Intensive Care Med
https://doi.org/10.1007/s00134-024-07753-5

EDITORIAL

How we use ultrasound in the management of weaning from mechanical ventilation

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Difficult weaning from invasive mechanical ventilation is associated with adverse clinical outcome and increased use of limited health care resources. Difficult weaning, characterized by failure of multiple spontaneous breathing trails (SBTs), can result from several causes, including impaired function of lung, heart, and respiratory pump [1]. In this editorial, we discuss how ultrasound may facilitate weaning from mechanical ventilation (Fig. 1).

Critical care ultrasound (CCUS), in the hands of proper trained staff, is a valuable diagnostic tool across all stages of mechanical ventilation, including the weaning phase. During mechanical ventilation, CCUS allows for assessment of readiness for weaning. In case of weaning failure, it can identify the causes of weaning failure, and assess cardiorespiratory function and treatment response.

The ABCDE-ultrasound approach allows clinicians to review the pathophysiology of weaning failure effectively [2]. It allows for assessment of readiness for weaning and to diagnose and monitor the cause of weaning failure. The detailed use of CCUS in daily practice, following the ABCDE approach, is discussed in subsequent sections.

CCUS examination in weaning: the ABCDE approach

In mechanically ventilated critically ill patients, ultrasound should be used as an adjunct to clinical parameters and physical examination. For the ABCDE-ultrasound assessment, the operator should be proficient in the basics of CCUS [3]. We propose that an ultrasound evaluation should be performed in most patients ventilated for > 48 h. The frequency of follow-up examinations is determined by the cause and course of the disease.

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Aeration score and pleural effusion

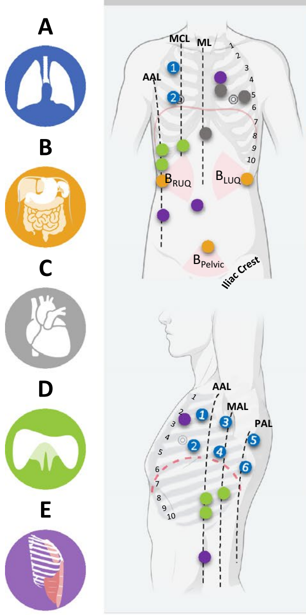
Lung ultrasound is an excellent tool to diagnose the pulmonary abnormalities hindering successful weaning. We use a 6-view lung ultrasound qualitative assessment to diagnose the cause of respiratory failure by assessment of lung sliding, pleural abnormalities, lung profiles (A/B/C), pleural effusion, and consolidations with or without dynamic air bronchograms [4]. One should be careful not to interpret lung ultrasound results in a deterministic fashion, as often more than one pulmonary problem is present in ICU patients [5]. A quantitative approach, using 12 views, is used to calculate the lung aeration score, which can be used to monitor pulmonary pathology over time [6]. To assess the risk of extubation failure, a succinct antero-lateral approach (including 8-views) before and at the end of an SBT can be used. An increase of ≥ 5 B-lines is associated with extubation failure, independently from LV filling pressures [7, 8]. Outcomes can be used to determine weaning readiness, diagnose the cause of weaning failure, and monitor disease progression and response to therapy.

Below the diaphragm

Increased abdominal pressure can affect respiratory mechanics and thereby weaning. Abdominal ultrasound, with a convex probe in the abdominal setting, is used to screen for free fluid in the peritoneal cavity. The aspect of the free fluid, hypo-anechoic versus heterogenous with a more hyperechoic aspect, and the presence of septae, may help differentiate between the cause of the free fluid, e.g., blood, ascites, or signs of complicated effusions. Ultrasound is used to guide paracentesis for both diagnostic and therapeutic purposes and monitoring treatment response.

Cardiac

Cardiac dysfunction is one of the most frequent causes of weaning failure. Ultrasound can be used to assess the



	WHERE	WHY	WHEN	WHAT
A		• To identify pulmonary congestion, consolidation, atelectasis, pleural effusion, pneumothorax	• Earlier phase (<24-48 h) • Weaning phase	• 6 view (1-2-6/side) qualitative approach to diagnose the problem via BLUE protocol • 12 view (1-6/side) quantitative approach to monitor lung aeration (LUS score: low risk <13; high risk>17) • 8 view (1-4/side) approach to assess risk of extubation failure (≥5 B-lines)
B		• To find ascites, pus or blood	• Weaning phase	• FAST protocol to detect free fluid and assess its appearance: ▪ Hypoechoic: probably uncomplicated ▪ Loculated: probably complicated
C		• To identify diastolic and systolic dysfunction, right ventricular failure, acute heart failure (left/right), fluid load	• Earlier phase • Weaning phase • After failing of the first SBT	• Start with basic examination • Advanced cardiac ultrasound, including TEE when necessary, when indicated • Diastolic impairment: E'<8 cm/s ▪ If EF reduced: E/A > 2 ▪ If EF normal: E/e'> 12
D		• To address the function of diaphragm	• After failing of the first SBT	• Subcostal view to assess excursion (low risk > 1-1.5cm bilateral; > 2.5 cm, unilateral) • Intercostal view to assess thickening fraction (low risk TFdi>30-35%) and thickness (decrease > 10% from baseline indicates atrophy)
E		• To assess the extra-diaphragmatic respiratory muscle activation and atrophy	• After failing of the first SBT • After failed extubation	• Parasternal view to assess parasternal intercostal muscle (low risk: TFic < 10%) • For abdominal wall muscle: reduced thickening fraction compared to baseline during cough indicates a high risk of extubation failure (combine with clinical assessment of cough)

