattening and RV/LV ratio alteration is highly suggestive of a diagnosis of pulmonary embolism (Konstantinides et al. 2020). Other important findings are represented by the direct visualisation of free-floating right heart thrombus or direct visualisation of deep venous thrombus during compression ultrasonography.

Echocardiography plays an interesting role also in the evaluation of septic patients (Vallabhajosyula et al. 2020). Common features of these patients are represented by potentially reversible myocardial depression, hypovolaemia, and altered vascular tone. Critical care echocardiography, evaluating central haemodynamic and heart, consents to guide management and directly evaluate the effect of therapy. The ultrasonographic evaluation must focus on evaluating cardiac output, cardiac contractility, and fluid responsiveness. Indeed, echocardiographic methods may help intensivists to determine the need for inotrope and fluid infusion (Shrestha and Srinivasan 2018; Guérin and Vieillard-Baron 2016). Dynamic parameters are used to predict a positive response to fluid. In mechanically ventilated patients and in sinus rhythm, distensibility index of

> “ultrasound can provide intensivists with useful information for quick decision-making and set or change therapeutic strategy, allowing a direct evaluation of the response of a specific treatment”

IVC and the respiratory of aortic blood flow are generally preferred.

With CCE, it is also possible to evaluate the diastolic function, although it requires a more advanced use. This is particularly important to define the tolerance to fluid administration: identifying ventricles that display a restrictive pattern (the most advanced form of diastolic dysfunction) may alert clinicians about the risk of pulmonary oedema/congestion with generous fluid resuscitation. Similarly, by analysing the doppler pattern of the hepatic, portal and renal veins (VeXUS score), it is possible to identify various degree of venous congestion.

During cardiopulmonary resuscitation, current guidelines recommend performing CCE, due to the important information that can be gained from this imaging technique. CCE allows to exclude treatable and reversible causes of cardiac arrest without interfering advanced life support protocols (i.e., cardiac tamponade, pulmonary embolism, tension pneumothorax, and hypovolaemia) and to guide consequent invasive procedures (i.e., pericardiocentesis, decompression of tension pneumothorax) improving the safety and efficacy of these interventions (Price et al. 2010; Balderston et al. 2021). Even more, CCE allows the evaluation of the quality of compression (direct and real-time evaluation of compression and relaxation of ventricles) and permits to discriminate true asystole from fine ventricular fibrillation; conditions with different therapeutic approaches. Echocardiography can permit to differentiate patients with pulseless electrical activity (PEA) without cardiac contractile activity (True-PEA) from patients in PEA but who still have cardiac contractile activity (False-PEA); an important prognostic data. Indeed, patients with false-PEA were more likely to have a Return of Spontaneous Circulation (ROSC) (Wu et al. 2018; Gaspari et al. 2021). Moreover, critical care echocardiography, both transthoracic (TTE) and transoesophageal approach (TEE), are fundamental for the management of veno-arterial ECMO in extracorporeal life support (ECLS) programme; from cannula insertion, maintenance, to weaning (Donker et al. 2018). Echocardiography represents a dominant bedside tool allowing disorder valuation, treatment optimisation, and weaning of extracorporeal treatment (Douflé and Ferguson 2016). Possible benefits of CCE during V-A ECMO are represented but not limited to evaluation of arterial and venous puncture size, the choice of peripheral or central ECLS, the presence of thrombus and the evaluation of vessel size, the correct placement of the cannula, the evaluation of the underlying cardiac condition and to evaluate optimal unloading of ventricles (Platts et al. 2012).

It is also worth highlighting the use of TEE in critical care settings. TEE represents another ultrasonography cardiovascular imaging modality (Prager et al. 2022). It requires the insertion of a flexible probe down into the oesophagus; consequently, the transducer's proximity to the heart and great vessel provides a good ultrasonic window (Peterson et al. 2003). TEE is generally performed when transthoracic approach is not diagnostic or feasible. Indeed, transthoracic ultrasound transmission can be altered by several confounding factors resulting in scarce image quality; hyperinflation, emphysema, pneumothorax, chronic obstructive pulmonary disease, obesity, chest wall injuries, or dressing tubing. Even more, TEE can allow the evaluation of structures typically difficult to evaluate with TTE such as the aorta, and left atrial appendage, and provide a superior evaluation of prosthetic heart valves and paravalvular leak and regurgitation, the evaluation of paravalvular abscesses and valvular endocarditis (Lengyel 1997; Michelena et al. 2010). TEE is generally performed during cardiac surgery, with precise procedural indications; evaluation of cardiac structure and function before cardiopulmonary bypass (CPB), monitoring of weaning from CPB, evaluation of surgical repairs and possible complications after CPB. Additionally, TEE finds indications during several haemodynamic and interventional procedures (e.g., percutaneous aortic valve implant, left atrial appendage closure, percutaneous closure of permeable oval foramen, and septal defect closure) (Hahn et al. 2014). Unfortunately, TEE is not widely available in the general intensive care unit.

There are attractive future technical advancements in CCE (e.g., three-

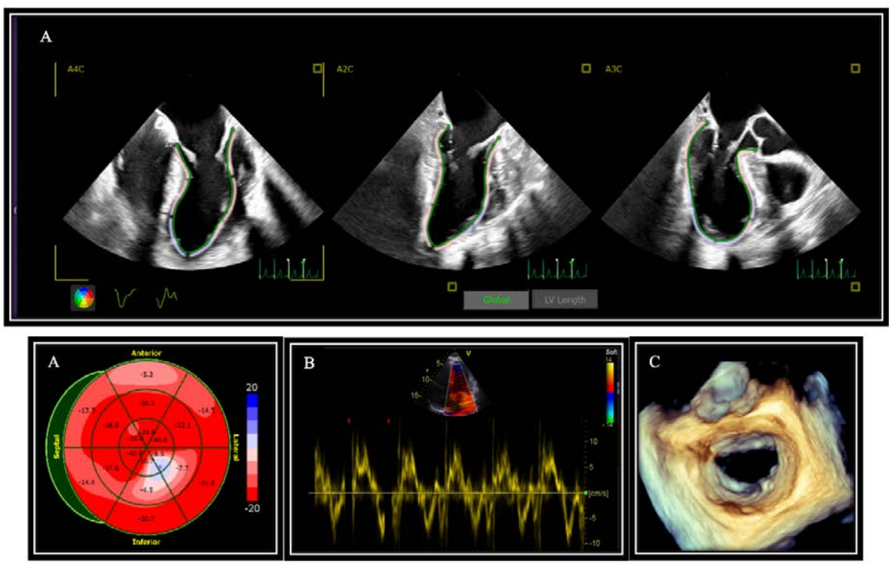

Figure 2. Examples of technical advancements in Critical Care Echocardiography. A. Speckle tracking; B. Tissue Doppler imaging; C. Three dimensional techniques

dimensional techniques, speckle tracking, tissue Doppler imaging, intracardiac echo (**Figure 2**) (Cinotti et al. 2015; Orde et al. 2018; Poelaert and Roosens 2007). Speckle tracking is a relatively new and very interesting technique for the evaluation of myocardial motion wall abnormalities and dyssynchrony. It requires specific software able to track frame to frame the motion through the cardiac cycle in multiple directions. Speckle tracking measurements are extremely useful in the assessment of myocardial contractility, left ventricular dysfunction, and filling pressures, allowing a two-dimensional non-Doppler angle-independent objective analysis of myocardial deformation. Consequently, deformation imaging analysis allows quantifying the thickening, the longitudinal and circumferential shortening of cardiac cycle. Finally, 3D echocardiography represents a useful diagnostic analysis for quantifying complex geometric shape volumes in multiplanes mode, allowing an accurate evaluation of cardiac chamber volumes and valvular anatomy. Unfortunately, 3D echocardiography requires significant offline data processing, and it is, at the present time, not commonly available in general intensive care units (unlike cardiovascular anaesthesia and cardiothoracic ICU).

Musculoskeletal Ultrasound

Intensive care unit-acquired weakness (ICUAW) represents a severe complication encountered in the intensive care unit (ICU). Muscular weakness is the direct consequence of critical illness polyneuropathy (CIP) and/or critical illness myopathy (CIM). The pathophysiological mechanisms are complex and not entirely understood; however, it seems that the synergism of metabolism, inflammation and immunity play a crucial role. Even more, weakness is also associated with medications (e.g., glucocorticoids), nutritional status, and prolonged muscular immobilisation (De Jonghe et al. 2022). Diagnosis is reached with clinical examination and electrophysiological tests (rarely with muscle biopsies). Muscle ultrasound can potentially play an interesting role to investigate muscle changes over time after admission in ICU. Long-term outcomes in heterogeneous ICUAW populations include transient disability in 30% of patients and persistent disabilities that may occur even in patients with nearly complete functional recovery (Formenti et al. 2019).

Muscular ultrasonography allows visualisation and classification of muscle characteristics by cross-sectional area, muscle layer thickness, echointensity by greyscale and the pennation angle. Healthy muscle tissue has a distinctive appearance by ultrasound: in axial images, muscle consists of primarily echolucent (dark) areas interspersed with small, bright, curved echoes of seemingly random orientations. In the sagittal plane, however, these bright echoes are seen to be the fibrous tissue that surrounds muscle fibres and fascicles and is recognisable as striations. Bipennate muscles present a central area of thickened fibrous tissue (central aponeurosis). If followed distally, this structure becomes the tendon. Except for visible arterial pulsations, healthy muscle is static at rest. However, with slow contraction, the central portion of the muscle can be seen to bulge with thinning of its more distal ends (Walker 2004).

Ultrasound may potentially detect the presence of chronic pathologic changes in muscle and measure its dimensions. Common features of critical illness myopathy and critical illness polyneuropathy include symmetric, flaccid limb weakness and ventilatory muscle weakness. Tendon reflexes are often reduced, especially with CIP.

Four main findings distinguish diseased muscle from healthy muscle: increased echogenicity, atrophy, increased homogeneity, and loss of bone shadow (Turton et al. 2016). Ultrasound parameters used to evaluate muscle architecture are:

1. **Cross-sectional area (CSA)**: Determined by the number and size of individual fibres within a muscle. The term 'muscle architecture' (parallel or pennate) refers to the physical arrangement of muscle fibres at the macroscopic level and determines the muscle's mechanical function. In a parallel muscle, the two CSAs coincide, as the fibres are parallel to the longitudinal axis; in pennate muscles, both areas may be used to describe the contraction properties. Muscle atrophy mainly affects type II fibres rather than a relatively equal loss of slow and fast fibres, resulting in the denervation/re-innervation process.
2. **Muscle layer thickness:** Easily identifiable with ultrasound, it has been shown that muscle loss in ICU patients could be monitored by thickness measurements, and it significantly correlates with CSA; however, its predictivity has not been proven in intensive care patients.
3. **Echointensity:** Measure of the image greyscale, reflects the muscle's composition. Increased echogenicity indicates more homogenous muscle. Ultrasonic echogenicity can be graded according to a score that classifies ultrasonic echogenicity semi-quantitatively into four levels, with higher grades corresponding to increased severity of muscle impairment.
4. **Pennation angle:** The angle of insertion of muscle fibres into the aponeurosis. This angle provides information about muscle strength. A higher pennation angle correlates with a muscle's capacity to generate force (Formenti et al. 2019).

Many studies, examining the association between muscle weakness and clinical outcomes have shown muscle weakness as an independent predictor of mortality, increased ventilator-dependent time, and prolonged ICU length of stay (De Jonghe et al. 2002; Sharshar et al.

2009; Ali et al. 2008).

Ideally, within the first 48h after admission to the ICU, the first muscular ultrasound assessment should be performed to define a baseline picture of the quadriceps muscle. At the same time, strength evaluation, using validated tools such as the Medical Research Council (MRC) scale should be also performed as soon as cognitive impairment allows. However, impaired mental status or a low MRC score dictates the need for additional examination for ICUAW, with the aim of preventing muscle weakness; in this case, serial revaluations by muscular ultrasound may represent a valuable aid. In this regard, reductions of 20% in muscle thickness, 10% of CSA, 5% in pennation angle, and an increment in echointensity of at least 8% seem reasonable indicators of ICUAW (Formenti et al. 2019).

Conclusion

Due to the complexity of critical care patients and the often difficult and limited possibility of clinical examination, imaging is playing an increasingly important role to help clinicians diagnose and monitor treatment at the bedside. Among all the different imaging techniques available nowadays, ultrasound can provide intensivists with a round-the-clock assessment of critically ill patients. Understandably, the medical history, clinical setting and therapies must be integrated into the medical assessment. However, it is important to highlight that specific training and a well-defined curriculum to achieve professional competence are warranted. Consequently, it has become increasingly important to understand and master all the possible applications and future innovations of ultrasonography in the critical care setting.

Conflict of Interest

None. ■

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Guiding Clinical Care Using Pancreatic Stone Protein

The role of point-of-care testing in the early identification and management of sepsis, the need for better sepsis markers to identify sepsis, an overview of the Pancreatic Stone Protein (PSP) and clinical evidence highlighting its effectiveness as a biomarker.

Pancreatic Stone Protein

Infections are a leading cause of morbidity and mortality among critically ill patients. The early detection of severe infections is essential to improve patient outcomes. To date, none of the biomarkers that have been investigated have proven to be effective in detecting life-threatening infections quickly and accurately. Despite this lack of effectiveness and sub-optimal performance, C-reactive protein (CRP) and procalcitonin (PCT) are widely used within the clinical setting.

Pancreatic stone protein (PSP) is a new biomarker that has been evaluated in numerous studies and different clinical settings, including emergency rooms and ICUs. PSP is a C-type lectin-binding protein from a family of proteins involved in inflammatory processes during infection and sepsis. Several clinical studies have shown the effectiveness of PSP in diagnosing infection, characterising its severity and predicting patient outcomes.

PSP and Sepsis

One of the most common reasons for admission to ICUs is sepsis. Sepsis is associated with significant morbidity and mortality, and its incidence continues to increase. However, the clinical recognition and assessment of sepsis can be challenging as its symptoms are highly variable and non-specific. Also, when treating sepsis patients, clinicians often face the dilemma of minimising unnecessary antibiotic prescriptions while ensuring timely administration to save lives. Biomarkers can play an important role in helping clinicians make timely and accurate treatment decisions.

There is no doubt that the early recognition and management of sepsis improves patient outcomes. Biomarkers like PSP can help in identifying early signs of infection and sepsis. If not recognised and managed early, sepsis can become life-threatening with septic shock and multiple organ failure (Pugin et al. 2021).

PSP has been studied in several patient cohorts, including critically ill, post-cardiac surgery, and severe burn patients.

> PSP shows high diagnostic accuracy in differentiating sepsis from non-infectious systemic inflammatory response syndrome

In particular, burn victims are in a state of hyperinflammation that can often camouflage septic events. This can delay diagnosis and targeted treatment in such patients and increase the risk of poor outcomes. There is a need to facilitate sepsis detection to help prevent further deterioration of the patients' condition (Klein et al. 2021).

Study findings showcase some unique features of PSP. It can discriminate septic events from non-septic ones in patients with high inflammatory stress levels. PSP levels significantly increase in the blood up to 72h before the manifestation of sepsis. Hence, close monitoring of PSP levels can help identify patients at high-risk of developing sepsis. Compared to other routine inflammatory biomarkers, PSP demonstrates a significant interaction between time and presence of sepsis, thus enabling clinicians to discriminate between patients who are septic compared to those who exhibit a non-septic course (Klein et al. 2021).

PSP is a promising biomarker for sepsis as it increases before clinically proven sepsis and shows a high level of robustness towards sterile inflammatory stimuli such as trauma or repetitive surgeries. During an infection, the pancreas rapidly releases high levels of PSP into the bloodstream, which results in two immunological pathways: direct aggregation and immobilisation of bacteria and binding and subsequent activation of neutrophil granulocytes. A study by Keel et al. (2009) showed that PSP is upregulated in blood after trauma, and these levels are related to the severity of infection. PSP also binds to and activates neutrophils. Polytrauma patients admitted to the ICU with increased PSP levels one day after admission are more likely to develop sepsis, compared to those whose PSP levels remain low or have a moderate increase. Serial measurements of PSP can help clinicians assess the risk of developing post-traumatic sepsis. Hence, PSP is an acute-phase protein and could be an effective marker for post-traumatic complications. Using the PSP biomarker on the abioSCOPE® enables Point-of-Care (POC) diagnostics for clinicians in the ICU and those in the emergency department.

Levels of pro-inflammatory markers are significantly altered due to trauma or surgery and present a major problem to clinicians as it can interfere with the clinical identification of infection. While this is true for all established markers, including C-reactive protein (CRP) and Procalcitonin (PCT), the robustness of PSP blood levels is an important criterion for a sepsis biomarker. PSP levels are not impacted by initial debridement and subsequent burn trauma-related surgeries. This highlights the specificity of PSP for infectious and septic events in burn patients (Klein et al. 2020). PSP has also shown the highest diagnostic accuracy among the tested biomarkers in differentiating sepsis from non-infectious systemic inflammatory response syndrome (SIRS) (Llewelyn et al. 2013).

A systematic review and meta-analysis aiming to determine the performance of PSP in diagnosing infection among hospitalised patients confirmed that PSP was able to detect infection and had high sensitivity and specificity. PSP performed better than both CRP and PCT. However, the combination of PSP and CRP further enhanced its diagnostic accuracy (Prazak et al. 2021).

Conclusion

The lack of a gold standard test to diagnose sepsis in critically ill patients and the often non-specific features of the entity sepsis highlight the need for a biomarker that could predict worsening clinical status, identify severe disease earlier, improve prognosis, have high diagnostic accuracy, be specific and sensitive to disease and quick and easy to implement and assess. Current clinical data on PSP emphasise its advantages for the early identification of sepsis. PSP is an effective biomarker with a short half-life. It also has high accuracy, predictive value, high sensitivity and specificity, and the PSP test is easy to perform at the POC. Serial measurements of PSP can facilitate patient management, guide antibiotic therapy, help reduce antibiotic resistance, and have the added advantage of POC technology at the bedside.

Key Points

- Pancreatic Stone Protein (PSP) is a promising biomarker for sepsis.
- Levels of PSP demonstrate a steep rise before clinically visible and/or proven sepsis.
- PSP is able to detect infection and sepsis in conditions of high inflammation, including trauma, peritonitis, infections, and burns.
- PSP can also be an effective tool for identifying patients at the highest risk of prolonged hospitalisation, more severe illness and need for intensive treatment.
- Rapid and easy evaluation of PSP is enabled thanks to the POC technology (abioSCOPE®), facilitating timely and accurate clinical decision making.

Disclaimer

Point-of-View articles are the sole opinion of the author(s) and they are part of the ICU Management & Practice Corporate Engagement or Educational Community Programme.

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The Role of Lung Imaging to Personalise Lung Ventilation in ARDS Patients

Computed tomography (CT) remains an invaluable technique to evaluate lung morphology and response to ventilatory strategy and to understand the pathophysiology of Acute Respiratory Distress Syndrome (ARDS) patients.

