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Diaphragm ultrasound in critically ill patients

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ABSTRACT

Diaphragm ultrasound (DUS) is a rapidly evolving and useful modality. Diaphragmatic dysfunction (DD) is common in critically ill patients and is associated with significant adverse outcomes such as need of intubation, prolonged mechanical ventilation, weaning failures, and mortality. Most commonly used indices in DUS are diaphragmatic excursion (DE) and diaphragmatic thickness fraction (DTF). As positive pressure ventilation affects these indices, so DUS should ideally done on spontaneously breathing patients. DE and DTF can be used to diagnose DD and to predict weaning outcome. Recent expert consensus has proposed cut off values for identification of diaphragmatic weakness and atrophy in critically ill patients. While performing DUS, it is recommended to scan the para-diaphragmatic areas to look for collapse/consolidation of the lungs, pleural effusion and any subdiaphragmatic pathology. As DUS is still in evolution, well designed randomized controlled trials are required to standardize the cut off values and to define the role of DUS for improving patient outcome.

Keywords: *critically ill, diaphragm dysfunction, diaphragm excursion, diaphragm thickness fraction, diaphragm ultrasound.*

INTRODUCTION

Diaphragm is a dome shaped musculotendinous structure separates thoracic and abdominal cavity. It is the major muscle of respiration, accounting for generation of approximately 70% of inspired tidal volume. Diaphragm ultrasound (DUS) is rapidly evolving and is useful modality in various clinical settings as it is non-invasive, easy to use, accurate and is reproducible. In critically ill patients diaphragmatic dysfunction (DD) is common and is associated with significant adverse outcomes such as need of intubation, prolonged ventilation, weaning failures, and mortality.[1] Prevalence of DD can exceed 60% (at the time of hospital admission) and may rise to as high as 80% in patients requiring prolonged mechanical ventilation (often ultimately lead to difficult weaning).[2]

This review aims to elaborate various indices to evaluate function of the diaphragm. Additionally the review will address following POCUS questions with clinical correlation:

- Am I dealing with DD?
- Is there any evidence of diaphragmatic atrophy?
- How to assess ventilatory induced diaphragmatic dysfunction (VIDD)?
- How to predict weaning failure by diaphragmatic assessment?
- What to assess in the para-diaphragmatic areas in patients with weaning failure?

Impact of ventilator mode on various diaphragmatic indices:

While doing DUS it is preferable for the patient to be on spontaneous mode because intermittent positive pressure ventilation (IPPV) and positive end expiratory pressure (PEEP) alters indices of DUS such as diaphragmatic excursion (DE) and diaphragmatic thickness (DT). IPPV augments diaphragmatic movements with greater lung inflation and larger DE. PEEP lowers the resting position of the diaphragm and reduces DE. IPPV reduces patient's effort and thus the DT at end inspiration. PEEP lowers the resting position of the diaphragm with higher diaphragmatic thickness at end expiration.[3]

Mechanical ventilation induces diaphragmatic injury referred to as "myotrauma". In critically ill patients it has been widely appreciated and recognized as ventilator-induced diaphragmatic dysfunction—VIDD.[1] Besides lung protective ventilation which is globally accepted, one should initiate diaphragm protective ventilation by frequent assessment of the diaphragm function. DE, DT and diaphragmatic thickening fraction (DTF) are the commonly used indices. DE is reduced in patients with DD. It may be absent in severe cases. Additionally we can appreciate paradoxical movement of diaphragm in cases of diaphragmatic paralysis. DT measurement helps to diagnose diaphragmatic atrophy on serial monitoring.

DTF is another index used to monitor diaphragmatic efforts in critically ill patients. In patients on positive pressure ventilation, we can optimize pressure support (PS) settings based on serial monitoring of DTF. If a given PS is excessive, DTF is reduced. This suggests that excessive PS is not allowing diaphragm to contract efficiently. Subsequently if the applied PS is sub optimal, then DTF is increased because the diaphragm is overworking. Thus, optimization of PS settings based on DTF is possible by DUS which ultimately protects diaphragm and may help to minimize VIDD.

