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ORIGINAL RESEARCH

Integration of Diaphragmatic Ultrasonography and Intra-Abdominal Pressure Measurement for Optimizing Weaning from Mechanical Ventilation

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Objective: The objective of this study was to evaluate the effectiveness of diaphragmatic ultrasonography in conjunction with intra-abdominal pressure (IAP) measurement for assessing diaphragm function and determining the optimal timing for weaning from mechanical ventilation (MV).

Methods: A cohort of 100 patients undergoing MV at the intensive care department of the Affiliated Hospital of Hebei University between January 2023 and July 2023 was enrolled. Spontaneous breathing trials (SBTs) were performed once patients met the weaning criteria. At the 30-minute mark of the SBT, diaphragmatic ultrasonography and IAP measurements were conducted. Based on weaning outcomes, patients were categorized into successful and failed weaning groups. Diaphragmatic excursion (DE), diaphragm thickening fraction (TFdi), diaphragmatic rapid shallow breathing index (D-RSBI), and IAP were compared between groups. The predictive value of these parameters in determining optimal weaning timing was analyzed using receiver operator characteristic (ROC) curves.

Results: Compared to the failed weaning group, the successful weaning group exhibited significantly lower values of D-RSBI and IAP values along with higher values of DE, TFdi, diaphragm thickness at end-inhalation (DTei), and diaphragm thickness at end-exhalation (DTee) ($p < 0.05$). In the single-parameter analysis, the area under the curve (AUC) values for D-RSBI, DE, TFdi, and IAP were 0.880 (95% CI: 0.811–0.948), 0.981 (95% CI: 0.960–1.000), 0.907 (95% CI: 0.872–0.972), and 0.838 (95% CI: 0.748–0.929), respectively. The optimal cut-off values were 13.5 breaths /(min*cm), 1.2 cm, 29.3%, and 5.6 mmHg, respectively. In combined parameter analysis, the combination of IAP and DE demonstrated the highest predictive accuracy.

Conclusion: The integration of diaphragmatic ultrasonography with IAP measurement is an effective approach for predicting weaning outcomes in patients undergoing MV. This combined assessment may assist clinicians in optimizing weaning strategies and improving patient outcomes.

Keywords: diaphragmatic ultrasonography, IAP, intra-abdominal pressure, MV, mechanical ventilation

Introduction

Mechanical ventilation (MV) is a crucial intervention for managing patients with respiratory failure in intensive care units (ICUs), with approximately 40% of ICU patients requiring MV.[1] However, prolonged MV is associated with an increased risk of complications, including ICU-acquired weakness (ICUAW), ventilator-associated lung injury (VILI), ventilator associated pneumonia (VAP), oxygen toxicity, and MV-associated diaphragm dysfunction.[2] Therefore, comprehensive patient assessment and timely determination of the optimal weaning point are essential to reducing the risk of weaning failure.[3] Several factors contribute to unsuccessful MV weaning, including respiratory muscle and diaphragmatic dysfunction, respiratory airway and pulmonary impairment, cerebral dysfunction, and cardiac insufficiency.[4]

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Among these, respiratory muscle and diaphragmatic dysfunction are particularly significant contributors.[5] Consequently, proactive management of underlying conditions and continuous monitoring of diaphragmatic functionality presents a promising strategy for successful weaning from MV.

The evaluation of the weaning process is a critical component of MV discontinuation. Current predictive indicators for successful weaning include respiratory system function scores, the Acute Physiology and Chronic Health Evaluation II (APACHE-II), the rapid shallow breathing index (RSBI), and the passive leg raise (PLR) test.[6–9] However, these indicators primarily focus on respiratory-related parameters and do not comprehensively assess abdominal function. Intra-abdominal pressure (IAP), which reflects the pressure between the abdominal wall and internal organs, and diaphragmatic ultrasonography are non-invasive, rapid, and clinically practical tools. Intra-abdominal hypertension (IAH) and abdominal compartment syndrome can lead to rapid organ deterioration.[10] An elevated diaphragmatic position can increase IAP levels,[11] subsequently contributing to respiratory dysfunction characterized by increased ventilatory resistance, hypoxemia, and hypercapnia.[11] Recent research has highlighted the utility of diaphragmatic ultrasonography, in combination with other factors, in determining the optimal timing for MV discontinuation, with clinical evidence supporting its efficacy. However, limited studies have examined the predictive value of combining IAP measurements with diaphragmatic ultrasound for assessing MV weaning outcomes.

