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Predictive Value of Diaphragmatic Thickening Fraction Combined with Cough Peak Flow Rate for Weaning from Mechanical Ventilation

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Abstract: *Objective:* To investigate the predictive value of diaphragm thickening fraction (DTF) combined with cough peak expiratory flow (CPEF) on the success rate of weaning from mechanical ventilation. *Methods:* The clinical data of patients undergoing invasive mechanical ventilation via oral endotracheal intubation in the ICU of our hospital from January 2022 to December 2023 were studied. All patients underwent a 30-minute spontaneous breathing trial (SBT) using low-level pressure support ventilation (PSV) after meeting the clinical weaning screening criteria. Among them, 150 patients who met the clinical weaning criteria were weaned from the ventilator. They were divided into a successful weaning group (n = 100) and a failed weaning group (n = 50) based on the weaning outcome. Clinical data, including age, gender, APACHE II score, duration of mechanical ventilation, DTF, and CPEF, were collected from 150 patients. The differences in clinical data between the two groups were compared, and the correlation between DTF, CPEF, and the success rate of weaning was analyzed. *Results:* There were no significant differences between the two groups in gender ratio ($\chi 2 = 0.884$, $P = 0.347 > 0.05$), age ($t = 0.350$, $P = 0.727 > 0.05$), and APACHE II score ($t = 1.295$, $P = 0.197 > 0.05$), but there was a significant difference in the duration of mechanical ventilation ($t = 3.766$, $P < 0.001$). The DTF and CPEF values in the successful weaning group were significantly higher than those in the failed weaning group ($P < 0.05$). ROC curves were drawn to predict the weaning results using DTF, CPEF, and the combination of DTF and CPEF. The results showed that the specificity of the combination of DTF and CPEF was comparable to that of either metric alone, but the sensitivity and AUC were significantly higher than those of either metric alone. *Conclusion:* The combination of DTF and CPEF can be used as an effective indicator to evaluate the weaning efficacy of mechanically ventilated patients, which has important clinical significance for guiding clinical weaning treatment, improving the success rate of weaning, reducing the incidence of ventilator-associated pneumonia, and shortening the length of hospital stay.

Keywords: Diaphragm thickening fraction; Cough peak expiratory flow; Mechanically ventilated patients; Weaning

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Mechanical ventilation, as an indispensable rescue measure in the field of critical care medicine, plays a pivotal role in saving the lives of critically ill patients, reducing mortality rates, and promoting recovery. It can effectively improve patients' respiratory function, buying valuable recovery time for the body, and is the preferred treatment option for acute respiratory failure. However, as an invasive therapeutic approach, mechanical ventilation is not flawless, and its potential risks and traumaticity cannot be ignored. For example, it may lead to complications such as ventilator-associated pneumonia and pneumothorax, and even have a negative impact on the long-term prognosis of patients [1]. During mechanical ventilation treatment, successful withdrawal from the ventilator is one of the important indicators to measure the effectiveness of the treatment. However, weaning from the ventilator is not an easy task, and a considerable number of patients face the challenge of difficult weaning. Even if the primary disease causing respiratory failure has been effectively controlled, 20% to 30% of patients still find it difficult to withdraw from the ventilator smoothly [2], and even worse, 3% to 9% of patients eventually develop ventilator dependency, which seriously affects their quality of life [3]. Prolonged mechanical ventilation and difficulty in withdrawing respiratory support not only increase patients' pain and economic burden but also lead to a series of complications, such as ventilator-associated pneumonia, lung infections, pneumothorax, respiratory muscle atrophy, etc., which further prolong ICU hospital stays [4], increase mortality rates [5, 6], and even affect patients' long-term prognosis [7]. Studies have shown that prolonged mechanical ventilation and difficulty in withdrawing respiratory support are independent risk factors affecting ICU patients' hospital stays and mortality rates [8]. Exploring the reasons for difficult weaning, numerous research results indicate [9-11] that fatigue or weakness of respiratory muscle groups, especially the diaphragm, is one of the main reasons for weaning failure. As the most important muscle for human respiratory movement, the diaphragm plays a crucial role in maintaining normal respiratory function [12]. However, in critically ill patients, due to iatrogenic factors such as surgical trauma, residual muscle relaxants, phrenic nerve block, and the influence of some primary and secondary diseases of the diaphragm itself, the incidence of diaphragm dysfunction significantly increases, becoming an independent risk factor for delayed weaning. Based on this, this study aims to jointly apply diaphragmatic thickening fraction and cough peak flow rate to observe the treatment effect of mechanically ventilated patients, predict the success of weaning, provide more comprehensive and accurate evaluation indicators for clinical treatment, guide clinical decision-making, and improve patient prognosis.