INDICES USED IN DUS:

1) Diaphragmatic excursion (DE):

Probe: Curvilinear probe with the indicator oriented towards the left with abdominal preset. **Position of the probe:** Place the probe at subcostal area in the midclavicular line with liver (right side) or spleen (left side) serving as an acoustic window. The transducer should be directed towards the dome of the diaphragm, directed medially and cephalad so that the ultrasound beam reaches the posterior part of the vault of hemidiaphragm perpendicularly and capture craniocaudal excursion of diaphragm on B mode. Diaphragm appear as hyperechoic curvilinear line, moving with respiration and located between liver (close to probe) and thorax (Figure. 1). After correct visualization of the hemidiaphragm on B-mode, M-mode is used to display the motion of the diaphragm. The inspiratory and expiratory craniocaudal displacements of the diaphragm is seen as hyperechoic sinusoidal line.

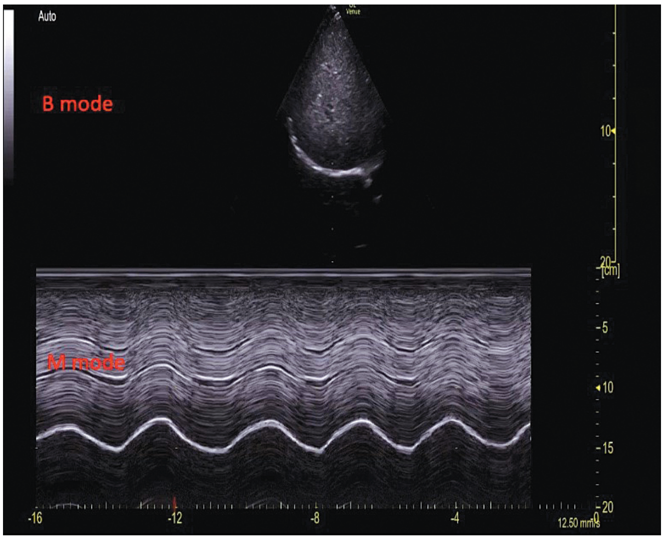

Figure 1. *Assessment of DE (B mode in the top Image and M mode in the bottom image).*

In clinical practice, its common to monitor right diaphragm because image acquisition of left hemidiaphragm can be at times difficult due to poor splenic window and is obscured by the air-filled stomach. It is observed that unilateral assessment of the right hemidiaphragm is an acceptable substitute for whole diaphragm assessment except in cases of suspected unilateral pathologies such as thoracic surgery, phrenic nerve or spinal cord injury, where measurements are to be obtained in both sides.[3]

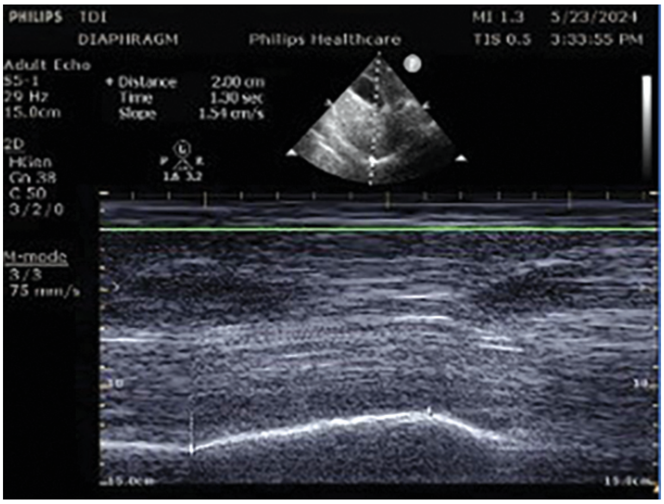

Figure 2. *Measurement of DE. Diaphragm is observed as a hyperechoic sinusoidal line. Peak to trough distance is the measure of DE. In this image, DE is 2.0 cm.*

Clinical significance of DE: DE on M mode is measured as the distance from trough to peak as shown in Figure. 2. Normal DE is 1.5 to 2 cm and on deep breathing up to 5 cm. DE < 2 cm is indicative of DD during quiet breathing, as per EXpert consensus On Diaphragm UltraSonography in the critically ill (EXODUS) statement.[3]

2) Diaphragmatic thickness (DT) :

DT of hemidiaphragms can be measured on B-mode at the end of a normal expiration (at functional residual capacity). DT is used for assessment of diaphragm atrophy, which is defined as a decrease in 10% or more of the diaphragm thickness on serial measurements. The thickness varies depending on which intercostal space is chosen, the hemidiaphragms being thicker at the lower intercostal spaces. During quiet breathing, the normal thickness has been estimated to be 1.20 mm to 2.79 mm at end expiration and 1.65 mm to 3.70 mm at end inspiration.[4]