This study aimed to evaluate whether diaphragmatic ultrasonography combined with IAP measurements can effectively predict MV weaning outcomes. Additionally, the predictive value of various diaphragmatic ultrasound parameters, in combination with IAP, was investigated to identify the most reliable predictor, with the goal of improving MV weaning success rates.

Data and Methods

General Information

Between January 2023 and July 2023, adult patients admitted to the ICU of the Affiliated Hospital of Hebei University were consecutively enrolled in this study. A total of 100 patients met the inclusion and exclusion criteria and were included in the final analysis. Ethical approval for this study was obtained from the local Institutional Ethics Committee (Approval No. HDFYLL-KY-2023-147), and the study was conducted in accordance with the principles outlined in the Declaration of Helsinki. Informed consent was obtained from the families of all participants prior to study enrollment. This study adheres to the Standards for Reporting Diagnostic Accuracy Studies (STARD) guidelines.[12]

Inclusion and Exclusion Criteria

Inclusion Criteria

Patients were eligible for inclusion if they:

(1) Were admitted to the ICU and required invasive MV for more than 48 hours, with no history of MV within the six months preceding hospitalization.

(2) Met the criteria for a spontaneous breathing trial (SBT).

Exclusion Criteria

Patients were excluded if they met any of the following conditions:

(1) Age below 18 years.

(2) Pregnancy.

(3) A postoperative condition requiring avoidance of ultrasonography.

(4) A medical history of myasthenia gravis, diaphragmatic dysfunction, or prior diaphragmatic surgery.

Study Methods

A total of 100 consecutive intubated patients undergoing a weaning trial were enrolled in the study. Patients were screened for enrolment when judged by the attending physicians as eligible for a spontaneous breathing trial according to the usual weaning guidelines, SBT test was performed for those who met the conditions (who were blinded to the diaphragmatic ultrasonographic parameters).[13] Before initiating the SBT, patients were required to meet the following conditions:

(1) Awake and alert.

(2) Hemodynamically stable (without the use of vasopressors).

(3) No severe complications, such as infection, coagulopathy, or pneumothorax.

(4) Requiring minimal ventilatory support and positive end-expiratory pressure (PEEP).

(5) Adequate oxygenation achieved through a mask or nasal cannula at the required fraction of inspired oxygen (FiO_2).

At the 30-minute mark of the SBT, bedside ultrasonography was performed to assess diaphragmatic excursion (DE), diaphragm thickness at end-exhalation (DTee), and diaphragm thickness at end-inhalation (DTei). The diaphragmatic thickening fraction (TFdi) was subsequently calculated, and IAP was measured (method described below). All physicians conducting the ultrasound assessments had completed at least three months of specialized ultrasound training and held certification from the Critical Care Ultrasound Study Group (CCUSG). Ultrasonographic evaluations were performed using the SonoSite M-Turbo ultrasound system (Sonosound Inc).

Comprehensive patient data were recorded, including the APACHE II scores,[14] arterial blood gas measurements, respiratory rates, tidal volumes, vital signs, and other relevant clinical parameters. Patients were then classified into either the successful or failed weaning groups based on the outcomes of MV discontinuation.

