The Role of Pocus in Acute Respiratory Failure

Subjects: Emergency Medicine

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Acute respiratory failure (ARF) is a challenging condition that clinicians, especially in emergency settings, have to face frequently. Especially in emergency settings, many underlying diseases can lead to ARF and life-threatening conditions have to be promptly assessed and correctly treated to avoid unfavorable outcomes. Point-of-care ultrasound (POCUS) gained growing consideration due to its bedside utilization, reliability and reproducibility even in emergency settings especially in unstable patients.

acute respiratory failure | lung ultrasound | upper airways management | pneumonia | pneumothorax | lung effusion

1. Introduction

Acute respiratory failure (ARF) is a life-threatening condition characterized by acute onset of hypoxemia due to many clinical disorders such as pneumonia, congestive heart failure, aspiration and trauma [1][2]. Ventilation/perfusion mismatch and impaired excretion of carbon dioxide are the principal components of respiratory failure leading to systemic hypoxia and tissue damage [3]. It is essential to promptly identify the underlying cause to put in place a tailored treatment to correctly face the pathophysiological mechanism of injury.

Over the last decades, point-of-care ultrasound (POCUS) has gained increasing consideration and widespread utilization among emergency care settings due to its availability at bedside, reliability, reproducibility and overall cost-effectiveness [4]. Furthermore, it is an essential tool to assess acutely ill patients in low-resources fields such as prehospital settings and in those so unstable that radiological images are difficult to obtain [5][6].

The overwhelming application of POCUS in the assessment of ARF has been reported in many clinical scenarios and settings that vary from upper to lower respiratory airways, from cardiovascular to respiratory muscles analysis.

2. The Role of Pocus in Acute Respiratory Failure

2.1. A: US & Airway

2.1.1. Endotracheal Tube (ETT) Positioning Assessment

The most common utilization of POCUS in upper airway assessment of patients with ARF reported in literature is the correct placement of the ETT in many studies and case reports that document US feasibility and reliability.

The incorrect positioning of the ETT expose critically ill patients at risk to develop severe complications and to secure a definitive airway. In clinical practice lung auscultation, End Tidal CO2 (ETCO2) and chest XR are commonly used to confirm ETT position, however US of airways and lung may also play a role.

US assessment of a correct intubation is based on the identification of the “double trachea sign” by the anterior neck approach. Firstly, this routine check was performed in the operating room, then applied in the emergency department. In this prospective observational study, operators performed bedside US within 3 min after patient arrival in ED or after endotracheal intubation. It was observed that sonographers achieved 100% accuracy with respect to determining the correct ETT position utilizing an anterior neck approach (while the intubators’ accuracy in assessing correct tube location was 97% compared to the clinical outcome).

In this randomized controlled study, a group of residents scanned cadavers’ necks to confirm a correct endotracheal intubation or esophageal intubation. They were blinded to endotracheal tube placement and had to scan using either the B-mode method or B-mode plus color-Doppler. Moreover, a limited scanning time was given: 6 s for scanning with B-mode and 8 s for scanning with B-mode plus color-Doppler. There were 91.7% correct identifications made with B-mode and 86.9% with B-mode plus color-Doppler (*p*-value = 0.007). Finally, a correlation between the year of training and higher accuracy in ultrasound-guided ETT placement identification was observed [7].

In this prospective educational study by Chenkin et al., they tried to define the learning curve of POCUS to confirm ETT placement after a 10 min web-based tutorial and two practical sessions; participants were asked to correctly recognize the ETT position from ultrasound videoclips among a series of 20 endotracheal and 20 esophageal ETT placements. The study reported a sensitivity of 98.3% (95% CI 96.3–99.4%) and a specificity of 100% (95% CI 98.9–100%) for the participant to indicate the correct or incorrect placement [8].

2.1.2. Upper Airways Damage Identification and Procedures

US visualization of upper airway structures and their abnormalities is a recent role of the POCUS application. Cases of laryngeal ACE-I-induced larynx edema [9] and trauma affecting the larynx have been approached with US to assess the extent of damage [10].

An important finding in upper airways US is cricoid membrane identification. US has been extensively used to guide invasive procedures and its role to support cricothyrotomy has been evaluated. In a prospective observational study emergency physicians applied a technique first learned in a cadaver laboratory and then applied in vivo. US did not affect the time of execution, as the mean time required was 24.32 s. This time was not affected by patient anatomy or body mass index (BMI) [11].