ML, middle line; MCL, middle clavicular line; AAL, anterior axillary line; MAL, middle axillary line; PAL, posterior axillary line; RUQ, right upper quadrant; LUQ, left upper quadrant; spontaneous breathing trial; LUS, lung ultrasound; FAST, the focused assessment with sonography in trauma; TEE: transesophageal echocardiography; EF, ejection fraction; TFdi: thickening fraction of diaphragm; TFic: thickening fraction of intercostal muscle

Fig. 1 The ABCDE-Ultrasound Approach to Weaning from Mechanical Ventilation. This figure illustrates the application of Critical Care Ultrasound during the weaning phase to assess readiness for weaning and diagnose the causes of weaning failure. The approach addresses the 'where' (location of ultrasound assessment), 'why' (indications for ultrasound during weaning), 'when' (timing of ultrasound in the weaning process), and 'what' (specific ultrasound parameters to evaluate)

mechanisms involved in weaning-induced cardiac failure. We start with a basic transthoracic cardiac ultrasound evaluation. The heart is examined in different views, e.g., parasternal long and short axis, apical two, three, four, and five chamber and subcostal. The size and function of both ventricles are estimated by eye-balling. Also, regional wall abnormalities or pericardial effusion can be detected.

If after this examination, no clear cause is identified and an obvious extra-cardiac cause is discarded, we perform a more advanced cardiac ultrasound examination. This is done by intensivist/clinician with advanced education in cardiac ultrasound. If no clear views can be obtained, we perform a transesophageal examination in selected patients. Assessment of diastolic function (E/A and E/e' ratios) when failing an SBT is very important [9]. Also, regional wall motion abnormalities, and stenosis and regurgitation of cardiac valves are assessed.

Treatment can include fluid removal, start of antihypertensive medication (ACE-inhibitors, calcium channel blockers, and nitrites), or anti ischemic treatment dependent on the problem identified, e.g., fluid overload, diastolic dysfunction, or cardiac ischemia. Follow-up is done by repeated ultrasound evaluation when indicated.

Diaphragm

Dysfunction of the diaphragm, the primary muscle for inspiration, is highly prevalent in ventilated patients. Diaphragm ultrasound is useful to exclude the diaphragm dysfunction as a contributor to weaning failure, especially after a failed initial SBT. We first measure diaphragm excursion (DE) via subcostal or subxiphoid approach, using liver or spleen as acoustic windows. If these approaches do not provide a clear view, an intercostal approach at the zone of apposition to measure the displacement of liver or spleen can serve as a qualitative alternative [2, 10]. DE is measured during spontaneous breathing without ventilator support. In cooperative patients, a maximal inspiratory effort can be performed to assess maximal excursion.

To obtain a comprehensive overview of the diaphragm contractility, we also measure diaphragm thickness and calculate the thickening fraction (TFdi) via the intercostal approach. A decrease in diaphragm thickness helps to detect atrophy, but an increase in thickness should be interpreted carefully, as edema and fibrosis may also play a role [11, 12]. Diaphragm dysfunction is diagnosed by DE of < 20 mm. A TFdi < 30–35% and DE < 10–15 mm have been shown to be predictive of weaning failure [13].

Extra-diaphragmatic muscles

Activating extra-diaphragmatic muscles can help compensate for diaphragmatic weakness, promoting successful SBT but potentially predicting weaning failure [14, 15]. In addition, expiratory muscle atrophy, which impairs airway clearance, may lead to extubation failure despite passing the SBT. We use ultrasound to assess their engagement during SBT by measuring thickening fraction. Our approach starts with the parasternal intercostals [15], followed by the rectus abdominis muscle, and then includes the external oblique, internal oblique, and transversus abdominis within the same window, where they appear as three parallel layers [12]. Given the abdominal geometry and the considerable mobility of the abdominal wall muscles, it is crucial to interpret ultrasound results while considering intra-abdominal pressure and the contraction of adjacent muscles. Thickening fraction of the intercostal muscles > 10% indicates higher risk of extubation failure.

Future directions

As discussed above, ultrasound already has a great potential to hasten liberation from invasive mechanical ventilation, especially by identifying reasons for failed SBT and extubation. However, we see further potential for ultrasound to improve care for these patients. First, clinical trials may help to improve the predictive performance of lung and diaphragm ultrasound for extubation failure. Although it is unlikely that a fixed cut-off value for diaphragm thickening fraction exists to predict extubation failure, a more comprehensive ultrasound assessment may appear of value. Second, today ultrasound is merely used as a diagnostic tool. Recent developments allow the use of ultrasound as a monitoring tool by acquiring continuous data, for instance during a weaning trial [16]. This will provide additional information, improving predictive performance, but also open windows to new indications, for instance monitoring patient–ventilator asynchronies, that play a role in diaphragm injury. Finally, more advanced ultrasound techniques may appear of value. For instance, speckle tracking ultrasonography may provide a better estimation of diaphragm function as compared to conventional thickening fraction [17], and very recently, a novel ultrasound technique has been described that allow quantification of diaphragm perfusion [18].

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Conflict of interest

The authors have no conflict of interest related to this manuscript.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Received: 14 October 2024 Accepted: 30 November 2024
Published online: 07 January 2025

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