Measurement of Ultrasound Index and Calculation of Related Indices

DE and Diaphragmatic Rapid Shallow Breathing Index (D-RSBI)

At the 30th minute of the SBT, a 2–5 MHz convex probe was positioned at the intersection of the anterior axillary line and the rib margin or between the midclavicular line and the rib margin to obtain a diaphragmatic view. The convex transducer marker was oriented towards the right side of the patient, with the tail of the probe inclined downward, allowing for an oblique-coronal visualization of the diaphragm. Using M-mode ultrasound, the distance between the highest and lowest points of diaphragmatic movement was measured. This measurement was repeated three times to determine an average value, which was recorded as the representative measurement for DE. The D-RSBI was then calculated using the formula: (respiratory rate [RR] / DE).

TFdi

The 2–5 MHz convex probe was replaced with a high-frequency linear array probe. The probe was positioned between the 8th and 9th ribs along the anterior or midaxillary line. The transducer marker was oriented towards the patient's head, enabling the visualization of the diaphragmatic layers, including the pleural and peritoneal layers. Using M-mode ultrasound, the distance between the diaphragmatic pleural and peritoneal layers was measured at both end-inhalation and end-exhalation. Each measurement was performed three times to obtain an average value. The TFdi was calculated using the following formula: TFdi = (DTei – DTee) / DTee ×100%.

Measurement of IAP

At the 30-minute mark of the SBT, IAP was measured using bladder manometry. The procedure was conducted as follows: The patient's bedside was adjusted to maintain a supine position. The patient was instructed to relax and empty the bladder before the procedure. A urinary catheter was inserted under sterile conditions and connected to a drainage bag and an infusion set using a three-way stopcock. Following disinfection, the pressure chamber of the urinary catheter was punctured, and 25 mL of warm sterile saline was instilled. After stabilizing the internal fluid level of the infusion set, the fluid column height was measured at end-expiration with reference to the mid-axillary line. The recorded value represented the bladder pressure, with conversions based on the formula: 1 cmH_2O = 0.735 mmHg.

Criteria for Successful and Failed MV Weaning

Successful MV weaning:

Patients were classified as successfully weaned if they met all of the following criteria:

(1) Successful completion of the SBT.

(2) No requirement for reintubation or MV support within 48 hours post-weaning.

(3) Survival for more than 48 hours following weaning from MV.

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Failed MV weaning:

Weaning failure was defined by any of the following criteria:

(1) Failure to complete the SBT.

(2) Requirement for MV reinstitution within 48 hours of weaning.

(3) Death or withdrawal from the study by next of kin.

Statistical Methods

Statistical analysis were performed using SPSS 25.0 software (IBM Corp. Released 2017. IBM SPSS Statistics for Windows Version 2.0. Armonk, NY: IBM Corp). Measurement data that followed a normal or approximately normal distribution were expressed as mean ± standard deviation (mean ± SD) and assessed for homogeneity of variance. Comparisons between the successful and failed weaning groups were conducted using the *t*-test. Non-normally distributed data were expressed as median and interquartile range (M [P25, P75]), with inter-group comparisons performed using the Mann–Whitney test.

Categorical variables were expressed as frequency and percentage (n, %) and analyzed using the chi-squared test. Logistic regression analysis was employed to identify factors associated with weaning outcomes. Receiver operating characteristic (ROC) curve analysis was conducted to determine the area under the curve (AUC) for individual and combined predictive indicators. The Youden's index was calculated to determine the optimal cut-off value, sensitivity, specificity, positive predictive value, and negative predictive value. A p-value < 0.05 was considered statistically significant.

Results

General Data

A total of 100 patients undergoing MV at the Affiliated Hospital of Hebei University were included in this study. Of these, 71 patients successfully weaned from MV, while 29 patients experienced weaning failure. Among the failed cases, 13 patients required reintubation or MV support within 48 hours post-weaning, 12 patients either passed away or had treatment discontinued by their families, and 4 patients were unable to pass the SBT. No patients with tracheostomy were included in the study. Table 1 presents a comparison of vital signs, laboratory test results, and other clinical parameters between the successful and failed weaning groups.

