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Use of Ultrasound to Check Diaphragmatic Thickness to Assist in Weaning

Rajani Sasikumar
Medical ICU, Rashid Hospital, Dubai, UAE

Abstract

Dysfunction of the respiratory muscles is now considered to be a serious complication of critical health issues. Diaphragm dysfunction has been associated to higher mortality and complications weaning with mechanical ventilation in patients getting invasive mechanical ventilation treating acute respiratory failure. Diaphragm dysfunction can occur in mechanically ventilated patients for a variety of factors, involving disuse atrophy with mechanical ventilation. Therefore, it is becoming increasingly essential for clinical and research priorities to measure and track diaphragm contractile activity, structural dimensions, as well as strength during mechanical ventilation. It is generally accepted that ultrasound may be used to visualize the diaphragm. The key indicators of diaphragm function have been developed over the past 15 years for mechanically ventilated patients to monitor changes in diaphragm size as well as function over time, to evaluate and diagnose diaphragmatic dysfunction, and to determine whether these indices can predict successfully exiting mechanical ventilation. These indices include diaphragm thickness, thickening fraction, as well as excursion.

Keywords: *Diaphragm, Diaphragm thickening fraction, Diaphragmatic excursion, Ultrasound, Weaning.*

Introduction

It might be difficult for anesthesiologists to wean mechanically ventilated patients inside the intensive care unit (ICU). 20% of ventilated patients had trouble weaning, on average. The main muscle associated with active inspiration is the diaphragm, and dysfunction of this muscle results in inadequate coughing along with respiratory failure. The majority of patients are weaned based on the intensivist's subjective clinical evaluation of them, which can occasionally result in errors of judgment. Numerous objective measurements as well as indices have been developed to increase weaning success but have limitations of their own. These include minute ventilation, tracheal occlusion pressure 0.1, rapid shallow breathing index (RSBI), as well as the CROP (Compliance, Rate, Oxygenation, Pressure) index. The most widely used method is RSBI, and numerous studies have shown it to be helpful in weaning; despite this, the suggested cut-off values in these studies vary, and some have come to the conclusion that RSBI is an insufficient tool for weaning ventilated patients.

The technical difficulties, lack of availability, and expensive cost of the methods that can evaluate the diaphragm function include fluoroscopy, trans-diaphragmatic pressure measurements and phrenic nerve conduction study. In order to evaluate diaphragm dysfunction, ultrasonography of the diaphragm has been used. The utilization of diaphragm ultrasound as a tool for detecting and tracking atrophy to determine which patients will eventually wean from mechanical ventilation and who will continue to be ventilator-free has generated a lot of support. In paediatric critical care, mechanical ventilation (MV) equipment is commonly used. In the pediatric critical care unit (PICU), MV

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Corresponding Author: anaedoc@gmail.com

assistance is provided to about 30% of the children [1]. MV assistance is not the end of treatment, though; the ultimate purpose is to help patients in weaning off MV support. It was suggested that weaning be divided into three categories: simple weaning, difficult weaning, as well as prolonged weaning at a worldwide consensus meeting on weaning from MV in 2007 [2]. According to a multicenter study, 10% of MV patients had a difficult weaning period lasting longer than 1 day but less than one week, while 9% had a lengthy weaning period lasting 1 week or more [3]. Weaning that is difficult and takes a long time is known as failure to wean (FTW). Clinical results for FTW are noticeably worse. FTW has been associated with the onset of ventilator-induced diaphragmatic dysfunction and intensive care unit-acquired weakness, according to studies. It is also an independent risk factor with mortality in ICU patients and a prolonged length of ICU stay [4-6]. As a result, every patient's weaning through mechanical ventilation represents an important step. A shorter MV and reduced difficulties can result from weaning at the appropriate time. In adult studies, weaning predictors have been used to increase the success rate of weaning. Examples include rapid shallow breathing index, maximum inspiratory pressure (PImax), airway occlusion pressure 0.1 s, as well as weaning index [7-9]. Unfortunately, there is not sufficient evidence to support the efficiency of predictors being superior to clinical judgment in terms of weaning success in children [10].

