


# Diaphragm Contraction Pressure Index: A New Forecasting Indicator for Weaning from Mechanical Ventilation

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**Purpose:** Failure to wean from mechanical ventilation can lead to prolonged hospital stays, increased incidence of ventilator-associated pneumonia, and higher mortality rates. This study aimed to explore the effectiveness of the diaphragm contraction pressure index (DCPI) in predicting weaning outcomes in patients undergoing mechanical ventilation, providing a scientific basis for successful weaning in clinical practice.

**Patients and Methods:** This prospective observational study included 286 individuals in the derivation cohort and 104 patients in the validation cohort, all of whom completed the spontaneous breathing trial (SBT). During SBT, ultrasound was used to quantify the right hemidiaphragm excursion (DE), diaphragm thickness (DTF) after inspiration and expiration, and DCPI. MIP values were gathered from the mechanical ventilator when the patients breathed peacefully. The derivation cohort determined the cut-off value of DCPI and compared these ultrasound diaphragm parameters. The validation cohort contributes to verifying the accuracy of DCPI.

**Results:** The weaning success group's DCPI in the derivation cohort was significantly higher than that of the weaning failure group ( $36.67\% \pm 7.02\%$  vs  $24.03\% \pm 5.78\%$ ,  $P < 0.001$ ). While the area under the receiver operating characteristic curve (ROC) (AUC) of DE, DTF, and MIP was 0.698 (95% CI, 0.615–0.771,  $P < 0.001$ ), 0.770 (95% CI, 0.693–0.837,  $P < 0.01$ ), and 0.811 (95% CI, 0.737–0.872,  $P < 0.001$ ), the ROC of DCPI was 0.954 (95% CI, 0.905–0.982,  $P < 0.001$ ), indicating good predictive performance for weaning success. The DCPI had a sensitivity of 94.1% and a specificity of 90.8%, with the ideal cut-off value set at  $\geq 30.0\%$ . Similarly, in the validation cohort, the AUC of DCPI for the predicted value is 0.952 (95% CI, 0.854–0.992,  $P < 0.001$ ).

**Conclusion:** Compared with DTF, DE, and MIP, DCPI dramatically improves the accuracy of predicting successful weaning.

**Trial Registration:** No. ChiCTR2100052470, Registered 28 October 2021.

**Keywords:** ultrasound, diaphragm, DCPI, predictive performance, mechanical ventilation, weaning

## Take Home Message

We developed the diaphragm contraction pressure index (DCPI), a novel sonographic assessment indicator for diaphragm function, for this observational cohort study. The DCPI's ROC for predicting the effectiveness of weaning off mechanical ventilation was 0.954 (95% CI, 0.905–0.982), higher than the maximal inspiratory pressure, diaphragm thickness, and diaphragm excursion.

## Introduction

Although mechanical ventilation rescues plenty of patients with critical illness, difficulties in weaning from that confront 20–30% of patients<sup>1–3</sup> which may induce ventilator-associated pneumonia, lengthen the duration in ICU, and increase mortality.<sup>4–6</sup> The

respiratory muscle dysfunction mainly contributes to the difficulty in weaning, of which the diaphragm frequently takes the central role.<sup>7</sup> Hence, the assessment of the diaphragm has been employed to predict the odds of successful weaning.

Compared to the other respiratory muscles, the diaphragm undertakes a dominating workload during the inspiration period.<sup>8</sup> The feeble diaphragm consequently compels the other accessory respiratory muscles to do more work, resulting in these muscles' fast fatigue, shortening the spontaneous breathing persistence time, and even leading to weaning failure.<sup>9</sup> Therefore, the proportion of the diaphragm workload during the breathing cycle could be an important indication of the weaning effort. Nevertheless, in the context that the maximum inspiratory pressure (MIP) has been developed to assess the whole endeavor of all respiratory muscles, which represents accurately inspiratory muscle strength,<sup>10</sup> the transdiaphragmatic pressure (Pdi), being a potential indicator of the diaphragm work, remains difficult to measure directly at the ICU bedside.<sup>11</sup>

Recently, transthoracic ultrasound has been increasingly applied in the intensive care setting to assess diaphragmatic function. Measurements of diaphragm thickness during PSV mode have been shown to correlate strongly with Pdi,<sup>12</sup> which is considered the gold standard for evaluating diaphragmatic workload. However, direct measurement of Pdi requires invasive procedures such as esophageal and gastric balloon catheter placement, which are technically demanding and not always feasible in critically ill patients. In contrast, ultrasound assessment of diaphragm thickness offers a simple, non-invasive, and reproducible method that can be performed at the bedside. Building upon these findings, we propose the DCPI, a novel parameter derived from changes in diaphragm thickness relative to inspiratory muscle strength. DCPI provides an indirect yet practical representation of the proportion of diaphragmatic work within the overall respiratory muscle effort, thereby offering clinicians a more comprehensive and less invasive tool to predict weaning outcomes.

