Original Article

Diaphragm Ultrasound as Aid in Successful Extubation from Mechanical Ventilation

Najma Reshi[1], Javid Iqbal Naqishbandi[2], Shabir Ahmad[3], Muhiba Shabir[4]

[1]DrNB Resident, Critical Care, Department of Anesthesiology & Critical Care, Government Medical College, Srinagar, J&K, India. [2]Professor & Head, Department of Anesthesiology & Critical Care, Government Medical College, Srinagar, J&K, India. [3]Professor, Department of Radiodiagnosis & Imaging, Government Medical College, Srinagar, J&K, India. [4]Senior Resident, Department of Anesthesiology, Kashmir Medical College, Srinagar and Head, Research Committee, Critical Care Education Foundation, Pune, Maharashtra, India.

Abstract

Background: Prolonged mechanical ventilation has long imposed significant challenges to the intensivists. While weaning failure is associated with several possible causes, diaphragmatic dysfunction has been found to be a significant contributor to weaning failure in mechanically ventilated patients. Predicting diaphragm function before attempting extubation can serve as a reliable monitoring parameter to predict the success of extubation in such patients. Ultrasound-based diaphragm measurements, particularly diaphragmatic thickness fraction (DTf%), are now emerging as reliable indicators of diaphragmatic function and have been used in predicting the success of extubation. **Material and Methods:** A prospective observational study conducted in the Surgical ICU of SMHS Hospital from May 2021 to Oct 2022 investigated the predictive value of Diaphragm Thickening Fraction (DTf) on weaning outcomes in 60 mechanically ventilated adults. Inclusion criteria included age ≥ 18, appropriate mental status, respiratory and cardiovascular stability, and no correctable comorbidities. Diaphragmatic measurements were taken via ultrasound, followed by spontaneous breathing trials. Weaning outcome was defined as successful or failed. Statistical analysis using SPSS software identified predictors of successful weaning. **Results:** This study found significant associations between Diaphragmatic Thickening Fraction (DTf) and extubation outcomes. The majority (75%) had DTf >30%. Successful extubation occurred in 44 (73.3%) patients, with significantly higher DTf values (42.3±9.1 vs 30.3±5.4, $p<0.001$). Multivariable logistic regression analysis revealed ventilation duration as the only independent predictor of extubation outcome ($p<0.005$). Other factors, including age, gender, and comorbidities, did not significantly impact extubation success. **Conclusion:** Our study finds Diaphragmatic Thickening Fraction (DTf) to be a significant predictor of extubation success, assessed through non-invasive, cost-effective ultrasonography. Evaluating DTf enables clinicians to accurately prognosticate extubation outcomes, anticipate reintubation risks, and inform decision-making.

Keywords: Mechanical ventilation, Diaphragm function, Ultrasound, Weaning, Extubation, Diaphragmatic Thickening Fraction (DTf).

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Introduction

The development of intensive care medicine has been driven by significant advancements in medical science, particularly in the use of mechanical ventilation to support critically ill patients. While mechanical ventilation forms a cornerstone of intensive care, prolonged mechanical ventilation (PMV) has emerged as a growing concern, with a substantial increase in long-term morbidity in patients, increasing healthcare costs and resource utilization. One of the common complications of prolonged mechanical ventilation is diaphragmatic dysfunction, where the diaphragm atrophy causes impaired functioning and limits the un-aided breathing excursions in the patient. The classic sign of diaphragmatic impairment is characterized by a reduced capacity to generate inspiratory pressure and flow, as measured by the negative pressure swing at the opening of an endotracheal tube in response to bilateral phrenic nerve stimulation.[1]

