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EDITORIAL

How I perform diaphragmatic ultrasound in the intensive care unit

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The diaphragm is a thin, dome-shaped muscle, comprising a costal and crural part, and a non-contracting central tendon. Muscle fiber activation shortens and thickens the diaphragm in the zone of apposition, moving the dome caudally. Diaphragm function, defined as the ability to contract and generate pressure, has substantial reserve capacity. However, clinically significant diaphragm weakness, a marked reduction in its force-generating ability, is an uncommon reason of respiratory failure causing admission to the intensive care unit (ICU). It more commonly develops in critically ill patients, even early during their ICU stay. The pathophysiology hereof remains incompletely understood, with disuse and inflammation recognized as key risk factors [1]. Critical illness-associated diaphragm weakness may complicate weaning and worsen outcomes [2]. Therefore, in specific clinical settings, evaluation of diaphragm function in the ICU is important. Ultrasound allows to noninvasively visualize the diaphragm function and activity at the bedside. In this article, we present our clinical experience with diaphragm ultrasound in daily care.

Practical aspects

Bilateral diaphragm ultrasound is feasible, but the right-sided approach is easier and usually sufficient, unless unilateral dysfunction is suspected [3, 4]. Assessment is performed in semi-recumbent position, with two approaches to visualize the diaphragm.

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Subcostal approach

A low frequency probe (2–5 MHz, abdominal or cardiac transducer) is positioned *subcostally* on the mid-clavicular line, angled cranially and perpendicular to the dome [3, 4] (Fig. 1). The diaphragm appears as a bright line covering the liver or spleen in the B-mode, moving towards the probe during inspiration. *Diaphragm excursion* (DE) is measured as the displacement during tidal breathing in the M-mode, with the M-line positioned perpendicular to the diaphragm movement. As passive displacement from ventilator inflation cannot be differentiated from active displacement, DE should be measured without inspiratory ventilator support (or minimal assist). Severely impaired excursion in a patient with adequate respiratory drive (e.g., $P0.1 \geq 2$ cmH_2O) suggests diaphragm weakness, while paradoxical movement indicates paralysis.

Intercostal approach

A high-frequency probe (7–12 MHz, linear transducer) is positioned at the antero- or mid-axillary line between the 8th and 11th intercostal space, perpendicular to the chest wall at the zone of apposition, preferentially in-line with the intercostal space, to allow diaphragm visualization across the full screen [3, 4] (Fig. 1). The diaphragm appears as a three-layered structure with a non-echogenic muscular layer, bordered by the echogenic pleural and peritoneal linings. A fibrous layer appears as a bright line in the center of the image. *Thickness* is measured in the B-mode at end-expiration (DTee) and peak-inspiration (DTpi), placing calipers at the internal margin of the pleural and peritoneal lining without including them. Alternatively, thickness can be measured in the M-mode, which provides more accurate timing within the respiratory cycle, whereas the B-mode offers superior spatial orientation. *Thickening fraction* (DTF) is calculated as ((DTpi-DTee)/DTee)*100. For accurate DTF

SUBCOSTAL APPROACH	INTERCOSTAL APPROACH

1. Baseline conditions

Patient positioning

Subcostal approach:

Place the patient in a semi-recumbent position (30-45°)

Intercostal approach:

Place the patient in a semi-recumbent position (30-45°)

Ventilator conditions[1]

Subcostal approach:

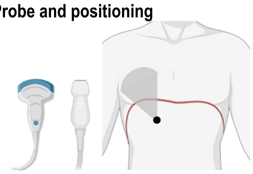
- Adequate respiratory drive (eg P0.1 >2cmH_2O)(no or minimal sedation)
- No (or minimal tolerable) ventilator support (intubated or extubated)

Intercostal approach:

- Adequate respiratory drive
- No (or minimal tolerable) ventilator support (intubated or extubated)

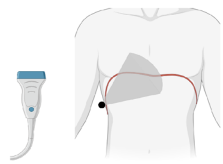
2. Probe and positioning

Subcostal approach:



