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ORIGINAL ARTICLE

Ultrasonographic evaluation of diaphragm thickness and excursion: correlation with weaning success in trauma patients: prospective cohort study

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Abstract

Purpose Prolonged mechanical ventilation (MV) subjects multiple trauma patients to ventilator-induced diaphragmatic dysfunction. There is limited evidence on the predictive role of diaphragm ultrasound (DUS) for weaning success in multiple trauma patients. Therefore, we evaluated Ultrasound of the diaphragm as a valuable indicator of weaning outcomes, in trauma patients.

Material and methods This prospective cohort study included 50 trauma patients from September 2018 to February 2019. DUS was performed twice: upon ICU admission and the first weaning attempt. The diagnostic accuracy of indexes was evaluated by ROC curves.

Results The study included patients with a mean age of 35.4 ± 17.37, and 78% being male. The median injury severity score was 75 (42–75). The failure group exhibited significantly lower right diaphragmatic excursion (DE) compared to the success group ($P = 0.006$). In addition, the failure group experienced a significant decrease in both right and left DE from admission to the first attempt of weaning from MV ($P < 0.001$). Both groups showed a significant decrease in inspiratory and expiratory thickness on both sides during weaning from MV compared to the admission time ($P < 0.001$). The findings from the ROC analysis indicated that the Rapid shallow breathing index (RSBI) (Sensitivity = 91.67, Specificity = 100), respiratory rate (RR)/DE (Right: Sensitivity = 87.5, Specificity = 92.31), and RR/TF (Thickening Fraction) (Right: Sensitivity = 83.33, Specificity = 80.77) demonstrated high sensitivity and specificity in predicting weaning outcome.

Conclusion In the context of patients with multiple trauma, employing DUC and assessing diaphragmatic excursion, thickness, RR/DE index, RR/TF index, and RSBI can aid in determining successful ventilator weaning.

Keywords Ultrasound · Diaphragm · Trauma · Ventilator weaning · Mechanical ventilation

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Introduction

Trauma is one of the most common causes of death worldwide [1, 2]. Direct diaphragmatic injury (contusion-laceration) is uncommon although its diagnosis is very important in patients with trauma [3–5]. Diaphragmatic injury is usually hidden, and diagnostic tests are usually not helpful. MV is a more common cause of diaphragm dysfunction since trauma patients admitted to an Intensive Care Unit (ICU) often require ventilation; this may be an especially important contributor to prolonged ventilation [6–8]. Unlike the gradual process of muscular wasting in extremities, diaphragmatic dysfunction occurs much more rapidly [9]. Other risk factors typically present in ICU patients such as inflammation, malnutrition, and hypoxia exacerbate this condition [10].

Determining the optimal time for weaning has a remarkable influence on patient outcomes, weaning difficulty is encountered in approximately a quarter of mechanically ventilated patients [11]. Several indices have been proposed for objective monitoring, such as including rapid shallow breathing index (RSBI), maximum inspiratory pressure (PI max), etc. [12]. However, they are of limited value for the prediction of weaning outcomes. For instance, initial satisfactory parameters could be attributed to the contribution of accessory inspiratory muscles, which are easily fatigued in the following hours after extubation.

Point-of-care ultrasonography is a feasible non-invasive imaging method that allows prompt and real-time measurement of structural and functional characteristics of the diaphragm with acceptable accuracy. Several studies have shown promising results with regard to the value of ultrasound study as an indicator of weaning outcomes. However, the majority have been conducted in medical or post-surgical patients [13, 14]. To our knowledge, none of these studies examined the use of diaphragmatic ultrasound to predict the success weaning from mechanical ventilation in patients with multiple trauma. Therefore, we designed the present study to investigate the role of ultra-sonographic evaluation of diaphragmatic dysfunction in the prediction of successful weaning in multiple trauma patients.

Material and methods

Patients and setting

From Sep. 2018 to Feb. 2019, we conducted a prospective observational study at Rajaee Hospital, a level I trauma center in Shiraz, Iran. The study included adult multiple trauma patients admitted to the ICU, expected to require mechanical ventilation for at least 72 h. Exclusion criteria were upper airway obstruction, diaphragm rupture, ascites, fibrosis, abdominal mass, spinal cord injury, pregnancy, poor ultrasound view due to obesity, or history of diaphragmatic disorders or neuromuscular problems.