The objective of this study is to investigate the application value of the Diaphragm Contractile Pressure Index (DCPI) in predicting weaning outcomes in mechanically ventilated patients. By evaluating the predictive performance of DCPI, this study seeks to provide clinicians with a scientific and reliable tool to more accurately assess the likelihood of successful weaning, thereby improving weaning success rates, reducing the incidence of ventilator-associated pneumonia, shortening hospital stays, and lowering patient mortality.

## Methods

### Study Design

This prospective observational cohort study was conducted in an adult Intensive Care Unit (ICU) of a teaching hospital (Yijishan Hospital, First Affiliated Hospital of Wannan Medical College, Anhui, China). Patients who met the inclusion criteria and underwent SBT between June 2021 and December 2023 were selected as the derivation cohort, and those admitted between January and December 2024 were selected as the validation cohort. The hospital ethics committee approved the study protocol (Approval Number 2018–03), which was registered on [chictr.gov](http://chictr.gov) (Registration No. ChiCTR2100052470). The participants or their relatives endorsed the informed consent. Two researchers accepted standardized point-of-care ultrasound training before the initiation of the study, which focused on lung and diaphragm ultrasound imaging. The study process was designed into two phases: the derivation section, which determined the cut-off value of DCPI, and the validation section to appraise the prediction performance of DCPI in the appropriate patients. This study was conducted in accordance with the Declaration of Helsinki.

### Study Subjects

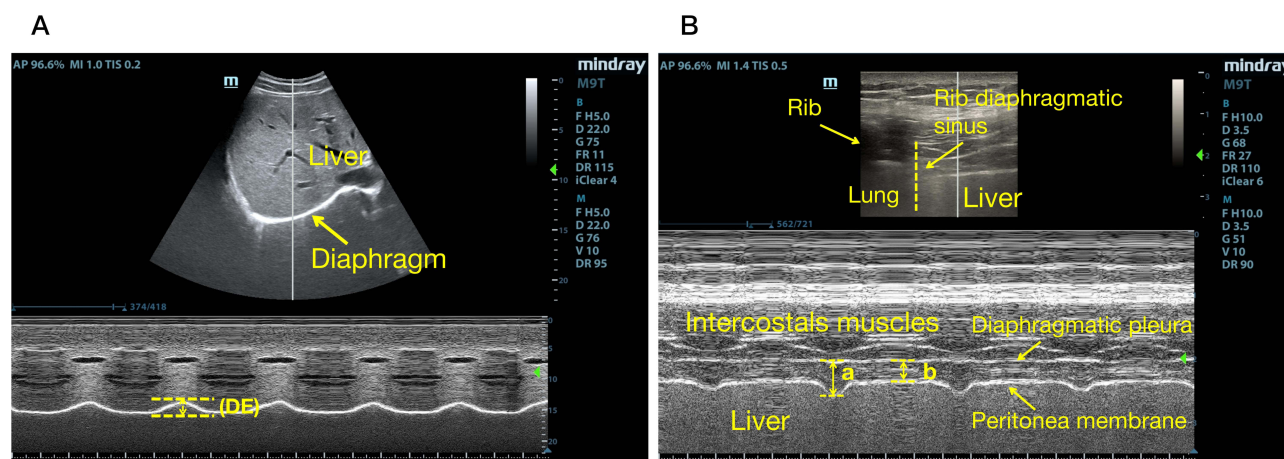
The study included each participant who completed the spontaneous breathing test (SBT) and had been intubated and ventilated for at least 48 hours. In the derivation cohort, patients were divided into the successful weaning group and the weaning failure group based on the weaning outcomes. However, patients who were younger than 18 years, with diaphragmatic paralysis or who were pregnant, were excluded. The inclusion and exclusion criteria of both section cohorts are the same.