- 2-5 MHz, abdominal or cardiac transducer
- The probe is positioned subcostally on the mid-clavicular line, angle directed medially, dorsally and cranially to reach the posterior third of the diaphragm
- Right side is easiest and sufficient unless unilateral involvement is suspected

Intercostal approach:

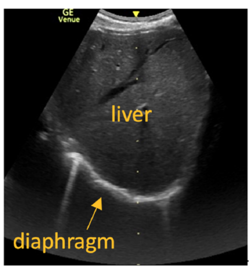


- 7-12 MHz, linear transducer
- The probe is positioned at the antero- or mid-axillary line between the 8th and 11th intercostal space, perpendicular to the chest wall at the zone of apposition, in line with the intercostal space
- Right side is easiest and sufficient unless unilateral involvement is suspected

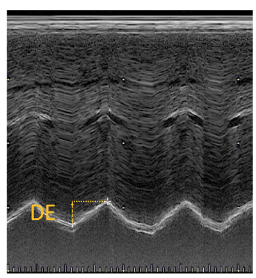
3. Image acquisition

Subcostal approach:

B mode



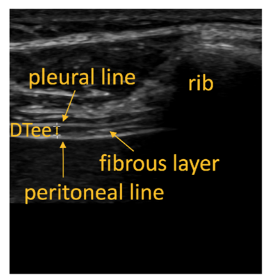
M Mode



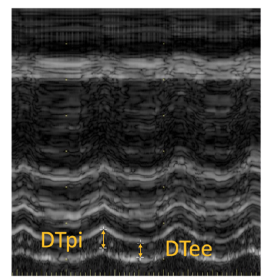
- Adjust depth to optimally capture excursion
- Adjust gain to optimize contrast with surrounding structures
- Adjust focus is used to optimize image quality
- Position the M line perpendicular to the diaphragm movement, focusing on the area with the greatest displacement
- Adjust sweep speed to obtain at least 3 respiratory cycles within 1 frame

Intercostal approach:

B mode



M Mode



- Adjust depth center the diaphragm
- Adjust gain to optimize contrast with surrounding structures
- Adjust focus is used to optimize image quality
- Position the M line perpendicular to the diaphragm
- Adjust sweep speed to obtain at least 3 respiratory cycles within 1 frame

4. Measurements

Subcostal approach:

- Measure DE during tidal breathing in M-mode
- Place the markers at the lowest (foot) and the highest point (apex) of the inspiratory slope and measure the distance between both on the vertical axis

Intercostal approach:

- Measure thickness at end inspiration (DTpi) and end-expiration (DTee) of the same respiratory cycle in the B mode or M mode
- Place the calipers perpendicular to the fiber direction closest at the internal margin of the pleural and peritoneal lining without including them
- Calculate DTF as (DTpi-DTee)*100/(DTee)
- To achieve representative results, obtain at least 3 measurements with a difference of <10%.

5. Normal values in healthy individuals[14]

Subcostal approach:

DE: seated, tidal breathing, end-expiration (values as mean±SD)
right: male: 2.0±0.5 cm; female: 1.9±0.5 cm
left: male: 2.2±0.6 cm; female: 1.9±0.5 cm

Intercostal approach:

Thickness: seated, tiddal breathing, end-expiration (values as mean±SD)
right: male: 2.1±0.4 mm; female: 1.9±0.4 mm
left: male: 2.0±0.4 mm; female: 1.7±0.3 mm

DTF: seated, tidal breathing, end-expiration (values as mean±SD)
right: male: 32±15%; female: 35±16%
left: male: 30±14%; female: 33±15%

6. Relevant thresholds/related to outcome

Subcostal approach:

DE:
DE <10-15 mm during tidal breathing: diaphragm dysfunction[4]

Intercostal approach:

DTF:
DTF_{max} <20%: diaphragm dysfunction[4]
DTF <25-33%: predicts weaning failure[9]
DTF <20%: predicts NIV failure[10]

[1] Ventilator conditions apply to the proposed indication of diagnosing diaphragm weakness. Virtual absence of ventilator support or specific levels of respiratory drive are not required for other situations, such as detection of asynchrony.