The first report of Acute Respiratory Distress Syndrome (ARDS) in 1967 described patients with severe hypoxaemia and bilateral chest x-ray infiltrates (Nash et al. 1967). After more than fifty years, similarly in the Berlin definition, ARDS was defined by the presence of bilateral opacities not fully explained by effusion, lobar/lung collapse or nodules at chest x-ray (Ranieri et al. 2012). Accordingly, at the present time, the ARDS definition requires no specific imaging criteria for chest x-ray.

The accumulation of fluid in the extravascular space due to the alteration in lung permeability is able to increase the lung density which is clearly shown on chest x-ray. However, when chest x-ray was compared to lung Computed Tomography (CT) scan in a group of patients admitted with a clinical diagnosis of ARDS, the overall diagnostic accuracy was only 72% (Figueroa-Casas et al. 2013). This low accuracy was due both to the non-specific criteria for ARDS diagnosis and to bedside portable radiographic system which presented technical limitations. The diagnostic accuracy, defined as the percentage of chest radiographies correctly interpreted by intensivists, was around 42%, but significantly increased to 55% after a training course (Peng et al. 2021).

The first report on CT applied in ARDS described the presence of dorsal central distribution of densities during the acute phase of the syndrome (Rommelsheim et al. 1983). Contrary to what chest x-ray commonly describes in ARDS patients, the lung CT shows, at a different extension, the presence of non-homogeneous lung disease together with the presence of alveolar consolidation, interstitial lung disease and normal lung areas (Owens et al. 1994). These alterations can present a diffuse, lobar or patchy distribution within the lung which can also change in the course of the disease and during mechanical ventilation (Puybasset et al. 2000). The mortality was significantly higher in the diffuse attenuations compared to lobar and diffuse pattern (Rouby et al. 2000).

In addition to a detailed morphological description of the lung disease, lung CT, by applying a quantitative analysis based on the voxel's CT number, can compute the amount of non-aerated, poorly aerated, normally aerated and hyperinflated regions, the lung weight and lung gas volume. Accordingly, ARDS patients showed an increase in the lung weight, reduction in the lung gas volume and, at different extension, the presence of normally, poorly, non-aerated lung tissue. The reduction in the lung gas volume was significantly reduced in the lower lobes (Gattinoni et al. 2001). Considering gas exchange, the impairment of oxygenation was directly correlated to the amount of lung inflation (Gattinoni et al. 1988).

Furthermore, CT scan is able to evaluate the effects of Positive End-Expiratory Pressure (PEEP), tidal volume, lung recruitability and hyperinflation. The increase of PEEP from 5 to 15 cmH_2O induced both an increase in the normally aerated tissue and a reduction in the non-aerated tissue (Gattinoni et al. 2006). The gas exchange impairment was associated with the anatomic alveolar recruitment suggesting that the normally inflated tissue, after the PEEP increase, was still perfused. The diffuse/patchy, and lobar distribution of the attenuations, resulted in a similar reduction of the lung gas volume in the lower lobes, while the diffuse/patchy attenuations caused a greater reduction in upper lobes compared to the lobar attenuations (Puybasset et al. 2000).

However, the effect on lung recruitment (i.e., the amount of lung tissue in which aeration can be restored) was quite variable. In a group of early ARDS patients, the lung recruitability was around 13% of the total lung weight (Gattinoni et al. 2006). The decrease in non-aerated tissue from 5 to 15 cmH_2O of PEEP was highly correlated with the percentage of potentially recruitable lung estimated at PEEP of 45 cmH_2O. Patients with a higher percentage of potentially recruitable lung had a higher lung weight, impairment of oxygenation and respiratory compliance. Unfortunately, the prediction of lung recruitment was poorly based on clinical indicators at low PEEP levels. The total amount of recruitable lung increased with the ARDS severity and was significantly different in mild, moderate and severe ARDS for the same PEEP level while it was not different according to the body mass index (Chiumello et al. 2016). Obese ARDS patients compared to non-obese ARDS patients had only a lower lung gas volume. Different clusters of ARDS were associated with response to PEEP. In patients with a diffuse attenuation pattern, the increase of PEEP was associated with a significant alveolar recruitment without overdistension, while PEEP caused a lower amount of recruitment with a higher amount of overdistension in lobar attenuation pattern (Puybasset et al. 2000a; Puybasset et al. 2000b). Patients with greater amount of non-aerated tissue and less normally aerated tissue had a higher mortality compared to patients with less non-aerated tissue and higher normally aerated lung regions (Caironi et al. 2015; Gattinoni et al. 2006).

Limiting the tidal volume to provide a possible reduction in the lung stress and strain is commonly used as a protective ventilatory strategy. However, it was observed in a group of ARDS patients that the application of a low tidal volume was associated with tidal hyperinflation in up to a third of the patients (Terragni et al. 2006). These patients had a lower and higher amount of normally aerated and non-aerated compartment compared to patients who did not show tidal hyperinflation.

When different bedside methods for PEEP selection, based on respiratory mechanics, end expiratory transpulmonary pressure and PEEP/FiO_2 (Fraction of Inspired Oxygen) table were compared, only the PEEP/FiO_2 table showed a weak relationship with lung recruitability (Chiumello et al. 2014). This method resulted in different PEEP levels according to the impairment of oxygenation.

CT scan is able to evaluate the effects of PEEP, tidal volume, lung recruitability and hyperinflation

Relatively low PEEP levels (<10 cmH_2O) are accurate to predict the severity of ARDS. Patients classified with moderate/severe ARDS according to the Berlin definition presented a significantly higher lung recruitability compared to moderate ARDS (Caironi et al. 2015).

Although the quantitative assessment is able to compute several clinical indicators, it is time consuming and rarely applied to daily clinical practice (Chiumello et al. 2012). Our group proposed a visual assessment of the alveolar recruitment according to changes in the non-aerated tissue (Chiumello et al. 2012). This visual assessment was able to discriminate with good accuracy patients with a high and low lung potential for lung recruitment (Chiumello et al. 2012).

The lung morphology at low PEEP levels may be associated with different response to recruitment manoeuvre. Patients with focal attenuations showed a lower recruitability and higher amount of hyperinflated compared to patients with non-focal attenuations (Constantin et al. 2010). As for lung morphology, a recent trial did not find any difference in the outcome between a standard ventilatory strategy with low PEEP and a personalised ventilation strategy based on lung morphology (low PEEP levels in focal ARDS and high PEEP levels in diffuse ARDS) (Constantin et al. 2019). However up to 21% of the patients were misclassified. The mortality was lower in the personalised group compared to the control group.

The typically morphologic characteristics in COVID-19 ARDS were the presence of a higher extension of ground glass opacities compared to consolidation, vascular enlargement and interlobular septal thickening (Yang et al. 2020). These alterations were more frequently peripheral, bilateral and involving higher than two lobes (Yang et al. 2020). The ARDS due to SARS-CoV-2 - COVID-19 Associated Acute Respiratory Distress Syndrome (CARDS) presented quite different characteristics compared to other forms of ARDS. The quantitative analysis showed similar lung weight in CARDS and ARDS but a significantly higher lung gas volume and a greater amount of normally aerated tissue (Chiumello et al. 2020; Gattinoni et al. 2020). In addition, when CARDS and ARDS were matched for similar respiratory mechanics characteristics, CARDS was more hypoxaemic and the venous admixture was not related to the amount of non-aerated tissue. These findings suggest that the hypoxaemia was more related to a perfusion-ventilation mismatch and pulmonary vascular impairment compared to typical ARDS.

At the present time, CT remains an invaluable technique to evaluate the lung morphology, the response to ventilatory strategy and to understand the pathophysiology of ARDS patients.

Conflict of Interest

None. ■

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Improving Haemodynamic Management of ICU Patients: Decatecholaminisation and Cardiac Stress Reduction

A summary of a symposium organised by AOP Health with presentations from Ricard Ferrer, Vall d'Hebron University Hospital, Barcelona, Spain; Bruno Levy, Centre Hospitalier Universitaire de Nancy, CHU Nancy · Réanimation Médicale Brabois, France; and Michael Fries, St. Vincenz Krankenhaus Limburg, Department of Anesthesiology, Germany.

Vasopressin in Catecholamine Refractory Septic Shock: Why, When and How?

Sepsis in critically ill patients should be considered a medical emergency. Septic shock is the most common cause of death in intensive care units (ICUs) with a mortality rate of 40 to 60% (Russell et al. 2008). Haemodynamic treatment in septic shock is typically guided by central venous pressure (CVP), mean arterial pressure (MAP) and central venous oxygen saturation ($ScvO_2$). In particular, MAP <60 mmHg is associated with high mortality (Varpula et al. 2005). As per the Surviving Sepsis Campaign Guidelines (SSC), timely and effective fluid resuscitation is essential to stabilise the patient. The guidelines recommend using a minimum of 30 ml/kg (ideal body weight) of IV crystalloids in initial fluid resuscitation (Evans et al. 2021). However, in recent years, this approach has been questioned as there is a lack of personalisation at the early phase of resuscitation.

The primary goals of fluid administration in septic patients is increasing intravascular volume, improving venous return and cardiac preload and increasing cardiac output. There is sufficient evidence to show a beneficial effect of combining fluids with vasopressors in the early phase of sepsis. Combining the two can increase mean systemic pressure and venous return and correct hypotension better. Also, a combined approach of fluids and vasopressors can limit fluid overload which is an independent factor of poor outcomes in patients with sepsis (Hamzaoui 2021). Early initiation of vasopressors in patients with septic shock has been shown to be associated with decreased short-term mortality, shorter time to achieve MAP and less volume of intravenous fluids within 6h (Yuting et al. 2020).

> **"vasopressin is an effective alternative to catecholamine vasopressors"**

Several studies have shown that in patients with septic shock, dopamine is associated with greater mortality and a higher risk of arrhythmic events compared to norepinephrine (De Backer et al. 2012). Norepinephrine is thus the vasopressor of choice. The SSC guidelines also recommend the use of norepinephrine as first-line vasopressor (Evans et al. 2021).

However, there are some patients with refractory septic shock who do not respond to norepinephrine. In these patients, a high dose of norepinephrine is associated with high mortality. In such cases, the SSC guidelines recommend vasopressin as second-line vasopressor to catecholamines. In clinical practice, vasopressin is added when norepinephrine dose is between 0.25-0.5 µg/kg/min. Activation of arginine-vasopressin is a hormonal response to vasodilation-related hypotension. It induces vasoconstriction through the activation of V1a receptors on the vascular smooth muscle cells. The activation of V1a receptors leads to platelet aggregation. Vasopressin also binds to V2 receptors leading to water re-absorption and V1b receptors stimulating insulin secretion. During septic shock, vasopressin plasma level is low. The more serious the infection, the lower is the vasopressin level. The vasoconstrictor properties of vasopressin are useful in the management of vasodilatory shock in patients with sepsis with low blood pressure and in decreasing norepinephrine infusion rate to facilitate decatecholaminisation (Demiselle et al. 2020). In the VASST trial, vasopressor and norepinephrine were administered to patients with septic shock who were resistant to fluids. Study findings showed no significant difference in 28-day mortality in the vasopressin and norepinephrine groups. There was also no significant difference in 90-day mortality, the rate of organ dysfunction, or the rate of serious adverse events between the two groups. Vasopressin infusion resulted in a rapid decrease in the total norepinephrine dose while maintaining MAP (Russell et al. 2008). Hence, vasopressin is an effective alternative to catecholamine vasopressors. The administration of vasopressin in addition to catecholamine vasopressors in patients with distributive shock has been found to be associated with a reduction in the risk of atrial fibrillation compared with catecholamines alone (McIntyre et al. 2018). The SSC review also shows that vasopressin with norepinephrine reduced mortality compared to norepinephrine alone. As per the guidelines, in patients where the use of high dose of norepinephrine is not feasible, the addition of vasopressin is recommended instead of escalating the dose of norepinephrine and to start vasopressin when the dose of norepinephrine is in the range of 0.25-0.5 mg/kg/min (Evans et al. 2021). However, this recommendation may have some flaws. Some experts recommend that the pharmacologic response to norepinephrine should be characterised individually and should be based on a dose-response curve (Guerci et al. 2022).

Landiolol for Beta-Blockade in ICU: Why, When and How

Beta-blockers have multiple effects, including effects on the heart, increase in diastolic time, decrease in myocardial oxygen consumption and improvement in metabolic efficiency. Beta-blockers are also cardioprotective, antithrombotic and may also have anti-inflammatory effects. Landiolol, an ultra-short-acting beta-blocker, has a very short half-life of about 4 minutes and a quick onset of action (1 minute) compared to esmolol with a short half-life of 9 minutes. The duration of effect with landiolol is 15 minutes compared to 30 minutes for esmolol. Landiolol has a minimal effect on the duration of the action potential in cardiomyocytes and does not alter myocardial contractility. In addition, systolic blood pressure with landiolol remains unchanged compared to esmolol which results in a dose-dependent reduction. Hence landiolol has a minimum negative inotropic action. **Table 1** highlights the key differences between the leading beta-blockers used.

In the ICU, beta-blockers like landiolol can be used for multiple indications including atrial fibrillation, chronic cardiac failure, arrhythmia and electrical storm, VV and VA ECMO, aortic dissection without acute aortic insufficient and Tako-Tsubo and pheochromocytoma.

In a study in patients with sepsis-related tachyarrhythmia, landiolol resulted in achieving a heart rate of 60-94 bmp at 24 hours compared to the control group and significantly reduced the incidence of new-onset arrhythmia. Landiolol was also well-tolerated. However, it is recommended that when used, blood pressure and heart rate should be closely monitored due to the risk of hypotension in patients with sepsis and septic shock (Kakikhana et al. 2020).

Case reports of critically ill patients with tachyarrhythmias also demonstrate successful treatment with a continuous intravenous administration of landiolol. Landiolol resulted in an effective decrease of heart rate with minimal effects on blood pressure (Gangi et al. 2022).

Beta-blockers like landiolol can also help improve oxygenation in patients on veno-venous extracorporeal membrane oxygenation (VV-ECMO). In a study in hypoxaemic patients on VV-ECMO, the use of beta-blockers was associated with a moderate increase in oxygen saturation within 12 hours after start of treatment (Bunge et al. 2019). Another study demonstrated the efficacy and safety of ultrashort acting beta-blockers in refractory hypoxaemia during VV-ECMO in patients with COVID-19 pneumonia. Therefore, beta-blockers could potentially be used as an alternative to other rescue therapies (Emrani et al. 2022).

Product	Onset of effect	Elimination half-life	Duration of effect	Cardio- β1: β2 ratio	Effects
Rapibloc® (Landiolol)	1 min	4 min	15 min	255	HR ↓↓ BP →
Esmocard® (Esmolol)	2 min	9 min	30 min	33	HR ↓ BP ↓
Atenolol	5 min	6–7 h	12 h	4.7	HR ↓ BP ↓
Metoprolol	20 min	3–7 h	5–8 h	2.3	HR ↓ BP ↓

Table 1. Key differences between leading beta-blockers used. Adapted from AOP Health, 2022, *Rapibloc (Landiolol hydrochloride): Rapid Rate Control with Myocardial Protection, brochure.*

Septic Shock Management: Clinical Case With Vasopressin and Landiolol

The incidence of and risk factors for cardiac events during catecholamine vasopressor therapy is well-established. Findings from an observational study showed that adverse cardiac events occurred in 48.2% of surgical intensive care unit patients with cardiovascular failure. The extent and duration of catecholamine vasopressor treatment was also independently associated with adverse cardiac events (Schmittinger et al. 2012).

A case study from St. Vincenz Krankenhaus Limburg demonstrates the benefits of using vasopressin with landiolol. A 55-year-old male had a venous saphena bypass. The patient had a CABG surgery in 2018, history, persistent atrial fibrillation along with non-insulin-dependent diabetes mellitus, arterial hypertension and hyperlipoproteinemia. This patient has a rare reason for septic shock: necrotising fasciitis. The patient was taken to the OR for surgery. He was started on regular antibiotic treatment but suffered another massive septic shock in the ICU. The patient had high requirements for norepinephrine. Echocardiogram results showed that the patient's ejection fraction was reduced to 30%. Myocardial infarction was ruled out because he had no regional wall motion abnormalities, but he had severe cardiomyopathy. On top of norepinephrine and dobutamine, the patient was also treated with vasopressin, which started with a dose of 1IU/hour and was increased once blood pressure started to decrease. As heart rate also started to increase, landiolol was added, starting at a low dose and eventually increasing to 4µg/kg/min. Although the patient remained in atrial fibrillation all the time, the frequency was reduced to a more acceptable range of around 90 to 100. His systolic pressure rose to about 110mmHg, and the amount of norepinephrine could be reduced. This shows how vasopressin can be used to increase blood pressure while reducing norepinephrine dose, while landiolol could be used for reducing heart rate, without negatively affecting blood pressure.

Conclusion

Septic shock should be handled as an emergency and it requires fast intervention. Hypotension should be resolved as quickly as possible while avoiding fluid overload and high norepinephrine dose. Vasopressin is recommended to be added at norepinephrine dose of 0.25-0.5µg/kg/min as per the SSC guidelines. This can help achieve target MAP while reducing norepinephrine doses and the adverse events related to it. It can also help reduce the risks of tachyarrhythmias and the need for RRT. The efficacy and safety of landiolol, an ultra-short-acting β-blocker, for treating sepsis-related tachyarrhythmias has been well-established in clinical studies. Landiolol has very high beta1-selectivity and effectively reduces heart rate with minimal negative effects on blood pressure and inotropy and is very well suited for the treatment of critically ill patients. ■

Disclaimer

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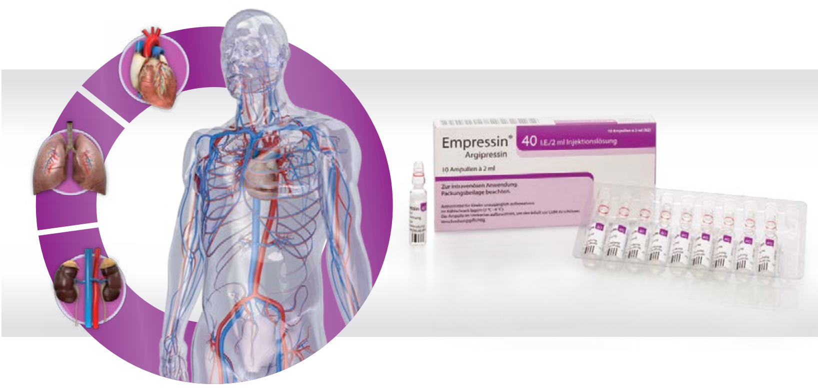

Imaging the Critically Ill Patient: Echocardiography

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Current applications and limitations of critical care echocardiography in the critical care context and its use in guiding the care of the critically ill patient.

Echocardiography in the ICU

Echocardiography is currently considered an essential diagnostic tool at the disposal of the intensivist – a significant change from less than two decades ago when editorials were still advocating for its uptake by critical care physicians (Cholley et al. 2006). Previously a service mainly delivered by cardiologists, echocardiography is now regularly performed by intensivists at the bedside, often as a goal-directed ultrasound examination to hasten the diagnostic process or to monitor haemodynamics. The uptake of ultrasound in common critical care practice is reflected in the development of multiple international guidelines and recommendations delineating the scope of critical care ultrasound and the required competencies for those performing it (Levitov et al. 2016; Wong et al. 2020; Kirkpatrick et al. 2020; Mayo et al. 2009; Expert Round Table on Echocardiography 2014).

