

Original Article



Analysis of the Value of Multiparameter Diaphragm and Intercostal Muscle Ultrasound Monitoring in Predicting Weaning Outcomes in Elderly Neurocritical Patients: Study Protocol for a Prospective Trial

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Abstract:

Background: The weaning process for elderly neurocritical patients is complex, with a high reintubation rate. Exploring accurate and effective weaning assessment methods to determine the optimal timing for weaning is of great significance for improving adverse outcomes in these patients. Studies have found that increased activity of accessory respiratory muscles is a compensatory mechanism when diaphragm dysfunction occurs. Therefore, building on traditional diaphragm ultrasound assessments, combining intercostal muscle ultrasound evaluations may improve the accuracy of predicting weaning outcomes in mechanically ventilated patients.

Methods: Mechanically ventilated neurocritical patients admitted to the ICU, EICU, and HDU of our hospital from January 2021 to June 2025 were selected. Patients were divided into a successful weaning group and a failed weaning group based on the final weaning outcome. Diaphragm and intercostal muscle ultrasound measurements were performed on the 2nd, 3rd, 4th, and 5th days of mechanical ventilation, at 30 minutes during the spontaneous breathing trial (SBT), and 2 hours after extubation. The evaluated parameters included: Tdiins, Tdiexp, DTF, DE, D-RSBI, Ticins, Ticexp, TFic, and TFic/DTF. Data analysis was conducted using R language (version 4.2.3) to determine the cutoff values of each parameter for predicting successful weaning and to identify the optimal parameter by comparing AUC values.

Discussion: This study innovatively applies multiparameter intercostal muscle ultrasound combined with diaphragm ultrasound to assess weaning in high-risk patients with diaphragm dysfunction. By observing multiple diaphragm and intercostal muscle ultrasound parameters over time, a multiparameter monitoring system was preliminarily established. This system not only validates the changes in diaphragm and intercostal muscle function over prolonged mechanical ventilation but also significantly improves the accuracy of predicting weaning success, providing clinicians with a comprehensive assessment of respiratory function in elderly neurocritical patients. Additionally, this multiparameter monitoring method facilitates early identification of patients at high risk of reintubation and allows for timely adjustments to treatment plans based on changes in diaphragm and intercostal muscle function, paving a new path for individualized treatment of neurocritical patients.

Keywords: Diaphragm, Intercostal muscle, Ultrasound, Neurocritical care, Elderly, Mechanical ventilation

1. Background

Elderly neurocritical patients often exhibit insufficient respiratory function due to impaired

airway protection and age-related pathophysiological changes in lung tissue and the diaphragm, making them a high-risk population for reintubation^[1]. Studies have shown that

diaphragm function gradually declines with age, and the incidence of diaphragm dysfunction in critically ill patients is as high as 80%, making it a significant cause of weaning failure^[2]. As the primary respiratory muscle, the functional state of the diaphragm directly affects weaning success. The weaning process in elderly neurocritical patients is influenced by multiple factors, such as respiratory center excitability, ability to expectorate independently, and changes in underlying disease conditions. These factors may operate independently of the relationship between respiratory muscle strength and respiratory load and impact weaning outcomes^[3-4]. Therefore, exploring accurate and effective weaning assessment methods to determine the optimal timing for weaning is crucial for reducing the duration of mechanical ventilation and improving adverse outcomes in elderly neurocritical patients.

Previous studies have reported that diaphragm ultrasound can serve as a reliable tool for assessing diaphragm function and predicting weaning outcomes in mechanically ventilated patients^[5]. Many researchers have used diaphragm ultrasound to predict weaning outcomes, demonstrating its value in this context^[6-8]. However, some studies argue that the use of diaphragm ultrasound alone for predicting weaning outcomes exhibits significant heterogeneity, and its accuracy remains controversial^[9]. Respiratory physiology research indicates that when the diaphragm, as the primary inspiratory muscle, cannot meet the body's needs, the accessory respiratory muscles, such as the intercostal muscles, become more active to compensate^[10]. Recent studies using ultrasound have found that the activity of the parasternal intercostal muscles is significantly higher in patients with diaphragm dysfunction than in those without^[11], further supporting the idea that increased accessory respiratory muscle activity is a compensatory mechanism for diaphragm dysfunction. Therefore, combining intercostal muscle ultrasound with traditional diaphragm ultrasound assessments may improve the accuracy of predicting weaning outcomes in mechanically ventilated patients.