Diaphragmatic Ultrasonography and IAP Indicators

The D-RSBI and IAP values were significantly lower in the successful weaning group compared to the failed weaning group ($p < 0.05$). Conversely, the successful weaning group demonstrated significantly higher TFdi, DTei, DTee, and DE values than the failed weaning group ($p < 0.05$). Table 2 provides a detailed comparison of IAP and diaphragmatic ultrasonographic indicators between the two groups.

Diagnostic Performance Metrics for Individual and Combined Indicators

The D-RSBI demonstrated an AUC of 0.880 (95% confidence interval (CI): 0.811–0.948). The optimal cut-off value was 13.51 breaths/(min*cm), with a corresponding sensitivity of 71.8% and specificity of 89.7%.

DE exhibited an AUC of 0.981 (95% CI: 0.960–1) and an optimal cut-off value of 1.15 cm. The sensitivity and specificity for DE were 95.8% and 89.7%, respectively.

TFdi demonstrated an AUC of 0.907 (95% CI: 0.872–0.972). The optimal cut-off value for TFdi was 29.29%, with sensitivity of 85.9% and specificity of 86.2%.

IAP had an AUC of 0.838 (95% CI: 0.748–0.929), with an optimal cut-off value of 5.625 mmHg. The sensitivity and specificity for IAP were 91.5% and 72.4%, respectively.

In the analysis of combined indicators, the combination of IAP and DE exhibited the highest predictive accuracy for successful MV weaning (Figures 1 and 2, Table 3).

Table 1 Comparison of General Characteristics and Physiological Indicators Between the Successful and Failed Weaning Groups, Presented as Mean ± Standard Deviation ($\bar{x} \pm s$), Frequency (n [%]), and Median [P25, P75]

Item	Successful Weaning Group (n = 71)	Failed Weaning Group (n = 29)	p-value
Sex (N, %)			0.097
Male	47 (66.2)	14 (48.3)	
Female	24 (33.8)	15 (51.7)	
Age (Years)	63 (48.0, 75.0)	67 (60.5, 75.0)	0.056
APACHE-II	11 (8.0, 17.0)	21 (16.0, 25.0)	<0.01
Heart rate (Beat/minute)	100.39±23.01	103.55±21.14	0.526
Body temperature (°C)	36.5 (36.2, 37.0)	36.5 (36.3, 37.5)	0.255
Systolic blood pressure (mmHg)	142±27	127±31	0.028
Diastolic blood pressure (mmHg)	77±15	71±17	0.131
Mean arterial pressure (mmHg)	98±17	90±20	0.062
Respiratory rate (RR) (Breath/ minute)	17 (15.0, 20.0)	17 (15.0, 20.0)	0.957
MV duration (Hours)	109 (63.0, 178.0)	196 (85.5, 336.5)	<0.01
Albumin (g/L)	28.78±6.01	30.40±5.26	0.208
pH	7.37 (7.3, 7.4)	7.42 (7.3, 7.5)	0.102
pCO2 (mmHg)	40 (32.0, 46.0)	40 (30.0, 49.5)	0.721
pO2 (mmHg)	101 (71.0, 162.0)	81 (62.5, 142.0)	0.298
Oxygenation index (mmHg)	218 (162.8, 308.0)	206 (99.5, 324.0)	0.450
Tidal volume (L)	0.50±0.070	0.45±0.100	0.028
Weight (KG)	75 (70.0, 80.0)	70 (61.5, 71.0)	<0.01
Tidal volume /Weight (L/KG)	6.2 (5.8, 7.1)	6.2 (5.8, 7.1)	0.302

Note: 1 mmHg = 0.133 kPa.
Abbreviation: APACHE-II, acute physiology and chronic health evaluation-II; MV, mechanical ventilation.