Ethical consideration

The study protocol adhered to the ethical principles outlined in the Helsinki Declaration of Bioethics and received approval from the Ethics Committee of Shiraz University of Medical Sciences (IR.sums.med.rec.1396.s208). Informed written consent was obtained from the legal guardians of the patients, ensuring their understanding and agreement to participate in the study.

Ultra sonographic evaluation

Ultrasonography was used to assess diaphragm thickness, contraction-induced thickness changes, and excursion on two occasions. The initial evaluation occurred during ICU admission. Ventilator settings during this stage included Synchronized Intermittent Mandatory Ventilation, tidal volume (VT) of 6–8 cc/kg ideal body weight (IBW), respiratory rate (RR) of 12–14 breaths per minute, pressure support of 12 cm H_2O, positive end-expiratory pressure (PEEP) of 5 cm H_2O, and fraction of inspired oxygen (FiO_2) of 40%. Daily RSBI was done, the subsequent assessment occurred during the first weaning attempt, which was initiated once the patients met the following criteria: improved breathing condition and resolution of underlying cause, satisfactory cough reflex, minimal or no purulent bronchial secretions, stable cardiovascular status (systolic blood pressure 90–160 mmHg, heart rate < 120 bpm), limited use of vasopressor medications (dopamine or dobutamine < 5 µg/kg/min or norepinephrine < 0.05 µg/kg/min), stable electrolyte levels, body temperature < 38 °C, oxygen saturation > 90% with $FiO_2 \leq 40\%$, PEEP ≤ 5, and no significant respiratory acidosis [15]. Weaning failure was defined as reintubation or the need to resume mechanical support within 24 h.

Previous studies mainly focused on evaluating the right side of the diaphragm during weaning [13, 15, 16]. However, considering the potential presence of traumatic diaphragmatic injury, we assessed both the right and left sides. In the time of USD at admission and weaning, sedation was discontinued (Richmond Agitation-Sedation Scale: − 1 to + 1), but we continued analgesic (Behavioral pain scale: 0–3), and ventilator settings were adjusted from Synchronized Intermittent Mandatory Ventilation (SIMV) to Continuous Positive Airway Pressure (CPAP) with a positive end-expiratory pressure (PEEP) of 5 cm H_2O and pressure support (PS) set to 0 for several minutes. After the ultrasound examination, the previous ventilator settings were restored or spontaneous breathing was allowed during weaning. The patients were examined in either the supine or semi-recumbent position using an Edge model ultrasound device (SonoSite, USA) with a linear, high-frequency probe (6–15 MHz) to measure diaphragm thickness. The probe was positioned at the mid-clavicular line, anterior to the costal margin, or at the anterior axillary line in the last intercostal space. Diaphragm thickness was determined by identifying the costophrenic sulcus, which consists of a central non-echogenic layer bordered by two echogenic layers representing the diaphragmatic pleura and peritoneum. The distance between the midpoints of the pleural and peritoneal lines was measured as diaphragm thickness. Measurements were taken at the end of three inspiratory and three expiratory phases across different respiratory cycles [17].

We calculated the diaphragm thickening fraction (TF) using the formula: (Thickness at end inspiration—Thickness at end-expiration) divided by Thickness at end-expiration, multiplied by 100 [18]. For diaphragm excursion assessment, patients were positioned supine. A curved probe (2–5 MHz) was placed along the anterior subcostal abdominal wall on the mid-clavicular line. The transducer head was guided backward, caudally, and slightly medially to visualize the diaphragm's dome through the acoustic windows provided by the liver and spleen.

Statistical analysis

Continuous variables were expressed as the mean ± SD or median (Q_1–Q_3), and the categorical variables were expressed as a number (percentage). Continuous variables were checked for normality using the Shapiro–Wilk test and the nonparametric Mann–Whitney U test was used to compare success and failure groups. Also, a paired t-test was used to compare subjects within each group. Receiver operating characteristic (ROC) curve analysis was used to identify optimal cutoff values of RSBI, RR/RDE, RR/LDE, RR/RTF, and RR/LTF with maximum sensitivity and specificity for prediction of weaning failure. The area under the curve (AUC) was also calculated, and the criteria to qualify for AUC were as follows: 0.90–1 = excellent, 0.80–0.90 = good, 0.70–0.80 = fair, 0.60–0.70 = poor and 0.50–0.60 = fail. The optimal cutoff point was established at the point of maximum accuracy. P-value < 0.05 was considered significant. All statistics were performed using SPSS 22.0 (IBM Corporation, Armonk, NY, USA), MedCalc (MedCalc Software bvba 13, Ostend, Belgium), and GraphPad Prism version 9.