For a considerable period, clinical studies have explored magnetic and electric phrenic nerve stimulation to diagnose and manage ventilator-induced diaphragmatic impairment. While the utilization of phrenic nerve stimulation still remains a part of active research especially for therapeutic purposes, in this study, we propose the use of a simple, non-invasive, easily available, bedside diaphragm ultrasound as an effective tool for measuring and monitoring diaphragm atrophy in mechanically ventilated patients. In recent clinical studies, diaphragm ultrasound has been shown to be an effective way of assessing the muscle function of the diaphragm, which is a major factor in being able to maintain adequate breathing after extubation. As such, it can provide clinicians with valuable information in helping to identify patients who are likely to respond to weaning

Address for correspondence: Dr. Muhiba Shabir, Senior Resident, Department of Anesthesiology, Kashmir Medical College, Srinagar and Head, Research Committee, Critical Care Education Foundation, Pune, Maharashtra, India.
E-mail: muhibashabir09@gmail.com

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attempts and be able to remain free of ventilator support after extubation. Moreover, it can also be used to track changes in the diaphragm's muscle function over time in order to give an accurate assessment of a patient's ventilatory status. Furthermore, the ultrasound can serve as a useful adjunct to traditional pulmonary function tests, providing a more comprehensive and holistic assessment of a patient's ventilatory status. Thus, diaphragm ultrasound has emerged as an important tool in the weaning process, and continues to be studied as a way of improving clinical outcomes for patients undergoing mechanical ventilation. Diaphragm ultrasound can evaluate diaphragm thickness, excursion, and contraction velocity, providing valuable information on diaphragmatic function.

Human studies in the recent past have suggested that diaphragm thickness measured during end inspiration is correlated with maximal inspiratory pressure. The change in diaphragmatic thickness during inspiration has been found to strongly correlate with inspired lung volume. Patients who exhibit an increase in diaphragmatic thickness during their critical illness are more likely to require prolonged mechanical ventilation, with excessive respiratory effort being a possible cause.[2] Since the diaphragm is the primary factor in unassisted breathing, it is essential to evaluate diaphragmatic function in order to accurately anticipate the outcome of extubation.[3]

To assess diaphragmatic function, the diaphragm thickness can be used as a surrogate tool to determine the degree of muscle impairment in mechanically ventilated patients. The diaphragm thickness is measured at end-expiration and end-inspiration using ultrasound at the zone of apposition, where the diaphragm meets the rib cage.[4] Besides, another parameter viz. the thickening ratio (TR), can also be used to determine the functionality of diaphragm. TR is calculated by dividing the thickness at end-inspiration by the thickness at end-expiration, with normal values ranging from 1.7 to 2. However, accurate measurements require consideration of position, gender, and side, as these factors impact diaphragm thickness and the percentage of thickening. For example, the percentage of thickening varies depending on position: 65% in supine, 97% in seated, and 174% in standing positions.[4] Therefore, by measuring diaphragm thickness and calculating indices like TR and percentage of thickening, clinicians can assess diaphragmatic function and diagnose diaphragm dysfunction. Alien B. et al found that the use of percentage of thickening of diaphragm at deep inspiration was a better tool in predicting hemiparesis of diaphragm in mechanically ventilated patients. In this study, we thus aim to utilize the DTf percentage in predicting the outcome of extubation in our study population.

Materials and Methods

This hospital based prospective observational study was conducted in the Surgical ICU of the Department of Anaesthesiology at Shri Maharaja Hari Singh (SMHS) Hospital from May 2021 to October 2022 after approval from the Institutional Ethical Committee of Government Medical College Srinagar. The study cohort comprised adult patients receiving mechanical ventilation for a duration exceeding 12 hours. Eligibility for inclusion was contingent upon meeting the following criteria: (1) admission to the surgical ICU with mechanical ventilation for >12 hours, (2) age ≥18 years, and (3) fulfillment of readiness-to-wean criteria, encompassing appropriate mental status, respiratory stability, cardiovascular stability, and absence of correctable comorbidities. Patients with surgical dressings over the right lower rib cage, pregnant women, individuals with unilateral or bilateral diaphragm paralysis, and where the family of patients refused participation were excluded from the study. Utilizing a convenience sampling approach, the study enrolled a total of 60 patients.