Many conditions, including acquired weakness, malnutrition, nervous system disorders, cardiovascular dysfunction, infections, and other diseases, might make it difficult to wean off MV [11-13]. Diaphragm weakening is frequently observed in MV patients and is probably a contributing reason to weaning failure, which is something that is becoming more widely recognized [14-16]. Diaphragmatic dysfunction (DD) has been identified in recent years as a common cause of weaning failure [14, 17-19] The direct visualization of a patient's diaphragmatic function is made possible by a relatively new medical technology called diaphragm ultrasonography [17-19]. This technique is rapid, simple, and noninvasive, making it suitable for use at the bedside. As a result, with the advancement of critical care ultrasonography, physicians can now utilize ultrasound to dynamically assess the pulmonary or extrapulmonary variables that may be contributing to respiratory failure and weaning failure. It is appropriate for use in ICU patients with MV [18, 19]. Today, it is simple to assess diaphragmatic movements at the bedside, including the amplitude, force, and velocity of contraction, specific motion patterns, and changes in diaphragmatic thickness during inhalation [17]. As a result, ultrasonography is a useful tool for the early detection and assessment of acquired weakness at the intensive care unit (ICU). It has been demonstrated that the amount and quality of the diaphragm as well as skeletal muscles as examined by ultrasound are connected to muscular strength and function [19].

The diaphragmatic excursion (DE) as well as diaphragm thickening fraction (DTF) are two potential diaphragm sonographic predictors. An ultrasonic probe is used to measure DE in the right midline of the axillary as well as left axillary posterior lines, respectively, of patients who are lying supine. The distance between the diaphragm movement's highest and lowest points in the M-mode is DE. DTF is calculated as (thickness at the end of inspiration-thickness at the end of expiration)/thickness at the end of the expiration and reflects the change in the thickness of the diaphragm throughout respiratory effort. The diaphragm is visible when the probe is positioned between the axillary frontline as well as the midline perpendicular to the chest wall, around ribs [8–10]. Between the peritoneum and the hyperechoic pleura is where the hypoechoic diaphragm can be found. The growing amount of evidence demonstrates that DD is essential to the weaning process.

Diaphragmatic ultrasound could better predict the results of weaning, according to numerous adult studies, and this evidence is of great value in guiding weaning in MV patients [20-22]. The evidence from diaphragmatic ultrasound, however, is insufficient because there aren't enough studies of it in the field of pediatric critical care medicine. The goal of this study is to briefly evaluate the ultrasound-based diaphragm measurement method and to list the most recent research results.

Role of Diaphragm

Goligher observed that the development of diaphragm atrophy was related to a prolonged period of mechanical ventilation, an increased length of stay in the intensive care unit, and a greater rate of complications. The implications of diaphragm atrophy secondary to mechanical ventilation have been recently documented [23]. It's interesting to note that patients who experienced a critical illness and had an increase in diaphragmatic thickness also had a greater the risk of needing prolonged mechanical ventilation, with too much respiratory effort possibly serving as the underlying cause. It was acknowledged by the authors that tissue oedema brought on by fluid resuscitation might possibly be a factor in this thickening. Patients who are mechanically ventilated have been shown to see a 6% or 7.5% reduction in diaphragmatic thickness daily. Although nearly half of the patients in their trial did experience atrophy, a subsequent investigation showed that the same proportion did not experience any loss, and an additional 10% reported increases in diaphragmatic thickness [4]. According to a recent study on children who are mechanically ventilated, diaphragmatic atrophy happens on average at a rate of 3.4% each day and is made worse by the application of neuromuscular blockade [25]. However, ultrasound-based diaphragmatic atrophy was not demonstrated in two papers [26,27]. However, compared to controls, one of these studies involved extubated sepsis survivors who had undergone at least five days of mechanical ventilation and were infected with sepsis (82% of whom had severe sepsis or septic shock). The authors acknowledge that rather than being based on data collected during the acute episode of sepsis, these results were based on a single measurement taken at a time in the patient's recovery from sepsis.