## Scheme of Weaning from Ventilation

A senior clinician and a respiratory therapist (RT) decided that the patients should try a spontaneous breathing trial (SBT). The ventilation parameters were as follows: FiO<sub>2</sub> was set at 35%, positive end-expiratory pressure (PEEP) was set at 3 cmH<sub>2</sub>O, pressure support ventilation mode (PSV) was set at 5 cmH<sub>2</sub>O, and pressure support level (PS) was set at 5 cmH<sub>2</sub>O. The patient was lying down in a semi-supine position when the diaphragm ultrasound pictures were taken, and MIP was also recorded, following 30 minutes of SBT. Clinicians and respiratory therapists responsible for the patient's care were unaware of the ultrasonography and MIP measures. The patients who fulfilled the criteria for the tolerance of SBT discontinued from the ventilator and were extubated.<sup>13</sup> Failure of the SBT was based on predefined criteria: Subjective criteria include neuropsychiatric symptoms like anxiety, stress, or mental inhibition, excessive perspiration, cyanosis, dyspnea, respiratory difficulty, and increased amplitude of the auxiliary breathing muscles. Objective criteria: ①FiO<sub>2</sub> ≥ 0.5, PaO<sub>2</sub> between 50~60 mmHg and PaO<sub>2</sub> less than 50 mmHg or SaO<sub>2</sub> < 90%; PaCO<sub>2</sub> > 50 mmHg or PaCO<sub>2</sub> increased by >8 mmHg; ②PH < 7.32 or pH decrease > 0.07; ③F/VT > 105 breaths/(min • L); ④RR > 35 breaths/min or increase ≥50%, HR > 140 beats/min or increase ≥20%; ⑤Systolic blood pressure >180mmHg or diastolic blood pressure <90 mmHg or increase ≥20%; ⑥Arrhythmia. If the patient exhibits any of the criteria mentioned above, and it persists for some time (3~5 minutes), the SBT test fails. The SBT test is successful if none of the previously listed conditions are met. Weaning failure is defined as the need for reintubation within 48 hours of extubation due to unstable vital signs, such as altered mental status, respiratory rate greater than 35 beats per minute, and hemodynamic instability (heart rate greater than 140 beats per minute, systolic pressure greater than 180 or less than 90 mmHg). Patients may need mechanical and non-invasive positive pressure ventilation to support respiratory function.

## Measurement of Diaphragmatic Excursion

A 3.5-MHz ultrasound probe was placed at the junction of the midclavicular or anterior axillary line and the costal margin, with the probe marker directed outward and downward so that the ultrasound beam was perpendicular to the posterior diaphragm. On the two-dimensional ultrasound image, the hyperechoic diaphragmatic line around the liver could be clearly visualized.<sup>12</sup> At this point, the mode was switched to M-mode ultrasound, and the measurement line was adjusted to be as perpendicular to the diaphragm as possible. The diaphragmatic motion trajectory was displayed along the measurement line, and diaphragmatic excursion was defined as the vertical distance from the baseline to the highest point of the curve (Figure 1A). Three respiratory cycles were measured, and the average value was recorded.



**Figure 1** Schematic diagrams of the ultrasound assessments.

**Notes:** (A) The DE was the vertical distance from the baseline to the highest point of the curve. (B) The anatomical structure of the diaphragm includes the visceral pleura, parietal pleura, and muscle tissue between them. The distance between the pleura and peritoneum determined the thickness of the diaphragm. (a) After inspiration, the diaphragm's thickness was measured. (b) The diaphragm thickness was measured at the end of expiration.

## Measurement of Diaphragmatic Thickness

A high-frequency 10-MHz probe was positioned in the 8th or 9th intercostal space between the anterior and mid-axillary lines, either along the intercostal space or with the probe marker oriented toward the patient's head, ensuring the ultrasound beam was perpendicular to the diaphragm. On the two-dimensional ultrasound image, the hyperechoic pleural and peritoneal layers could be seen, with the hypoechoic diaphragmatic muscle layer in between. Diaphragm thickness was defined as the distance between the pleural and peritoneal layers.<sup>14</sup> After localizing the diaphragm in two-dimensional mode, the probe was switched to M-mode, and the measurement line was adjusted to be perpendicular to the diaphragm. M-mode displayed variations in diaphragm thickness along the measurement line throughout the respiratory cycle. The diaphragm thickness at end-expiration during quiet breathing and at end-inspiration during quiet breathing were measured (Figure 1B). Three respiratory cycles were recorded, and the average values were used to calculate the diaphragm thickening fraction (DTF).

$$\text{DTF} = \frac{\text{End - inspiratory thickness} - \text{End - expiratory thickness}}{\text{End - expiratory thickness}} \times 100\%$$

## Measure MIP

When the patients were breathing normally and the head of the bed was raised 45 degrees, MIP data were obtained from the mechanical ventilator (Puritan Bennett<sup>TM</sup> 840, Medtronic, Minneapolis, USA). The respiratory therapist set the PEEP as 0 cmH<sub>2</sub>O to decrease the measuring error, held the button "Negative Inspiratory Force, NIF" and recorded the maximum value during the three inspiratory efforts or continuous 20 seconds. The mean value of the three measurements was chosen.

All ultrasound measurements in this study were performed by a respiratory therapist and a physician, both certified in standardized ultrasound training. Inter-observer reliability testing was conducted to ensure the consistency of the measurements. The formula for calculating DCPI is defined as follows;

$$\text{DCPI} = \frac{\text{Thickness at the end of inspiration} - \text{Thickness at the end of expiration}}{\text{MIP}} \times 100\%$$