1. Materials and Methods

1.1. General Information

The clinical data of patients undergoing invasive mechanical ventilation via oral endotracheal intubation in the ICU of our hospital from January 2022 to December 2023 were selected for study. All patients underwent a 30-minute spontaneous breathing trial (SBT) using the low-level pressure support ventilation (PSV) method after meeting the clinical weaning screening criteria. Inclusion criteria: (1) Age ≥ 18 years; (2) Endotracheal intubation and mechanical ventilation treatment for more than 24 hours, meeting the clinical weaning screening conditions. Exclusion criteria: (1) Age < 18 years; (2) Pregnancy; (3) Tracheotomy; (4) Patients with diaphragmatic paralysis.

1.2 Methods

1.2.1 Measurement of DTF (Diaphragmatic Thickening Fraction):

A high-frequency probe with a frequency of 10 MHz was placed between the anterior and mid-axillary lines at the 8th or 9th intercostal space, with the probe marker facing the patient's head, so that the ultrasound beam was perpendicular to the diaphragm. On the two-dimensional ultrasound image, the highly echogenic pleural and peritoneal layers were displayed, with the non-echogenic diaphragm layer in between. The thickness of the diaphragm was measured as the distance between the pleural and peritoneal layers. After locating the diaphragm with two-dimensional ultrasound, the mode was switched to M-mode ultrasound, and a measurement line was selected to be as perpendicular to the diaphragm as possible. The end-expiratory diaphragmatic thickness was measured at the end of quiet exhalation, and the end-inspiratory diaphragmatic thickness was measured at the end of quiet inhalation. Measurements were taken over three respiratory cycles, and the average values were calculated to determine the DTF [DTF = (end-inspiratory diaphragmatic thickness - end-expiratory diaphragmatic thickness) / end-expiratory diaphragmatic thickness × 100%].

1.2.2 Measurement of CPEF (Cough Peak Expiratory Flow):

After the respiration became relatively stable, 1-2 drops of normal saline were instilled into the endotracheal tube through a disposable closed suction catheter, with 2 ml per drop. The patient's cough reflex was observed, and the peak expiratory flow rate during coughing was measured using a built-in lung flowmeter in the ventilator. The measurement was performed five times, and the average value of the three strongest cough peak flows was taken as the final measured value. After completing the measurements, the tube was removed and the ventilator was withdrawn according to the normal procedure, and routine necessary oxygen inhalation and nebulization treatment were provided.

1.2.3 Other Indicators:

Relevant clinical data such as patients' age, gender, BMI, APACHE II score, duration of mechanical ventilation, and oxygenation index were collected to provide a comprehensive assessment of health status.

1.3 Observation Indices

The patients' age, gender, APACHE II score, duration of mechanical ventilation, DTF, CPEF, and weaning success or failure were recorded.

1.4 Statistical Methods

SPSS 25.0 statistical software was used. Normally distributed measurement data were expressed as Mean ± SD, and an independent sample t-test was used for comparison between the two groups. Non-normally distributed data were expressed using the median M and interquartile range (IQR), and the Mann-Whitney U test was used for comparison between groups. Count data were expressed as frequency [n(%)], and the χ^2 test was used for comparison between groups. A *P*-value < 0.05 was considered statistically significant. A receiver operating characteristic (ROC) curve was plotted to evaluate the predictive value of DTF, CPEF, and their combination for successful weaning, and sensitivity and specificity were calculated based on the optimal cutoff value.