There are some case reports about patients presenting with a critical mass in the larynx. Upper airways US permitted to evaluate their extension and to identify the feasibility of cricothyroidotomy instead of emergency tracheostomy. In one of these cases, US was also applied to visualize the hyoid bone to assess short hyomental distance ratio, high pre-tracheal anterior neck thickness and tongue size to predict endotracheal tube size [12][13].

2.1.3. Laryngeal Edema Assessment Pre-Extubation

The assessment of the larynx is important to predict extubation failure. Usually, this is evaluated by a leak test (difference between expiratory tidal volumes with the cuff inflated and deflated). Two prospective observational studies evaluated the air column width differences (ACWD) (width of air between the vocal cords seen by laryngeal ultrasonography) as a predictive index of extubation failure. In the first study ACWD ≥ 1.6 mm predicted laryngeal edema with 0.706 and 0.702 sensitivity and specificity, respectively; the area under the receiver operating characteristic curve of laryngeal ultrasound was 0.823 (95% confidence interval, 0.698–0.947) and that of cuff leak test was 0.840 [14]. In the other study, both laryngeal US and leak test resulted in having a positive predictive value < 20% cuff leak test (cut-off point: 249 mL) and showed a sensitivity and specificity of 75% and 59%, respectively.

2.2. B: US and Breathing

2.2.1. Protocols on Lung US

The BLUE protocol (**Figure 1**) is a flow chart to approach acute respiratory failure and its differential diagnosis by lung US (LUS) in a standardized way proposed by Lichtenstein and updated in 2008 [15].

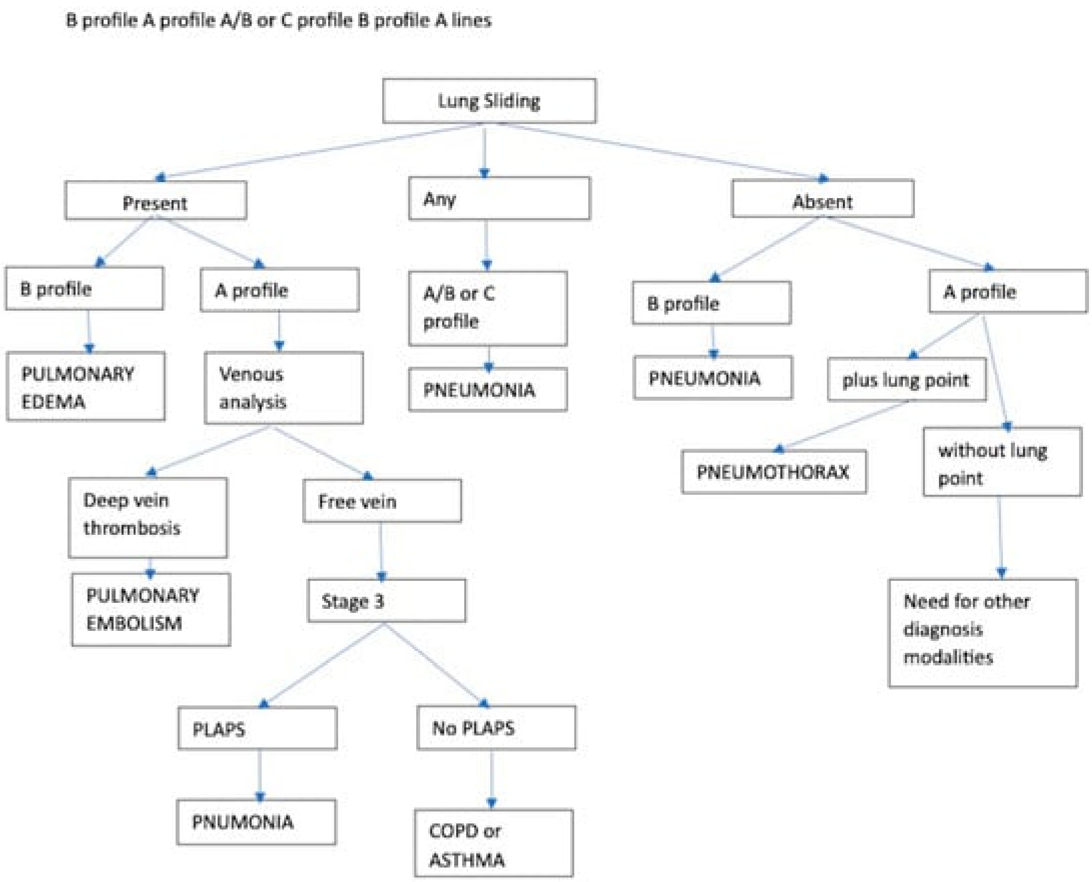

Figure 1. The Blue Protocol ([16], modified).