Results

Between Sep 2018 and Feb 2019, 70 patients were admitted to the ICU. Out of these, 58 were eligible for our study. Eight patients were excluded, leaving 50 patients for analysis (Fig. 1).

Table 1 represents the demographic information of patients. Patients aged 18–82 years with an average age of 35.4 ± 17.37, the majority of patients were male (78%) with a median injury severity score (ISS) of 75 (42–75) were included in the study.

GCS score at admission time was 7 (5.75–9.25) and 10 (9–11) when weaning from mechanical ventilation. The median length of patients stay in ICU was 13.5 (9–18) days, and the median duration of mechanical ventilation was 10 (6–14) days. The rate of successful first-attempt weaning from MV and the mortality rate was 52% and 2%, respectively.

Table 2 presents a comparison of parameters between two groups: patients who successfully weaned from mechanical ventilation (MV) and those who failed to wean from MV.

In the success group, parameters such as RR ($P < 0.001$), RSBI ($P < 0.001$), MV duration ($P < 0.001$), and ICU duration ($P < 0.001$) were significantly lower. Conversely, the TV (ml/kg IBW) was significantly higher in the success group ($P < 0.001$).

We compared parameters between success and failure groups and also compared each parameter on admission time and time of weaning from MV, then represented them in Table 3.

After analyzing the most paramount variables, the results showed that all the variables except RET (cm) (0.28 (0.27–0.33) vs. 0.27 (0.25–0.28), $P = 0.003$), and RIT (cm) (0.20 (0.18–0.21) vs. 0.18 (0.17–0.19), $P = 0.002$), which were significantly higher in the successful group than the failure group, the rest of the variables did not differ between the two groups at the admission time (P > 0.05).

At the time of weaning from MV, the GCS (11(10–13) vs. 10 (8.25–10), $P = 0.001$), and RDE (cm) (1.24 (0.95–1.56) vs. 1.03 (0.82–1.22), $P = 0.006$) were higher in the success groups, and the other parameters were not statistically different ($P > 0.05$).

From the intra-group comparison of the variables in the time interval of admission and weaning from mechanical ventilation, significant changes have occurred for most of the variables, both in the successful and the failure groups.

GCS score has increased over time ($P < 0.001$). The right and left diaphragmatic excursion (LDE and RDE) did not change in the successful group ($P > 0.05$), while RDE and LDE decreased significantly in the failure group ($P < 0.001$) (Fig. 2A and B).