Abbreviations: DTpi: diaphragm thickness at peak-inspiration; DTee: diaphragm thickness at end-expiration; DTF: diaphragm thickening fractio; DTF_{max}: diaphragm thickening fraction during maximal inspiratory maneuver; DE: diaphragm excursion.

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Fig. 1 Practical aspects of diaphragm ultrasound measurement, patients should be without or on minimal ventilator support, as higher assist levels lower DTF due to diaphragm unloading [3]. Thickness shows no correlation with diaphragm function and inconsistent data on the correlation between DTF and diaphragm function suggest that DTF also may not be a reliable surrogate [5–7].

Measurements of DT, DTF, and right hemidiaphragm excursion are repeatable and reproducible by experienced operators [5]. At least 40 training examinations are recommended before independent practice [3].

Areas of application in daily care

In our experience, diaphragm ultrasound is particularly valuable in the diagnostic workup of patients with SBT or extubation failure, aiding clinical decision-making. Approximately, 20–30% of mechanically ventilated patients are difficult-to-wean and require a systematic approach to identify and correct reversible causes. We consider diaphragm ultrasound as an essential part of the multimodal diagnostic approach for these patients as it provides clinically relevant information by identifying or excluding diaphragm dysfunction as a potential contributor. In addition, diaphragm ultrasound is highly valuable in cases of unexplained respiratory failure due to neuromuscular disease, leading to ICU admission. It can also confirm unilateral or bilateral traumatic phrenic nerve lesions.

The preferred method for diagnosing diaphragm weakness is measuring DE with the subcostal approach on the right, or bilaterally if unilateral dysfunction is suspected. Dysfunction, possibly explaining weaning failure, is diagnosed when DE < 10–15 mm during tidal breathing [4]. Diaphragm paralysis is diagnosed by paradoxical upward movement during inspiration. If subcostal imaging is hindered, the intercostal approach may allow visualization of diaphragm movement. Due to inconsistent correlation between supra-and infra-diaphragmatic movement and lack of reference values, we use this approach qualitatively to rule out severe weakness. Although DTF-max < 20% was proposed for diagnosing weakness, we remain critical as DTF may not reliably reflect diaphragm function [7] and maximal efforts are hard to achieve in this population. If diaphragm weakness is identified in difficult-to-wean patients, efforts should focus on reducing the respiratory load (e.g. fluid overload, atelectasis, pleural effusion, and dynamic hyperinflation). When excluded, other causes of weaning failure should be ruled out (e.g. heart failure and psychological factors).

Despite these valuable clinical indications, diaphragm ultrasound cannot yet be recommended for decision-making on performing a spontaneous breathing trial (SBT) or extubation. Although it may predict SBT and weaning outcomes, studies are heterogenous, observational and use variable cutoffs [8, 9]. Furthermore, diaphragm dysfunction not necessarily precludes successful weaning [2]. Similarly, although observational data suggest diaphragm ultrasound may predict non-invasive ventilation (NIV) failure [10], lack of prospective studies prevents its use for intubation decisions in NIV-treated patients. Finally, DTF was proposed for optimizing inspiratory effort, the work produced by the diaphragm, termed 'diaphragm protective ventilation' [3, 4]. Practical implementation is hampered by the lack of validated norms for normal effort and concerns that DTF not reflect true effort [7].

Future prospects

Diaphragm ultrasound holds potential as a non-invasive tool for detecting asynchronies during mechanical ventilation, often missed by waveform monitoring and linked to poor prognosis. A new, operator-independent device enabling continuous diaphragm monitoring is promising [11]. In addition, novel ultrasound-derived parameters, such as strain and stiffness from speckle tracking and shear-wave elastography, show promise as more reliable indicators of diaphragm function in healthy individuals and hold potential for assessing diaphragm effort [12, 13].

Take-home message

Diaphragm ultrasound is a valuable, bedside non-invasive method for diagnosing or excluding diaphragm dysfunction in difficult-to-wean patients. It also plays a role in identifying diaphragm weakness as a cause of respiratory failure in select cases and diagnosing traumatic phrenic nerve injury.

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Declarations

Conflict of interest

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