Ultrasound and the Diaphragm

Since well over 40 years ago, it has been possible to use ultrasonography to see the diaphragm [28] However, measuring the size and function of the diaphragm during mechanical ventilation has only recently been done using diaphragmatic ultrasound. Diaphragm thickness and diaphragm excursion are two measurements generated from ultrasonography that are frequently utilized [29]. A phased array probe is typically used to assess diaphragm excursion, with the goal of imaging the posterior third of the diaphragm. The probe is positioned in the subcostal margin near the mid-clavicular line. Even though some studies have employed B-mode imaging to quantify diaphragmatic excursion [30], M-mode imaging generates images that show the diaphragm's movement over time and enables precise measurement of diaphragmatic displacement across a respiratory cycle [31]. The diaphragmatic excursion may be consistently measured in a supine or recumbent position in healthy volunteers, and it varies with sex and height [32]. Excursion is higher throughout forced inspiratory breathing [33,34] and is known to favorably correlate with lung inspiratory volumes [30].

In order to see the diaphragm as a three-layered structure positioned between the two echogenic layers of the pleura as well as the peritoneum, the thickness of the diaphragm is measured in the zone of apposition utilizing a higher-frequency (> 10 MHz) linear probe [35]. It is possible to measure thickness using both

B- as well as M-mode techniques [36]. (Figure 1) The strength of the diaphragm has previously been linked to its thickness [37], but not to its endurance / fatigability [38]. It can be assessed at expiration either end inspiration, as well as during both tidal and maximum breathing. It seems to be thicker in an upright position compared to supine posture [39]. The thickening fraction, which is typically expressed as [(End Inspiratory Thickness End Expiratory Thickness) or End Expiratory Thickness [40] and serves as a measure of the work of breathing, is obtained by comparing expiratory with inspiratory thickness [41]. Although there are differences in these definitions, diaphragm dysfunction can be defined using these measurements: Based on the existence of paradoxical movement in the instance of the paralyzed diaphragm [29] or utilizing non-ultrasound techniques like the measurement of twitch pressures, it has been described as a thickening fraction of 32-36% and a tidal excursion of below 11-14 mm [42, 43]. However, it has been demonstrated that using ultrasonic techniques is more efficient than using traditional techniques like fluoroscopy to identify diaphragm dysfunction [44].

In 2017, a systematic review as well as a meta-analysis46 were conducted to evaluate the evidence regarding the utility of diaphragm ultrasound in predicting effective weaning from mechanical ventilation [45]. The combined work of greater than 30 individual publications was evaluated in two more meta-analyses that were published in 2018 [47, 48] (with the exception of three additional papers that focused just on lung ultrasonography rather than diaphragm ultrasound).

The systematic review concentrated on the utilization of diaphragmatic ultrasound in four key areas: diagnosis of diaphragmatic dysfunction, prediction of successful weaning from mechanical ventilation, assessment of ultrasound's ability to measure muscular workload in comparison to other well-known measurements like transdiaphragmatic pressure, as well as description of variations in diaphragm atrophy across studies [45, 48].

Four studies were examined with regard to weaning from artificial ventilation, and two of them described diaphragm excursion either using M-mode ultrasound [49] or by calculating organ displacement [50]. The diaphragmatic thickening fraction was evaluated in the two final experiments. [51, 52]. All four investigations came to the same conclusion: each measurement can indicate whether weaning will succeed or fail, with the most sensitive and specific cut-off values being [11–14] mm for excursion and 30–36% for thickening fraction.

Weaning failure was defined by Li et al. as the need for re-intubation within 48 hours, while Llamas-lverez et al. defined it as death, unscheduled non-invasive ventilation, tracheostomy formation, as well as the failure of a spontaneous breathing trial within 72 hours. Qian defined weaning failure more widely as a failed spontaneous breathing trial, re-intubation, the application of non-invasive ventilation, or death. Similar AUC characteristics were reported by Li and Llamas-Lverez when using the diaphragm thickening fraction (0.83 vs 0.87). Both Llamas-lverez et al. and Li et al. came to the conclusion that any measurement is suitable to predict successful extubation, as well as that thickening fraction may aid to predict weaning failure. Weaning failure was more common when diaphragmatic dysfunction was present, and excursion as well as thickening fractions were greater in patients who were successfully weaned, according to Qian, who also discovered that pooled specificity for predicting weaning success was comparable to Llamas-Lverez's work.