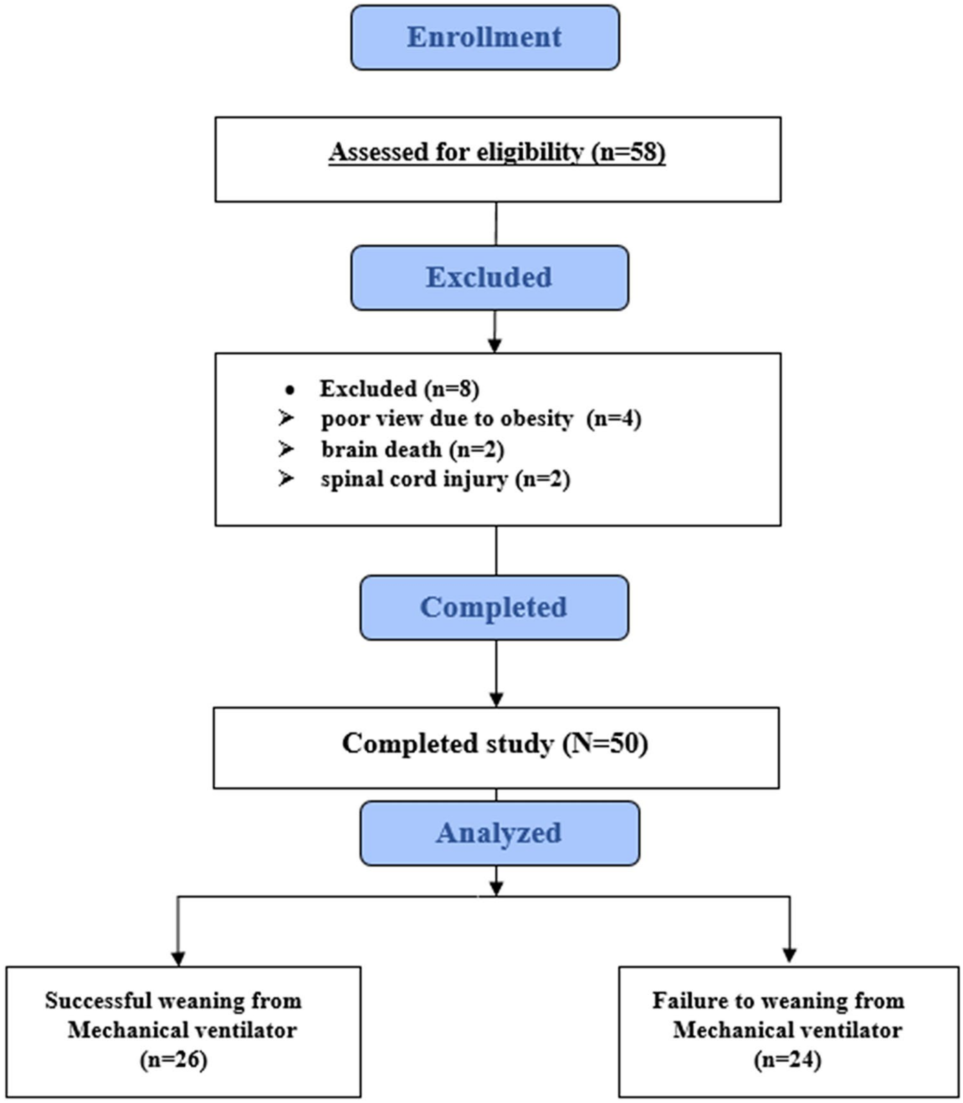

Fig. 1 STROBE chart of patients

We saw a decrease in the right and left expiratory thickness (RET and LET) and inspiratory thickness (RIT and LIT) in both successful and failed groups ($P < 0.001$) at weaning from the MV. On the other hand, there was no change in the left and right diaphragmatic thickening fraction (LTF and RTF) in the time interval between admission and weaning from mechanical ventilation in the two groups ($P > 0.05$) (Fig. 2C and D).

The results of ROC analysis based on the successful and failed results of the variables RSBI (RR/TV), RR/RDE, RR/LDE, RR/RTF, and RR/LTF are shown in Table 4 and Fig. 3.

The findings revealed that, following the RSBI index, the RR/RDE index demonstrated the highest sensitivity (87.5%) and specificity (92.31%) in predicting the time for successful weaning from mechanical ventilation. The remaining calculated indicators also exhibited a minimum sensitivity of 87.5% and a specificity of 80%.

Discussion

Choosing the right time for weaning traumatic patients from mechanical ventilation in the ICU is debated [19]. Prolonged intubation and complicated weaning increase ICU readmission rates [20]. Despite available data, there are no reliable tools for optimal extubation timing. Subjective decisions can be harmful [21]. Critical care ultrasonography is increasingly used for therapeutic and diagnostic purposes [22, 23]. Its use for diaphragmatic evaluation during weaning in trauma patients is beneficial but lacks well-designed studies.

Goligher et al. concluded that monitoring diaphragmatic thickness in ventilated patients is feasible and relevant to diaphragm function [24]. Previous ultrasound studies examining the diaphragm during weaning from MV primarily focused on medical patients with pre-existing healthy diaphragms before ICU admission and mechanical ventilation. Consequently, ultrasound evaluations

Table 1 Demographic data of total study population

Age (year)	35.4 ± 17.37 26.5(23–48.5)
Sex, male	39 (78%)
Injury severity score (ISS)	75 (42–75)
Chest trauma	
Right	9 (18%)
Left	5 (10%)
Bilateral	24 (48%)
None	12 (24%)
Abdominal trauma	
Liver	3 (6%)
Spleen	1 (2%)
Both	3 (6%)
None	43 (86%)
Brain trauma	41 (82%)
Multiple trauma	24 (48%)
GCS	
Admission time	7 (5.75–9.25)
Weaning from MV	10 (9–11)
ICU duration (days)	13.5 (9–18)
MV duration (days)	10 (6–14)
Successful first-attempt weaning from MV	26 (52%)
Mortality	1 (2%)

The values indicate median (Q1–Q3), frequency (percentage)