It is based on the identification and interpretation of easy LUS findings indicating normal lung surface (bat sign, lung sliding, A-lines), pleural effusions (quad and sinusoid sign), lung consolidations (fractal and tissue-like sign), interstitial syndrome (lung rockets or B lines), pneumothorax (stratosphere sign and the lung point) and venous thrombosis (compressive venous ultrasound) [16].

Mastering this basic echographic semiology allows clinicians to seek after the principal differential diagnosis affecting pulmonary parenchyma and pleural space: pneumonia, hemodynamic pulmonary edema, exacerbated chronic obstructive pulmonary disease or asthma, pulmonary embolism or pneumothorax [17].

Prospective observational studies have been conducted to verify sensitivity and specificity, comparing diagnoses made by BLUE and final discharge diagnoses. In two articles that evaluated 37 and 50 patients respectively, pneumonia and pulmonary edema were diagnosed with sensitivities of 88–94% and 86–92% and specificities of 90–94% and 87–100%, respectively [18][19].

However, some evidence suggests that the BLUE protocol did not always reach a correct diagnosis. A case of a pregnant woman affected by the rupture of a pulmonary hydatid cyst and a case of pulmonary hemorrhage not identified by BLUE protocol have been reported [20][21].

Indeed, BLUE is not the only protocol proposed to assess causes of respiratory failure. FALLS is a development of BLUE protocol based on initial basic cardiac sonography assessment, that allows to sequentially rule out obstructive, then cardiogenic, then hypovolemic shock for expediting the diagnosis of distributive (usually septic) shock [22].

Specifically for pneumonia, ultrasonographic findings are subpleural consolidations, positive air bronchogram within an echo-poor area and basal effusion [23][24].

Pneumothorax ultrasound echographic diagnosis is deeply accepted and supported by evidence. Different findings can identify PNX:

- Abolition of lung sliding alone, sensitivity 100% specificity 78%;
- Absent lung sliding plus the A-line sign, sensitivity 95% specificity 94%;
- Lung point, sensitivity 79% specificity 100% [25].

While LUS demonstrated good reliability in diagnosing PNX and it is easily deployable by emergency physicians in clinical practice [26], clinicians should exercise caution and always correlate clinical presentation to avoid misinterpretation of US findings. Other factors, such as hypercapnia and BMI in patients with COPD and asthma, as well as pneumothorax or pleural talcage, can contribute to the loss of lung sliding [27]. In a case report describing an acute exacerbation of COPD, a patient presented a large bulla that mimicked a lung point to POCUS without an actual PNX [28].

Acute Respiratory Distress Syndrome (ARDS)

A particular mention to ARDS, US has been investigated for diagnostic and monitorization purposes, as it can predict CT findings about lung aeration, monitor lung re-aeration during treatment and identify tidal volume recruitment [29].

Many prospective observational studies evaluated lung ultrasound scores in ARDS. Firstly, the combination of LUS plus pulse oximetry showed a better diagnostic accuracy than chest radiography plus blood gas analysis [30]. Moreover, LUS correlated well with oxygenation (P/F ratio) and seems to have a prognostic value about survival in mechanically ventilated patients and post-extubation distress syndrome [31][32][33][34].

LUS application in ARDS assessment has been so extensively studied that a possible correlation with a genetic polymorphism in the plasma platelet-activating factor was published. G994T polymorphism, combined with LUS score, showed a negative correlation with respiratory failure index, the need for ventilation, lactic acid levels, SOFA score, etc. A combination of LUS score and G994T polymorphism may be employed as a potential prognostic marker for ARDS [35] (**Figure 2**).