Re-intubation limitations were set at 48 or 72 hours for certain trials, while some research used non-invasive ventilation to identify weaning failure. Individual studies varied regarding ways they defined weaning failure. Each study's inclusion criteria are different;

whereas some studies only involved patients who had already experienced a failed experiment [51], another study only included patients who had undergone their first spontaneous breathing trial [52]. In Li's meta-analysis, 4 of the studies used the patient in a supine posture, while the remaining 9 studies used semi-recumbent patients. These changes in the ultrasonic technique used also result in additional differences. Although probe position was the same throughout all trials, there were significant differences in probe frequency as well as ultrasound machine manufacturer due to the use of 12 distinct types of ultrasound machines with frequencies ranging from 3.5 to 10 MHz. The patient population growth varies as well, notably in terms of age and sex. It is well known that diaphragmatic excursion in deep breathing is adversely correlated with age and that females exhibit less diaphragmatic excursion [30]. However, several research only reported measurements of the right side of the diaphragm, possibly because it is more challenging to image the left diaphragm since the lung blocks the view. Many investigations included both the left as well as right sides of the diaphragm [33]. At the final least, there are differences in the time points during a spontaneous breathing trial during which measurements are taken, through ultrasound images being obtained at the beginning or end of spontaneous breathing. Additionally, some researchers assessed diaphragmatic function following extubating, while others did so during mechanical ventilation, with further differences in the ventilatory mode used. In order to evaluate the diaphragm at a time when it might be fatigued, it has been recommended that pre-extubating is the ideal time to perform a diaphragm ultrasound. The methodology for a new study has been released, but the findings are not yet available. The study involved doing ultrasounds at regular intervals over two hours of spontaneous breathing [53].

Prior to a trial of spontaneous breathing, a recent study specifies cut-offs for diaphragm thickness to forecast successful weaning [54]. The outcomes are consistent with the previously established cut-offs with patients weaning through pressure support [55]. However, there are also outcomes that are in conflict. For instance, a study analyzing diaphragm excursion using the displacement of the spleen and liver discovered that the organs' displacement by 1.2 cm was the optimum cut-off for predicting effective extubation [56]. However, it has been noted before that there is limited correlation between solid organ movement as well as diaphragm excursion [57]. Another recent study indicated that the best predictor of extubation failure in patients undertaking their first spontaneous breathing trial was diaphragmatic excursion rather than thickening fraction [58]. In line with the larger range of Intra Class Correlation (ICC) coefficients provided by the systematic review, the most recent reliability study has established values for inter- (0.987) as well as intra-observer variability (0.986) [59].

Dres and colleagues evaluated the effectiveness of tracheal pressure measurements made throughout supra-maximal phrenic nerve stimulation during a spontaneous breathing experiment versus diaphragm ultrasound readings [22]. They not only discovered that the optimal sensitivity as well as specificity for liberation from mechanical ventilation were associated with a lower stimulated pressure than previously believed [19], but they also noted that a thickening fraction of higher than 25.8% gave equivalent accuracy of estimation in comparison to phrenic nerve stimulation, with AUC-ROC values of 0.80 as well as 0.82 for phrenic nerve stimulation as well as diaphragm thickening fraction, respectively.

Considering the probable cardiac causes of a failed respiratory weaning, combining diaphragmatic ultrasonography with echocardiography may be a possible method for the prediction of successful weaning [60]. Transthoracic echocardiography has been used to evaluate diaphragmatic excursion and the ratio of mitral Doppler inflow velocity (E) with annular tissue Doppler wave velocity (Ea, E/Ea ratio) in patients who were extubated following a successful spontaneous breathing trial (SBT) [61]. The authors discovered that both E/Ea as well as left ventricular ejection fraction values could be used to predict respiratory failure after 48 hours of extubation, while diaphragmatic excursion was more effective at predicting reintubation within a week of extubation.

In a different study, diaphragmatic excursion, lung ultrasonography, and echocardiography were all combined to determine whether they could accurately predict extubation failure in patients undergoing a pressure support ventilation trial [62]. Although diaphragm ultrasonography contributed the least of the 3 modalities to successfully predicting weaning, the findings were validated in a smaller sub-study of patients breathing through a T-tube. Additionally, recent small observational research that combined echocardiography as well as lung ultrasound for the assessment of aeration with diaphragmatic ultrasound found that the only reliable indicators of effective extubation were lung aeration and indications of diastolic dysfunction [63].