GCS Glasgow coma scale score, *MV* Mechanical ventilator

were conducted only once during the weaning process. In these studies, the right side diaphragm was typically chosen for assessment due to the liver providing a favorable acoustic window. However, considering the potential for trauma-related diaphragmatic injury, our study examined both the right and left sides. In another study by Ali ER et al., normal values for diaphragm excursion were reported as 2 ± 15.83 cm before mechanical ventilation and 2.4 ± 11.2 cm in healthy control volunteers [25]. The reduced excursion observed in our patients upon admission may be attributed to the trauma itself or the effects of initiating mechanical ventilation in the emergency room prior to transfer to the ICU. In the failure group, both RDE and LDE significantly decreased in the second evaluation compared to admission, suggesting a decline in the diaphragm's force-generating capacity and compromised diaphragmatic motion. Lu et al. demonstrated that diaphragmatic movement is a preferable factor for predicting the outcome of weaning from MV [26]. Similarly, Farghaly et al. described diaphragmatic movement as a reliable indicator for assessing the outcome of weaning from MV [27].

Normal diaphragmatic thickness before mechanical ventilation in healthy individuals is reported as 0.25 ± 0.13 cm [30]. In our study, the diaphragm thickness was initially higher than the reported normal value, considering that the average age of the patients in our study was 35 years, this difference can be since the patients are younger. Previous studies have demonstrated that mechanical ventilation can lead to diaphragmatic atrophy. Schepens et al. found a correlation between the duration of mechanical ventilation and the degree of diaphragmatic atrophy [28], and we observed this phenomenon in all of our subjects [29, 30].

However, we did not observe any significant differences in diaphragmatic thickening fraction between the success and failure groups, nor did it change from admission to weaning from MV within each group. In multiple trauma patients, the diaphragm thickening fraction might not have an influential role in the weaning outcome in contrast to its excursion. In post-elective surgery patients who are admitted to the ICU for ventilator support, diaphragm thickness is a better means for detecting respiratory dysfunction [31].

It is worth mentioning that despite the improvement in the Glasgow Coma Scale Score (GCS) and low mortality rate during the patients' ICU stay, approximately half of them experienced failure in ventilator weaning, which is a significant rate. The failure group had a significantly longer duration of mechanical ventilation and ICU stay.

Table 2 Comparison of parameters between success and failure groups in the weaning time

	Success ($n = 26$)	Failure ($n = 24$)	P value
RR (breaths/min)	18 (16–19.25)	32.5 (28.5–35)	< 0.001*
TV (ml/kg IBW)	457.5 (420–493)	282.5 (250–308.75)	< 0.001*
RSBI (breath/min/L)	38 (33.3–43.38)	117.5 (111.6–133)	< 0.001*
MV duration (days)	6.5 (4–9.25)	13.5 (10–15)	< 0.001*
ICU duration (days)	9.5 (7–13.25)	17.5 (14–20)	< 0.001*
Time between two ultrasonography evaluations (days)	6.5 (4–8.25)	8 (6–10)	0.052

The values indicate median (Q1–Q3)

RR Respiratory rate, *TV* Tidal volume, *RSBI* Rapid shallow breathing index, *MV* Mechanical ventilator

*Indicates significant *P* value

Table 3 Comparison of parameters between success and failure groups and within each group