2 Results

2.1 Comparison of Clinical Data Between the Two Groups

Among all patients, 150 met the weaning criteria. In the successful weaning group (n=100), there were 62 males and 38 females, with a mean age of (62.23 ± 11.50) years, an APACHE II score of (19.42 ± 3.46), and a duration of mechanical ventilation of (7.22 ± 3.14) days. In the failed weaning group (n=50), there were 27 males and 23 females, with a mean age of (64.07 ± 10.98) years, an APACHE II score of (20.35 ± 5.27), and a duration of mechanical ventilation of (9.52 ± 4.20) days. There were no significant differences between the two groups in gender ratio ($\chi 2 = 0.884$, $P = 0.347 > 0.05$), age ($t = 0.350$, $P = 0.727 > 0.05$), and APACHE II score ($t = 1.295$, $P = 0.197 > 0.05$). However, there was a significant difference in the duration of mechanical ventilation ($t = 3.766$, $P < 0.001$).

Table 1 Comparison of Clinical Data Between the Two Groups

Group	Number of Cases(n)	Gender(n)		Age(±s, years)	APACHEII Score (±s, points)	Mechanical Ventilation Time (±s, days)
		Male	Female			
Successful Extubation Group	100	62	38	62.23±11.50	19.42±3.46	7.22±3.14
Failed Extubation Group	50	27	23	64.07±10.98	20.35±5.27	9.52±4.20
χ^2/t Value		0.884		0.350	1.295	3.766
P-value		0.347		0.727	0.197	<0.001

2.2 Comparison of DTF and CPEF between the Two Groups

As shown in Table 2, the DTF of the successful weaning group (100 cases) was (35.27 ± 10.52)%, and the CPEF was (180.42 ± 50.34) L/min. The DTF of the failed weaning group (50 cases) was (22.81 ± 8.76)%, and the CPEF was (120.65 ± 34.85) L/min. There were significant differences between the two groups in both DTF ($t = 7.214$, $P < 0.001$) and CPEF ($t=7.535$, $P < 0.001$).

Table 2 Comparison of DTF and CPEF between the two groups

Group	Number of Cases(n)	DTF(±s, %)	CPEF(±s, L/min)
Successful Extubation Group	100	35.27±10.52	180.42±50.34
Failed Extubation Group	50	22.81±8.76	120.65±34.85
χ^2/t Value		7.214	7.535
P-value		<0.001	<0.001

2.3 Predictive Value of DTF, CPEF, and Their Combination for Successful Weaning

ROC curves were plotted for DTF, CPEF, and the combination of DTF and CPEF to predict weaning results. The results showed that the sensitivity and specificity of DTF for predicting weaning success were 55.60% and 92.20%, respectively, with an AUC of 0.812. The sensitivity and specificity of CPEF for predicting weaning success were 62.60% and 90.20%, respectively, with an AUC of 0.832. The sensitivity and specificity of the combination of DTF and CPEF for predicting weaning success were 78.80% and 92.20%, respectively, with an AUC of 0.905. The specificity of the combination of DTF and CPEF was comparable to that of either predictor alone, but the sensitivity and AUC were significantly higher than those of either predictor alone. See Table 3 and Figure 1.