This paper will review the current applications and limitations of ultrasound in the critical care context and will conclude with a recommendation on how to determine the appropriate modality of ultrasound for a specific patient.

Terminology

Critical Care Echocardiography (CCE) has been suggested as an umbrella term for all echocardiography performed by intensivists. It can be divided into basic and advanced CCE, where both include transthoracic and transoesophageal modalities (Vieillard-Baron et al. 2019). Two terms frequently applied to describe a goal-directed ultrasound examination performed according to a standardised but limited scanning protocol are FoCUS (Focused Cardiac Ultrasound) (Neskovic et al. 2018; Via et al. 2014) and PoCUS (Point of Care Cardiac Ultrasound). However, definitions and scope vary across the literature. Other protocols developed were FATE – an abbreviated (Focus Assessed Transthoracic Echocardiographic) protocol for screening and monitoring (Jensen et al. 2004), FICE (Focused Intensive Care Echocardiography), FUSIC (Focused Ultrasound in Intensive Care), RUSH (Rapid Ultrasound for Shock and Hypotension), and many more. The American Society of Echocardiography (ASE) differentiates between ultrasound-assisted physical examination (UAPE), cardiac POCUS, critical care echocardiography (CCE), and standard transthoracic echocardiography. The ASE offers definitions for these terms, which include diagnostic expectations, application frequency, interpretation of findings, quantification, indication, and documentation for the different modalities (Kirkpatrick et al. 2020). They detail the necessary teaching requirements, ranging from weeks (UAPE) to years (standard transthoracic echocardiography).

The myriad of terms utilised to describe cardiac ultrasounds performed by intensivists and the lack of standardised, universally accepted definitions for the different modalities pose specific challenges – both in their practical application and in developing training programmes and competency assessments. The lack of a standard curriculum for ultrasound training in critical care (Kanji et al. 2016) and the variability in curriculum content and accreditation pathways (Wong et al. 2019) can compromise the quality of critical care ultrasound delivered in daily practice.

Basic Critical Care Echocardiography

A limited imaging protocol – as is the case in UAPE, basic CCE, FoCUS, or PoCUS - is designed to answer simple questions (e.g., basic assessment of ventricular function, presence or absence of a pericardial effusion) and guide immediate management. The clinician performing the examination should have the competency to acquire and interpret the findings and integrate them within the clinical context. The operator should specify which ultrasound protocol was chosen and understand its inherent limitations. Significant findings might be missed when performing a restricted ultrasound protocol due to the intrinsic shortcomings of basic CCE (e.g., no assessment of valvular pathologies nor use of Doppler modalities) (Douflé et al. 2022; Falaye and Gershon 2017) and the limited experience of the sonographer (Adhikari et al. 2014; Rajamani et al. 2020). Unfortunately, there is a paucity of literature assessing the frequency of missed findings when applying limited ultrasound modalities; the review of images acquired with basic CCE, PoCUS, or FoCUS is further complicated by the fact that they are not routinely recorded; they may be performed after-hours and findings are usually documented in the form of a chart note. The lack of systematic review by clinicians with advanced knowledge of ultrasound leads to a lost opportunity for ongoing feedback. In addition, not all basic ultrasound examinations are followed by a standard echocardiographic study, which could uncover pathologies missed during the initial assessment.

Without the competency to convert a limited imaging protocol to a comprehensive critical care echocardiogram, clinicians should exert caution when relying on basic ultrasound to guide clinical management. Restricted ultrasound protocols can rule in specific pathologies but ruling out a diagnosis might require advanced echocardiography. Advanced CCE should be considered a necessary modality to complement basic CCE in guiding the care of critically ill patients.

Advanced Critical Care Echocardiography

Advanced CCE requires echocardiography skills comparable to cardiologists' and the ability to convert a focused, limited examination into a comprehensive echocardiogram. Ideally, advanced CCE should include competency in both transthoracic (TTE) and transoesophageal (TEE) ultrasound since they each provide specific advantages. TTE is a non-invasive procedure and may allow a better alignment than TEE for Doppler modalities – for instance, when assessing the velocity of tricuspid regurgitation or measuring the Tricuspid Annular Plane Systolic Excursion (TAPSE). There are virtually no contraindications to performing a TTE; however, it requires a more extended training period, and image acquisition might be limited due to patient-specific characteristics, such as mechanical ventilation or prone positioning, making it a highly operator-dependent technique (Teran et al. 2020; Ugalde et al. 2018; Ugalde et al. 2022). TEE is less operator-dependent, can analyse structures not accessible through transthoracic echocardiography (Teran et al. 2020; Ugalde et al. 2018; Ugalde et al. 2022; Evrard et al. 2020), and provide additional information. Skills to perform a critical care TEE can be mastered in a shorter time (Charron et al. 2013). Being an invasive diagnostic modality, performing a transoesophageal echocardiogram is not without risk. However, complications in the critically ill population, with patients usually supported with mechanical ventilation, are rare and consist mainly of unintentional dislodgment of feeding tubes (Huttemann et al. 2004). The other possible risks intensivists performing TEE should be aware of are injury of the hypopharynx or the oesophagus.

> **"basic ultrasound examinations are usually insufficient to answer complex questions regarding underlying pathologies and haemodynamic interactions"**

The lack of readily available equipment can be a limitation for using TEE in the ICU. Not every unit has access to a dedicated transoesophageal echocardiography probe that can be cleaned rapidly and efficiently and deployed for multiple patients with a rapid turnover. In addition, since TEE is not yet part of all CCE curricula, competency and accreditation in the performance of TEE can be challenging to obtain for non-anaesthesia-trained intensive care physicians.

Applications of Critical Care Echocardiography

Aside of its use in the initial assessment on admission and the clinical examination, CCE can provide additional information in managing pathologies commonly encountered in the ICU. A transthoracic echocardiogram is usually performed first, with a subsequent transoesophageal echocardiogram if the transthoracic views are inadequate or insufficient to answer the clinical question. The use of transoesophageal echocardiography has been shown to change management in the critical care population (Garcia et al. 2017). For any given patient, a basic echocardiographic examination can assist in ruling in specific diagnoses – e.g., the presence of pericardial effusion or significant ventricular dysfunction – but might need to be followed by a comprehensive echocardiogram to ascertain the diagnosis or guide management.

Echocardiography in patients with shock

In patients with undifferentiated shock, echocardiography can assist in determining the underlying aetiology. Once the aetiology of shock is established, focused CCE can be repeated as needed to guide the patient's management. Transoesophageal echocardiography plays a major role in the post-cardiac/thoracic surgery population as echogenicity may be limited in the immediate postoperative period. TEE may also identify subtle, localised pericardial effusion or haematoma, which might be missed on a TTE.

Echocardiography for haemodynamic monitoring

Most haemodynamic parameters can be estimated with the use of echocardiography (Narasimhan et al. 2014). Both TTE and TEE can additionally assist in the prediction of fluid responsiveness. Transoesophageal echocardiography may provide information on the respiratory variation of the diameter of the superior vena cava (ΔSVC), which has been shown to have the highest specificity for predicting fluid responsiveness when compared to the respiratory variations of the diameter of inferior vena cava (ΔIVC) and respiratory variations of the maximal Doppler velocity in the left ventricular outflow tract (ΔVmaxAo) (Vignon et al. 2017).

Echocardiography in respiratory failure and mechanical ventilation

CCE can identify cardiac causes of respiratory failure, assess heart-lung interactions, and assist in identifying aetiologies for weaning failure (Warraich et al. 2011; Mongodi et al. 2013; Tavazzi et al. 2016; Moschietto et al. 2012; Adamopoulos et al. 2005). In patients with ARDS, CCE can detect the presence of acute cor pulmonale and monitor how changes in mechanical ventilation parameters – like titration of PEEP, prone positioning, or recruitment manoeuvres - influence RV dysfunction (Repessé et al. 2016; Repessé et al. 2012; Chiumello and Pesenti 2013).

Echocardiography in monitoring patients on ECLS

Echocardiography is an essential monitoring tool for patients supported with ECLS – aiding in the pre-ECLS assessment, as a guidance during the cannulation process to ensure correct cannula positioning, assist in troubleshooting and/or avoiding potential complications. CCE is an invaluable monitoring tool once the patient is successfully cannulated (Morales-Castro et al. 2022; Douflé et al. 2015; Douflé et al. 2022).

Echocardiography in cardiac arrest

In cardiac arrest, echocardiography can help diagnose certain reversible causes and identify patients with pulseless electrical activity who are still exhibiting myocardial contractility (Flower et al. 2021; Price et al. 2010; Volpicelli 2011; Blyth et al. 2012; Blaivas and Fox 2001; Tsou et al. 2017; Breitkreutz et al. 2006; Breitkreutz et al. 2007). Besides establishing a diagnosis, TEE in cardiac arrest helps monitor the efficiency of cardiopulmonary resuscitation (Giorgetti et al. 2020; Yamagishi et al. 2018). It is important to note, however, that the use of TTE has been shown to prolong the duration of chest compression interruptions (Clattenburg et al. 2018). Therefore, only experienced practitioners should be performing the ultrasound in the setting of a cardiac arrest.

The Future

Echocardiography performed by intensivists has undoubtedly established its role in the care of the critically ill patient. However, there are still inconsistencies in terminology, scope, and required competencies.

> **every intensive care unit should aim to have one or more trained and board-certified practitioners able to perform a comprehensive echocardiogram**

The accuracy of image acquisition and interpretation is highly operator-dependent, especially if the operator is only trained in basic ultrasound modalities. A limited ultrasound protocol performed by a physician with advanced echocardiographic expertise is not equivalent to a restricted protocol performed by a physician with basic training. Physicians with advanced expertise can recognise subtle abnormalities (even from a limited protocol) and extend the examination when necessary. Furthermore, basic ultrasound examinations are usually insufficient to answer complex questions regarding underlying pathologies and haemodynamic interactions. At a minimum, images acquired during basic examinations should be saved and reviewed with someone proficient in advanced echocardiography – to adjudicate the accuracy of the study, to ensure that major findings were recognised, and to determine if a comprehensive examination, either as a TTE or a TEE, is required in the specific clinical context (Johri et al. 2020).

Basic and advanced CCE, including both transthoracic and transoesophageal approaches, should be regarded as a necessary complement in the ICU. In recent years, most ICU physicians have acquired some knowledge of basic image acquisition and interpretation. While most intensivists can be trained to perform basic echocardiography, not everyone will develop comprehensive knowledge and skills in advanced CCE. Thus, every intensive care unit should aim to have one or more trained and board-certified practitioners able to perform a comprehensive echocardiogram and supervise practitioners engaged in echocardiographic training (Cholley et al. 2006). Alternatively, close collaboration with cardiology or anaesthesiology may help provide ongoing expertise and training.

Conclusion

Echocardiography is an essential imaging modality for the critically ill, which is easy to apply, readily available, and with no or minimal risk for the patient. However, caution should be exerted when relying solely on findings from restricted imaging protocols. Basic and advanced cardiac ultrasound should be considered complementary modalities and, whilst not every individual intensivist needs to be trained in advanced echocardiography, every intensive care unit should be able to provide the full spectrum of echocardiographic examination (or closely collaborate with other specialties such as cardiology or anaesthesiology) to guide the care of the critically ill patient.

Conflict of Interest

None. ■

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The Clinical Utility of Estimated Plasma Volume in Critical Care

An overview of clinical evidence that demonstrates the prognostic value of estimated plasma volume (ePVS) in critically ill patients.

Relevance

Plasma volume (PV) is the total volume of blood plasma – the extracellular fluid volume of the vascular space. It is associated with regulating interstitial and intravascular spaces; hence it can be an effective marker for volume overload (Kim et al. 2022).

Monitoring and managing volume status in critically ill patients are essential, whether in sepsis, cardiology, post-operatively or in dialysis (Metkus 2022; Rosner and Mullholland 2022). Traditionally, clinicians have relied on physical examination and physiologic variables such as heart rate and blood pressure to determine the need for fluid therapy. However, clinical examination alone is insufficient to guide this decision. Techniques that identify unstable patients and those who may respond to intravenous fluid are needed, as careful use of intravenous fluid is important for improved patient outcomes (Mackenzie and Noble 2014).

Estimated plasma volume (ePVS) is a useful diagnostic and prognostic tool. Elevated ePVS is associated with clinical outcomes in critically ill patients. ePVS has been found to be independently associated with cardiovascular outcomes, rehospitalisation, and death in patients with heart failure (HF) (Turcato et al. 2020). In patients with Acute Respiratory Distress Syndrome (ARDS), ePVS is associated with mortality and ICU- or ventilator-free days (Niedermeyer at al. 2021). A sustained increase in ePVS indicates a congestion status and is associated with a negative patient prognosis and increased mortality. Therefore, volume status is an equally relevant variable for therapeutic decision-making along with IV fluid administration, diuresis, treatment with vasopressors and intubation (Metkus 2022; Rosner and Mullholland 2022).

With ePVS determination and progress monitoring over time (ePV), volume status can be assessed. This allows for prompt initiation of therapy and, if necessary, an adjustment of therapy. In general, the measurement of PV is often difficult. Simple, non-invasive methods, such as medical history, weight, radiographs, and invasive techniques, such as transcardiopulmonary methods (PiCCO), are used for ePVS determination. Both approaches are labourious, costly, and not always available (Metkus 2022; Rosner and Mullholland 2022).

Alternatively, based on measured haemoglobin and haematocrit values, ePVS can be calculated using the Strauss formula:

$$\Delta ePVS = 100 \times \frac{\text{hemoglobin (g/dL)(before)}}{\text{hemoglobin (after)}} \times \frac{100 - \text{hematocrit (\%)(after)}}{100 - \text{hematocrit (before)}} - 100$$

There is another formula that can also help with ePV estimation. It is an extension of the Strauss formula by Duarte et al. It provides an instantaneous measurement of PV using haematocrit and haemoglobin data from a single time-point (Kobayashi et al. 2021).

$$ePVS = (100 - \text{hematocrit (\%)}) / \text{hemoglobin (g/dL)}$$

Clinical Studies and Case Studies

Congestion is a well-established predictor of outcomes in patients with HF, as it can lead to worsening disease and is associated with high mortality. In the event of inadequate therapy or residual congestion at discharge, there is a high risk of rehospitalisation. Therefore, a better understanding of the pathophysiology of congestion is extremely important, as is the need for finding more personalised therapies (Kobayashi et al. 2021; Boorsma et al. 2020).

In patients with acute HF, PV could increase by nearly 40%. This can lead to impairment of pulmonary function (Kobayashi et al. 2021). Volume overload with haemodynamic and clinical congestion can be a complex process in patients with acute and chronic HF. Multiple factors contribute to the accumulation and redistribution of fluid, ultimately resulting in volume overload and organ congestion. While clinical signs and symptoms can help alert clinicians of a change in volume status, there is still a need for quantitative measurement of blood volume in the patient as it can help guide treatment and/or adjust therapy (Miller 2017).

Findings from a study with 324 HF patients showed that the extent and composition of intravascular volume expansion significantly affected clinical outcomes. The impact of volume profiles varied with the progression of HF. Intravascular volume profiles were also predictive of the risk of HF admission, readmission or death (Kelly et al. 2021).

Transcatheter aortic valve implantation (TAVI) is an essential treatment option for severe aortic stenosis (AS). Subclinical congestion in patients undergoing TAVI is associated with worse clinical outcomes. However, this congestion often remains undetected during routine clinical assessment. Non-invasive techniques to calculate PV based on weight and haematocrit can improve prognosis in patients with HF. In 2021, in a prospective study of 859 patients undergoing TAVI, Seoudy et al.

(2021) investigated the association between increased PV and poorer patient outcomes. Increased PV occurred in 535 patients. A significant increase in rehospitalisations and all-cause mortality within one year after TAVI (p=.001) were demonstrated. These findings show that increased PV in the subclinical range is a reliable marker (Seoudy et al. 2021).

In ARDS, a severe but common complication in ICU patients, optimal fluid management is extremely important (Niedermeyer at al. 2021).

In a study with 3165 ARDS patients a mean and median PVS of 5.9% was determined. Yet 68% of those patients had a positive PVS. Variations from the median were associated with outcome: a PVS above median resulted in a 30.6% mortality rate, whereas a lower PVS resulted in a 21.6% mortality rate (Niedermeyer et al. 2021).

Sepsis is often associated with haemorrhagic shock, Clarkson's syndrome and vasodilation. To ensure haemodynamic stability, plasma replacement therapy is often necessary (Marx et al. 2021). Volume status assessment and therapy monitoring are essential in these patients to detect and avoid lung or kidney congestion. Inadequate and aggressive fluid administration can lead to poor patient outcomes. Hence, fluid management needs to be carefully considered and monitored (Kalantari et al. 2013; Vincent 2019).

In a study with 1502 patients with fever at the emergency department, researchers evaluated the ePVS value registered at the time of admission and derived from complete blood count. 3.4% of the patients died at 30 days, and 5.3% of patients had a diagnosis of sepsis. The median ePVS in patients who died was higher compared to patients who survived (6.01dL/g vs 4.49dL/g, p<.0001). Hence, the ePVS value appears to be an effective tool for predicting the presence of sepsis and 30-day mortality (Turcato et al. 2020).

In another prospective study with 100 patients admitted to the ICU with sepsis or septic shock, in-hospital mortality was 47%, and the ePVS was found to be correlated with the amount of total fluids administered 24 hours before admission. The mean ePVS in patients who died was higher than in those who survived (7.7 ± 2.1 dL/g vs. 6.6 ± 1.6 dL/g, P = 0.003). These findings also show that ePVS can be used as a novel prognostic factor in patients with sepsis or septic shock.

Conclusion

The clinical evidence clearly shows the prognostic value of ePVS. Using Strauss or Duarte's formula to estimate PV is a useful strategy that can help improve patient outcomes. PV must be closely monitored and assessed through measurements of ePVS as ePVS is associated with in-hospital mortality and worsening outcomes. ePVS estimation remains an underutilised strategy despite clinical evidence of its prognostic value in heart failure and sepsis. ■

Key Points

- Monitoring and managing volume status in critically ill patients are essential, whether in sepsis, cardiology, post-operatively or in dialysis.
- Estimated plasma volume (ePVS) is a useful diagnostic and prognostic tool.
- Elevated ePVS is associated with clinical outcomes in critically ill patients.
- Volume overload with haemodynamic and clinical congestion can be a complex process in patients with acute and chronic HF.
- Volume status assessment and therapy monitoring are also essential in patients with sepsis.
- ePVS estimation remains an underutilised strategy despite clinical evidence of its prognostic value in critical care.

For more information on ePV and its use in critical care, download the white paper here.