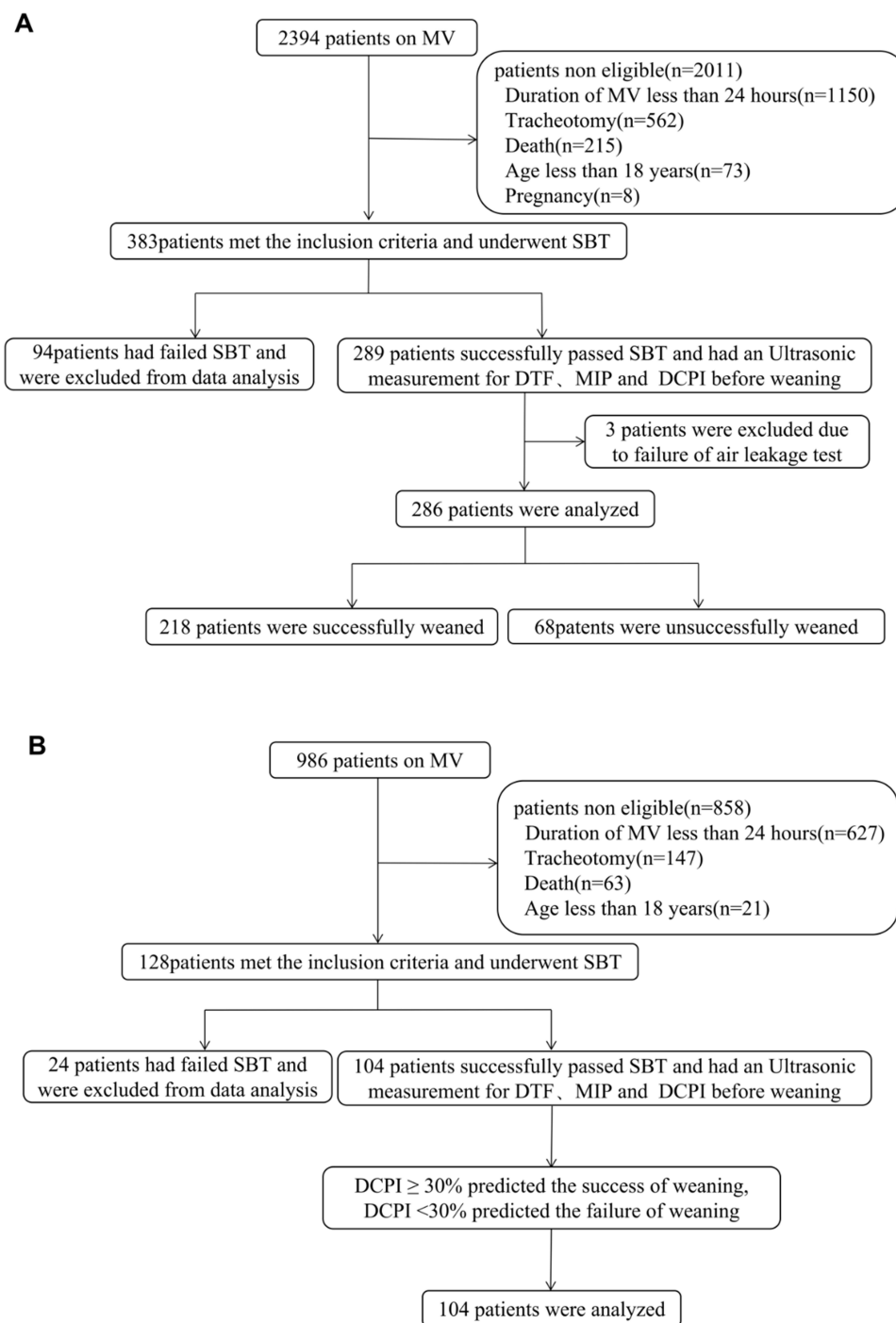
## Statistical Analysis

The sample size of the derivation section was calculated via PASS software, version 15.0. Based on the data of DE and DTF, the area under the ROC curve (AUC) for prediction performance was approximately 70%. The data from our pilot work, which included ten patients and yielded the AUC of 0.75, we estimate 143 patients for the derivation cohort, with a power of 80%, at the 5% two-sided significance level.

The statistical program SPSS 20.0 (SPSS Inc., Chicago, IL, USA) was used for the statistical analysis. The mean  $\pm$  standard deviation is the expression for normally distributed measurement data, and independent sample *t*-tests were employed to compare the two groups. The median (M) and interquartile range (IQR) are used to express data with non-normal distributions, and Mann-Whitney *U*-tests were employed to compare the groups. Enumeration data were expressed as frequencies (percentages) [n (%)], and the groups were compared using either Fisher's exact tests or chi-square testing. The threshold for statistical significance was set at  $P < 0.05$ . To assess the effectiveness of the DTF and MIP for the prediction of successful weaning, a receiver operating characteristic (ROC) curve was created, and the ideal critical value was used to compute the sensitivity and specificity.

## Results

We screened a consecutive sample of 2394 patients in the derivation cohort to build the predicted cut-off value of DCPI from June 2021 to December 2023, and 286 patients met the inclusion criteria and underwent SBT. To verify the reliability of the DCPI formula, we screened another 986 patients from January 2024 to December 2024 for the validation cohort, and 104 patients were finally retained in the subsequent SBT process. The two recruitment flows are shown in Figure 2, and both cohorts' characteristics are presented in Table 1.