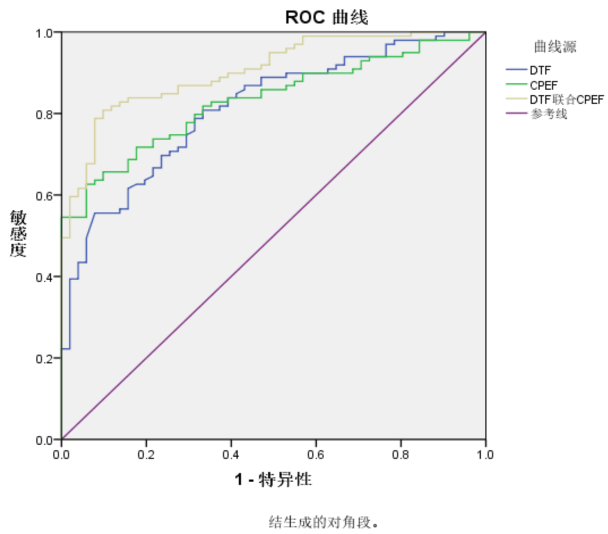

Figure 1: ROC Curves for DTF, CPEF, and Their Combination

Table 3: Analysis of ROC Curves for DTF, CPEF, and Their Combination

Indicator	AUC Value	95%CI	Cut-off Value	Sensitivity (%)	Specificity(%)
DTF	0.812	0.744~0.881	35.240	55.60	92.20
CPEF	0.832	0.770~0.895	164.455	62.60	90.20
DTF combined with CPEF	0.905	0.859~0.951	0.727	78.80	92.20

3.Conclusion

Traditional methods of diaphragm function evaluation, such as fluoroscopy, transdiaphragmatic pressure measurement, and phrenic nerve conduction, although provide some reference value, have limitations due to their invasiveness and operational complexity, restricting their widespread clinical application, especially in critically ill patients. In recent years, cough peak expiratory flow (CPEF) has gradually gained international recognition as a simple, noninvasive, reproducible, and easy-to-operate method for evaluating cough ability [13]. During coughing, patients need to engage respiratory muscle groups, including the diaphragm and intercostal muscles, with the contraction of the diaphragm being particularly important. The powerful contraction of the diaphragm can rapidly increase intrathoracic pressure, forcing gas to be expelled quickly from the body, and CPEF, as an important indicator to measure cough intensity, can indirectly reflect the functional status of the diaphragm. Mechanical ventilation is an important treatment for respiratory failure, but prolonged mechanical ventilation can easily lead to complications such as ventilator-associated pneumonia and tracheal intubation injury. Therefore, it is crucial to safely withdraw the ventilator as early as possible. Evaluating whether patients meet the conditions for ventilator withdrawal is key to successful withdrawal. Currently used evaluation indicators include respiratory mechanics indicators and blood gas analysis indicators, but these indicators have certain limitations. DTF is an objective indicator reflecting diaphragm function. The diaphragm is the main muscle of respiratory muscles, and its functional status directly affects patients' respiratory capacity. Evaluation indicators of diaphragm function include diaphragmatic displacement (DD), diaphragmatic thickening fraction (DTF), diaphragm contraction speed, and diaphragm excursion-time index. Studies have shown [13, 14] that DTF is closely related to lung volume and is an effective indicator for observing successful ventilator withdrawal, with important clinical value and research significance.

The results of this study showed that the DTF and CPEF values of patients in the successful ventilator withdrawal group were significantly higher than those in the failed ventilator withdrawal group. After ROC curve analysis, the sensitivity and AUC of DTF combined with CPEF were significantly higher than those of either alone, indicating that the combined application of DTF and CPEF can more accurately observe and predict the success rate of ventilator withdrawal in mechanically ventilated patients. However, this study still has certain limitations: (1) This study is a retrospective study, and there is a certain bias in the data; (2) The sample size is relatively small, and further studies with larger sample sizes are needed to validate the conclusions.

In summary, DTF and CPEF are effective indicators for evaluating the efficacy of ventilator withdrawal in mechanically ventilated patients, and the combination of the two has higher accuracy in predicting the success rate of ventilator withdrawal. Therefore, in clinical practice, by jointly monitoring DTF and CPEF, treatment plans can be adjusted in a timely manner to improve patients' success rate of ventilator withdrawal and shorten the duration of mechanical ventilation.

Disclosure statement

The author declares no conflict of interest.

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