All patients on mechanical ventilators falling within the inclusion criteria of the study were assessed daily for readiness-to-wean criteria, and diaphragmatic measurements were taken using ultrasound a few minutes before starting the spontaneous breathing trial (SBT). For measuring the diaphragmatic thickness (DT), a 7-10 MHz ultrasonographic probe was placed below the right costal margin and the diaphragm was imaged as a structure with three distinct layers. Subsequently, the Diaphragm Thickening Fraction (DTf) percentage was calculated as (DTi - DTe) / DTe × 100 and recorded for each patient enrolled in the study. Patients who passed the SBT were followed up for 48 hours after extubation. The primary endpoint was weaning outcome, defined as either weaning success (maintenance of spontaneous breathing for >48 hours following extubation) or weaning failure (inability to maintain spontaneous breathing, tracheostomy, or delayed extubation).

Study Variables and Statistical Analysis: The study variables included age, gender, residence, presence of comorbidities, primary cause of admission, and diaphragmatic thickening fraction percentage. Data were analyzed using SPSS software, with categorical variables expressed as frequencies and percentages, and continuous variables expressed as mean ± SD. Pearson's chi-square test, Student's t-test, and multivariable logistic regression were used to determine associations and control for confounding variables.

Results

Out of the included sixty patients, 53% of patients were males and 47% were females. A total of 88% had associated comorbidities. Figure 1 depicts the age range of patients included in the study. The mean age of patients was calculated to be 48.72 ± 15.77 years.

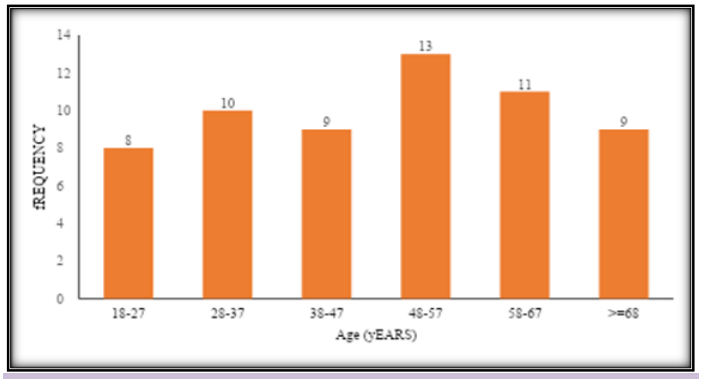

Figure 1: Distribution of study participants as per their age

The primary causes for admission to the intensive care unit (ICU) among the study cohort were diverse, with the majority (51.7%, n=31) being admitted for non-surgical reasons. Elective surgery accounted for 28.3% (n=17) of admissions, while emergency surgery comprised 20% (n=12) of the cases.

[Table 1] illustrates the values of DTf measured in the study participants using ultrasound. The outcome of SBT and the association of extubation with the measured DTf is shown in [Table 2] and illustrated in [Figure 2]. Patients with successful extubation had a mean DTf(%) of 42.3 ± 9.1, whereas those with failed extubation had a significantly lower mean DTf(%) of 30.3 ± 5.4 ($p < 0.001$). The bivariate analysis revealed an Independent sample t test value of 4.52 between DTf and extubation outcome. The average values of blood pressure measurements and respiratory rates after extubation are presented in [Table 3]. The post-extubation average ABG analysis values in patients with successful and failed extubation are depicted in [Table 4]. Our study results did not find a statistically significant association between age and extubation [Table 5]. Patients ≤45 years old had a success rate of 79%, while those >45 years old had a success rate of 71%. However, a statistically significant association was found between gender and extubation outcome (p-value = 0.04). Females had a higher success rate (86%) compared to males (63%) [Table 6].