Another combination strategy used the Rapid Shallow Breathing Index (RSBI) and the diaphragm thickening fraction. A cut-off value of 100-105 breaths/min/liter is associated with effective extubation, according to the 1991 description of RSBI,64 which is defined as the ratio of respiratory frequency to tidal volume [65, 64, 66]. According to a recent study, RSBI alone, with a ROC-AUC of 0.96 and a sensitivity and specificity of 100%, was the most accurate technique for predicting the outcome of extubation when compared to measures obtained from diaphragm ultrasonography [66]. This confirms earlier research showing a thickening fraction cut-off of 36% had sensitivity, specificity, as well as positive predictive value that were equivalent to but ultimately lower to RSBI [52]. However, when combined with a diaphragm thickening fraction larger than 26%, RSBI was a more accurate measure of a patient’s ability to successfully wean of mechanical ventilation than RSBI alone [67]. The right diaphragm’s thickening fraction was found to be just as accurate as this combined technique, according to the researchers who suggested that in the future it would take the place of RSBI as the most frequently employed weaning measure.

Summary

Since a few years earlier, it has been unable to accurately measure diaphragm activity at the bedside. When used to evaluate diaphragmatic function, chest X-rays frequently have low sensitivity and specificity. Alternatively, the gold-standard technique of twitch magnetic phrenic nerve stimulation and measurement of transdiaphragmatic pressure using oesophageal and gastric balloons are invasive and difficult to perform at the bedside [68]. Due to its easy availability, non-invasiveness, and ability to take repeated measurements, ultrasound has been essential in the evaluation of diaphragmatic function.

Zambon et al. examined the importance of diaphragmatic ultrasonography in ICU patients earlier this year, finding that it performed well as a weaning index [69]. In contrast to these earlier findings, more extensive research, particularly from China, where ultrasound had quickly emerged in the ICU, revealed DE or DTF had a higher sensitivity and same specificity for predicting weaning outcomes. Increased DE and DTF were found in the weaning success group, and these factors were strongly associated with the weaning outcome. When used as weaning indices in mechanically ventilated patients, DE and DTF measurements conducted during an SBT both performed well. Studies found that weaning success groups had considerably higher DE than failure groups did [18, 19, 70-74]. Extubation failure is also caused by an imbalanced load on the respiratory muscles [75, 76]. Since it produces over 70% of the total tidal volume through inspiration in healthy individuals, the diaphragm is regarded as the major respiratory muscle and plays a crucial role in the development of respiratory muscle endurance [77]. Strength in the diaphragm as well as intrathoracic and intra-abdominal pressure combine to produce diaphragmatic movement. Thus, ultrasonography-based evaluation of the DE may be a significant tool for assessing a patient’s capacity for sustained respiration. According to one study [28], DE was not significantly different between the success and failure groups (15.8 ± 5.2 mm vs 18.4 ± 10.2 mm, p>0.05), but DE (30 min to 10 min during SBT) was greater in the failure group than in the success group (1.07 ± 0.64 mm vs 3.33 ± 3.17 mm, p <0.05). The timing of the measurements may be responsible for the difference. While DE was measured by Gong and Zhang at 0, 10, and 30 min after the start of SBT [78], others did so during MV18 or after SBT [73]. The mean values of the maximal DE were considerably higher in individuals who were successful at their first attempt at weaning in one study [79] that employed maximal rather than mean DE as the ultrasonography assessment (4.1±2.1 vs 3±1.8 cm, p=0.04). The sensitivity and specificity of diaphragmatic ultrasonography in predicting weaning failure were 59% (39%-77%) and 71% i.e., (57%-82%) with an AUC of 0.65 i.e., (0.51-0.78) at a threshold of MDE 2.7 cm. For predicting weaning failure, there was no statistically significant difference among MDE values as well as Medical Research Council scores (p=0.73). Since the diaphragm thickness measured by M-mode ultrasound is non-invasive and repeatable, it is helpful for evaluating how well the muscles are working and how much that contributes to the respiratory workload [80]. DTF is thought to be a more reliable measurement for the assessment of diaphragmatic function because of the individual variability in the thickness of the diaphragm. However, there was a considerable amount of variation among the component studies. Early on during their stay in the ICU, DD is prevalent in patients who are mechanically ventilated and is to blame for delayed weaning, more days spent on MV, and mortality [81, 82] Despite the diagnostic criteria for DD by ultrasound have not yet been unified, pressure support ventilation [83] found that DTF and DE were, respectively, very strongly as well as moderately correlated to endotracheal pressure following phrenic nerve stimulation, which was thought to be the gold standard for DD (r=0.87, p <0.001 and 0.45, p=0.001).