All patients (*n* = 50)		Success (*n* = 26)	Failure (*n* = 24)	*P* value
GCS				
Admission time	7 (5.75–9.25)	7 (6–9.25)	6 (5–9.5)	0.29
Weaning from MV	10 (9–11)	11 (10–13)	10 (8.25–10)	0.001*
P value	< 0.001*	< 0.001*	< 0.001*	
RDE (cm)				
Admission	1.49 (1.18–1.83)	1.49 (1.14–1.71)	1.50 (1.20–1.85)	0.91
Weaning from MV	1.10 (0.90–1.38)	1.24 (0.95–1.56)	1.03 (0.82–1.22)	0.006*
P value	0.001*	0.34	< 0.001*	
LDE (cm)				
Admission	1.41 (1.09–1.70)	1.36 (1.09–1.60)	1.43 (1.07–1.85)	0.64
Weaning from MV	1.11 (0.92–1.39)	1.20 (0.92–1.50)	1.08 (0.92–1.34)	0.26
P value	0.008*	0.55	< 0.001*	
RET (cm)				
Admission	0.28 (0.26–0.30)	0.28 (0.27–0.33)	0.27 (0.25–0.28)	0.003*
Weaning from MV	0.25 (0.22–0.26)	0.25 (0.22–0.28)	0.25 (0.22–0.25)	0.049
P value	< 0.001*	< 0.001*	< 0.001*	
LET (cm)				
Admission	0.28 (0.26–0.30)	0.27 (0.26–0.31)	0.28 (0.27–0.28)	0.95
Weaning from MV	0.24 (0.22–0.27)	0.25 (0.22–0.27)	0.24 (0.22–0.27)	0.57
P value	< 0.001*	< 0.001*	< 0.001*	
RIT (cm)				
Admission	0.19 (0.17–0.20)	0.20 (0.18–0.21)	0.18 (0.17–0.19)	0.002*
Weaning from MV	0.16 (0.15–0.17)	0.17 (0.16–0.18)	0.16 (0.15–0.17)	0.13
P value	< 0.001*	< 0.001*	< 0.001*	
LIT (cm)				
Admission	0.18(0.17–0.20)	0.18 (0.17–0.20)	0.18 (0.17–0.19)	0.29
Weaning from MV	0.17(0.15–0.18)	0.17 (0.15–0.18)	0.16 (0.15–0.19)	0.15
P value	< 0.001*	< 0.001*	< 0.001*	
RTF				
Admission	50 (38.55–60.27)	50 (36.28–62.33)	52.78 (39.34–58.82)	0.86
Weaning from MV	47.05 (37.5–59.11)	54.24 (37.5–64.7)	46.85 (41.59–56.25)	0.52
P value	0.52	0.26	0.58	
LTF				
Admission	52.78 (44.45–58.89)	47.55 (43.33–62.5)	54.58 (47.36–58.58)	0.35
Weaning from MV	46.67 (40.87–58.82)	46.85 (37.44–59.11)	46.66 (41.17–58)	0.97
P value	0.15	0.42	0.18	

The values indicate median (Q1–Q3)

RDE Right diaphragmatic excursion, *LDE* Left diaphragmatic excursion, *RET* Right expiratory thickening, *LET* Left expiratory thickening, *RIT* Right inspiratory thickening, *LIT* Left inspiratory thickening, *RTF* Right diaphragmatic thickening fraction, *LTF* Left diaphragmatic thickening fraction

*Indicates significant *P* value

This underscores the potential magnified impact of prolonged ventilation on overall patient care. Similar observations have been reported in other studies [27, 32].

Another noteworthy finding is that the failure group exhibited a significantly higher respiratory rate, coupled with a lower tidal volume, resulting in a markedly elevated rapid shallow breathing index (RSBI). This breathing pattern, characterized by excessive effort, may have contributed to earlier patient exhaustion and subsequent weaning failure. The RSBI is widely used due to its straightforward calculation; however, to enhance its predictive value, various modifications have been suggested, including serial measurements and assessing the rate of change [33]. RSBI serves as an indicator of the interplay between the mechanical load placed on the respiratory muscles and their ability to counteract it during