Disclaimer

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Tests Available:

pH

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Hb

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Na

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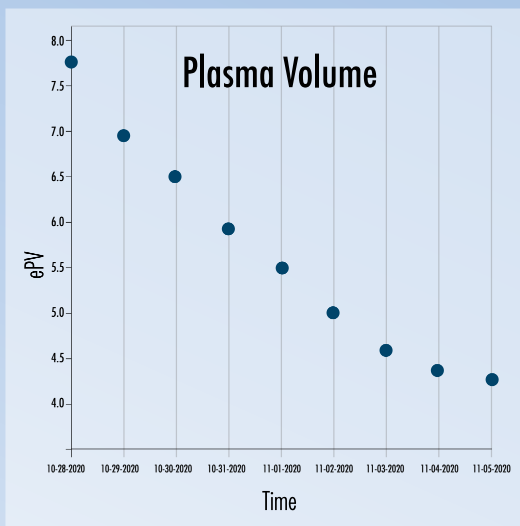

Prime Plus screen showing ePV values

Plasma volume status is vital in testing critically ill patients but is extremely difficult and costly to obtain, particularly as a POC test. Plasma volume assessment affects almost every aspect of a patient's care, including giving IV fluids, diuresing, starting vasopressors, initiating renal replacement therapy, deciding on transfusion requirements and intubation and extubation.[1,2]

Nova's Prime Plus® blood gas analyzer automatically calculates patient plasma volume status using the Strauss formula, which requires measured hemoglobin (Hb) and measured hematocrit (Hct) in order to calculate ePV (estimated plasma volume). Prime Plus reports ePV as part of a comprehensive panel including tests for kidney function, electrolytes, metabolites, gases, and acid/base. It also stores prior ePV values and displays them as a patient trend (ΔePV) graph.

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Point of Care Ultrasound: The Critical Imaging Tool for the Critically Unwell

This article aims to discuss the specific role of point of care ultrasound (POCUS) in the diagnosis and management of pathology in the critical care setting, as well as a specific tool to aid in invasive procedures. We discuss the ABCDE assessment of patients within critical care using POCUS.

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Introduction

Since its introduction, the use of bedside ultrasound has become a ubiquitous examination tool in modern intensive care medicine. It has seen exponential growth, often being the go-to diagnostic and therapeutic imaging modality for specific system-based pathologies. Moreover, it has been utilised in the monitoring and guidance of physiological organ support, and has become the gold standard for the guidance of many invasive procedures.

Competency in Point of Care Ultrasound (POCUS) requires training, experience and tight governance in order to truly benefit patient care. Additionally, it requires a focused consideration of the sensitivity and specificity profile of any imaging modality selected. This provides the practitioner with a 'rule in' or 'rule out' approach, ensuring the path of least harm when basing critical treatment decisions on sonographic findings. POCUS, as the fifth pillar of clinical examination, augments the time sensitive decisions often required to reverse many life-threatening conditions, removing potential guesswork or uncertainty in their execution.

Diagnostic errors can be made when solely utilising clinical skills within such high-pressure settings. Indeed, there may be no time to wait for further diagnostic portable imaging (e.g., portable x-ray). A skilled POCUS operator can rapidly obtain answers to questions at the bedside, providing real-time information on aetiologies. Similarly, dynamic management can be instigated there and then, negating the need for further imaging, tests or transportation to distant places with its associated risks.

We live in an era of rapid technological advancement and with this, ultrasound devices have become miniaturised. Practitioners can pull these devices from their pockets as easily as a stethoscope from around the neck. Where one listened, one can see and where one imagined, one can image. It is purported that POCUS has improved diagnostic accuracy, reduced time to treatment, and potentially increased the survival of ward patients in acute respiratory or circulatory emergencies (Zieleskiewicz et al. 2021).

Specific training programmes are numerous within the United Kingdom and Europe. For example, the UK Intensive Care Society offers a structured and comprehensive accreditation programme known as FUSIC (Focused Ultrasound in Intensive Care). This modularised scheme offers accreditation in whole body ultrasound, including advanced vascular access and haemodynamic assessment. This system will be further discussed throughout this article (Intensive Care Society 2021).

This article aims to summarise and support a protocol-based approach with POCUS as a key imaging tool in the critically unwell patient, both from the initials 'A to E' and point of care assessment and for the ongoing management during an intensive care episode. It will also highlight the role of POCUS within clinical examination and its essential utilisation in procedure guidance on critical care (**Figure 1**).

A - AIRWAY

FUSIC airway, forthcoming

Airway ultrasound can be utilised for various purposes:

- Identification of anatomy - delineation of the relevant anatomy pertinent prior to performing a percutaneous tracheostomy, as well as real-time needle guidance. This includes identification of vascular anomalies which may either facilitate or preclude the placement of percutaneous tracheostomy on intensive care (Tremblay and Sales 2011).

Figure 1. The 'A to E' assessment of a patient using POCUS (Wilkinson J)

- Emergency preparation - identification and marking of the cricothyroid membrane in patients with anticipated difficult airways, prior to definitive intubation. This can offer a vital safety net if emergency front-of-neck access is required, particularly in patients with difficult anatomy.
- Identification of oesophageal intubation - a 'double trachea' sign appears if the oesophagus is inadvertently intubated.

B – BREATHING: Respiratory System

FUSIC Lung

Within ICU practise, lung ultrasound has become a modality with a high yield, devoid of the need for any transport or unnecessary irradiation. Not only does it aid the detection of both acute and chronic pathologies, but it is also a well-established addition for the guidance of thoracic procedures. This is particularly poignant, as for many years, the ultrasound of air-filled spaces was considered pointless.

Several diagnostic protocols exist to standardise diagnoses, the most famous of which is the Bedside Lung Ultrasound in Emergency (BLUE) protocol (**Figure 2**) (Lichenstein 2015). There are also more detailed multi-zone scan protocols within lung ultrasound. One such protocol is the 12-lung zone protocol to assess lateral, anterior and posterior pulmonary segments (Gargani et al. 2020).

The BLUE protocol provides the clinician with a sonographic diagnostic pathway, to ascertain why a patient may be hypoxic (Breitkopf et al. 2022). It considers:

- Fluid - pulmonary oedema, pleural effusions
- Thrombus – pulmonary embolism/ DVT
- Pre-existing disease – COPD/asthma exacerbation
- Infection – pneumonia
- Emergencies – pneumothorax

Compared to standard imaging approaches, CT and x-ray respectively, a 9-point lung ultrasound protocol in ventilated patients has been shown to strongly correlate with specific Computerised Tomography (CT) features of respiratory failure. Moreover, it significantly exceeds the sensitivity and specificity profile of chest x-ray in this patient subgroup (Tierney et al. 2020).

Some sonographic features of normal lung include:

- The presence of lung sliding – occurs only when there is no separation between the parietal and visceral pleura (therefore no pneumothorax).
- 'Seashore sign' on M-mode – an arte-

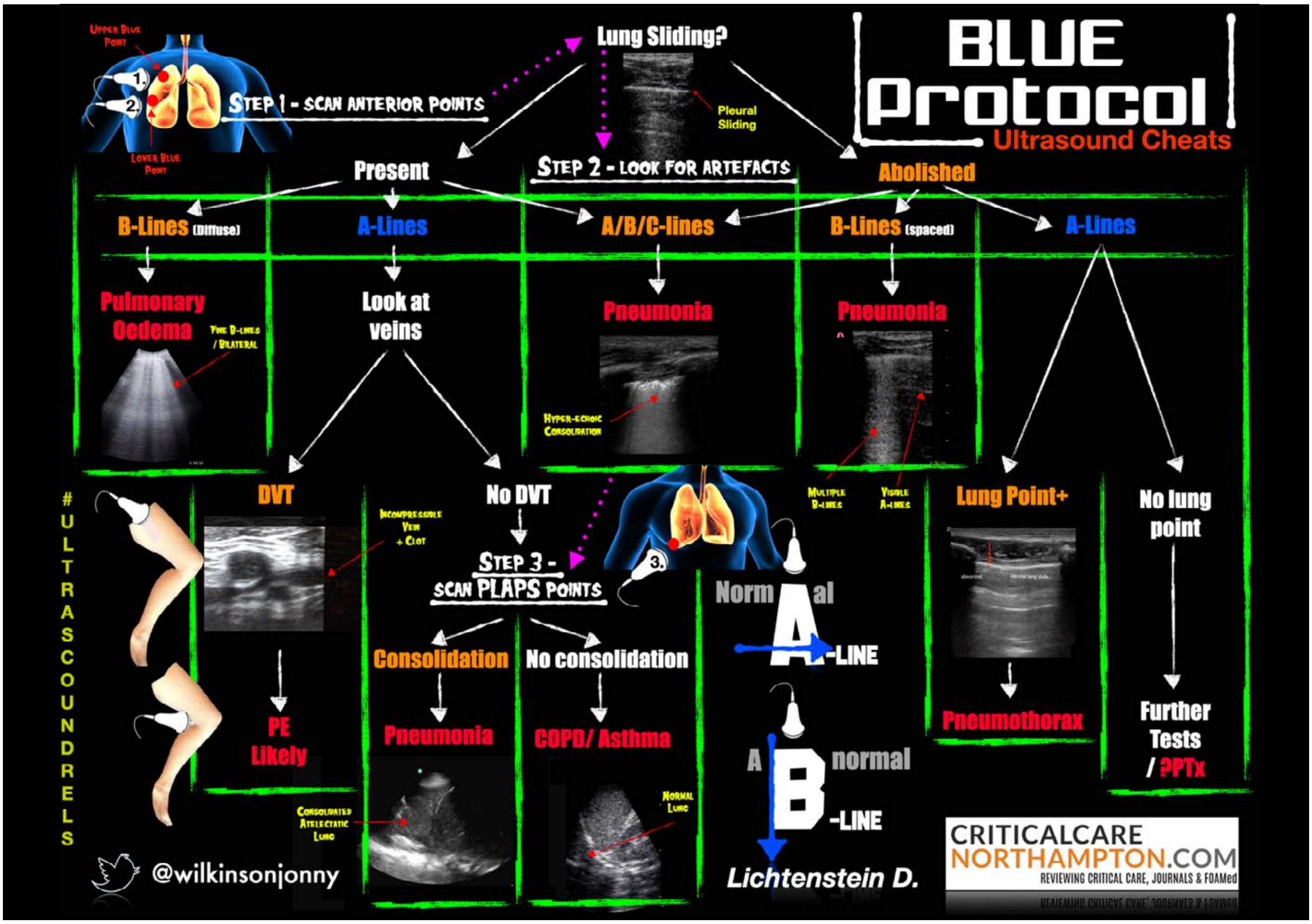

Figure 2. Lichstenstein's BLUE protocol. Reproduced with permission (Wilkinson J)

factual pattern created by sliding pleura (resembling sand, sea and a horizon).

- The presence of horizontal bands called "A-Lines" – appearing as sub-pleural reflections of the pleural layer above (signifying uninterrupted aerated lung below) (Lichenstein 2005).

In diseased lung and pleura, underlying pathologies produce interruptions to the normal tissue/air interface. Many of these result in either the addition, or absence, of specific ultrasound features compared to that of a normal lung.

Some sonographic (not exhaustive), artefactual appearances at the upper anterior lung points include:

- B-lines – uninterrupted, hyperechoic artefacts that extend from the pleural line, right down the entire length of the US screen. They usually result from the presence of an air fluid interface (either interstitial or alveolar fluid next to alveolar air), which can be cardiogenic (pulmonary oedema), or non-cardiogenic (pneumonia, contusion, ARDS, fibrosis) (Bouhemad et al. 2007).
- Absence of lung sliding – signifies the pleural layers are either separated or stuck together or absence of respiration. In a pneumothorax there is associated loss of any B-lines and preservation of A-line profile (Breitkopf et al. 2022).
- Stratosphere/barcode sign on M-mode – lack of pleural sliding of the normal M-mode appearance (produces the so called 'sand on the beach' appearance). This is a sign 95.3% sensitive and 91.1% specific for pneumothorax (Lichenstein 1995).
- Lung point – a horizontally moving interruption to the pleural line, created by the point where a pneumothorax meets normal lung. This is pathognomonic of pneumothorax.
- Pleural effusion – hypoechoic areas usually seen at the lung bases, surrounding underlying, often compressed, lung. This appears as a very clearly delineated structure, almost similar in appearance to the abdominal organs below the diaphragm. Effusions often cause compression atelectasis until drained. Various formulae exist in order to gauge volumes (Bouhemad et al. 2007). It must be pointed out that many pleural effusions are not apparent on plain film radiography yet are more than clear on ultrasound.
- Consolidated lung – normal air-filled lung cannot be viewed with US as the air reflects the sound waves. Consoli-

dation, on the other hand, transmits ultrasound and appears as hypoechoic areas within the lung tissue, as more sound waves are transmitted by fluid/infected tissue. Air bronchograms may be seen as bright white branching structures. As a result of the infective process, B-lines can appear in the upper zones, often spaced out with normal A-line profiling in between. Subtle areas of consolidation are often far more apparent on ultrasound, than they are visible on a plain chest radiograph.

Such pathology, as described above, may necessitate the need for invasive procedures such as chest drains, or diagnostic/therapeutic pleural aspiration. These procedures carry risk from an anatomical perspective (malposition, pneumothorax, breach of intercostal neurovascular bundles). Pleural effusions are poorly located from a radiographic perspective and represent the location at the time at which the image was taken, so are subject to alterations in patient positioning. Real time ultrasound represents a safe approach to locating appropriate sites for drainage/aspiration, identifying local structures and ensuring safe needle positioning + guidewire location, as opposed to a landmark technique. (Millington and Koenig 2018).

C – CIRCULATION: Cardiovascular System and Haemodynamics

FUSIC Heart

In the UK, the FUSIC heart module is by far the most popular of the modular accreditations (Intensive Care Society 2021). There are five standard views (**Figure 3**):

- Parasternal Long Axis (PLAX)
- Parasternal Short Axis (PSAX)
- Apical 4 Chamber (A4C)
- Subcostal 4 chamber
- Inferior Vena Cava (IVC) view

Within those five views are five basic questions:

- Is the left ventricle significantly dilated or impaired?
- Is the right ventricle significantly dilated or impaired?
- Are there features of low venous return?
- Is there a pericardial effusion?
- Is there a pleural effusion?

The above questions are often extremely hard to answer with clinical examination alone, often resulting in best guesswork to align with, or support the clinical picture. Sonography provides a window in to quantify and clearly spot many of the binary answers required to the binary questions.

FUSIC-HD

The new advanced FUSIC-HD module contains 10 more systematic questions, aimed at answering why a patient has

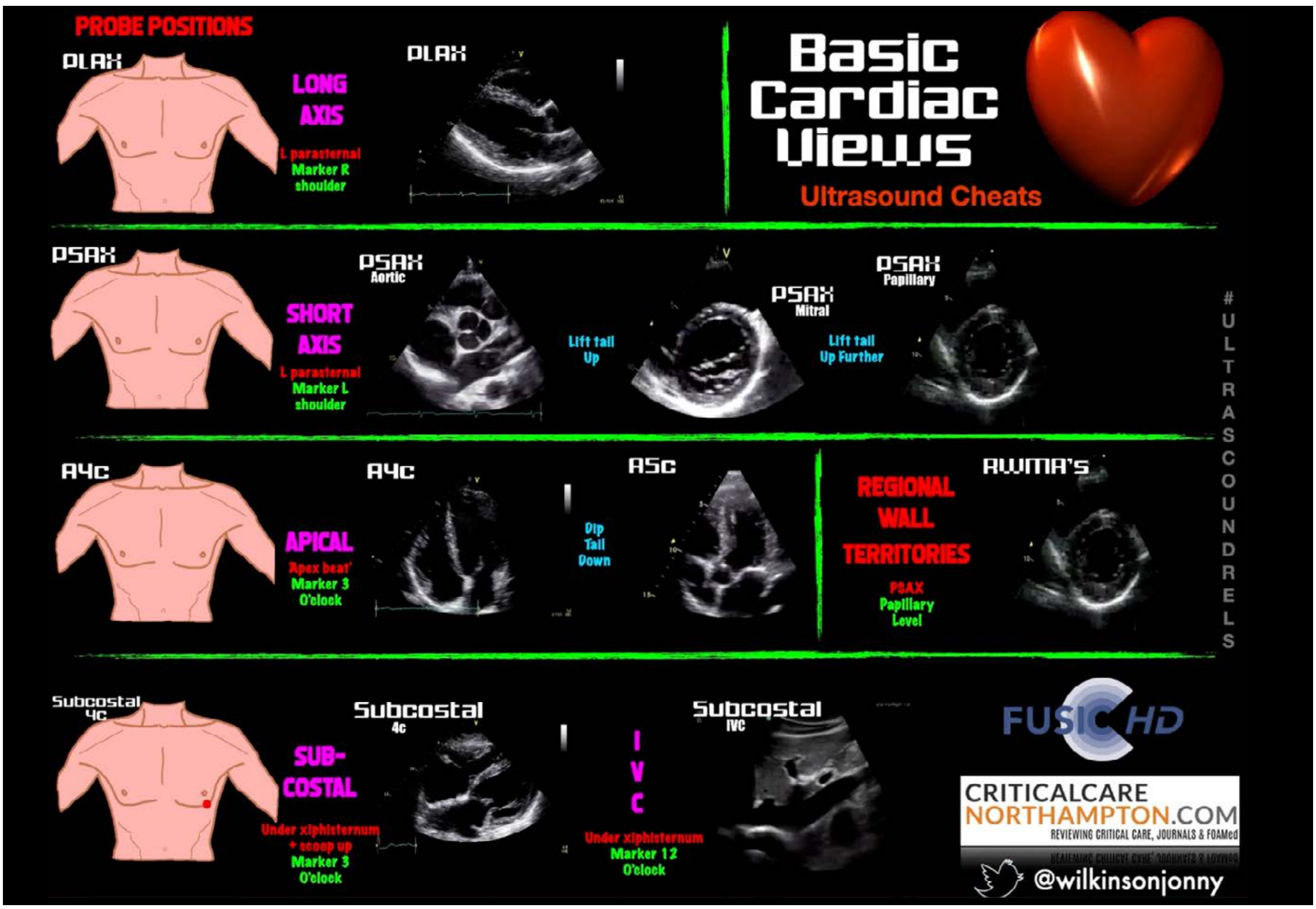

Figure 3. Basic cardiac views (Wilkinson J)

haemodynamic compromise (Miller et al. 2022):

1. Is stroke volume abnormal?
2. Is stroke volume responsive to fluids, vasopressors or inotropes?
3. Is the aorta abnormal?
4. Is the aortic valve, mitral valve or tricuspid severely abnormal?
5. Is there dynamic left ventricular outflow tract obstruction?
6. Is there a regional wall motion abnormality?
7. Is left atrial pressure raised?
8. Is pulmonary artery pressure raised?
9. Are there echocardiographic features of cardiac tamponade?
10. Is there venous congestion?

Using a flow:volume:pressure approach, one can more accurately assess whether a patient will be preload tolerant, or intolerant to IV fluid resuscitation, and/or whether vasopressors are better indicated. Moreover, the inclusion of many dynamic parameters allows the clinician to monitor the response to any critical treatment decisions made thereon. The final of the questions looks at venous congestion as a cause of organ dysfunction (particularly renal), and/or general deterioration. Sadly, this is a situation sometimes seen in patients where overzealous IV fluid resuscitation. This is especially the case when combined with cardiac impairment. Here, we utilise the venous excess (VExUS) score to de-resuscitate patients, using diuretics or renal filtration, in order to alleviate the effects of congestion.