Based on this research background, this study adopts a prospective approach to investigate whether multiparameter ultrasound assessments of the diaphragm and parasternal intercostal muscles

can predict weaning outcomes in elderly neurocritical patients. The study compares this combined assessment with traditional weaning prediction parameters and diaphragm ultrasound parameters to validate whether the combined approach offers better predictive performance, provides a more comprehensive reflection of overall respiratory muscle function, and demonstrates general applicability in predicting weaning outcomes in elderly neurocritical patients. Additionally, the study examines the reproducibility and consistency of intercostal muscle ultrasound measurements to verify the reliability of this technique.

2. Methods

2.1 Study Participants

Mechanically ventilated neurocritical patients admitted to the ICU, EICU, and HDU of our hospital from January 2021 to June 2025 were selected. Inclusion criteria: 1) Received invasive mechanical ventilation for ≥ 24 hours; 2) Age ≥ 60 years; 3) Diagnosed with a central nervous system disease confirmed by imaging. Exclusion criteria: 1) Neuromuscular diseases such as Guillain-Barré syndrome or amyotrophic lateral sclerosis; 2) Chronic airway diseases (e.g., bronchial asthma, COPD); 3) Severe underlying cardiac conditions (e.g., congenital heart disease, dilated cardiomyopathy, valvular heart disease); 4) Conditions affecting respiratory muscle ultrasound measurements (e.g., severe chest trauma, recent thoracic surgery, pathological obesity); 5) Patients receiving ECMO treatment; 6) Patients refusing reintubation; 7) Pregnant women; 8) Patients receiving palliative care for advanced cancer or end-stage disease.

2.2 Study Groups

Patients were divided into a successful weaning group and a failed weaning group based on the final weaning outcome. Successful weaning was defined as no need for mechanical ventilation within 48 hours after extubation. Failed weaning was defined as SBT failure or reintubation required within 48 hours after extubation. The criteria for SBT failure were derived from international weaning protocols^[12]. SBT was considered failed if at least one of the following criteria was met: 1) SpO₂ $< 90\%$ with FiO₂ $\geq 50\%$; 2) Acute respiratory distress (RR ≥ 40 /min, agitation, cyanosis); 3) Systolic arterial pressure

≥ 180 mmHg; 4) Arrhythmia; 5) Respiratory acidosis ($\text{pH} \leq 7.32$) with $\text{PaCO}_2 \geq 50$ mmHg. If none of these failure criteria were met after

weaning, the SBT was considered successful. The study flowchart is shown in Figure 1