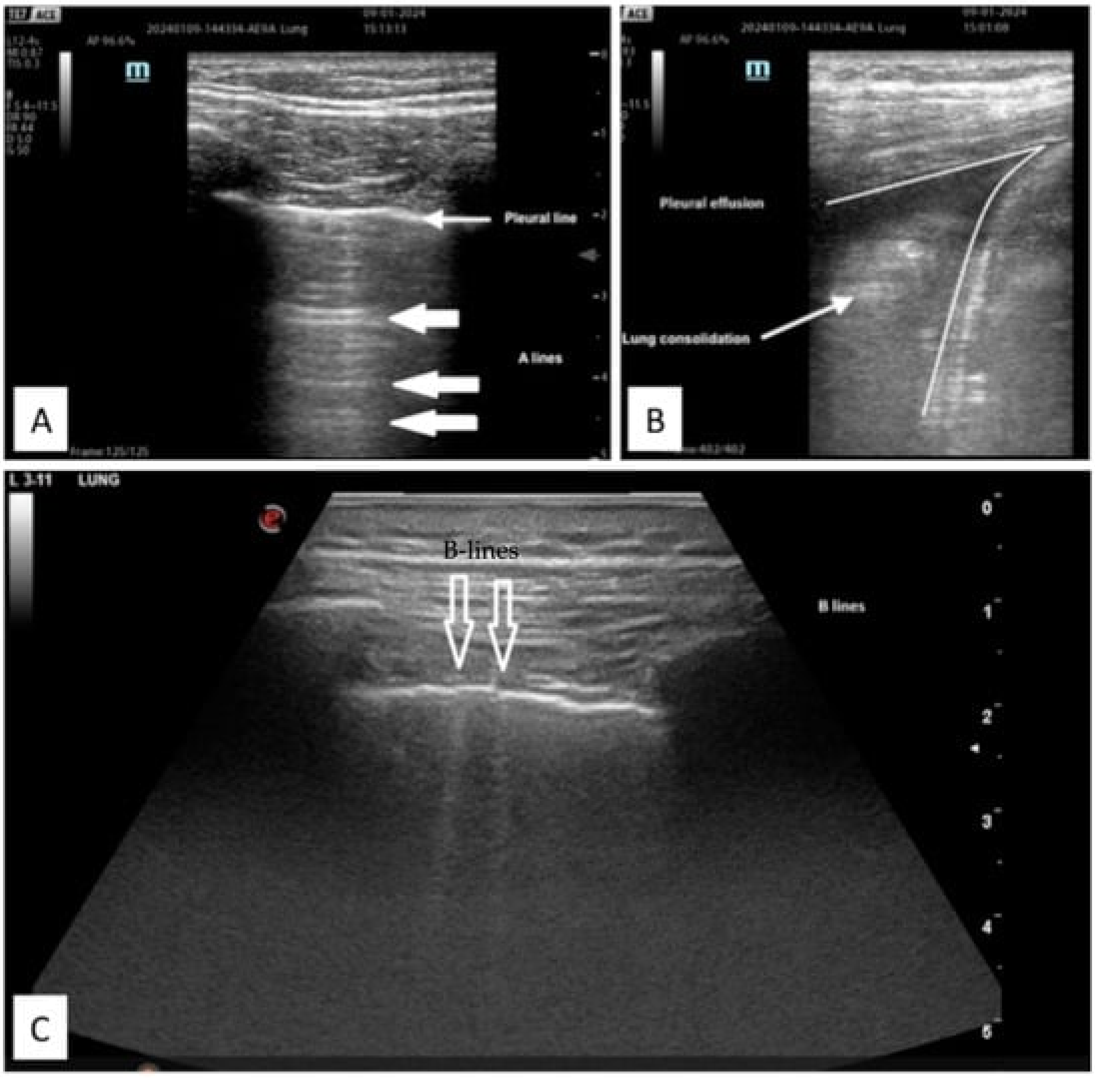

Figure 2. Example of LUS images of (**A**) normal aerated lung with pleural and A-line; (**B**) pleural effusion and associated parenchymal consolidation; (**C**) B-lines sign of interstitial syndrome.

2.2.2. Diagnostic Accuracy

In this prospective observational study conducted by Barman et al., POCUS was performed after a first clinical diagnosis was made. Out of 108 enrolled patients, initial clinical diagnosis was appropriate in 67.5% of cases, after POCUS assessment the diagnostic accuracy raised to 88% adding or changing the diagnosis in 37% of cases. Similar improvements were observed in the treatment plan decided before and after POCUS, in 36% of cases treatment decisions were changed. This study highlights how POCUS can improve diagnostic accuracy and lead to different treatment choices in clinical practice [36].