Cardiac Arrest

An algorithmic approach referred to as Echo Guided Life Support (EGLS) has been suggested (Lanctôt et al. 2011), supported by the implementation & training in FEEL (Focused Echocardiography in Emergency Life Support). This course has been designed as an adjuvant for advanced life support and aims to develop knowledge and skills in obtaining the appropriate and relevant ultrasound windows to identify reversible causes of cardiac arrest, in an ongoing arrest situation (Resuscitation Council 2022).

Examples where POCUS can assist within the 4H's and 4T's of PEA arrest (although not all are included):

- Thromboembolus/Pulmonary Embolus (PE)
  - McConnell's sign (hyperdynamic RV apical cap with poor basal movement)/Reduced tricuspid annular plane systolic excursion(TAPSE)/Right Ventricular (RV) pressure overload/ massive Tricuspid Regurgitation (TR)/ Deep Vein Thrombus (DVT) found in the lower limbs
- Tamponade
  - Massive pericardial effusion with RV

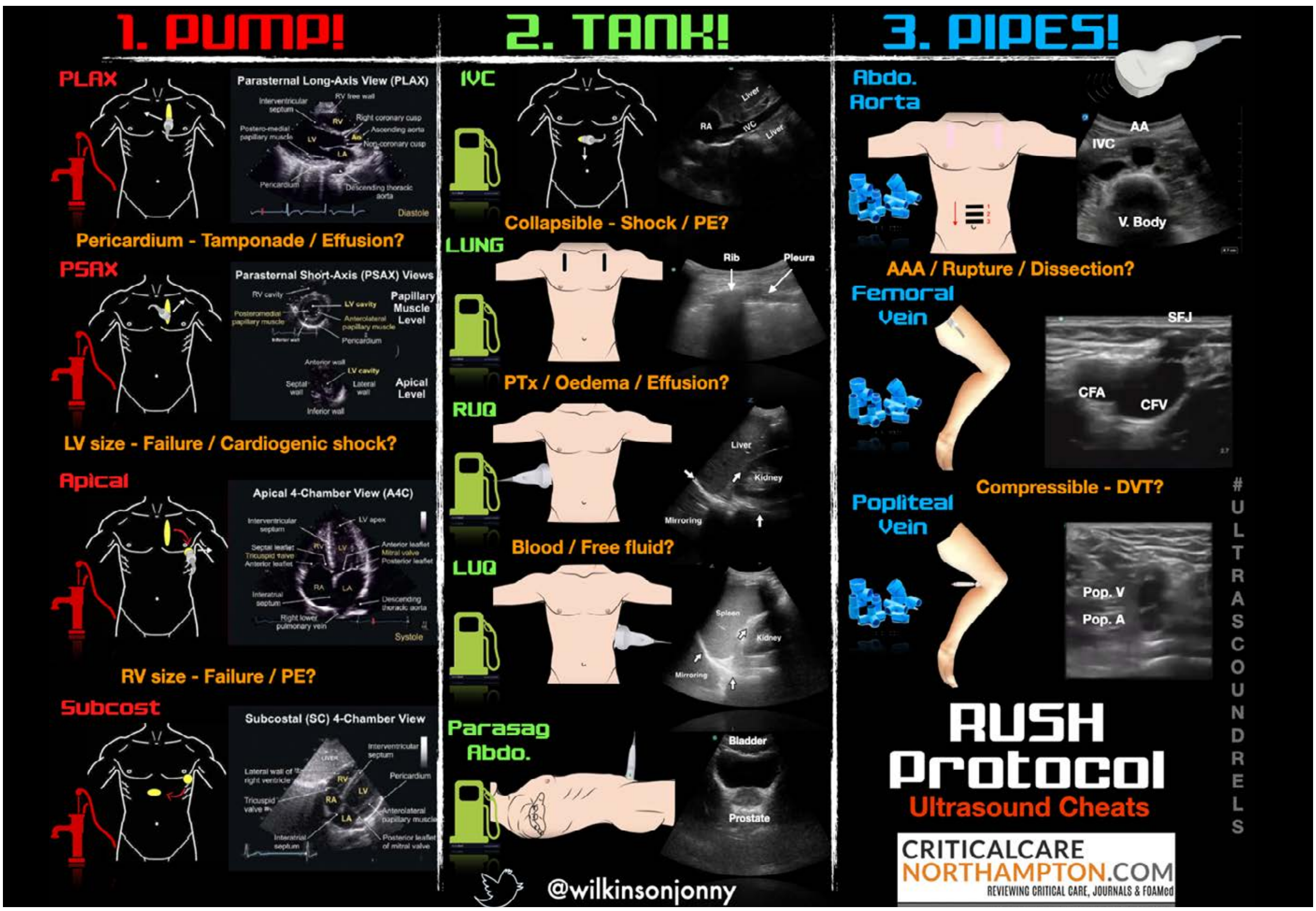

Figure 4. RUSH protocol (Wilkinson J)

diastolic collapse/Right Atrial (RA) systolic collapse/plethoric IVC
- Tension pneumothorax
  - Absence of pleural sliding/no lung pulse/lung point/stratospheric M-mode
- Hypoxia
  - Multiple other sonographic indicators within this list/B-lines on lung ultrasound/collapse-atelectasis/severe consolidation
- Hypovolaemia
  - Kissing Left Ventricular walls/collapsing or near absent IVC/Rapid ventricular rate (Flower et al. 2020)

One final area of growth within EGLS is in governing whether cardiac arrest patients are in true Pulseless Electrical Activity (PEA) or pseudo-PEA. Distinguishing between the two relies on POCUS and directs the provider as to the correct ongoing management. The former requires ongoing Advanced Life Support with cardiac massage, whilst the latter may require push-vasopressor therapy over continued cardiac massage. The vasopressor approach to pseudo PEA is supported by an evidence base, though small, with return of circulation rates of 70.4% for those in pseudo-PEA, 20.0% for those in true PEA, and 23.5% for those in asystole (Flato et al. 2015).

Protocols

As well as FUSIC-HD, there are other highly useful protocols to aid recognition of the causes of undifferentiated shock. Many may avoid the requirement for further CT imaging and indeed may identify a clear cause where immediate surgical intervention is the priority. One such example is the Rapid Ultrasound in Shock (RUSH) protocol, which uses a "Pump, Pipes and Tank" approach (**Figure 4**) (Seif et al. 2012):

- Pump = Heart
- Pericardial Effusion, LV contractility & RV dilatation
- Tank = volume loss/status
- Fullness - IVC size & collapsibility
- Leaks - presence of haemorrhage identified during FAST & thoracic ultrasound
- Compromise - Pneumothorax & Rupture. Aortic Aneurysm & Dissection
- Pipes = DVT

This approach has been shown to reduce many diagnostic uncertainties governing the shock state (Shokoohi et al. 2015).

D – DISABILITY: CNS (Central Nervous System)

FUSIC neuro, forthcoming

Given the bony anatomy of the skull, there are limited avenues for the application of POCUS to image the central nervous system. Although CT imaging remains the most accepted method of detecting signs of raised ICP, midline shift, space occupying lesions & cerebrovascular catastrophes, ultrasound does have a role in certain scenarios. The use of a transorbital window allows the user to assess pupillary light reflexes and potentially monitor changes in intracranial pressure through the serial measurement of optic nerve sheath diameter as a surrogate marker, in the absence of orbital trauma or haemorrhage (Bhatt et al. 2020).

Utilising a trans-temporal window, one can exploit the relatively thin aspect of the temporal bone to perform transcranial ultrasound. With the use of Doppler flow, the transcranial approach can then be manipulated as a safe, rapid and non-invasive method to further assess and monitor ICP, cerebral blood flow in the context of brain death and to diagnosis and guide management of cerebral artery vasospasm (Lau and Arntfield 2017).

More recent literature supports this, with transcranial Doppler providing a key role in the screening and monitoring of middle cerebral artery vasospasm, with 89-98% sensitivity in the critical care patient (Dinsmore et al. 2022). The authors also describe a method of non-invasive ICP monitoring, through the serial trend measurement of optic nerve sheath diameter, and the detection of midline shift via trending of the calculation of the difference in measurement from ipsilateral temporal bone to the 3rd ventricle on both sides. Once again, it is the trend in these values supported by clinical information that helps guide treatment, rather than a one-off value. There are key limitations such as artefact interference due to bone, and no real consensus on upper limit values.

Overall, these approaches require a high level of competence, but highlight the use of brain ultrasound as an alternative imaging technique for the diagnosis and management of certain neurological pathologies on intensive care.

E - EVERYTHING ELSE

Abdominal Ultrasound

FUSIC Abdomen

Under certain circumstances, the use of CT imaging is more accurate than ultrasound in the context of abdominal pain (Lameris et al. 2009). In the critically ill trauma patient, the abdominal focused abdominal sonography in trauma (FAST) protocol has a high specificity (99.5%) and sensitivity (94.8%) as a screening tool for haemoperitoneum and abdominal free fluid. However, it is unable to determine the exact source of extravasation (Basnet et al. 2020). In the context of a positive FAST scan with significant cardiovascular compromise (e.g. aneurysmal rupture), there is an indication to proceed to immediate surgical intervention without the delays of further imaging, demonstrating the rapid use of ultrasound in interventional management in the abdominal setting. However, a negative FAST scan does not equate to complete rule out of any significant pathology in the unstable patient. There is more evidence in support of performing serial FAST scans to improve diagnostic yield (**Figure 5**) (Zieneldin et al. 2017).

Outside of the FAST protocol, POCUS can be used for a variety of other roles (Balmert et al. 2017):

- Hepatobiliary system
  - Assessment of liver architecture and flow patterns
  - Assessment for gallstones and ductal abnormalities
  - The presence of ascites and real-time guidance of paracentesis catheters/ needles
- Vascular system
  - Assessment of aortic diameter for aortic aneurysm
- Genito-urinary system
  - Assessment of the correct placement of urinary catheters + bladder volume assessment.
  - Assessment of hydronephrosis

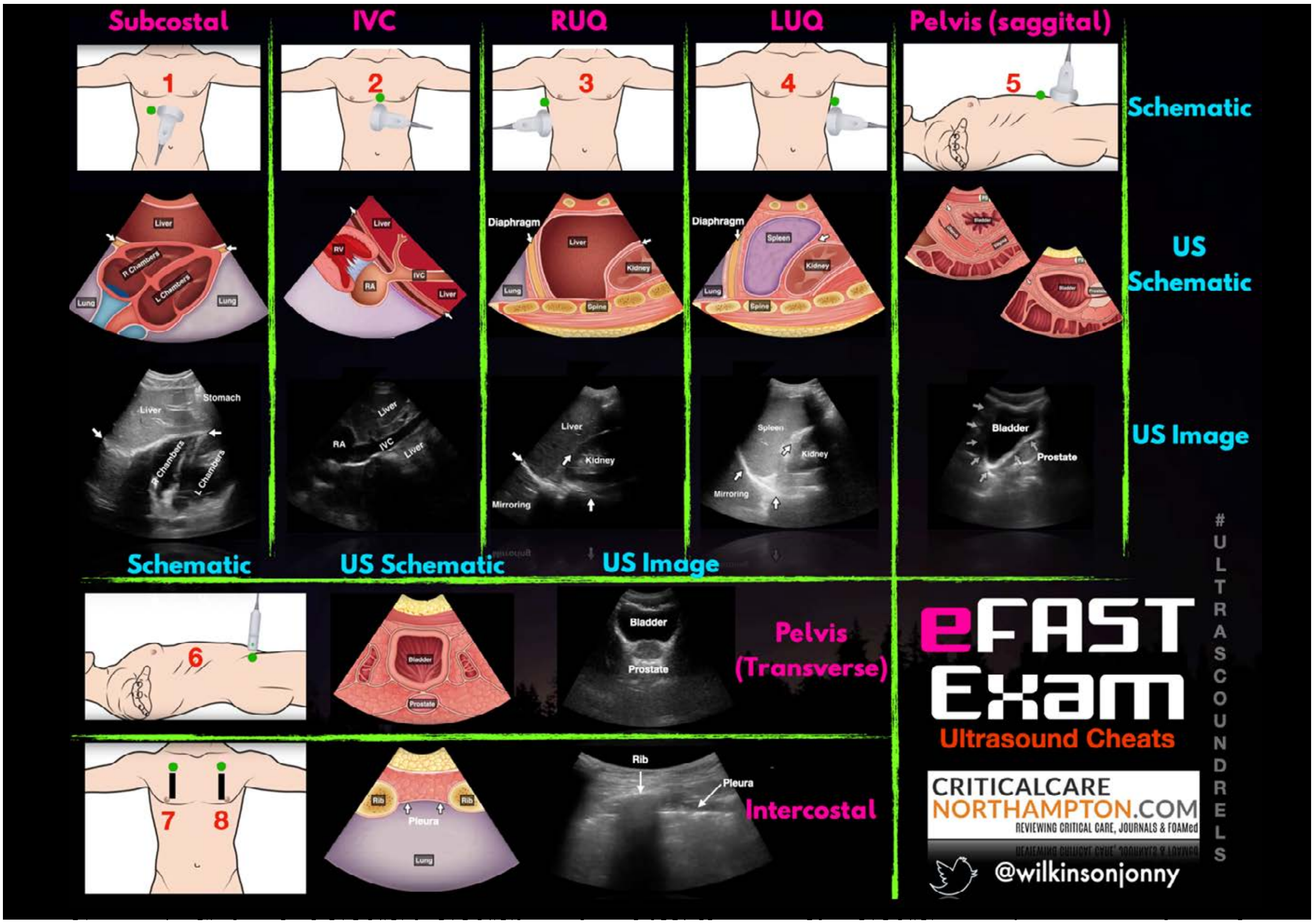

Figure 5. Extended FAST (eFAST) protocol (Wilkinson J) – FAST scan + incorporation of upper anterior chest wall views looking for pneumothorax

   - Interrogation of the renal resistive index (RRI) as an indicator of impending acute kidney injury.
   - Assessment for the presence of renal calculi
- Gastric and intestinal
   - Identification of gastric residual volume
   - Correct placement of a nasogastric tubes
   - Assessment of small bowel obstruction/perforation (Kameda and Taniguchi 2016)

Invasive Procedures

Ultrasound can assist the safe placement of various indwelling catheters (**Figure 6**). The classic example is the direct visualisation and utilisation of static and dynamic guidance for the siting of central venous catheters/dialysis catheters. One can see the vessel, highlighting it with colour and pulsed wave Doppler to gauge whether arterial or venous. The needle can then be directed in plane or out-of-plane into the vessel and subsequently, the wire and catheter can be visualised as they pass into the vessel guiding correct position prior to dilatation, avoiding misplacement. POCUS can even inform whether the catheter is safe to use, without the need for any accompanying plain radiographs, and can rapidly identify any potential complications such as pneumothorax or haemorrhage (Saugel 2017).

Ultrasound can also guide paracentesis of ascites, in particular, highlighting abdominal wall vessels and negating the risk of penetration in patients with deranged liver function/clotting disorders. The same goes for thoracocentesis, with the recommendations that ultrasound should be used over anatomical landmark techniques.

DVT

FUSIC DVT

Ultrasound provides excellent resolution of vascular structures and is therefore a useful tool in the detection of deep vein thromboses, with a structured training and assessment programme as part of FUSIC (Intensive Care Society, 2021). Basic 3-point compression of the great veins from the sapheno-femoral junction, down over the common femoral vein mid-thigh, to the popliteal vein behind the knee, provides a high sensitivity to rule in a DVT between these points. Almost all DVT's resulting in a PE arise from above the knee, therefore these 3 points are an adequate series in isolation. The addition of colour flow and pulsed wave Doppler to basic 2D ultrasound imaging, upgrades the series to duplex and triplex phase accordingly.

In the context of pulmonary embolism,

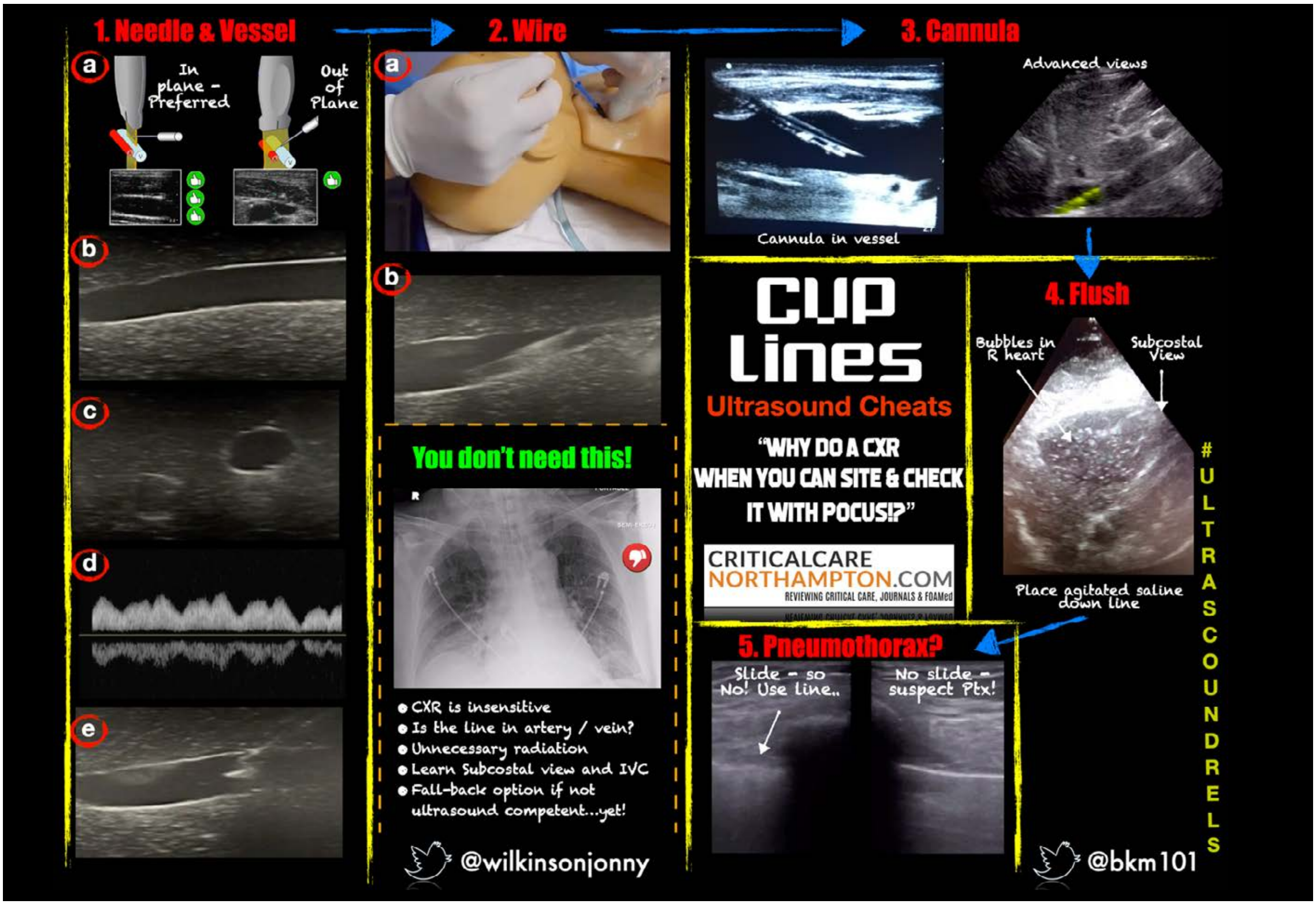

Figure 6. POCUS protocol for safe insertion and checking of an indwelling venous catheter (Wilkinson J)

a multi-organ POCUS approach is needed to select suitable patients for further CT imaging. In resource poor settings, along with the clinical history and examination, heart and lung ultrasound may be the only imaging modality available. While right ventricular strain suggests that a PE is more likely, this finding is non-specific and other potential causes must also be considered (Lieveld et al. 2022). However, the absence of RV strain in a patient with haemodynamic instability means that PE is unlikely to be the cause. Further evidence is required to fully compare both modalities to determine which is the best diagnostic tool (Cao et al. 2022). Nevertheless, clear ultrasound findings in the presence of a severely unstable patient, with a suggestive clinical history, may assist in the decision-making process for thrombolysis in the absence of 'higher' imaging (Marti et al. 2015).