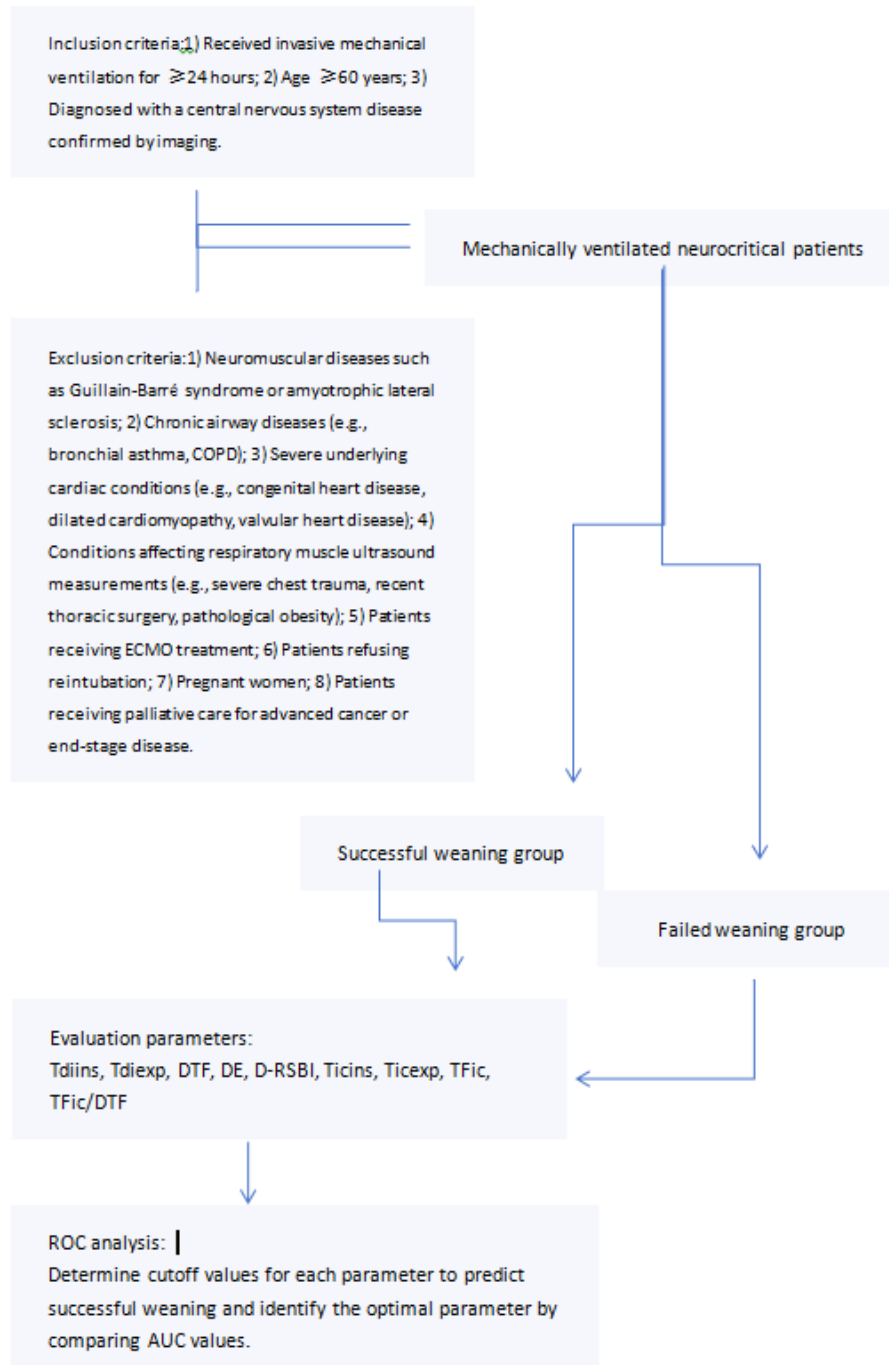


Figure 1 Study flowchart

2.3 Research Methods

2.3.1 Ultrasound Parameter Collection

Respiratory muscle ultrasound measurements were performed on the 2nd, 3rd, 4th, and 5th days of mechanical ventilation, at 30 minutes during SBT, and 2 hours after extubation. SBT was conducted under the following conditions: 1) The cause of mechanical ventilation had improved or

been resolved; 2) $\text{FiO}_2 \leq 0.40$, oxygenation index ≥ 250 mmHg ($1 \text{ mmHg} = 0.133 \text{ kPa}$), $\text{PEEP} \leq 5-8$ cmH_2O ($1 \text{ cmH}_2\text{O} = 0.098 \text{ kPa}$), $\text{pH} \geq 7.25$; 3) Hemodynamic stability, no signs of myocardial ischemia (e.g., abnormal heart rate, blood pressure fluctuations), and no significant hypotension (no or minimal vasopressor use); 4) Ability to breathe spontaneously. SBT was performed using standardized parameters^[12] (FiO_2 30%, PSV 6

cmH₂O, PEEP 5 cmH₂O, duration 30 minutes).

2.3.2 Diaphragm Ultrasound Measurement Methods

Diaphragm ultrasound measurements: Referencing previous studies^[13], patients were placed in a supine position, and a 10–15 MHz linear array probe was positioned in the 8th–10th intercostal space along the mid-axillary line, perpendicular to the chest wall. The optimal acoustic window displaying the three-layer structure of pleura-diaphragm-peritoneum was identified (Figure 2). In M-mode, diaphragm thickness at end-inspiration (T_{diins}) and end-

expiration (T_{diexp}) were measured, and diaphragm thickening fraction (DTF) was calculated as: $(T_{diins} - T_{diexp}) / T_{diexp}$. For diaphragm excursion (DE) measurements: A 3.5–5 MHz phased array probe was placed between the right anterior axillary line and midclavicular line below the costal margin, directed cephalad. In M-mode, the hyperechoic line (diaphragm) above the liver was observed during respiration. DE was defined as the maximum displacement of the diaphragm during respiration (Figure 3). Diaphragmatic rapid shallow breathing index (D-RSBI) was calculated as RR / DE .