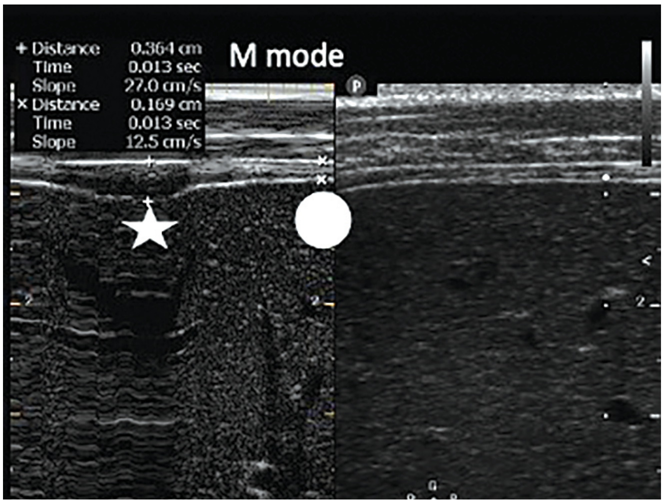

Figure 3. *Diaphragm at the Zone Of Apposition (ZOAP) view on M mode (★End inspiratory thickness: 0.36cm, ●End expiratory thickness: 0.16cm)*

3) Diaphragm Thickening fraction (DTF):

It is the index to measure respiratory effort and diaphragmatic contractile function on M mode. As diaphragm contracts, it thickens and shortens. DTF represents diaphragmatic inspiratory activity. It is measured from the center of the parietal pleural line to the center of the peritoneal line at end-expiration (Tdi-exp) and at end-inspiration (Tdi-insp). DTF is calculated as the difference between Tdi-insp and Tdi-exp divided by Tdi-exp. The value is multipled by 100 to obtain DTF in percentage (Figure. 3). **Probe:** High frequency linear probe is placed in the zone of apposition (ZOAP) with the indicator oriented cephalad. ZOAP is defined as the region where diaphragm is opposed to the rib cage and is located caudal to the costo-phrenic sinus. **Position of the probe:** Place the probe at the midaxillary line or slightly anteriorly, approximately between the 8^{th} and 11^{th} rib, angled perpendicular to the chest wall (where the diaphragm anchors to the lower 6 ribs). The diaphragm appears as a three-layered hypoechoic structure sandwiched between echogenic parietal peritoneum and parietal pleura. One may see third hyperechoic line in the middle of the non-echogenic layer, considered to be the fibrous layer in the centre of the diaphragm. Calliper placement should be close to the pleural and peritoneal line (not including these lines in the measurement). No consensus was achieved on the optimal breathing pattern for obtaining measurements of DTF.[4]

Clinical significance of DT and DTF:

In critically ill patients, more than 10% decrease in DT from baseline is the proposed cut-off for diagnosis of diaphragm atrophy, as per EXODUS statement.[3] Normal DTF is >36%. DTF less than 20-30% is suggestive of diaphragmatic weakness and correlates with increased ICU length of stay and increased days of mechanical ventilation.

Various studies have reported superiority of DTF over DE as a marker of diaphragm function.[5,6] DiNino et al. prospectively assessed diaphragm thickening by ultrasound as percent change in between end-expiration and end-inspiration: (Δtdi%) as a useful index to predict extubation success or failure during spontaneous breathing trials. They measured Δtdi% during tidal breathing in 63 ventilated patients. The combined sensitivity and specificity of a Δtdi% ≥ 30% for extubation success was 88% and 71% respectively. The positive predictive value and negative predictive value were 91% and 63% respectively. The area under the receiver operating characteristic curve was 0.79 for Δtdi%.[7] Similar results have been obtained by Ferrari et al. where DTF cut off of > 36% was associated with extubation success with a sensitivity of 0.82, a specificity of 0.88, a positive predictive value (PPV) of 0.92, and a negative predictive value (NPV) of 0.75.[8]

Diaphragm ultrasound in weaning failure:

DUS is a promising diagnostic tool to predict weaning outcome and to predict extubation success. Numerous studies, meta-analyses and systematic reviews have evaluated the use of DUS to predict weaning success. One prospective study has shown that DTF is useful index to predict weaning. DTF had the high sensitivity of 97% and specificity of 81% [ROC AUC (CI), 0.91 (0.84–0.99); $p < 0.001$].[9] In a meta-analysis published in 2018, (involving 13 studies and 742 subjects) the pooled sensitivities for DE and DTF were 0.786 and 0.893, and the pooled specificities were 0.711 and 0.796, respectively. The area under curve (AUC) for DE and DTF were 0.8590 and 0.8381.[10] Integrated approach of DE and DTF, along with lung ultrasound score (LUS) and the rapid shallow breathing index (RBSI) were used as indices to evaluate weaning outcome and they had highest sensitivity and specificity. They observed that DTF has higher sensitivity and specificity for the prediction of successful weaning when compared with other indices. Sensitivity of DTF (94%) was greater than that of RBSI (85%), that of LUS (71%), and that of DE (65%). The combination of RSBI, LUS, DE and DTF performed well in predicting weaning outcome with AUC of 0.919, sensitivity of 96% and specificity of 89%.[11] DE values of 11–14 mm and DTF <30–36% is predictive of weaning failure.

In addition, while evaluating diaphragm clinicians should evaluate para-diaphragmatic areas to look for pleural effusion, atelectasis, collapse, consolidation, ascites and subdiaphragmatic abscess.

Diaphragm by Tissue doppler imaging (TDI):

Parameters such as inspiratory acceleration time, max relaxation time, peak contraction velocity, peak expiration velocity and velocity time integral are calculated with TDI. Soilemezi et al.[12] showed that healthy volunteers and patients who were successfully weaned had lower values for parameters such as peak contraction velocity, peak relaxation velocity and maximal relaxation rate compared with patients with weaning failure.[12]

Speckle tracking ultrasound (STUS)

It is a novel method of analysis of the diaphragm by observing contraction of muscle fibers in the direction of movement (longitudinal). The STUS software measures their displacement and deformation movement of the speckles which is the ultrasound signals reflected from microstructures in the tissue. A cluster of speckles form a kernel. Stronger the contraction of the diaphragm, the closer kernels come together (strain) which causes granularity on diaphragm imaging. Hatam et al. had analysed diaphragm deformation (transverse strain) in STUS. They found that transverse strain correlated well with DTF.[13] Speckle tracking ultrasonography for assessment of diaphragmatic function is better than 2D ultrasonographic measurements as per a feasibility study done by Fritsch SJ et al.[14]

Shear Wave Elastography

Ultrasound shear wave elastography is a new imaging method that creates source of vibration resulting in tissue deformation and generating a shear wave which can be quantified as Shear Modulus (SM). It is a real-time quantification of tissue mechanical properties used to estimate the diaphragmatic force. The shear wave velocity directly correlates with tissue stiffness and active muscle force and higher SM indicates greater tissue stiffness.[15]

LIMITATIONS

Although DUS has various advantages, several limitations need to be considered while applying it in clinical practice. DUS is operator depended and the expertise should be achieved through various training sessions and practice. The diaphragmatic thickness varies between the individuals and the measurement will also depend upon the anatomical location of imaging. Serial measurements and proper demarcation of probe placement at specific locations can overcome this problem. The left hemidiaphragm is often difficult to visualize due to smaller splenic window and stomach shadow. Recent expert consensus has recommended that unilateral assessment of the right hemidiaphragm is an acceptable substitute for the assessment of entire diaphragm except in cases of suspected unilateral pathologies.[3] Lastly, poor acoustic window, as in obese patients, is also a limiting factor for DUS.

Table 1. Uses of DUS and cutoff values for identification of various conditions:

Diaphragmatic dysfunction (DD):
DE< 2 cm during quiet breathing.

No consensus on cut off value of DTF as per EXODUS statements

Diaphragmatic atrophy:
More than 10% decrease in DT on serial measurements of diaphragm

Ventilator Induced Diaphragmatic Dysfunction (VIDD):
DTF < 20-30% is suggestive of diaphragmatic weakness (Normal DTF: >36%)

High risk of weaning failure:

DE <11–14 mm

DTF <30–36%

Pathologies to be assess in para-diaphragmatic areas:
Hepatization of lung and pleural effusion.