Furthermore, in this interventional study by Sen et al. about the medical emergency team activities, POCUS was proved to be feasible and reliable for in-hospital emergency management [37].

Diagnostic accuracy has also been evaluated for single pathology. The accuracy of LUS in a prospective observational study [38] is reported below:

- Pneumonia, standard, 0.74, ultrasound, 0.87;
- Acute hemodynamic pulmonary edema standard, 0.79, ultrasound, 0.93);
- Decompensated COPD standard, 0.8, ultrasound, 0.92;
- Pulmonary embolism standard, 0.65, ultrasound, 0.81;

Two meta-analyses [39][40] report sensitivity and specificity for the following diagnosis comparing the standard of care to US:

- Pneumonia/consolidation 89–92% and 94–97%;
- Heart failure/interstitial syndrome 90–95% and 91–93%;
- Pleural effusion 95% and 99%;
- COPD/asthma (A profile) 78% and 94%.

POCUS diagnostic accuracy has also been assessed comparing specifically LUS to CT scan findings in ARF patients. Overall, LUS sensitivity and specificity were 82.7–92.3% and 90.2–98.6% reaching a global agreement with CT scans ranging from 0.640 (0.391–0.889) to 0.934 (0.605–1.000) with an average of 0.775 (0.577–0.973) [39].

2.2.3. Time-to-Diagnosis Improvement

POCUS turned out to be useful also in shortening the time to reach a diagnosis and reducing patient overall management. One of Lichtenstein's works on US is reported to save up to two hours for diagnosis and management [15].

The mean time for diagnosis was shorter in POCUS application versus standard care. In these two prospective observational studies and a prospective randomized study, the time needed for a diagnosis was 12–42 min with POCUS, against 79–270 min with usual clinical care [41][42][43].

2.2.4. Diaphragm Ultra-Sound (DUS)

Other than lung ultrasound, the evaluation of the diaphragm in ARF has been studied to assess the entity of respiratory distress. Even if DUS is not precisely standardized yet [44], with US is possible to obtain information about diaphragm movement.

As the diaphragm is the most important inspiratory muscle, its dysfunction has a great impact on the deterioration of respiratory function. Indeed, literature about DUS has been focused on its predictive value: prediction of respiratory failure, NIV failure and weaning/extubation failure [45].

To quantify diaphragm movement by DUS clinicians can measure (see **Figure 3**):