**Figure 2** Recruitment flows of the derivation and validation cohorts.

**Notes:** (A) Screening protocol of the prospective cohort and (B) screening protocol of the prospective validation cohort.

All the diaphragm assessment parameters in the derivation cohort, including DCPI, DE, DTF and MIP, were significantly higher in weaning success group ( $36.67\% \pm 7.02\%$ ,  $1.85 \pm 0.38$ ,  $34.75\% \pm 7.82\%$ , and  $33.57 \pm 8.50$ ) than those in weaning failure group ( $24.03\% \pm 5.78\%$ ,  $1.64 \pm 0.23$ ,  $24.81\% \pm 4.50\%$ , and  $25.72 \pm 4.28$ ,  $P < 0.001$ ), as shown in [Table 2](#).

[Table 3](#) shows the duration of MV, the time of endotracheal intubation, the period of ICU stay, and the rate of tracheotomy was considerably lower in the weaning success group than in the weaning failure group ( $P < 0.05$ ), even though there was no difference in the mortality rate or total hospital days between the two groups in the derivation cohort ( $P > 0.05$ ).

**Table 1** Patient Characteristics of the Derivation and Validation Cohorts

Clinical Data		Derivation Cohort		$P^a$	Validation Cohort		$P^a$	$P^b$
		Weaning Success (n = 218)	Weaning Failure (n = 68)		Weaning Success (n = 80)	Weaning Failure (n = 24)		
Age		63.27±16.14	66.65±13.37	0.27	65.28±16.68	64.33±11.87	0.857	0.696
Sex	Male	134 (61.5%)	38(55.9%)	0.561	48(60.0%)	10 (41.7%)	0.262	0.583
BMI		21.82±1.95	21.67±2.91	0.723	21.94±2.74	22.33±2.00	0.627	0.501
HR (beats/min)		85.91±11.42	87.68±8.61	0.407	87.45±5.89	86.08±8.08	0.522	0.614
MAP (mmHg)		78.77±7.11	76.59±6.41	0.112	76.88±4.58	77.25±3.48	0.795	0.214
PH		7.39±0.05	7.39±0.06	0.595	7.40±0.05	7.38±0.05	0.213	0.841
Lac (mmol/L)		1.50±0.69	1.63±0.37	0.157	1.63±0.20	1.56±0.28	0.356	0.375
PaO <sub>2</sub> /FiO <sub>2</sub>		248±40.37	236±38.33	0.108	244.08±29.92	236.33±29.05	0.433	0.568
APACHE II score		17.99±2.27	18.50±2.51	0.268	17.93±2.19	18.33±2.27	0.576	0.803
Weaning failure								
Noninvasive Ventilation		-	21 (30.88%)	-	-	5 (20.83%)	-	0.347
48-hour reintubation		-	47 (69.12%)	-	-	19 (79.17%)	-	
Diseases								0.916
Post-Operative		124 (43.4%)		-	46(44.2%)		-	
Pulmonary infection		32(11.2%)		-	14 (13.5%)		-	
Trauma		20 (7.0%)		-	4 (3.8%)		-	
Alimentary Tract hemorrhage		18 (6.3%)		-	4 (3.8%)		-	
Coronary Heart Disease		14 (4.9%)		-	10 (9.7%)		-	
ARDS		14 (4.9%)		-	6 (5.8%)		-	
AECOPD		12 (4.2%)		-	8 (7.7%)		-	
Septic Shock		12 (4.2%)		-	6 (5.8%)		-	
Poisoning		10 (3.5%)		-	0 (0.0%)		-	
Acute Myocardial Infarction		8 (2.8%)		-	2 (1.9%)		-	
Post-CPR		6 (2.1%)		-	2 (1.9%)		-	
Acute Heart Failure		6 (2.1%)		-	0 (0.0%)		-	
Others		10 (2.8%)		-	2 (1.9%)		-	

**Notes:**  $P^a$  for the difference between the Failed weaning group and the Successful weaning group.  $P^b$  for the difference between the Derivation cohort and the Validation cohort.

**Abbreviations:** BMI, Body Mass Index; HR, Heart Rate; MAP, Mean Arterial Pressure; APACHE II, Acute Physiology and Chronic Health Evaluation II; ARDS, Acute Respiratory Distress Syndrome; AECOPD, Acute Exacerbation of Chronic Obstructive Pulmonary Disease; CPR, Cardiopulmonary Resuscitation.