Conclusion

Overall, point of care ultrasound remains a critical tool in the assessment, diagnosis, and management of pathology in the critically unwell patient. With much improved access to modern, ever more portable ultrasound equipment, POCUS has become an essential adjunct for practitioners both within the critical care unit and outside on the wards, or in the emergency department. Multiple accreditation programmes are available, many of which arm the clinician with an extremely solid base in whole body, diagnostic ultrasound. It is the authors opinion that POCUS should be introduced early on in the training schemes of both medical and non-medical practitioners. With good quality training users will be able to embrace its benefits and limitations in order to make many rapid critical treatment decisions at the bedside of the sickest patients, often avoiding the need to transport them to places with a lower safety profile for further imaging.

Conflict of Interest

Jonny Wilkinson, Marcus Peck and Ashley Miller receive honoraria from GE Healthcare. MP and AM are co-chairs of the FUSIC committee. JW is a member of the FUSIC committee. ■

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For full references, please email editorial@icu-management.org or visit https://iii.hm/1iny

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Rapid Assessment of Fluid Responsiveness and Tolerance With Ultrasound of the Neck Vessels in Critically Ill Patients

Ultrasonographic assessment of the neck vessels in critically ill patients contributes to rapid and non-invasive management of fluids in order to evaluate responsiveness and tolerance, as well as blood volume status.

Introduction

There are multiple ways to evaluate the responsiveness and tolerance to IV fluids, as well as venous congestion, in critically ill patients. For these purposes, some static variables have traditionally been used, such as central venous pressure (CVP) and inferior vena cava diameter (IVCd), up to dynamic variables like pulse pressure variation (PPV), stroke volume variation (SVV), passive leg raising (PLR) combined with continuous measurement of cardiac output (CO) and stroke volume (SV), inferior vena cava variation index (IVCvi) and internal jugular vein variation index (IJVvi), velocity time integral variation (VTIv) of the left ventricle outflow tra ct (LVOT) and internal carotid artery peak systolic flow variation (ICASFv).

For a long time, placing a central venous catheter to measure CVP or placing a catheter in the pulmonary artery to measure pulmonary artery occlusion pressure were parameters to decide upon the administration of IV fluids in shock patients (Rivers et al. 2001); in present day, CVP is considered a reference point to stop IV resuscitation, in addition to evaluating venous congestion; later, the dynamic variable PPV was widely used to assess fluid responsiveness (Michard et al. 1999; Yang and Du 2014). Both techniques have the disadvantage of requiring an invasive device; furthermore, they imply additional financial costs. In the last decade, point-of-care ultrasound (POCUS) has been proposed as a non-invasive, low-cost device to evaluate fluid responsiveness and tolerance, such as the assessment of the inferior vena cava (IVC) and transthoracic echography (TTE), which require some degree of expertise; nonetheless, neck vessels are relatively easy to assess with ultrasound, and may provide prompt information for decision-making in critically ill patients, while properly correlating with other methods.

Ultrasonographic Assessment of Neck Vessels to Evaluate Fluid Responsiveness and Tolerance

Positive responsiveness to fluids is defined as an increase in SV of 10 to 15%, and therefore of CO after the administration of an IV fluid challenge, usually 5 to 10% of the estimated blood volume. The neck is an accessible anatomical region in most critically ill patients in Intensive Care Units (ICU), emergency departments (ED) and operating rooms (OR), unlike the ultrasonographic evaluation of the IVC and transthoracic echocardiography which may not be feasible or may be technically difficult to obtain images from, such as in patients with abdominal or chest pain, patients with abdomen or chest surgeries, patients on mechanical ventilation (MV) or on prone position, obese or ascites patients, or patients with chest wall deformities or with a poor anatomic window. Performing an ultrasonographic scan to the internal jugular vein (IJV) and the common carotid artery (CCA) could be much easier and faster than other methods and may provide valuable information to manage fluid therapy in critically ill patients, particularly in patients with circulatory shock (**Table 1**).

Evaluation of Fluid Responsiveness With the Internal Jugular Vein

IJV is a superficial vessel that lies beneath the sternocleidomastoid muscle, and it can be easily observed with an ultrasound. Cyclic changes in the pressure and volume of the intrathoracic systemic venous compartment induced by mechanical ventilation or spontaneous breathing can be transmitted to extrathoracic veins, which makes the evaluation of blood volume possible.

Technique

For this approach, a high-frequency linear transducer (10 MHz) with B and M modes is required. With the head of the patient at 30 to 45°, the transducer is placed transversely to the trachea at the level of the cricoid cartilage, to subsequently slide laterally to the line that goes along the angle of the mandible until observing the IJV and the CCA, the former being usually more lateral, of greater diameter, oval in shape, collapses on compression, distends with Valsalva manoeuvre, has a continuous flow and has thinner walls compared with the CCA. Once the image of the jugular vein is cantered, caution must be taken not to press it with the transducer to avoid

Internal jugular vein variation index (IJVvi)	IJVvi (%) = (maximum diameter - minimum diameter)/ [(maximum diameter+minimum diameter)/2)]×100	Cut-off > 12,99%, ↑ CO 15%, sensitivity 91,43 %, specificity 82,86 % and AUC of 0,88 (CI 0,78–0,94).	Ma et al. 2018
Internal jugular vein diameter variation index (IJVdvi)	IJVdvi = [(maximum diameter - minimum diameter)/maximum diameter)]×100	Cut-offs from 9.7% to 28.7% in patients under controlled MV. >11.4% in patients with spontaneous MV (CPAP-PS), sensitivity 83 % and specificity 94 %. >36% in MV without mechanical support (CPAP). >36% with PLR, sensitivity 78 % and specificity 85 %, AUC of 0,872.	Haliloglu et al. 2017 Iizuka et al. 2020
Internal jugular vein (IJV) distensibility index	[(maximum diameter - minimum diameter)/minimum diameter]×100	Cut-off >18 %, sensitivity 80% and specificity 95%, before fluid challenge (AUC of 0.915).	Guarracino et al. 2014 Broilo et al. 2015
Internal jugular vein diameter ratio (IJVdr)	IJVdr = IJV diameter during Valsalva/ IJV minimum diameter at end-expiration	> 4 is considered normal: normal CVP and may tolerate fluids. <4 considered abnormal. <2 suggests severe congestion.	Simon et al. 2010 Pellicori et al. 2014
Internal jugular vein and common carotid artery diameter ratio	IJV/CCA ratio	IJV/CCA ratio <1.75 predicts CVP < 10mmHg, sensitivity 84.62%, specificity 52.17%, PPV 66% and NPV 75%.	Bano et al. 2018
Internal carotid artery peak systolic flow variation (ICASFv)	ICASFv = (MaxCDPV – MinCDPV)/ [(MaxCDPV+ MinCDPV)/2]×100	11 to 14% predicts fluids responsiveness in MV, sensitivity and specificity near 86%. ≥13% in spontaneous breathing.	Song et al. 2014 Ibarra-Estrada et al. 2015
Change in carotid flow time (CFTc)	CFTc	≥24,6% CFTc increase with PLR predicts fluid responsiveness, sensitivity 60%, specificity 92%.	Jalil et al. 2018
End-inspiratory and end-expiratory occlusion manoeuvre	(End-expiratory occlusion–End-inspiratory occlusion/End-inspiratory occlusion)x100	13% cutoff, though there is insufficient evidence.	Jozwiak et al. 2017 Kenny et al. 2020

Table 1. Fluid responsiveness and tolerance predictors in neck vessels

unnecessary manipulation, in order to reduce the risk of a vasovagal reflex; for these purposes, we suggest leaning the operating hand in some bone structure or on the patient's bed. We then switch to M-mode and measure the maximum and minimum IJV diameter.

Internal jugular vein diameter variation index (IJVdvi), which can be calculated with the formula: (maximum diameter - minimum diameter)/[(maximum diameter - + minimum diameter)/2)]×100, predicts fluid responsiveness capacity in postoperative patients and patients with controlled MV, with sensitivity of 91.43%, specificity of 82.86%, and AUC of 0.88 (CI 0.78–0.94) with a cut-off point of > 12.99 %, and shows good correlation with SVV (r = 0.51, p < 0.01 and AUC 0.88 vs. 0.97, p = 0.03) with good agreement between the variability of measurements made by two evaluators (Ma et al. 2018).

IJVdvi measurement can be performed with the formula: [(maximum diameter–minimum diameter)/maximum diameter)] ×100. Also known as IJV collapsibility index, it predicts adequate fluid responsiveness with cut-off points from >9.7% to >28.7% in patients under controlled MV, >11.4% in patients on spontaneous mode MV, and >36% in patients without MV (Haliloglu et al. 2017; Iizuka et al. 2020).

IJVdvi has also been described with the following formula:

[(maximum diameter–minimum diameter)/minimum diameter]×100

Also known as IJV distensibility index, it has a cut-off point of >18% for prediction of fluid responsiveness in patients with controlled MV and sepsis, with sensitivity of 80% and specificity of 95% for fluid responsiveness prediction (Guarracino et al. 2014).

Note: multiple authors describe internal jugular vein diameter variation as "collapsibility" or "distensibility" according to the phase of the respiratory cycle and MV mode, which may lead to confusion, thus we propose to only name it as internal jugular vein diameter variation index (IJVdvi), whilst taking into consideration the cut-off points referred to in the studies according to the type of patient.

Measurement of the Internal Jugular Vein Diameter Ratio for Assessment of Venous Congestion

It has been determined that a CVP >8mmHg is associated with greater risk of acute kidney injury, while CVP >10 mmHg has been associated with greater mortality risk. The previously proposed goals of 8-12 mmHg in early resuscitation in patients with sepsis are no longer recommended. One proposal to assess the systemic venous congestion is the IJV diameter ratio (IJVdr), which is the ratio between the maximum IJV diameter during Valsalva manoeuvre and the resting diameter at the end of the expiratory phase. It can be performed in patients without MV, with a low inter-rater error bias. Even in patients with heart failure, a good correlation with NT-proBNP plasma levels has been documented, with a cut-off point of <2 (Simon et al. 2010; Pellicori et al. 2014). Resting IJV diameter is low (0.10-0.15cm), and it usually increases up to 1 cm during Valsalva manoeuvre; this is similar between patients with and without heart failure. Normal IJVdr is >4, which identifies patients who have normal CVP and who may be able to tolerate fluids. When IJVdr is <4, it is considered abnormal, and if it reaches <2, it is considered a case of severe congestion. IJVdr calculation is performed with the following formula: IJV diameter during Valsalva/ IJV minimum diameter at the end of the expiration. Another alternative method to estimate CVP is the measurement of the internal jugular vein and common carotid artery diameter ratio, which is known as the IJV/CCA ratio, with a cut-off point of <1.75 to predict CVP <10 mmHg with sensitivity of 84.62% and specificity of 52.17%, positive predictive value (PPV) of 66% and negative predictive value (NPV) of 75% (Bano et al. 2018). Measurement of anteroposterior IJV diameter (AP-IJVd) measured at 2 cm above the clavicle, also correlates with CVP. An AP-IJVd <7 mm adequately correlates with a CVP <10 mmHg in patients without MV in the supine position (r= 0.92) (Donahue et al. 2008).

It is important to mention the limitations that the assessment of the IJV has, which are similar to that of the assessment of the IVC and the CVP. Any increase in the intrathoracic pressure can generate IJV distensibility and therefore underestimate its variation as occurs in mechanically ventilated patients with high positive end-expiratory pressure (PEEP), tension pneumothorax, severe air trapping, venous outflow obstruction such as venous stenosis, superior vena cava syndrome, cardiac tamponade, severe tricuspid regurgitation, heart failure, low lung compliance, arrhythmias, or jugular vein thrombosis. In the case of patients with spontaneous ventilation with vigorous respiratory effort, modifications in the IJV diameter will be significant and may overestimate its variation.

Evaluation of Fluid Responsiveness With the Internal Carotid Artery

CCA is another superficial, easy-to-access vessel for ultrasonographic assessment. It has been shown that in shock patients, deviation of blood flow is greater in this territory, which confidently reflects the status of systemic resistance and the respirophasic variation of SV.

Technique

To perform this evaluation, a linear transducer and pulsed Doppler are required. With the head of the patient at 30°, the transducer is placed in the longitudinal plane of the internal carotid artery with the probe orientation marker towards the patient's head, and pulsed Doppler is applied placing the sample volume at the centre of the vessel lumen with angle correction, observing the trace of the systolic flow spectrum and its variance with the patient's respiratory cycle (**Figure 1**). Preferably, the sampling sweep is increased to more easily observe the peak systolic flow velocity (PSFV); the one with the highest velocity is identified and compared with the one with the lowest velocity by using the following formula:

CCApsfv = (Maximum psfv–Minimum psfv)/[(Maximum psfv+Minimum psfv)/2]×100

Common carotid artery peak systolic flow velocity variation (CCApsfv) with cut-off points of >11 to 14% predicts fluid responsiveness in patients under controlled

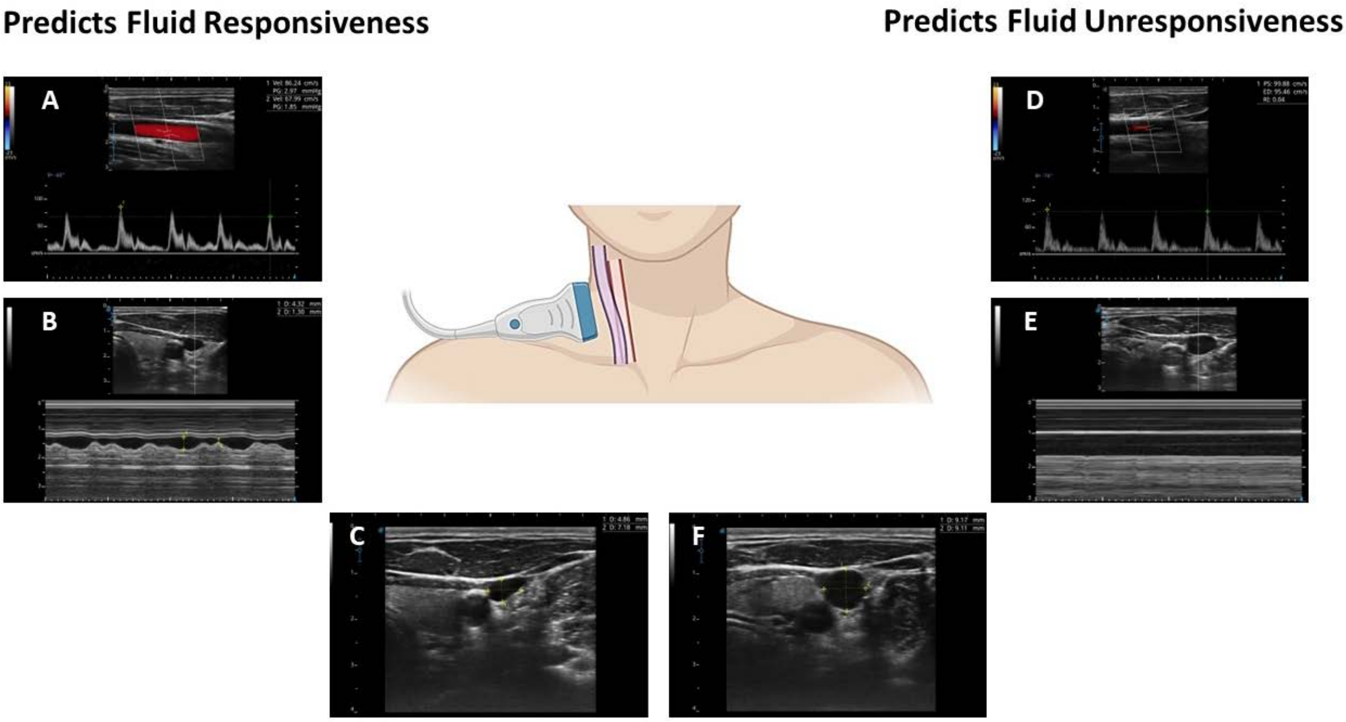

Figure 1. Assessment of fluid responsiveness with ultrasound of the neck vessels.
A: Common carotid artery peak systolic flow velocity variation of 23.6 %. B: M-mode assessment of the anteroposterior diameter of the internal jugular vein with a variability of 69.7%. C: Internal jugular vein in transverse plane with anteroposterior diameter of 4.86 mm. D: Common carotid artery peak systolic flow velocity variation of 4.5 %. E: Lack of variation of the internal jugular vein. F: Internal jugular vein in transverse plane with anteroposterior diameter of 9.17 mm.

MV with an excellent correlation with SVV ($r = 0.84$; $p < 0.001$). In spontaneous ventilation, cut-off points greater or equal to 13% for prediction of fluid responsiveness has been established (Song et al. 2014; Ibarra-Estrada et al. 2015).

Another assessment which is not affected by changes in spontaneous breathing is the measurement of the change in carotid flow time (CFTc), by measuring the maximum velocity; subsequently, passive leg raising is performed for 60 seconds. An increase in CFTc of more than 24.6% is expected in order to consider fluid responsiveness, with sensitivity of 60% and specificity of 92%.

On the other hand, in patients who are under MV, the end-inspiratory and end-expiratory occlusion manoeuvre can be performed, with a separation of 15 seconds, observing the pattern of change in pulsed Doppler flow velocity of the carotid artery with a cut-off point of 13% for precise fluid responsiveness prediction (Jalil et al. 2018).

The most important limitations of this technique, which can decrease its clinical predictive value, can be recalled with the mnemonics "LIMITS"- L: Low heart rate (HR)/respiratory rate (RR) (for instance, severe bradycardia, high ventilator frequency), I: Irregular heartbeats, M: Mechanical ventilation with low tidal volume or high total PEEP, I: Increased abdominal pressure, T: Thorax open, and S: Spontaneous breathing (Michard et al. 2015), which is why it is advisable to use at least two assessment techniques of fluid responsiveness to increase certainty in evaluation and clinical judgment (Michard et al. 2015).

Conclusion

Neck vessels ultrasonography is a simple, non-invasive technique that allows for evaluation of fluid responsiveness and tolerance in critically ill patients.

Conflict of Interest

None. ■

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POCUS in Critical Care Physiotherapy: Give Me Sight Beyond Sight

An overview of the main ultrasonographic tools that allow physiotherapists to improve their evaluation in the critical patient, described through the mnemonic PHISIO.