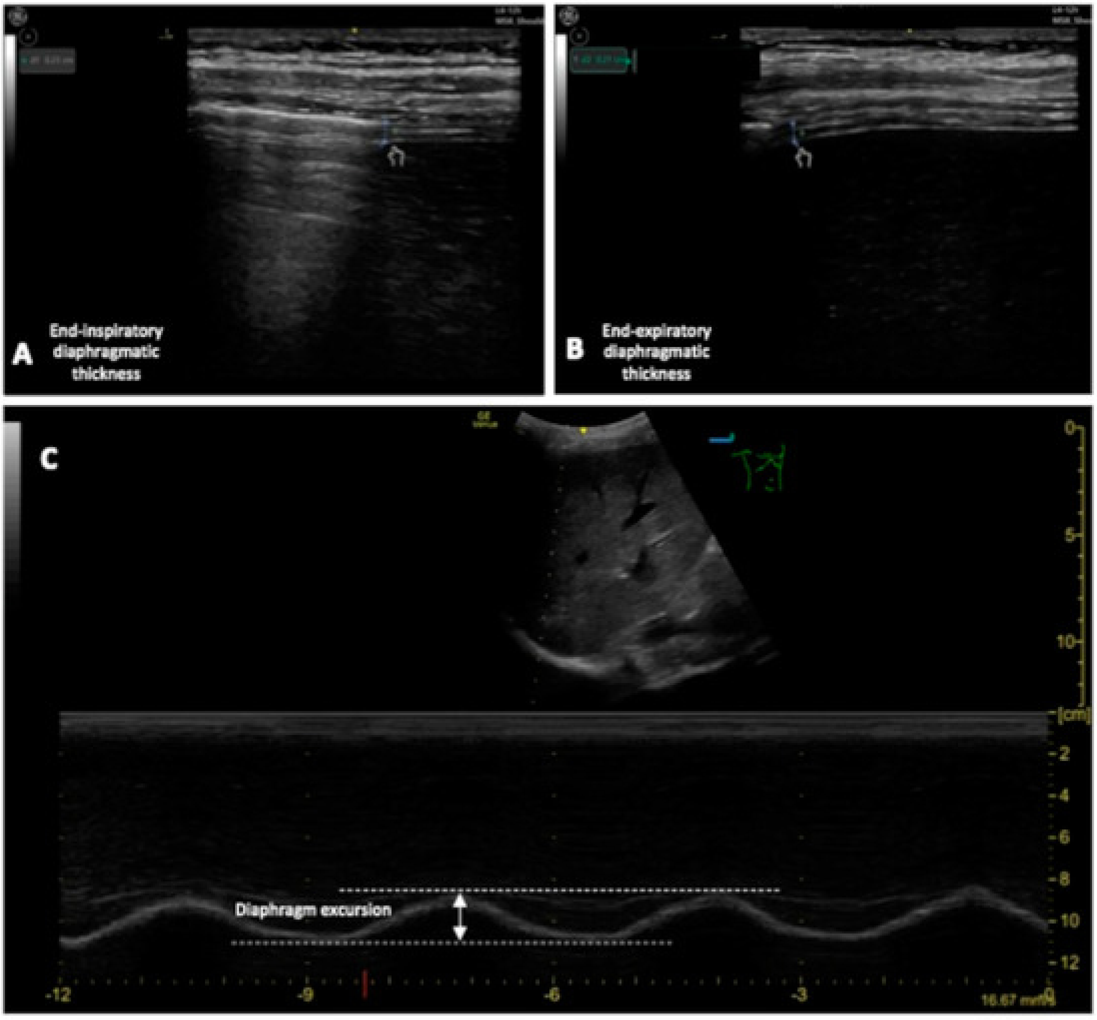

Figure 3. (**A**,**B**): Measurement of the end-inspiratory and end-expiratory diaphragmatic thickness; (**C**) measurement of the DE.

- Diaphragm thickening fraction (DTF), measurement of the difference in end-inspiratory and end-expiratory diaphragmatic thickness, expressed as a fraction;
- Diaphragm excursion (DE), the diaphragmatic altitude difference between expiration and inspiration [46] (**Figure 3**).

The main limitations of the technique are as follows: diaphragm excursion varies with BMI, movements of the organs continuous to the diaphragm are not reliable to estimate diaphragm movements, in intercostal insonation lung may obstacles tidal evaluation of the diaphragm and in subcostal positioning of the probe may diminish lung interposition but US incidence angle may affect measuring precision [46].

DTF reduction proved to be a reliable tool to assess the risk of respiratory failure in patients affected by pneumonia. (The optimal DTF cut-off was 23.95%, with an OR: 0.939, p = 0.0416, 69.23% of sensitivity, 83.78% of specificity, 88.57% of negative predictive value and 80% of accuracy) [47].

Studies about COPD focus on the prediction of NIV failure. They found that diaphragm ultrasound showed great potential to evaluate diaphragm function, especially to assess changes in diaphragmatic function in patients with stable COPD and to predict the success rate of NIV and MV weaning in patients with acute exacerbation [48].

DUS was employed also in a comparative study to assess diaphragm work during different techniques of respiratory support therapies [49].

Spontaneous breathing trials are commonly performed before extubation to predict post-extubation NIV or risk of reintubation. DUS may contribute to assessing this prediction [50].

3. Conclusions

POCUS application to assess ARF is becoming a useful and reliable tool, especially in emergency settings supported by growing scientific evidence. The availability of an ultrasound machine in increasing settings allows its application in many different clinical conditions, thus its utilization should be implemented and reported to increase literature evidence on its potentiality.

Emergency medicine is one of the main disciplines where POCUS may make the difference between life and death being useful also in procedural intervention guidance if needed. Individual competence, poor resources and adverse environmental conditions may limit its application; however, updated and new ultrasound technology may help clinicians to fill these gaps. Unfortunately, the grade of scientific evidence on POCUS such as clinical trials is poor, and its increasing utilization should lead to conducting studies with a stronger level of evidence such as clinical trials.

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