Table 2 Indicators of IAP and Diaphragm Ultrasound in the Successful and Failed Weaning Groups ($\bar{x} \pm s$) (n [%]) (M [P_{25}, P_{75}])

Item	Successful Weaning Group (n = 71)	Failed Weaning Group (n = 29)	p-value
DE	1.433 (1.3, 1.5)	0.933 (0.8, 1.1)	<0.01
D-RSBI	12.143 (10.2, 14.0)	18.649 (14.8, 22.4)	<0.01
TFdi	0.36±0.07	0.24±0.05	<0.01
DTee	1.800 (1.5, 2.0)	1.500 (1.4, 1.9)	0.021
DTei	2.500 (2.0, 2.8)	1.900 (1.7, 2.4)	<0.01
IAP	4.690 (4.1, 5.2)	6.120 (5.3, 8.7)	<0.01

Notes: TFdi: diaphragm thickening fraction = (diaphragm thickness at end-inhalation – diaphragm thickness at end-exhalation)/ diaphragm thickness at end-exhalation ×100% = (DTei – DTee)/ DTee ×100%. DTei: diaphragm thickness at end-inhalation.
Abbreviations: DE, diaphragmatic displacement; D-RSBI, diaphragmatic rapid shallow breathing index; DTee, diaphragm thickness at end-exhalation; IAP, intra-abdominal pressure.

Discussion

Use of MV is a critical intervention in ICUs; however, determining the optimal timing for weaning following the resolution of the underlying condition remains a significant challenge for clinicians. Each year, numerous studies on MV emphasize the ongoing efforts of ICU physicians to refine strategies for optimizing weaning timing and preventing complications such as ICUAW, VILI, and VAP.[15] Various factors contribute to failed weaning, with respiratory muscle and diaphragm dysfunction playing a particularly significant role.[16] Traditional methods for assessing diaphragmatic function are not routinely utilized in clinical practice due to their invasive nature or exposure to radiation.[17] However, the

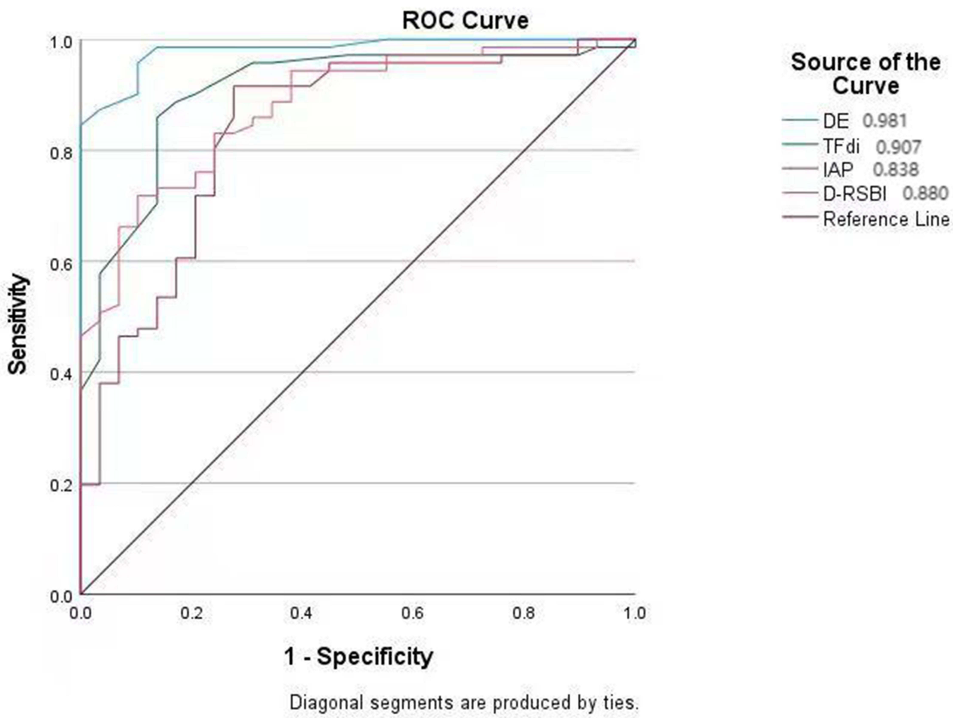

Figure 1 ROC curve depicting the diagnostic performance of individual indicators, including IAP, DE, D-RSBI, and TFdi.
Abbreviations: ROC, receiver operator characteristic; DE, diaphragmatic excursion; TFdi, diaphragm thickening fraction; IAP, intra-abdominal pressure; D-RSBI, diaphragmatic rapid shallow breathing index.