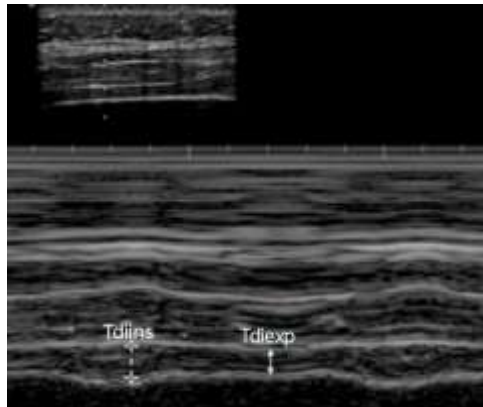


Figure 2. Schematic diagram of diaphragm thickening fraction (DTF) measurement

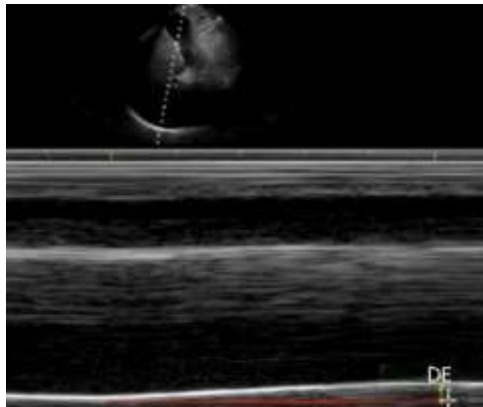


Figure 3. Schematic diagram of diaphragm excursion (DE) measurement

2.3.3 Intercostal Muscle Ultrasound Measurement Methods

Referencing previous studies^[10]: Patients were placed in a supine position, and a 10–15 MHz linear array probe was placed vertically approximately 6 cm lateral to the sternum at the second intercostal space. Gain was adjusted to achieve optimal contrast with surrounding structures, clearly displaying the three-layer

concave structure (intercostal muscles) between the ribs (Figure 4). The thickness of the central muscle layer was defined as intercostal muscle thickness (T_{ic}). In M-mode, intercostal muscle thickness at end-inspiration (T_{icins}) and end-expiration (T_{icexp}) were measured (Figure 5), and intercostal muscle thickening fraction (TF_{ic}) was calculated as: $(T_{icins} - T_{icexp}) / T_{icexp}$. The intercostal muscle compensation index (TF_{ic}/DTF) was also calculated.



Figure 4. Schematic diagram of intercostal muscle ultrasound measurement

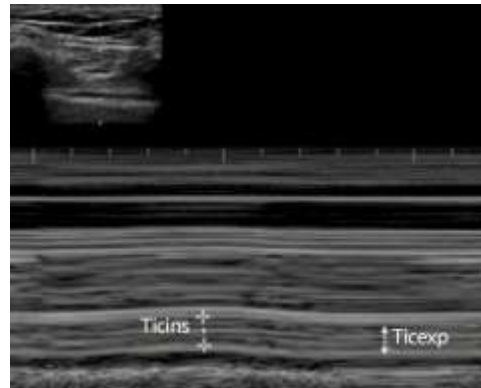


Figure 5. Schematic diagram of intercostal muscle thickening fraction (TFic) measurement

All ultrasound parameters were measured three times consecutively during calm and regular breathing, and the average value was recorded. A Philips CX50 ultrasound system (Philips Healthcare, USA) was used for all measurements, performed by a single physician certified in critical care ultrasound in China.

2.4 Statistical Analysis

Data analysis was performed using R language (version 4.2.3). Normality of continuous variables was assessed using the Shapiro-Wilk test. Normally distributed data were expressed as mean \pm standard deviation and compared using independent samples t-tests. Non-normally distributed data were expressed as median (Q1, Q3) and compared using the Mann-Whitney U test. Categorical data were expressed as frequencies or percentages and compared using chi-square or Fisher's exact tests. Univariate and multivariate logistic regression analyses were used to identify factors influencing weaning outcomes in neurocritical mechanically ventilated patients. Receiver operating characteristic (ROC) curves were plotted to analyze the diagnostic performance of individual and combined parameters in predicting weaning outcomes. Area

under the curve (AUC) comparisons were performed using DeLong's test. A P-value <0.05 was considered statistically significant.