CONCLUSION

DUS is rapidly evolving in both critical care practice and research. Indices like DE and DTF are useful for identification of patients with diaphragmatic dysfunction and the patients at risk of weaning and extubation failure (Table 1).

REFERENCES

1. Santana PV, Cardenas LZ, Albuquerque ALP. Diaphragm Ultrasound in Critically Ill Patients on Mechanical Ventilation-Evolving Concepts. Diagnostics (Basel). 2023;13(6):1116. [PubMed | Google Scholar | DOI]
2. Vetrugno L, Guadagnin GM, Barbariol F, Langiano N, Zangrillo A, Bove T. Ultrasound Imaging for Diaphragm Dysfunction: A Narrative Literature Review. J Cardiothorac Vasc Anaesth. 2019;33:2525–36. [PubMed | Google Scholar | DOI]
3. Haaksma ME, Smit JM, Boussuges A, et al. EXpert consensus On Diaphragm UltraSonography in the critically ill (EXODUS): a Delphi consensus statement on the measurement of diaphragm ultrasound-derived parameters in a critical care setting. Crit Care. 2022;26(1):99. [PubMed | Google Scholar | DOI]
4. Thimmaiah VT, Geetha MJ, Jain KP. Evaluation of thickness of normal diaphragm by B mode ultrasound. Int J Contemp Med Res. 2016;3:2658–60. [Google Scholar]
5. Umbrello M, Formenti P, Longhi D, et al. Diaphragm ultrasound as indicator of respiratory effort in critically ill patients undergoing assisted mechanical ventilation: a pilot clinical study. Crit Care. 2015;19:161. [PubMed | Google Scholar | DOI]
6. Vivier E, Mekontso Dessap A, Dimassi S, et al. Diaphragm ultrasonography to estimate the work of breathing during non-invasive ventilation. Intensive Care Med. 2012;38:796–803. [PubMed | Google Scholar | DOI]
7. DiNino E, Gartman EJ, Sethi JM, McCool FD. Diaphragm ultrasound as a predictor of successful extubation from mechanical ventilation. Thorax. 2014;69(5):423-7. [PubMed | Google Scholar | DOI]
8. Ferrari G, De Filippi G, Elia F, Panero F, Volpicelli G, Aprà F. Diaphragm ultrasound as a new index of discontinuation from mechanical ventilation. Crit Ultrasound J. 2014 Jun 7;6(1):8. [PubMed | Google Scholar | DOI]
9. Samanta S, Singh RK, Baronia AK, Poddar B, Azim A, Gurjar M. Diaphragm thickening fraction to predict weaning-a prospective exploratory study. J Intensive Care. 2017;5:62. [PubMed | Google Scholar | DOI]
10. Li C, Li X, Han H, Cui H, Wang G, Wang Z. Diaphragmatic ultrasonography for predicting ventilator weaning: A meta-analysis. Medicine (Baltimore). 2018;97(22):e10968. [PubMed | Google Scholar | DOI]
11. Li S, Chen Z, Yan W. Application of bedside ultrasound in predicting the outcome of weaning from mechanical ventilation in elderly patients. BMC Pulm Med. 2021;21(1):217. [PubMed | Google Scholar | DOI]
12. Soilemezi E, Savvidou S, Sotiriou, P, Smyrniotis D, Tsagourias M, Matamis, D. Tissue Doppler imaging of the diaphragm in healthy subjects and critically ill patients. Am J Respir Crit Care Med. 2020;202:1005–12. [PubMed | Google Scholar | DOI]
13. Hatam N, Goetzenich A, Rossaint R, et al. A novel application for assessing diaphragmatic function by ultrasonic deformation analysis in noninvasively ventilated healthy young adults. Ultraschall Med. 2014;35:540–6. [PubMed | Google Scholar | DOI]
14. Fritsch SJ, Hatam N, Goetzenich A, et al. Speckle tracking ultrasonography as a new tool to assess diaphragmatic function: a feasibility study. Ultrasonography. 2022;41(2):403-415. [PubMed | Google Scholar | DOI]
15. Aarab Y, Flatres A, Garnier F, et al. Shear Wave Elastography, a New Tool for Diaphragmatic Qualitative Assessment: A Translational Study. Am J Respir Crit Care Med. 2021;204(7):797-806. [PubMed | Google Scholar | DOI]