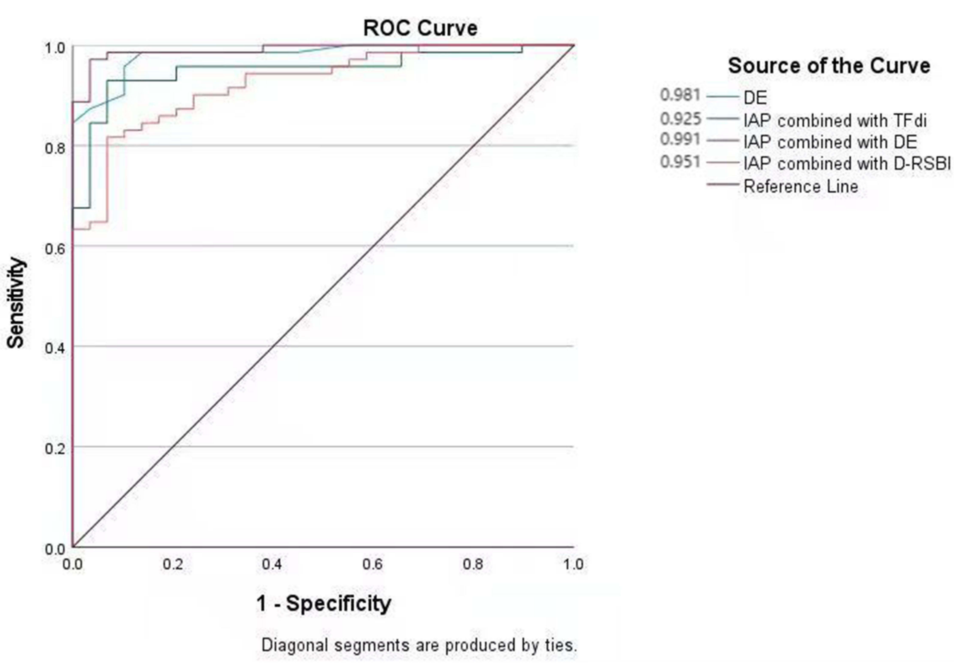

Figure 2 ROC curve illustrating the diagnostic performance of DE and combinations of two indicators, including Combination 1, Combination 2, and Combination 3. Combination 1: D-RSBI combined with IAP; Combination 2, DE combined with IAP; Combination 3: TFdi combined with IAP.
Abbreviations: ROC, receiver operator characteristic; DE, diaphragmatic excursion; TFdi, diaphragm thickening fraction; IAP, intra-abdominal pressure; D-RSBI, diaphragmatic rapid shallow breathing index.

Table 3 Accuracy of D-RSBI, DE, TFdi, IAP, and Combination of These Indicators in Predicting MV Weaning Outcomes

Indicator	AUC (95%)	Cut-Off Value	Sensitivity (%)	Specificity (%)	Accuracy Rate for Predicting Positivity	Accuracy Rate for Predicting Negativity	*p*- value	Youden's Index
D-RSBI Breaths/(min*cm)	0.880 (0.811–0.948)	13.51	71.8	89.7	94.4	62.1	0.035	0.615
DE (cm)	0.981 (0.960–1)	1.15	95.8	89.7	95.8	89.7	0.011	0.855
TFdi (%)	0.907 (0.842–0.972)	29.29%	85.9	86.2	90.1	79.3	0.033	0.721
IAP (mmHg)	0.838 (0.748–0.929)	5.625	91.5	72.4	95.8	37.9	0.046	0.639
D-RSBI+IAP	0.925 (0.875–0.975)	-	81.7	93.1	93	65.5	0.025	0.748
DE+IAP	0.991 (0.977–1)	-	97.2	96.6	98.6	93.1	0.007	0.938
TFdi+IAP	0.951 (0.910–0.993)	-	93.0	93.1	95.8	75.9	0.021	0.861