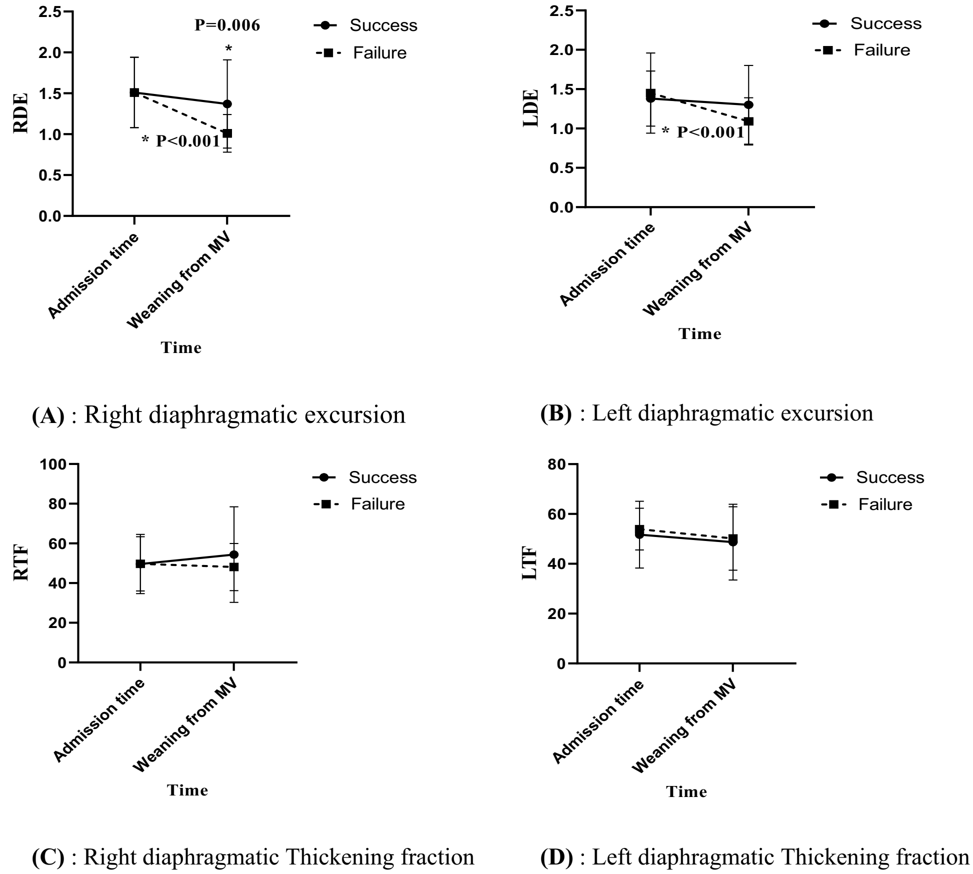

Fig. 2 Comparison of trends of diaphragmatic excursion and thickening fraction between success and failure groups between admission and time of weaning from MV

Table 4 ROC analysis results

	Threshold[a]	Sensitivity	Specificity	AUC	95% CI	*P* value
RSBI(RR/TV)	> 69.4	91.67	100	0.955	(0.85–0.99)	< 0.0001*
RR/RDE	> 21.51	87.5	92.31	0.929	(0.82–0.98)	< 0.0001*
RR/LDE	> 21.43	83.33	88.46	0.899	(0.78–0.97)	< 0.0001*
RR/RTF	> 0.48	83.33	80.77	0.86	(0.73–0.94)	< 0.0001*
RR/LTF	> 0.48	87.5	84.62	0.85	(0.72–0.93)	< 0.0001*

[a]based on Youden index

*Indicates significant *P* value

the weaning process from mechanical ventilation. Even in cases where the diaphragm's function is compromised, such as due to trauma or mechanical ventilation, the accessory inspiratory muscles can temporarily compensate and provide ventilation [34]. The accessory inspiratory muscles, while less efficient in ventilation compared to the diaphragm, are also more prone to fatigue. This increased fatigue can contribute to weaning failure. Moreover, multiple trauma patients may experience damage to these accessory inspiratory muscles, further increasing the likelihood of failure. Consequently, the RSBI may not be a reliable indicator for liberating multiple trauma patients from mechanical ventilation. Relying solely on RSBI without considering the underlying causes of failure can be risky. For example, patients with airway issues, excessive secretions, or weak cough cannot be solely assessed for weaning based on RSBI [34, 35]. Ahmad Abbas et al. in 2018 found that D-RSBI (RR/DD) is superior to traditional RSBI (RR/VT) in predicting the outcome of weaning in acute exacerbations of COPD patients [36].

In light of this, we developed the RR/DE index, which relies on the ratio of respiratory rate (RR) to ultra-sonographic diaphragmatic excursion (DE) on the right or left sides. The results of receiver operating characteristic (ROC) analysis demonstrated that RR/RDE could help predict successful ventilator weaning. This index exhibited a sensitivity of 87.5, a specificity of 92.31, and a threshold value below 21.51. Similarly, the RR/LDE index, which