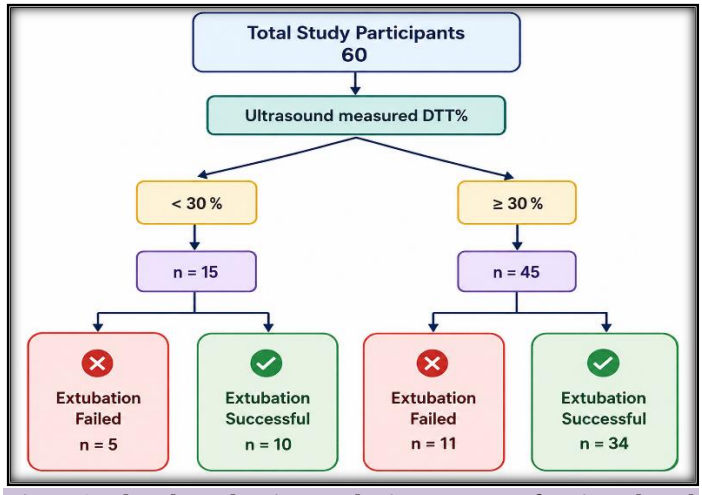

Figure 2: Flowchart showing extubation outcome of patients based on Diaphragmatic thickening fraction (DTf) %.

Table 1: Distribution of study participants based on their Diaphragmatic thickening fraction.

Diaphragmatic Thickening fraction (%)	Frequency (n)	Percentage (%)
≤ 30%	15	25.0%
>30%	45	75.0%
Total	60	100.0

Table 2: Association between Diaphragmatic Thickening Fraction and extubation outcome. (Chi square test value- 0.455)

DTf%	Extubation outcome		*P value
	Successful	Failed	
≤30	10	5	
>30	34	11	0.05

Table 3: Comparison of the vital parameters of study participants after attempts of extubation with categorization into groups based on eventual extubation outcomes.

Variables	Successful extubation (n= 44) Mean ± S.D	Failed extubation (n=16) Mean ± S.D
Systolic Blood Pressure (mmHg)	132.0 ± 17.2	102.4±13.2
Diastolic Blood pressure (mmHg)	75.2± 11.2	70.4± 9.4
Mean Arterial Pressure (mmHg)	93.4± 10.5	94.2± 10.8
Respiratory Rate (breaths/min)	20.7 ± 6.2	20.3 ± 4.9
Glassgow Coma Scale (GCS)	11.42 ± 1.48	10.96 ± 0.84
SpO2 (%)	93.84 ± 2.54	87.80 ± 1.66
Heart Rate (beats/minute)	93.80 ± 4.74	114 ± 6.42

Table 4: Comparison of Arterial Blood Gas parameters of study participants based on extubation outcome.

Variables	Successful extubation (Mean ± S.D)	Failed extubation (Mean ± S.D)
PH	7.430±1.20	7.46±1.80
pCo2 (mmhg)	40.20±8.20	43.80±11.20
HCo3 (mEq/L)	24.70±10.20	22.30±10.40
Na+ (mmol/L)	137.60±54.20	143.20±57.10
K+ (mmol/L)	3.50±0.50	4.10± 0.90
Ca+ (mg/ dl)	9.50±1.70	10.00±2.10
Lactate (mmol/L)	1.30± 0.30	2.00±0.50

Table 5: Association between extubation outcome and age. (Chi square test value- 0.448)

Age (years)	Extubation outcome		P-value
	Successful	Failed	
≤45	15	4	0.50
>45	29	12	

Table 6: Association between extubation outcome and gender. (Chi square test value- 4.115)

Gender	Extubation outcome		P-value
	Successful	Failed	0.04
Female	24	4	
Male	20	12	