Abbreviations: AUC, area under the curve; DE, diaphragmatic excursion; D-RSBI, diaphragmatic rapid shallow breathing index; TFdi, diaphragm thickening fraction; IAP, intra-abdominal pressure.

widespread integration of ultrasonography in the management of critically ill patients has enabled bedside assessment of diaphragmatic function, offering distinct advantages such as non-invasiveness, simplicity, and repeatability. Consequently, ultrasonographic monitoring has emerged as a valuable tool for guiding the timing of MV weaning.

This approach demonstrates superior predictive efficacy compared to conventional weaning predictors; however, it is not without limitations.[18] In this study, the successful weaning group exhibited a significantly elevated DE compared to the failed weaning group with a cut-off value of 1.15 cm, a sensitivity of 95.8%, sand a specificity of 89.7%. These findings are consistent with previous studies.[19] However, DE measurements are influenced by factors such as abdominal compliance and the activity of chest and abdominal wall musculature. Furthermore, diaphragm thickness is primarily indicative of inspiratory effort rather than overall diaphragmatic function.[20]

The TFdi reflects the degree of diaphragmatic contraction and is closely correlated with the electrical activity of the diaphragm (EAdi) and transdiaphragmatic pressure. In this study, TFdi had a cut-off value of 29.29%, with a sensitivity of 85.9%, a specificity of 86.2%, and an AUC of 0.907. Research conducted by Theerawit et al[21] indicates that TFdi exhibits superior predictive accuracy compared to DE. This discrepancy may be attributable to variations in sample size, data acquisition measurement techniques, and patient positioning during examination. Additionally, DE measurements are susceptible to external influences such as abdominal compliance and thoracoabdominal muscle activity, which may lead to inaccuracies.

Furthermore, some researchers have questioned the reliability of DE measurements, as they may be confounded by passive ventilatory support. While PEEP levels are generally low during assisted ventilation weaning, it remains challenging to differentiate between DE resulting from active diaphragmatic contraction and passive displacement caused by ventilatory assistance. Consequently, DE measurements during assisted mechanical ventilation may be overestimated. Additionally, this study did not strictly differentiate between patients undergoing weaning via a T-tube trial versus pressure support ventilation, which may have introduced bias and influenced the study's conclusions.

Recent studies have introduced an innovative metric known as D-RSBI, which is calculated by dividing the respiratory rate by DE. The D-RSBI is posited to offer improved enhanced accuracy compared to the traditional RSBI.[22] This improvement stems from the closer correlation of DE with diaphragmatic function compared to tidal volume. The RSBI reflects the overall capacity of all inspiratory muscles. In cases of diaphragmatic dysfunction or inhibition of diaphragmatic movement, auxiliary inhalation muscles may compensate for ventilation, resulting in tidal volume generation. However, this compensatory procedure is limited in duration due to the lower endurance and heightened susceptibility to fatigue of auxiliary inspiratory muscles. Consequently, the relationship between tidal volume and diaphragmatic function, particularly when auxiliary inspiratory muscles are engaged, appears to be weaker compared to DE.[23] Consistent with previous findings,[24] the present study identified a D-RSBI threshold of 13.51 breaths/(min*cm) as a predictor of weaning failure.

IAH is defined by a persistently elevated IAP $\geq$ 12 mmHg. Studies have reported that the incidence of IAH in ICU patients can reach 25%, with an associated increase in mortality rates.[25] The presence of IAH primarily affects respiratory mechanics by displacing the diaphragm cranially, increasing intrapleural pressure, reducing chest wall compliance, and decreasing lung capacity.[26] In this study, an IAP threshold of 5.625 mmHg was identified as a predictor of weaning failure. These findings are consistent with those reported by Xingwei et al,[27] although minor discrepancies in cut-off values were observed. These variations likely stem from differences in the study populations; whereas their study focused on critically ill patients with pancreatitis, the present study included MV patients with diverse underlying conditions.