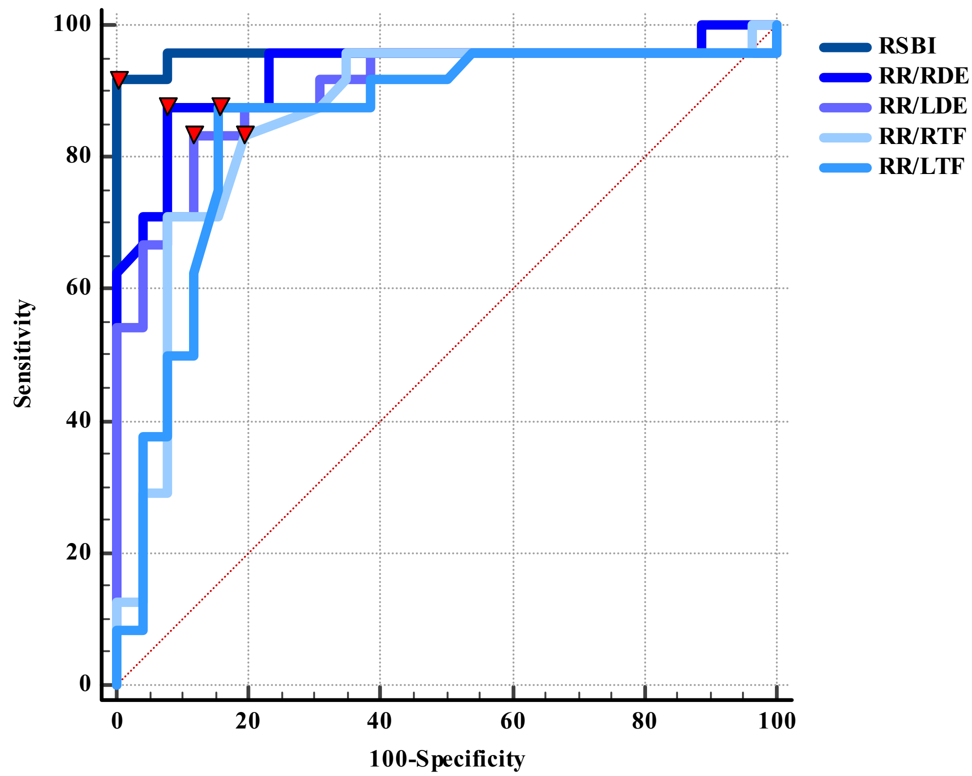

Fig. 3 ROC curve

considers the left ultra-sonographic DE, showed a sensitivity of 83.33, a specificity of 88.46, and a lower cutoff value of 21.43.

In addition, we introduced the RR/TF index, utilizing the ratio of respiratory rate (RR) to ultra-sonographic diaphragmatic thickening fraction (TF) on the right or left side. The RR/RTF index displayed a sensitivity of 83.33, a specificity of 80.77, and a threshold below 0.48. Similarly, the RR/LTF index, based on the left ultra-sonographic diaphragmatic thickening fraction, exhibited a sensitivity of 87.5, a specificity of 84.62, and a threshold below 0.48. In multiple trauma patients, these indicators, in conjunction with the RSBI index, can aid in predicting the success of weaning from mechanical ventilation. The crucial aspect of the RSBI threshold index for weaning from mechanical ventilation is that a score below 105 serves as the decision criterion. However, in the current study conducted on multiple trauma patients, the RSBI threshold score was found to be below 70. When the RSBI score is below 70, there is no issue. However, if the score falls between 70 and 105, conventional guidelines suggest that the patient can be weaned from the ventilator. Nevertheless, based on the findings of our study, it was determined that the patient is not yet ready to be separated from the ventilator. Hence, incorporating ultrasound-derived indexes in conjunction with RSBI can contribute to making more informed decisions regarding weaning from mechanical ventilation.

Limitation

Given the limited number of patients in our study, it was not feasible to explore potential correlations between diaphragmatic dysfunction and specific types of trauma, such as chest trauma. Nevertheless, our study is the first to assess the left hemidiaphragm in this context. It is important to note that the acoustic window provided by the spleen occasionally resulted in poorer views, making the measurements on the left side less reliable compared to the right side.

Conclusion

Our study findings indicate that relying solely on RSBI as a criterion for weaning from a ventilator in multiple trauma patients is not reliable. Therefore, we recommend incorporating diaphragm ultrasonography and measuring DE and thickness, in addition to utilizing the (RR/DE) and (RR/TF) indexes, alongside the RSBI index. By considering these additional factors, healthcare providers can make more accuracy for predicting of successful weaning from the ventilator for patients with multiple trauma.

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Author contributions F.Z. participated in the study conception, proposal writing, manuscript writing and editing, and final draft. G.S. contributed to the study design, writing manuscript drafts, and manuscript revision. M.M. participated in study design, proposal writing, and data collection. S.P. contributed to study conception, proposal preparation, and data collection. G.A.S. participated in the study conception, findings interpretation, and revising manuscript. N.S. participated in study design, data analysis, and interpretation results. M.B. participated in data analysis, manuscript writing, editing, and final manuscript preparation. M.M. participated in study conception, proposal writing, and data collection.

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Availability of data and materials All data will be available on request.

Declarations

Conflict of interest The authors declare no conflict of interest.

Ethics approval and consent to participate The study protocol was in accordance with the Declaration of Helsinki and Good Clinical Practice guidelines and approved by Ethics Committee of Shiraz University of Medical Sciences. Written informed consent was taken from all the patients.

Consent for publication All authors made an agreement for publication.

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