**Table 2** Weaning Parameters Between Success and Failure Groups in the Derivation Cohort

	All (n = 286)	Weaning Success (n = 118)	Weaning Failure (n = 68)	t	P
DCPI (%)	33.66±8.63	36.67±7.02	24.03±5.78	10.547	<0.001
DE (cm)	1.80±0.36	1.85±0.38	1.64±0.23	3.085	0.002
DTF (%)	32.39±8.32	34.75±7.82	24.81±4.50	9.235	<0.001
MIP (cmH <sub>2</sub> O)	31.71±8.39	33.57±8.50	25.72±4.28	7.167	<0.001

The ROC curves demonstrate the predictive performance of DCPI, DE, DTF, and MIP in the derivation cohort's weaning success group, shown in Figure 3 and Table 4. At a cut-off value of 30.0%, the DCPI showed excellent diagnostic performance, with an AUC of 0.954 (95% CI: 0.905–0.982,  $P < 0.001$ ), and corresponding sensitivity and specificity of 94.1% and 90.8%, respectively. For DE, a cut-off value of 1.7 cm yielded an AUC of 0.698 (95% CI: 0.615–0.771,  $P < 0.001$ ), with sensitivity and specificity of 76.2% and 61.8%. The DTF, with a cut-off of 29.5%, produced an AUC of 0.770 (95% CI: 0.693–0.837,  $P < 0.01$ ), sensitivity of 88.2%, and specificity of 71.6%. Lastly, the MIP demonstrated an AUC of 0.811 (95% CI: 0.737–0.872,  $P < 0.001$ ) at a cut-off of 26.5 cmH<sub>2</sub>O, with sensitivity and specificity of 84.4% and 73.5%, respectively.

**Table 3** Clinical Characteristics Between Success and Failure Groups in the Derivation Cohort

Clinical Characteristics	All (n = 286)	Weaning Success (n = 218)	Weaning Failure (n = 64)	t/ $\chi^2$	P
Duration of ventilation (day)	5.33 (2.30–6.20)	3.93 (2.00–5.40)	9.81 (3.40–13.83)	-5.342	<0.001
Intubation time (day)	4.85 (2.30–6.20)	3.93 (2.00–5.40)	7.81 (3.50–10.18)	-5.088	<0.001
In-hospital mortality	18 (6.3%)	12 (5.5%)	6 (8.8%)	0.484	0.487
Tracheotomy rate	26 (9.1%)	8 (3.7%)	18 (26.5%)	16.303	<0.001
Length of ICU stay (day)	9.08 (4–10)	7.61 (4–7)	13.76 (5.75–19.50)	-3.940	<0.001
Hospital stay (day)	24.83 (13–31)	25.08 (13–31)	24.03 (12–40)	-0.197	0.844

**Notes:** The duration of ventilation included the duration of mechanical ventilation during tracheal intubation and tracheotomy; Values in the table are presented as the median with the IQR in parenthesis, or as a number with the percentage in parenthesis, as appropriate.

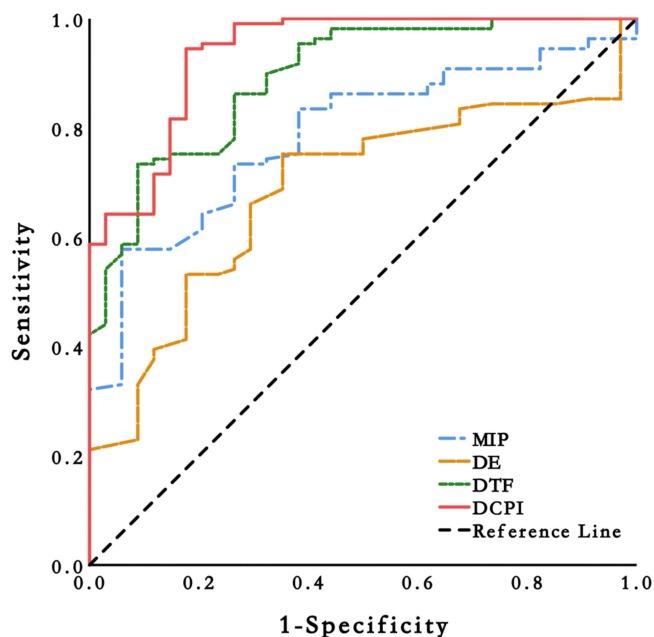
With an AUC of 0.952 (95% CI, 0.854–0.992,  $P < 0.001$ ), DCPI's predictive performance in the prospective validation cohort was similar to that of the derivation cohort, as shown in Figure 4. When the cut-off value was 30.0%, the DCPI's sensitivity and specificity were 0.93 and 0.92, respectively, with a PPV of 0.91 and an NPV of 0.89.

## Discussion

In this work, we introduced the novel parameter – DCPI – instead of Pdi, which represents the differential value of diaphragm thickness after inspiration and expiration, and is more readily obtainable via ultrasonography. When the best cut-off value was equal to or greater than 30.0 mm/cmH<sub>2</sub>O, the AUC of DCPI for prediction performance was 0.954, markedly superior to DE, DTF, and MIP. With the prominent sensitivity (94.1%) and specificity (90.8%), similar results were obtained in the prospective validation cohort. DCPI could help the clinician estimate who can sweep through the weaning procedure.