Introduction

Ultrasound is considered to be the fifth pillar of the physical examination to provide and improve patient care (Narula et al. 2018). In critically ill patients, the limited time to make differential diagnoses and decisions in treatment are crucial for patient survival. Point of Care of Ultrasound (POCUS) can help with these needs in the intensive care unit (ICU) by reaching an accurate diagnosis and providing adequate management, resulting in a valuable diagnostic tool (Díaz-Gómez et al. 2021; Lau and See 2022). Furthermore, POCUS applications have been gaining strength and evidence in respiratory care and physical rehabilitation. The use of this tool seems to be setting itself as a powerful ally for physical therapists treating critically ill patients.

The main ultrasonographic evaluations that will allow physiotherapists to improve their evaluation and attention in the critical patient are described below through the mnemonic "PHISIO" (**Figures 1-2**).

P = Pulmonary

Pulmonary ultrasound is currently feasible for the diagnosis of respiratory failure through the BLUE (Bedside Lung Ultrasound in Emergency) protocol (Leidi et al. 2020; Lichtenstein et al. 2004). However, it is useful for the physiotherapist to identify different types of ultrasound profiles to guide chest physiotherapy and in-depth respiratory monitoring (Lichtenstein et al. 2004; Le Neindre et al. 2016). According to the ultrasound profile presented by the patient, the physiotherapist can guide and apply different care strategies or treatments. For example, in the case of B-lines, non-invasive mechanical ventilation (NIV), PEP devices and active early mobilisation including verticalisation through sitting and standing can be applied. The goal would be to improve aeration and pulmonary ventilation through devices, positioning or exercise (Le Neindre et al. 2016; Hickmann et al. 2021). It is important to mention that in the case of pulmonary coalescence and subpleural consolidations, precautions should be taken into account by the rehabilitation staff. Early mobilisation (EM) or rehabilitation protocols in the ICU need to ensure the cause of respiratory failure has been stabilised to be safe. Pulmonary oedema or an infectious process can be monitored with ultrasound allowing us to observe changes over time and deciding the correct timing in the initiation of an early mobilisation programme (Le Neindre et al. 2016).

A common finding in critically ill patients can be the presence of pulmonary consolidations and will suggest pneumonia (dynamic air bronchogram) accompanied by clinical criteria, or atelectasis (static air bronchogram) (Lichtenstein et al. 2009; Sartori and Tombesi 2010). In the case of pneumonia, the effect of the antibiotic must be assessed and airway clearance techniques may be considered. On the other hand, when facing atelectasis, bronchial hygiene techniques such as those that favour peak expiratory flow (Marti et al. 2013; Amaral et al. 2020), manual or mechanical hyperinflation (Paulus et al. 2012; Assmann et al. 2016; Tucci et al. 2019), PEP devices, positioning in different decubitus, cough assistance and verticalisation (Le Neindre et al. 2016; Westerdahl et al. 2005; Volpe et al. 2018; Gates et al. 2021) can be some tools that may help the resolution of such problems. Also, pleural effusions, empyema and haemothorax can be identified faster through ultrasound compared to x-ray (Soni et al. 2015; Walsh et al. 2021). This allows early interventions such as pleural drainage accompanied by breathing exercises with PEP devices (Dos Santos et al. 2020) that improve ventilation and lung function, as well as prevent diaphragmatic dyskinesia (Le Neindre et al. 2016; Leech et al. 2015; Valenza-Demet et al. 2014). NIV should be applied with caution as it may limit lymphatic drainage and consequently pleural drainage. The use of conventional oxygen therapy devices or high-flow oxygenation therapy combined with active exercise and inspiratory muscle training (IMT) is preferable for pleural drainage due to the negative pressure generated (Walden et al. 2013).

Finally, the overall Lung Ultrasound Score (LUS) of >17 points allows us to determine the failure in the Spontaneous Breathing Trial (SBT) during the weaning process. Similarly, >6 B lines in anterolateral fields, may indicate weaning-induced pulmonary oedema (WIPO) (Santangelo et al. 2022). It is important to consider previous pulmonary pathologies and the evaluation of echocardiography for this matter.

H = Heart

The evaluation of the haemodynamic status of the critical patient through ultrasound has become a routine practice to determine clinical stability (Santangelo et al. 2022; Kashani et al. 2022). Echocardiography may be performed before and after early mobilisation in specific conditions, as well as during the weaning of mechanical ventilation. The basic and advanced Focus Assessed Transthoracic Echo (FATE) aims at cardiopulmonary monitoring, ensuring safety before rehabilitation and for successful extubation (Kashani et al. 2022; Vieillard-Baron et al. 2019; Nagre 2019; Leidi et al. 2020).

It is important to mention that qualitative visual evaluation is one of the great competencies to be developed for the rapid detection of cardiac alterations, before carrying out specific measurements. The evaluation of the four cardiac chambers in any view allows for determining the shape, size and movement of the ventricles, atriums and septum. A right ventricle (RV) dilation can be caused by volume overload

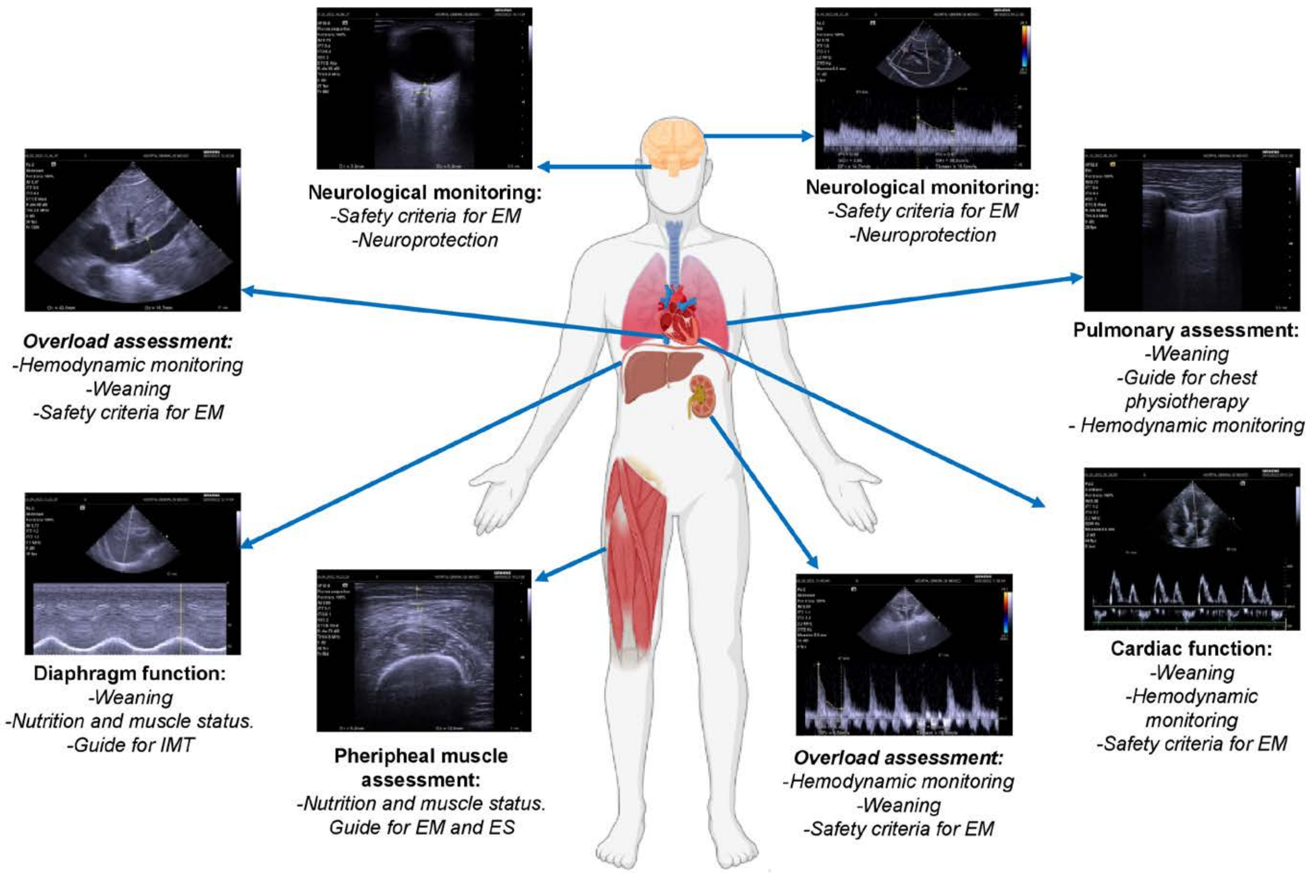

Figure 1. The usefulness of the different PHISIO evaluations through POCUS
EM = Early mobilisation; IMT = Inspiratory muscle training; ES = Electrical stimulation

and delayed MV weaning (Denault et al. 2018). Other causes are acute pulmonary embolism (PE) which contraindicates EM in these acute phases. In this case, if dilation is enough to compress the left ventricle, D-sing appears in systole and diastole, among other signs such as non-compressible lower limb veins (Falster et al. 2022; Dabbouseh et al. 2019). This must be accompanied by clinical criteria: tachycardia, desaturation, respiratory distress, hypotension and there may be an elevation of the D-dimer. Atrial dilation may be suggestive of diastolic dysfunction and consequently failure to weaning. Pericardial evaluation is useful for the physiotherapist as moderate-severe pericardial effusion could contraindicate EM if it's accompanied by haemodynamic instability (Picano et al. 2018). In addition to the heart chambers, visualisation of large vessels such as the inferior vena cava (IVC) can be helpful to identify hypovolaemia on its collapse and dilation in fluid overload.

The systolic and diastolic functions can be assessed in a more specific and advanced way. Some examples are LV fraction shortening (LVFS), mitral annulus and tricuspid plane systolic excursion (MAPSE and TAPSE), among others (Lang et al. 2015; Hernandez-Suarez et al. 2019; Shah et al. 2019). They are complementary and useful haemodynamic measurements in shock. During the SBT an evaluation of the LV ejection fraction (LVEF) <40%, transmitral flow and tissue Doppler with their respective measurements: E/A ratio >2 and E/é >13 may indicate failed weaning (Santangelo et al. 2022; Vetrugno et al. 2020; Roche-Campo et al. 2019; Suárez et al. 2016). These measurements also allow us to obtain a more specific vision of the heart and its relationship with clinical stability during physiotherapist interventions. However, they require more training and studies supporting echocardiography in patients undergoing a rehabilitation programme in the ICU.

I = Intracranial Pressure

One of the few contraindications for early mobilisation and other physiotherapeutic interventions is elevated intracranial pressure (ICP), >20mmHg (Hernandez et al. 2021; Kumar et al. 2020; Oklowski and Shah 2017; Martínez et al. 2021). The gold standard for ICP measurement is the intraventricular catheter; however, it has some limitations (Nag et al. 2019; Hawryluk et al. 2022). A feasible alternative for neuromonitoring is measuring the diameter of the optic nerve sheath (ONSD) and the determination of the pulsatility index (PI) of the middle cerebral artery (MCA) through ultrasound (Chacko 2014; Robba et al. 2019).

A >5mm ONSD indicates ICP >20mmHg. This measurement is performed in a bilateral transorbital window without excessive pressure, avoiding damage or triggering a vagal stimulus (Cannata et al. 2022; Stead et al. 2021; Raffiz and Abdullah 2017; Aduayi et al. 2015). The evaluation of cerebral blood flow (CBF) can be performed by the sonogram and the PI. Colour Doppler and pulsed modes in the transtemporal window are required to find and display the MCA at midbrain zones (Robba et al. 2019; Lau and Arntfield 2017). Once the sonogram is obtained, its morphology and PI are evaluated to determine cerebral vascular resistance and CBF alterations. A PI 0.6-1.1 is considered normal, higher (>1.1) or lower (<0.6) values indicate elevated ICP and hyperaemia respectively (Álvarez-Fernández et al. 2009). Complementing these evaluations, the Lindergaar index can be performed with an index >3 indicating vasospasm (Hernandez et al. 2021; Robba and Taccone 2019; Robba et al. 2019).

Neuromonitoring with POCUS can be performed in any critical patient since neuroprotection is needed in any critical scenario, especially to identify the cause of a deterioration of the acute neurological state.

S = Shock

One of the main competencies that have to be developed is the identification of shock in critically ill patients. There are clinical findings that allow us to identify a patient in shock. However, sometimes determining the cause is difficult with conventional physical examination alone (Gonzalez et al. 2020a). POCUS allows us to distinguish the cause of the state of shock in the presence of haemodynamic deterioration and consequently an intervention plan (Schmidt et al. 2012; Zieleskiewicz et al.2021; Gonzalez et al. 2020b). Some findings are tachycardia, delayed capillary filling, mottled skin, oliguria or any other clinical data of tissue hypoperfusion, considering that hypotension by itself is not synonymous with shock, but is the most common delayed manifestation (Corradi et al. 2020). There are different protocols such as RUSH and FALLS that can be applied in our daily practice (Leidi et al. 2020; Ávila-Reyes et al. 2021; Paul and Panzer 2021).

In addition, seeking free fluid in the context of trauma may indicate haemorrhage with hypovolaemic shock (Mok 2016). In patients with thoracic trauma, the identification of haemothorax, pneumothorax and cardiac tamponade are essential. The FAST-E protocol allows the identification of the main problems with abdominal, pelvic and thoracic trauma (Desai and Harris 2018). The other causes of shock such as infection, pulmonary thromboembolism and cardiac disorders will be mentioned in other sections.

Patient safety assessment for early mobilisation initiation should go beyond a checklist. POCUS provides safety in all physical therapy interventions, as well as identifying potentially lethal complications.

I = Inspiratory and Peripheral Muscles

Muscle wasting is one of the main complications that occur in critical patients. This is due to many factors, such as immobilisation, MV, and drugs (Martínez et al. 2021; Umbrello and Formenti 2016). In the case of the diaphragm, diaphragmatic dysfunction (DD) may occur and consequently increase the risk of delaying or failing in the weaning process (Goligher et al. 2019). The physiotherapist can perform diaphragmatic ultrasound (DUS), through diaphragmatic excursion (DE) and diaphragmatic thickening fraction (DTF) (Tuinman et al. 2020). During SBT, cut-off points >2 cm and 30-36% respectively are considered for successful weaning. Lower measurements are considered DD (Haaksma et al. 2022), while no movement indicates diaphrag-

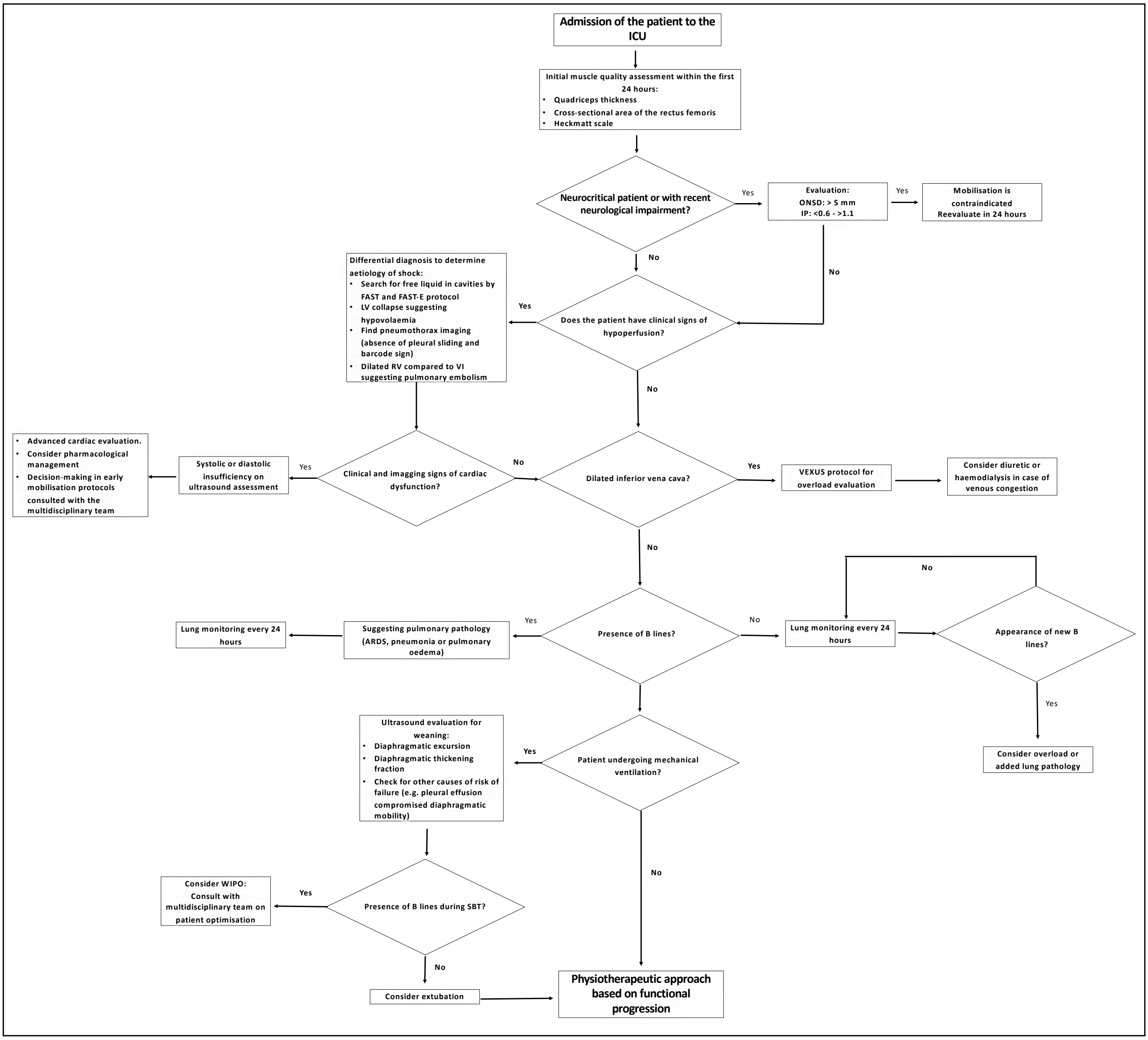

Figure 2. Algorithm: Physiotherapy evaluation with POCUS

matic paralysis. When the physiotherapist encounters these alterations and difficult weaning, he can use interventions such as IMT with linear loading devices and EM (Le Neindre et al. 2016; Haaksma et al. 2022). In this case, the DUS will become the functional-muscular monitoring in response to treatment.

Another frequent muscle complication is ICU-acquired weakness (ICU-AW), present in 32% to 80% of critically ill patients (Wang et al. 2020). This makes it susceptible to worse clinical outcomes (Goligher et al. 2019). There are different methods to assess muscle strength and status in the ICU. Muscle ultrasound (MUS) is one of them with the advantage of being applied from early stages and in non-cooperative patients. Some measurements are muscle thickness (MTh), the cross-sectional area of the rectus femoris (CSA), penation angle (PA), echogenicity employing the Heckmatt scale and greyscale analysis by histogram (Formenti et al. 2019). These measurements can be performed routinely during the critical patient's stay. A 20% and 10% decrease in MTh and CSA, respectively, indicates significant muscle loss and probable ICU-AW. In addition, the MUS allows optimising monitorisation such as nutritional contribution.