3. Discussion

The primary causes of weaning failure in elderly neurocritical patients include the complexity of underlying diseases, respiratory muscle weakness, and related complications, which make it difficult for patients to maintain spontaneous breathing after weaning, thereby increasing the risk of failure^[14]. Research indicates that aging is associated with ultrastructural changes in the diaphragm, such as abnormal muscle fiber size and shape, increased collagen deposition, and reduced cross-sectional area, all of which impair diaphragm function^[15]. Compared to younger patients, elderly neurocritical patients generally exhibit more pronounced diaphragm atrophy and weakened diaphragm movement^[16-17]. Accurate monitoring and assessment of diaphragm function are crucial for determining the optimal timing for weaning in these patients.

Previous studies have primarily focused on the predictive value of single diaphragm ultrasound parameters for weaning outcomes^[18]. However, elderly neurocritical patients often present with

contradictory findings across different diaphragm ultrasound parameters. For example, some patients with prolonged mechanical ventilation may have a thin diaphragm, making DTF measurements challenging and leading to underestimation. This suggests that single-parameter measurements may be affected by various factors, such as patient cooperation or complex pathophysiological changes in the diaphragm, particularly in elderly neurocritical patients. Some patients with reduced diaphragm thickness or DTF may still maintain high diaphragm excursion, possibly due to compensatory mechanisms involving other respiratory muscles. In such cases, abnormal parameters may misguide clinical decisions, unnecessarily prolonging mechanical ventilation and adversely affecting outcomes. This highlights that single parameters often reflect only one aspect of diaphragm function and fail to provide a comprehensive assessment of respiratory mechanics. For instance, diaphragm thickness evaluates atrophy, DTF represents diaphragm strength, and DE and D-RSBI reflect lung ventilation and respiratory effort, respectively^[19]. While diaphragm ultrasound is the most suitable tool for monitoring diaphragm function in critically ill patients, the complexity of conditions in elderly neurocritical patients undermines the reliability of single parameters. Therefore, a multiparameter diaphragm ultrasound monitoring system is necessary for a detailed assessment of diaphragm function in these patients.

When the diaphragm is impaired or weakened, it is no longer the sole respiratory muscle involved in breathing. Studies have shown that under conditions of increased respiratory drive, accessory respiratory muscles such as the intercostal muscles are activated earlier and more intensely than the diaphragm^[20-21]. Consequently, some researchers argue that relying solely on diaphragm assessment to guide weaning is insufficient^[22].

Respiratory muscle ultrasound can reveal changes in both the diaphragm and intercostal muscles. Building on previous research, this study innovatively combines multiparameter intercostal muscle ultrasound with diaphragm ultrasound to assess weaning in high-risk patients with diaphragm dysfunction. By observing multiple diaphragm and intercostal muscle ultrasound

parameters (diaphragm: Tdiins, Tdiexp, DTF, DE, D-RSBI; intercostal muscles: Ticins, Ticexp, TFic, TFic/DTF), a multiparameter monitoring system was preliminarily established. This system addresses the clinical need for precise respiratory muscle monitoring in elderly neurocritical patients, validates the changes in diaphragm and intercostal muscle function over prolonged mechanical ventilation, and significantly improves the accuracy of predicting weaning outcomes. It provides clinicians with a comprehensive tool for assessing respiratory function in these patients. Moreover, this multiparameter monitoring method facilitates early identification of high-risk patients for reintubation and enables timely adjustments to treatment plans based on changes in diaphragm and intercostal muscle function. For example, when diaphragm function is found to be weakened, ventilator settings can be optimized or targeted diaphragm training can be implemented. Thus, incorporating multiparameter diaphragm and intercostal muscle assessments opens new avenues for individualized treatment of neurocritical patients.

Availability of Data and Materials

The datasets generated during and/or analyzed during the current study

are publicly available.

Ethics Declarations

Ethics Approval and Consent to Participate

Not applicable.

Consent for Publication

Not applicable.

Competing Interests

All the authors declare no competing financing interests.

Author Contributions

Conceptualization: Yanfang Long, Kehui Hu.

Formal analysis: Yanfang Long.

Investigation: Yanfang Long.

Methodology: Kehui Hu.

Writing – original draft: Yanfang Long.

Writing – review & editing: Yanfang Long.

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