In this single-center observational study, we have innovatively established DCPI as a new parameter to predict whether the patients can successfully separate from the ventilator and verified the superiority of that over the other indicators, such as DE, DTF, and MIP.

During the past decades, clinicians were increasingly enthusiastic about applying ultrasound at the ICU bedside, as the methodological superiority of low cost, non-invasive, and easy reproducibility,<sup>15,16</sup> as if it had been a matter of course



**Figure 3** ROC curves for weaning parameters in the derivation cohort.

**Notes:** In the derivation cohort's weaning success group, the AUCs for the predictive performance of DCPI, DE, DTF, and MIP were 0.944 (95% CI: 0.893–0.975), 0.698 (95% CI: 0.615–0.771), 0.890 (95% CI: 0.827–0.936), and 0.811 (95% CI: 0.737–0.872).

**Table 4** AUC<sub>ROC</sub> of Prediction Performance of DCPI, DTF, MIP and DE for Weaning Success

Parameter	AUC <sub>ROC</sub> (95% CI)	Cut-Off	Sensitivity	Specificity	Youden Index (J)
DCPI <sup>a</sup> (%)	0.954 (0.905–0.982)	30.0	94.1%	90.8%	0.849
DE <sup>c</sup> (cm)	0.698 (0.615–0.771)	1.7	76.2%	61.8%	0.3791
DTF <sup>b</sup> (%)	0.875 (0.810–0.925)	29.5%	88.2%	71.6%	0.5979
MIP <sup>d</sup> (cmH <sub>2</sub> O)	0.770 (0.693–0.837)	26.5	86.2%	64.7%	0.5094

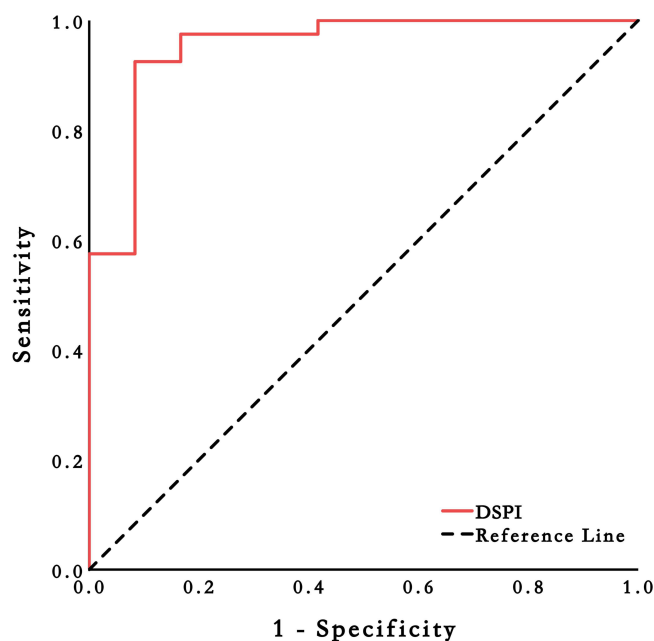
**Notes:** a–b,  $Z = 5.331$ ,  $P < 0.001$ ; a–c,  $Z = 2.152$ ,  $P < 0.05$ ; a–d,  $Z = 3.967$ ,  $P < 0.001$ ; b–c,  $Z = 3.262$ ,  $P < 0.01$ ; b–d,  $Z = 1.244$ ,  $P > 0.05$ ; c–d,  $Z = 2.222$ ,  $P < 0.05$ .

**Abbreviations:** DCPI, Diaphragm contraction pressure index [DCPI = (diaphragm thickness at the end of inspiration–diaphragm thickness at the end of expiration)/MIP\*100%]; DE, diaphragm excursion; DTF, diaphragm thickness fraction [DTF = (end-inspiratory diaphragm thickness – end-expiratory diaphragm thickness)/end-expiratory diaphragm thickness × 100%]; MIP, maximal inspiratory pressure.

that ultrasonographically visual assessment of pathological diaphragm could effectively assist in disconnecting from the ventilator in critically ill subjects.<sup>17,18</sup> Nevertheless, that is not the end of the controversy.

In a recent systematic review, twenty studies on diaphragm ultrasound availability were thoroughly examined and revealed the optimistic value.<sup>19</sup> Although four studies underlined the superiority of DE or DTF in predicting extubation odds, several intrinsic vulnerabilities confined the extension of these ultrasonic indicators. On the one hand, the best cut-off of DE and DTF to identify the diaphragm dysfunction remained in doubt. On the other hand, the prediction performance, represented as the AUC, fell short of being immensely satisfying. In this study, the best cut-off values calculated for DE and DTF were 1.7 cm and 29.5%, a more demanding standard than the previous studies. They merely yielded the reluctant diagnostic capability (AUCs were 0.698 and 0.770).<sup>20–22</sup> When the spotlight was turned on the more rigorous methodology and the cut-off value, for instance, multiple-centered study design, diaphragmatic dysfunction was defined as DE < 10 mm or DTF < 30%, the reliability of these parameters is more frustrating.<sup>23</sup>