O = Overload

Fluid infusion is a common practice in the ICU around the world for early-stage resuscitation. However, it has been described that fluid overload generates complications in critical patients and even increased mortality (Perez-Nieto et al. 2021). Within fluid therapy, four phases have been described to guide the objectives (ROSE): resuscitation, optimisation, stabilisation and evacuation (Malbrain et al. 2022). While the physiotherapist does not direct fluid resuscitation, difficulties can be encountered in the progression of patient functionality due to poor fluid management and fluid overload (Perez-Neito et al. 2021).

Irrational fluid use may increase the severity of critical patient respiratory involvement, even in those with MV (Ogbu et al. 2015). Among the main respiratory complications are pulmonary oedema, pleural effusion, alteration of pulmonary compliance, reduction of the PaO_2/FiO_2 ratio, increase MV days and difficult weaning. Moreover, the presence of pulmonary B lines suggests pulmonary oedema; however, fluid overload is not the only cause. A targeted evaluation should be done to rule out other causes such as heart failure with LV alterations, inflammatory process (e.g., ARDS) or WIPO. Visualisation of ICV is a good start to differentiate between these possible causes: a dilation or diameter >2 cm indicates volume overload (Argaiz et al. 2021). The complementary evaluation of venous congestion by Venous Excess Ultrasound Score (VEXUS) can be useful. VEXUS protocol evaluates the flow of the hepatic, portal vein and intra-renal veins to identify such congestion (Rola et al. 2021; Galindo et al. 2021).

In the context of physiotherapy and respiratory progression, the presence of pulmonary B lines dilated IVC with a collapse index <50% or altered VEXUS suggests fluid overload (Argaiz et al. 2021; Galindo et al. 2021). Volume clearance should be considered to see if there would be an improvement in ventilatory parameters, the use of diuretics or haemodialysis in case of renal injury may be alternative in the treatment (Beaubien-Souligny et al. 2020).

Although human beings are formed mostly by water, this does not mean that it can't harm the critically ill. Everything can be harmful with an inadequate dose; fluid therapy is no exception.

Conflict of Interest

None. ■

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Bedside Point-of-Care Ultrasound Use in the Critically Ill

Historical Perspectives and a Path Forward

Critical Care Ultrasound is a rapidly evolving field with an ever-expanding footprint in ICUs. While much progress has been made, ongoing efforts need to continue towards demonstrating impact on patient-oriented outcome measures and on defining educational curricula and competency requirements.

Point-of-care ultrasound (POCUS) is the real-time acquisition, interpretation, and clinical application of findings by the bedside clinician. This obviously differs from imaging obtained through traditional pathways leading to many advantages and applications of POCUS in the imaging of critically ill patients. Portability, rapid deployment, and non-invasiveness are major advantages allowing clinicians to answer clinical questions at the bedside and avoiding unnecessary risks and resources of intrahospital transport in pursuit of other imaging modalities. Critically ill patients are known to be at risk for adverse events during intrahospital transport due to multiple reasons including communication breakdown, multiple complicated and bulky pieces of life-supporting equipment, and haemodynamic instability (Blakeman and Branson 2013; Fanara et al. 2010; Warren et al. 2004). In a recent meta-analysis by Murata et al. (2022), an intrahospital transport adverse event rate of 26.2% (95% CI: 15.0–39.2) was shown. While life threatening events related to intrahospital transport were overall low at 1.47% in this study, the cumulative risk of transport and resource allocation must be weighed carefully when making these decisions for critically ill patients.

Critical Care Ultrasound (CCUS) has a growing number of indications and applications. Ultrasound guidance is recognised as the standard of care for improving safety and decreasing procedural complications during bedside procedures such as central vascular access, thoracentesis, and paracentesis (Saugel et al. 2017; Silverberg and Kory 2013; Ultrasound Guidelines: Emergency, Point-of-Care and Clinical Ultrasound Guidelines in Medicine 2017; Dancel et al. 2018; Havelock et al. 2010; Mayo et al. 2009; Cho et al. 2019; Millington and Koenig 2018). While the current evidence base for other applications has limitations overall in regards to small study sizes, reproducibility, and lack of demonstrated effects on patient-centred outcomes, areas undergoing further study that are of particular interest for those who care for critically ill patients include assessment of cardiac function, volume status and fluid responsiveness, presence of venous congestion, and confirmation of appropriate positioning of life-supporting devices such as temporary left-ventricular assist devices (LVADs) (Jalil and Cavallazzi 2018; Boyd et al. 2016; Cecconi et al. 2014; Beaubien-Souligny et al. 2020; Balthazar et al. 2021). A recent comprehensive consensus document was published by the European Society of Intensive Care Medicine (ESICM) detailing what the committee believed to represent reasonable expectations for basic skills of the intensivist in CCUS. In total, 74 total statements were made with strong agreement obtained for 49 of the CCUS skill items. These statements encompassed the breadth of heart, brain, lung, abdomen, and vascular CCUS imaging (Robba et al. 2021).

Historically, POCUS use in evaluating the critically ill was born out of Emergency Medicine (EM). The first position paper supporting POCUS use was written in 1990 by the American College of Emergency Physicians (ACEP) (ACEP Council resolution on ultrasound 1990) which was followed by a second document by the Society of Academic Emergency Medicine (SAEM) in 1991 (SAEM - Ultrasound position statement). POCUS training and competency has since become part of the standard for EM physician residency training with the first guidelines published by ACEP in 2001, defining the seven core POCUS competencies of the EM physician (ACEP emergency ultrasound guidelines 2001). POCUS education is now a requirement by the American College of Graduate Medical Education (ACGME) as part of EM residency to include training and competency in POCUS "for the bedside diagnostic evaluation of emergency medical conditions and diagnoses, resuscitation of the acutely ill or injured patient, and procedural guidance" (ACGME Program Requirements for Graduate Medical Education in Emergency Medicine ACGME-approved focused revision: June 12, 2022; effective July 1, 2022). Emergency ultrasound guidelines from ACEP help direct this requirement with benchmark recommendations that residency trainees should perform 25-50 exams of a particular application and depending on the number of applications utilised, complete 150-300 total exams during their training that have all undergone quality assurance (QA) review by emergency ultrasound faculty (Ultrasound Guidelines: Emergency, Point-of-Care and Clinical Ultrasound Guidelines in Medicine 2017).

Now thirty plus years later, critical care is still defining and refining its own path to POCUS success. As evidence for the growing use and interest in CCUS over time, the Société´ de Réanimation de Langue Française (SRLF)/American

College of Chest Physicians (ACCP) first described the criteria for competence in critical care ultrasonography. This document primarily focused on the various different skills and knowledge necessary to develop competency in pleural, vascular, thoracic, and basic and advanced echocardiography, although no minimum training requirement recommendations were made (Mayo et al. 2009). This was followed by International Guidelines in 2011, where it was recommended that in order to obtain competence in general CCUS and basic critical care echocardiography (BCCE), training should include attendance of a 10 hour training course for each discipline that focused on didactics, cases, and image-based learning. There was no overall consensus gained on the minimum number of studies that needed to be performed to obtain competence, although it was recommended that 30 fully supervised transthoracic echocardiograms was sufficient to obtain competence in basic critical care echocardiography (International expert statement on training standards for critical care ultrasonography 2011). The Society of Critical Care Medicine (SCCM) later published robust guidelines in 2015 and 2016 that offered evidence-based support for POCUS use by appropriately trained intensive care unit (ICU) practitioners in the areas of general POCUS and echocardiography, respectively (Frankel et al. 2015; Levitov et al. 2016). In the SCCM guidelines, it was assumed that those utilising ultrasound in the ICU would be "suitably trained and competent in the technical and interpretative components of the relevant examination". The authors noted further that, "It is beyond the scope to these guidelines to describe in detail the elements of training and competency"(Frankel et al. 2015). Also in 2015, Eliot et al. published CCUS learning goals for anaesthesia CC trainees, in which it was recommended that learners perform ≥50 exams that are all reviewed with expert CCUS faculty (Fagley et al. 2015). In 2019, through a collaboration between the National Board of Echocardiography, Inc., (NBE) and nine other specialty societies, the Special Competence in Critical Care Echocardiography board certification was first offered to intensivists and other appropriately experienced clinicians. This board certification includes a requirement of 150 comprehensive echocardiograms in addition to passing a written board exam. This represented a major step towards setting a bar of excellence obtainable for intensivists, although it did not address the minimum training requirements to support competency for general CCUS and BCCE use in the ICU (Díaz-Gómez et al. 2017; Panebianco et al. 2021). This was later followed by Rajamani et al. in 2022, with the publication of a longitudinal competence pathway for basic critical care echocardiography (BCCE). Pathway highlights include attendance of an introductory course, the performance of at least 40 BCCE exams with ongoing QA review and feedback, and subsequent summative and cognitive assessments along the path to competency achievement. This document represents the most evidence-based and robust longitudinal description of a pathway to competence in an application of CCUS to date.

"ultrasound guidance is recognised as the standard of care for improving safety and decreasing procedural complications during bedside procedures"

In the United States, the ACGME sets the standard and core requirements for residency and fellowship training programmes. As noted previously, ACGME core EM residency requirements include gaining competency with POCUS in evaluation and diagnosis, resuscitation, and procedural guidance (ACGME Program Requirements for Graduate Medical Education in Emergency Medicine ACGME-approved focused revision: June 12, 2022; effective July 1, 2022). ACEP guidelines then provide specific recommendations to benchmark a path to basic competency (Ultrasound Guidelines: Emergency, Point-of-Care and Clinical Ultrasound Guidelines in Medicine 2017). For reference, the ACGME requirements for Critical Care fellowship training programmes in regard to CCUS are variable and are listed in **Table 1.**

The variability in recommendations likely exists as there is overall a paucity of evidence as to what constitutes POCUS competence in the critical care realm (Rajamani et al. 2020). Without prospectively validated longitudinal studies demonstrating a path to sustained basic competence, it is obviously challenging for national and international societies to make formal recommendations regarding a benchmark. Given the heterogeneity of ACGME programme requirements regarding POCUS education and the lack of a clear benchmark for basic CCUS competence, the amount and intensity of ultrasound training in fellowship has been highly variable. In one survey of Surgical Critical Care programme directors in the U.S. published in 2018, >75% of responding programmes believed that CCUS in training should be a priority although the educational curricula utilised was highly variable. Despite the strong support for CCUS training, less than a quarter of surveyed programmes required a benchmark number of studies to be performed (24.6%) or required fellows to save images (21.3%). 7.5% of programmes still provided no CCUS training at all, although this was an improvement from prior surveys (Carver 2018). A 2014 survey of ACGME-accredited surgical, medicine, anaesthesia, and pulmonary critical care programmes similarly demonstrated a large of amount of variability in CCUS training. Less than half of all programmes reported a specific curriculum, and this held across the surgical (31%), medicine (33%), anaesthesia (46%), and pulmonary (43%) subspecialties. Perhaps more concerning, only 38% of programmes performed image review, which is an essential component to feedback and improvement (Mosier et al. 2014). Wong et al. (2019) previously noted the relative paucity of formal training programmes and competencies in CCUS internationally, as well. It is worth noting that this heterogeneity and low percentage of programmes with formal curricula

Fellowship Programme	POCUS Education Requirement Verbiage
Critical Care Medicine	• "Fellows must demonstrate competence in procedural and technical skills, including use of ultrasound techniques to perform thoracentesis and place intravascular and intracavitary tubes and catheters" • Regarding use of ultrasound, "fellows must demonstrate knowledge of indications, contraindications, limitations, complications, techniques, and interpretation of results of those diagnostic and therapeutic procedures integral to the discipline, including the appropriate indication for and use of screening tests/procedures"(ACGME Program Requirements for Graduate Medical Education in Critical Care Medicine ACGME-approved Focused Revision: February 7, 2022; Effective July 1, 2022).
Pulmonary and Critical Care Medicine	• "Fellows must demonstrate competence in procedural and technical skills, including use of ultrasound techniques to perform thoracentesis and place intravascular and intracavitary tubes and catheters". • "Fellows must demonstrate knowledge of imaging techniques commonly employed in the evaluation of patients with pulmonary disease or critical illness, including the use of ultrasound" (ACGME Program Requirements for Graduate Medical Education in Pulmonary Disease and Critical Care Medicine ACGME-approved Focused Revision: February 7, 2022; effective July 1, 2022).
Surgical Critical Care	• "Fellows must have supervised training that will enable them to demonstrate competence in the following critical care skills: application of transoesophageal and transthoracic cardiac ultrasound"(ACGME Program Requirements for Graduate Medical Education in Surgical Critical Care ACGME-approved focused revision: June 12, 2022; effective July 1, 2022).
Anaesthesiology Critical Care Medicine	• "The ICU must have ultrasound equipment available to perform diagnostic assessment for procedures such as thoracentesis, paracentesis, vascular access (i.e., peripherally-inserted central catheters, central catheter placement, and arterial cannulation), and comprehensive ultrasound evaluation, including echocardiography and focused assessment with sonography examinations (i.e., Focused Assessment with Sonography for Trauma – FAST)." • Fellows must demonstrate knowledge of those areas appropriate for a subspecialist in anaesthesiology critical care medicine, including monitoring equipment for the care of critically-ill patients and basic concepts of bioengineering, to include the principles of ultrasound, Doppler, and other medical imaging techniques relevant to critical care medicine" (ACGME Program Requirements for Graduate Medical Education in Anesthesiology Critical Care Medicine ACGME-approved focused revision: June 13, 2020; effective July 1, 2020).
Neurocritical Care	• No requirements regarding ultrasound education (ACGME Program Requirements for Graduate Medical Education in Neurocritical Care ACGME-approved: September 26, 2021; effective September 26, 2021).

Table 1. ACGME Programme Requirements for Ultrasound Training in Critical Care Fellowship

continues to exist despite calls for a formal CCUS curriculum by Neri et al. all the way back in 2007. Common barriers reported in the survey studies include lack of faculty expertise, insufficient time, and not enough bedside scanning supervision (Carver 2018; Mosier et al. 2014). In summary, we now have a bar of excellence as set by the Special Competence in Critical Care Echocardiography board certification followed by a framework for obtaining BCCE competency but have highly variable curricular and educational offerings in fellowship training and do not have clear benchmarks on what constitutes overall basic competence for CCUS in its many applications. This has resulted in significant heterogeneity amongst educational offerings by ACGME accredited critical care fellowship programmes in the U.S.

While recognising the training, curricular, and evidentiary limitations mentioned above, it must be acknowledged that ultrasound is also already in use in ICUs throughout the world. As ongoing efforts are underway to better define the training requirements and path to competence, efforts must continue to increase the quality of current CCUS use in individual ICUs and hospital systems. While credentialing, privileging, and billing are outside of the focus and scope of this article, the core elements of a successful CCUS programme will be discussed. For starters, an ultrasound with appropriate transducer(s) that can perform the variety of CCUS skills is a necessity. As technology is constantly changing, the layout of the ultrasound equipment will continue to adapt and change as well. Traditional cart-based setups include separate probes for vascular and body imaging, while newer technologies are allowing for hand-held devices and for the functions of the various probes to be combined into a single probe (Baribeau et al. 2020; Lee and DeCara 2020). There are benefits and limitations to these different probe and machine configurations as related to cost, image quality, and portability. Consultation with a local ultrasound expert is recommended when deciding on the best setup to meet the needs of the individual ICU. Given increasing overall complexity of patient populations, expanding use of new technologies such as temporary mechanical cardiac support, and growing expectations of basic CCUS skills for intensivists along with the availability of Special Competence in Critical Care Echocardiography board certification, a machine capable of performing the full array of cardiac and Doppler assessments in addition to procedural-based and vascular imaging is becoming a necessary piece of equipment in the modern ICU (Safford et al. 2007; Robba et al. 2021; Díaz-Gómez et al. 2017; Bartos 2020; Balthazar et al. 2021). The machine should be digital imaging and communications in medicine (DICOM) capable so that images and clips can be transferred automatically to an image archiving system. Storing images and clips is imperative to ensure the best patient care, standardised documentation, clear communication amongst the care team, and QA (Flannigan and Adhikari 2017; Lewis et al. 2022). Each individual programme can decide how to store images, whether it be sending the studies directly to a system such as picture archiving and communication system (PACS), or to an intermediary archiving software repository that allows for separate delineation and storage of academic and diagnostic studies (Mani 2021). Archived images from studies should be reviewed for QA by the local ultrasound director or expert, with feedback provided and remediation performed when necessary. The overall framework for the process will have to be ultimately determined by the programme, but previous guidelines suggest QA review of all images be performed during the benchmarking or training process and at least 5-10% of ongoing studies performed by credentialed clinicians continue to undergo QA review (Ultrasound Guidelines: Emergency, Point-of-Care and Clinical Ultrasound Guidelines in Medicine 2017). Image review and overall administration of a successful programme can be very time consuming so protected time or similar arrangement for the director of the CCUS program similar to the model utilised successfully in EM should be considered (Compensated Time for Faculty Academic Administration and Teaching Involvement 2019). Depending on the size of the overall programme and volume of studies performed, it may become necessary to have more than one clinician with time protected to assist with this job duty.

In conclusion, CCUS is a rapidly evolving field with an ever-expanding footprint in ICUs. While much progress has been made, ongoing efforts need to continue towards demonstrating impact on patient-oriented outcome measures and on defining educational curricula and competency requirements. With ongoing use a reality in the modern ICU, a formal CCUS programme is essential to ensure best practices and QA.

Conflict of Interest

None. ■

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MANAGEMENT & PRACTICE

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Miami, Florida, USA
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JANUARY 2023

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11-14 Society for Technology in Anesthesia Annual Meeting 2023
Las Vegas, Nevada, USA
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21-24 2023 SCCM Critical Care Congress
San Francisco, California, USA
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22-27 17th ESRA Winter Week Conference 2023
Längenfeld, Austria
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27-29 ASA® ADVANCE 2023: The Anesthesiology Business Event
Orlando, Florida, USA
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29-3 FEB 28th International Winter Symposium in Intensive Care Medicine 2023
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30-2 FEB Arab Health 2023
Dubai, United Arab Emirates
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FEBRUARY

2-3 3rd World Congress on Surgery, Surgeons and Anes-thesia
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9-15 EuroAfrica 2023
Cairo, Egypt
https://iii.hm/1ind

24-26 CRITICARE 2023 - 29th Annual National Conference of the Indian Society of Critical Care Medicine
Indore, India
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MARCH

21-24 42nd ISICEM International Symposium on Intensive Care & Emergency Medicine
Brussels, Belgium
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APRIL

15-18 33rd ECCMID
Copenhagen, Denmark
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26-29 11th EuroELSO 2023
Lisbon, Portugal
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MAY

7-9 22nd European Congress of Trauma and Emergency Surgery (ECTES)
Ljubljana, Slovenia
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19-24 ATS 2023
Washington, DC, USA
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31-2 JUN 9th World Congress of the ERAS Society 2023
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3-5 Euroanaesthesia 2023
Glasgow, Scotland
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14-16 Critical Care Reviews Meeting 2023
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