Future Directions

The focus of additional study is on predicting the success of extubation in particular patient categories. In the future, there should be more high-quality studies performed. In critical care medicine, small trials have a greater possibility of reporting larger positive results than large trials. The interpretation of meta-analyses incorporating small trials should be done with caution.

Conclusion

The effectiveness of diaphragmatic ultrasonography as a predictor of successful weaning regarding mechanical ventilating has been well investigated and is still being investigated. In ICU patients, DD has been discovered to be a predictor of weaning failure. However, more research is required to establish the diagnostic standards for DD with ultrasound and the diagnostic performance of DD to predict weaning results. Due to the significant variance in study design and demographic, it is still challenging to draw general generalizations from specific studies. It is impossible to compare outcome measures because definitions of terms like a failed breathing trial or a failure extubating have not been defined across research. There are currently no randomized control trials available, and established cut-offs for assessments of diaphragmatic ultrasonography have not yet been agreed upon.

Despite the fact that diaphragmatic ultrasound is a promising diagnostic tool, greater standardization in protocols, measurements, and ventilatory settings is needed for future study and clinical application. In this section, should have a discussion corresponding to the results. To achieve good think:

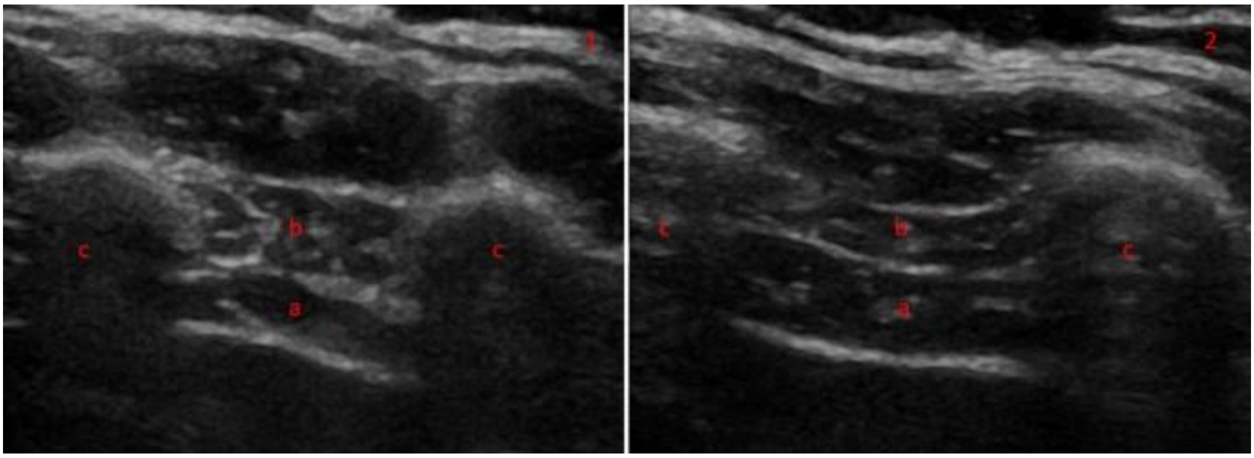

Figure 1. Diaphragm Thickness in B-mode Thoracic View at end Expiration (1) and Inspiration (2) in a Healthy Volunteer. The Diaphragm can be between two Echogenic Layers (a) with the Intercostal Compartment above (b). The Two Muscle Layers Sit between Two Ribs (c).

Conflict of Interest

No conflict of interest.

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