On the other hand, previous research on weaning has also focused on analyzing the effects of the rapid shallow breathing index during weaning, and it performed excellently.<sup>24–26</sup> However, we did not include RSBI as a direct weaning index in our comparative analysis, as all patients underwent evaluation through a spontaneous breathing trial (SBT), which indirectly reflects



**Figure 4** ROC curves for weaning parameters in the validation cohort.

**Note:** The prospective validation cohort's DCPI AUC was 0.952 (95% CI, 0.854–0.992,  $P < 0.001$ );

RSBI. Notably, all patients had an RSBI of less than 105 breaths/min/L. SBT also evaluated whether the patient exhibited symptoms such as cyanosis and difficulty breathing, indirectly indicating that the patient did not experience respiratory distress.

Based solely on the data from patients who meet the inclusion criteria of this study, the 48-hour reintubation rate after extubation is high (>15%). However, because the study covered patients on mechanical ventilation for more than 24 hours and the actual number of patients on mechanical ventilation significantly exceeds the number of cases in this study, the 48-hour reintubation rate at our center is much lower than the data presented.

Moreover, even more importantly, when the diaphragm's core status has been highly prized, the accessory respiratory muscles, including the intercostal muscle, should not be ignored as the essential contributors to the whole breathing process. Despite the primary breathing workload undertaken by the diaphragm during normal breathing, the accessory muscles engage more breathing effort after diaphragm dysfunction.<sup>8</sup>

Therefore, in a small-sized observational study, including healthy volunteers and critically ill patients, Dres et al presented the parasternal muscle thickening correlated with diaphragm dysfunction and could similarly predict failure of the spontaneous breathing trial as DTF.<sup>9</sup>

We know that during normal breathing, the diaphragm mainly works. When the function of the diaphragm is abnormal, increased work is done by the accessory respiratory muscles during breathing. However, compared with the diaphragm in physiology, these accessory muscles possess weak respiratory endurance and are more liable to fatigue. When the respiratory capacity load from the accessory muscles accounts for a relatively high proportion during the entire respiratory effort, the patients are not capable of persevering in prolonged spontaneous breathing, which always leads to weaning failure.<sup>27</sup> When the ratio of diaphragmatic work is high, the patient maintains better spontaneous breathing, and the success rate of weaning is higher. Hence, evaluation of the diaphragm and the whole accessory respiratory muscles workload should be regarded as the more appropriate paradigm, which MIP has usually appraised in previous studies.<sup>10,11</sup> The value of MIP reflects the pressure generated by all breathing muscles; the pressure generated by the work of the diaphragm can be expressed as transdiaphragmatic pressure (Pdi). Therefore, the ratio of Pdi to MIP indicates the proportion of diaphragmatic work done by the patient during breathing. When Pdi is well-represented as the diaphragm's workload, the higher proportion of Pdi to MIP indicates that the patients are more likely to achieve successful weaning. However, the measurement of Pdi requires precise catheter placement technology, specific materials, and a ventilator, and the clinical application rate of Pdi is not high. Studies have shown that the diaphragm thickness measured using ultrasound in PSV mode highly correlates with Pdi.<sup>12</sup>

## Study Limitations

Several limitations exist in our study. First, as a preliminary exploration, this study is still inevitably a monocentric and small-scale research. However, the outstanding reliability of the new parameter will encourage us to verify it further in multicenter research. Second, the convenient acquisition of high-quality images prompted all ultrasound procedures to be performed on the right side. Third, except for diaphragm appraisal, we did not adequately investigate the patients' cardiac function, consciousness level and cough, which also contribute to weaning failure. Finally, the limitations of ultrasound measurements, including operator-dependence and poor reproducibility, should be explicitly mentioned.

## Conclusion

DCPI of right diaphragm  $\geq 30.0\%$  is used as the threshold, it has potential or better predictive value than traditional parameters, but it still needs to be verified in multi-center and large sample studies.

## Abbreviations

DCPI, diaphragm contraction pressure index; MIP, maximum inspiratory pressure; SBT, spontaneous breathing trial; DE, diaphragm excursion; Pdi, transdiaphragmatic pressure; DTF, diaphragm thickness; ROC, receiver operating characteristic curve.

## Data Sharing Statement

All data generated or analyzed during this study are included in this published article.

## Ethics Approval and Informed Consent

The protocol was approved by the Human Ethics Committee of Yijishan Hospital, First Affiliated Hospital of Wannan Medical College (Approval Number 2018-03), and informed consent was obtained from all patients or their relatives. The consent to participate was applicable.

## Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

## Funding

This study was funded by the University Scientific Research Program of Wannan Medical College in 2024 (WK2024LC07; SJD202407).

## Disclosure

The author(s) report no conflicts of interest in this work.

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