Discussion

The weaning of patients from prolonged mechanical ventilation has long been a considerable challenge for intensivists. In addition to multiple factors that contribute to weaning failure, diaphragmatic dysfunction constitutes a significant role in further complicating successful extubation. While abnormal diaphragmatic function is observed in phrenic nerve injury, in neuromuscular diseases,[5-10] after abdominal or cardiac surgery,[11,12] critically ill patients requiring prolonged ventilation develop ventilator induced diaphragm dysfunction. There are several traditional tools available to assess diaphragm function like fluoroscopy, computed tomography (CT) scan, transdiaphragmatic pressure measurement, diaphragmatic electromyography, phrenic nerve stimulation and magnetic resonance imaging (MRI). However, these are associated with some significant inherent challenges such as the need of skilled operators, complexity of procedure, need to shift the patients to CT or MRI rooms, and the risks of radiation. Ultrasound, on the other hand, is gaining recognition for its fast, easy, and accurate evaluation of diaphragmatic function in the ICU population without the need for invasive measures. It can be used to quantify normal and abnormal movements in a variety of clinical conditions. Recent studies, therefore, have sought to harness the utility of ultrasound in assessing diaphragmatic function in mechanically ventilated patients and predicting extubation success, thereby providing critical insights that inform clinical decision-making and enhance patient outcomes. Ultrasound enables the measurement of key parameters, including diaphragmatic thickness, excursion, and contraction velocity, providing valuable insights into diaphragmatic function (13). This study aimed to investigate the role of DTf% as a predictive index for successful extubation in ICU patients. Consistent with prior research recommendations, this study employed M-mode ultrasonography to assess diaphragm function by measuring diaphragm excursion and contraction velocity (14). Additionally, diaphragm thickening fraction (DTf%) was evaluated, which has been shown to predict extubation outcomes during spontaneous breathing trials (SBTs) conducted on either T-piece or pressure support ventilation (PSV) modes of mechanical ventilation.

Our study confirmed that DTf% >30% is significantly associated with successful weaning outcomes. These results are consistent with studies conducted in the past in which DTfs with a cutoff point higher than 30 and 34, were shown to be indicative of successful weaning and better ICU outcomes.[15-17] This is particularly significant given that the lower the DTf, the higher the risk of weaning failure and poor ICU outcomes. Therefore, it is essential for clinicians to consider the DTf cutoff point when assessing a patient's risk of weaning failure and poorer ICU outcomes. Besides, our analysis of results also revealed distinct patterns in the association between extubation outcome and demographic variables. The age of the patient did not significantly influence extubation outcome, with a similar distribution of successful and failed extubations across age groups ≤45 and >45 years ($p = 0.503$). In contrast, gender showed a significant association with extubation outcome ($p = 0.04$), with females having a higher proportion of successful extubations (8,14) compared to males. Similar results were reported in a study conducted by S K Epstein et al which concluded that men are more likely to require reintubation as compared to women.[18]

Ultrasound-based diaphragm measurements, particularly the DTf, are increasingly being recognized as reliable indicators of a successful extubation. Various studies conducted in this field have revealed that the DTf is highly correlated to the successful outcome of a patient's extubation. In fact, the DTf can be employed to accurately estimate the risk of reintubation, making it a valuable tool in the decision-making process. Moreover, measuring the DTf can provide an early warning of the potential for reintubation, allowing physicians to intervene and adjust the treatment plan accordingly. This can be particularly useful for patients who are at higher risk for reintubation, as well as those who have been recently extubated. Thus, the DTf has proven to be a remarkably reliable predictor of extubation outcomes, offering a valuable insight into a patient's condition and helping to ensure a successful outcome.

The study concludes that DTf (%) is significantly associated with extubation outcome and can be used to predict the success of extubation. The use of ultrasound-based diaphragm measurements, particularly DTf (%), can provide a more accurate prognosis for extubation success and help clinicians make informed decisions about patient care.

However, the small sample size of the study limits its use. Hence, further prospective studies are needed to ascertain the reliability of diaphragm ultrasound and determine the most generalizable DTf (%) threshold value.

Conclusion

Our study finds Diaphragmatic Thickening Fraction (DTf) to be a significant predictor of extubation success, assessed through non-invasive, cost-effective ultrasonography. Evaluating DTf enables clinicians to accurately prognosticate extubation outcomes, anticipate reintubation risks, and inform decision-making

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Conflicts of interest

There are no conflicts of interest.

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