As a result, IAP emerges as a key prognostic indicator for successful MV weaning, warranting careful consideration by clinicians. Furthermore, the combination of different indices, such as D-RSBI with IAP, DE with IAP, and TFdi with IAP, provides a more comprehensive and robust framework for predicting adverse outcomes associated with MV weaning.

Based on the findings of the present study, the combination of DE and IAP demonstrated the highest accuracy in predicting successful MV weaning, surpassing the predictive performance of any single indicator or other combined indices. These results highlight the potential of DE combined with IAP as a valuable prognostic tool for assessing MV weaning outcomes. However, despite its high predictive accuracy, the omission of respiratory rate assessment in this study may have introduced bias. The observed difference in predictive accuracy between D-RSBI and the DE-IAP combination underscores the importance of conducting a comprehensive systemic evaluation rather than attributing the variation solely to the interaction between MV weaning parameters. Given the limited existing literature on DE combined with IAP as a prognostic marker for MV weaning, further studies are required to validate these findings and assess the potential influence of chance on the observed outcomes. The MV weaning success rate of 71% observed in this study was slightly higher than previously reported rates. This discrepancy may be attributed to the relatively homogeneous patient population, which included a high proportion of postoperative cases. Additionally, the measurement of diaphragmatic ultrasound parameters requires a high level of operator proficiency. In this study, a single physician conducted all ultrasound assessments, ensuring consistency and reliability in the recorded data. However, the lack of evaluation of inter-operator variability in diaphragm ultrasound measurements remains a limitation.

The limitation of this study is the absence of baseline assessments of diaphragmatic function and IAP upon patient admission, preventing a dynamic evaluation of these parameters over time. Future studies should aim to address this limitation by incorporating longitudinal assessments. Furthermore, despite the prospective design, this study was limited by its small sample size and single-center nature, potentially restricting the generalizability of the findings. Therefore, larger-scale, multicenter prospective studies are warranted to validate these results and further explore the clinical utility of DE and IAP in guiding MV weaning decisions.

Conclusions

Monitoring IAP enables the early detection of IAH, which may contribute to respiratory dysfunction and impact MV weaning outcomes. The combination of IAP with diaphragmatic ultrasonographic indicators represents a promising predictive approach for assessing MV weaning success, potentially improving patient prognosis. However, further large-scale, multicenter studies are required to validate these findings and refine clinical guidelines for the evaluation and management of critically ill patients undergoing MV weaning.

Abbreviation

MV, mechanical ventilation; ICU, intensive care unit; SBT, spontaneous breathing trial; ICUAW, ICU-acquired weakness; VAP, ventilator associated pneumonia; VILI, ventilator-induced lung injury; DE, diaphragmatic excursion; APACHE II, Acute Physiology and Chronic Health Evaluation II; IAP, intra-abdominal pressure; IAH, intra-abdominal hypertension; ROC, receiver operator characteristic; AUC, area under the curve; DT, diaphragmatic thickness; TFdi, diaphragm thickening fraction; D-RSBI, diaphragmatic rapid shallow breathing index; DTei, diaphragm thickness at end-inhalation; DTee, diaphragm thickness at end-exhalation; MG, myasthenia gravis.

Data Sharing Statement

All data generated or analysed during this study are included in this article. Further enquiries can be directed to the corresponding author (Zhi Chen).

Ethics Approval and Consent to Participate

The study was conducted in accordance with the Declaration of Helsinki(as was revised in 2013). The study was approved by Ethics Committee of the Affiliated Hospital of Hebei University (No.HDFYLL-KY-2023-147). Written informed consent was obtained from all participants.

Consent for Publication

Consent for publication was obtained from every individual whose data are included in this manuscript.

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Disclosure

The authors declare that they have no competing interests.

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