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Systematic review

Diaphragmatic ultrasonography as a predictor of ventilatory weaning: a systematic review

Ultrassonografia diafragmática como preditora de desmame ventilatório: uma revisão sistemática

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ABSTRACT

Objective: To review the evidence on diaphragmatic ultrasonography as a predictor of success in ventilatory weaning, using the PICO methodology and keywords: Ultrasound, Diagnostic imaging, Diaphragm, Weaning, Intensive Care Unit, Artificial Respiration, Mechanical Ventilation, Ventilator Weaning. **Methods:** Published cohort studies were used without language and year restrictions that addressed the use of ultrasound to predict success in weaning and ventilatory extubation. Studies with patients under 18 years of age, case reports, literature reviews, results that do not bring a cutoff value for thickness and diaphragmatic excursion and the definition of failure in the weaning and extubation process were excluded. **Results:** 459 were found, and after exclusion due to duplication and reading of titles and abstract, only 11 were selected by the inclusion criteria. The samples ranged from 34 to 193 individuals. **Conclusion:** We can evidence that the use of USG to assess the thickness and excursion of the diaphragm in patients undergoing invasive ventilatory support is effective in predicting success in the weaning and extubation process. The Diaphragmatic Ultrasonography has great applicability to assess the ability to predict success or failure in removing invasive ventilatory support.

Keywords: diaphragmatic ultrasound; mechanical ventilation; weaning; airway extubation.

RESUMO

Objetivo: Revisar as evidências sobre a ultrassonografia diafragmática como preditor de sucesso no desmame ventilatório, usando a metodologia PICO e palavras-chave: Ultrassom, Diagnóstico por imagem, Diafragma, Desmame, Unidade de Terapia Intensiva, Respiração Artificial, Ventilação Mecânica, Desmame do Ventilador. **Métodos:** Estudos de coorte publicados foram usados sem restrições de idioma e ano que abordaram o uso de ultrassom para prever o sucesso no desmame e extubação ventilatória. Foram excluídos estudos com pacientes menores de 18 anos, relatos de casos, revisões de literatura, resultados que não trouxessem valor de corte para espessura e excursão diafragmática e definição de falha no processo de desmame e extubação. **Resultados:** Foram encontrados 459 estudos; após exclusão por duplicação e leitura de títulos e resumo, apenas 11 foram selecionados pelos critérios de inclusão. As amostras variaram de 34 a 193 indivíduos. **Conclusão:** Podemos evidenciar que o uso da USG para avaliar a espessura e excursão do diafragma em pacientes submetidos a suporte ventilatório invasivo é eficaz em predizer o sucesso no processo de desmame e extubação. A ultrassonografia diafragmática tem grande aplicabilidade para avaliar a capacidade de predizer sucesso ou falha na remoção do suporte ventilatório invasivo.

Palavras-chave: ultrassom diafragmático; ventilação mecânica; desmame, extubação.

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Introduction

One of the main causes of referral to the intensive care unit (ICU) is the need for invasive mechanical ventilation (IMV) [1,2]. Patients need IMV when they lose the ability to perform spontaneous ventilation due to respiratory failure or are unable to protect the airways by lowering the level of consciousness [3,4].

IMV can cause deleterious effects for the patient and diaphragmatic dysfunction (DD) is among the most important, causing weakness and atrophy due to disuse, prolonging the time spent on mechanical ventilation, risk of tracheostomy, complications up to one year after discharge from the ICU and impact on the mortality rate [3-7].

Weaning is a transitory process between the support of mechanical ventilation and spontaneous ventilation; it is also classified in categories according to the time of MV. Within intensive care units, and especially in patients on invasive ventilatory support, weaning becomes one of the main objectives of the multidisciplinary team. There are several causes for failure in the weaning process, in this scenario it is important to use accurate methods to predict success and avoid complications for the patient [8].

Several diagnostic techniques are used to assess diaphragmatic functions [9,10]. Among them, diaphragmatic ultrasonography (USG) has become increasingly used, proving to be very important in the intensive care environment and in the assessment of the critical patient. This method is accessible and can evaluate in real time the function and structure of the diaphragm, being able to detect changes that may difficult the weaning [1,3,4,11,12].

Parameters such as excursion and thickness are some of the findings that guide us to identify atrophy, paralysis and other diaphragmatic dysfunctions [1]. In this sense, Carrie *et al*. [13] assessed the performance of diaphragmatic USG to predict failure in weaning in patients under IMV using the maximum diaphragmatic excursion measurement, confirmed the ventilator-induced diaphragmatic dysfunction (VIDD) and suggests that the diaphragm is very sensitive to the absence of activity.

Llamas-Álvarez *et al*. [14] performed a review and suggest that diaphragmatic USG is a predictor in ventilatory weaning in critically ill patients. Therefore, the objective of this study was to review the evidence on diaphragmatic ultrasonography as a predictor of success in ventilatory weaning.

Methods

This is a systematic review and the guiding question of this study was: "What is the current evidence on diaphragmatic ultrasonography to predict success in weaning?".

The following databases were systematically searched: Pubmed, Scielo (Scientific Electronic Library Online), Lilacs (Latin American and Caribbean Literature in

Health Sciences), VHL (Virtual Health Library) and Science Direct. The keywords used were: Ultrasound, Diagnostic imaging, Diaphragm, Weaning, Intensive Care Unit, Artificial Respiration, Mechanical Ventilation, Ventilator Weaning; synonyms and related words added by the Boolean operators "AND" and "OR", according to the Health Sciences Descriptors (DeCS). The survey was conducted in April 2020.

Eligibility criteria

We selected cohort studies without language and year restrictions which used the ultrasound to predict success in weaning and ventilatory extubation. Studies with patients under 18 years of age, case reports, literature reviews, results that do not bring a cutoff value for thickness and diaphragmatic excursion and the definition of failure in the weaning and extubation process were excluded and due to difficulty in translation we also excluded articles in Chinese.

Data extraction

The articles collected through the searches in the databases were selected by tracking the titles (first stage), abstracts (second stage) and complete reading (third stage). Then, an exploratory reading of the selected studies was carried out and, later, selective and analytical reading. The data extracted from the articles were systematized: authors, title, journal, year, summary and conclusions, in order to enable the obtaining of relevant information for the research.

The selection process, data extraction from articles and identification of methodological aspects was carried out by two independent reviewers. When there was any disagreement between them, the reviewers read the entire article again for reassessment. If the disagreement persists, a third independent reviewer assessed and made the final decision. The research followed the items of the PRISMA [15] protocol for systematic reviews.

Results

Four hundred and fifty-nine articles were found, and after exclusion due to duplication and reading of titles and abstracts, only eleven were selected according to the inclusion criteria. Those studies that did not make clear the values found with ultrasound to predict success in weaning / extubation (59) or articles with a literature review design or case reports (54) were also excluded from the study. The flowchart in Figure 1 shows all the criteria and databases used to select the articles.

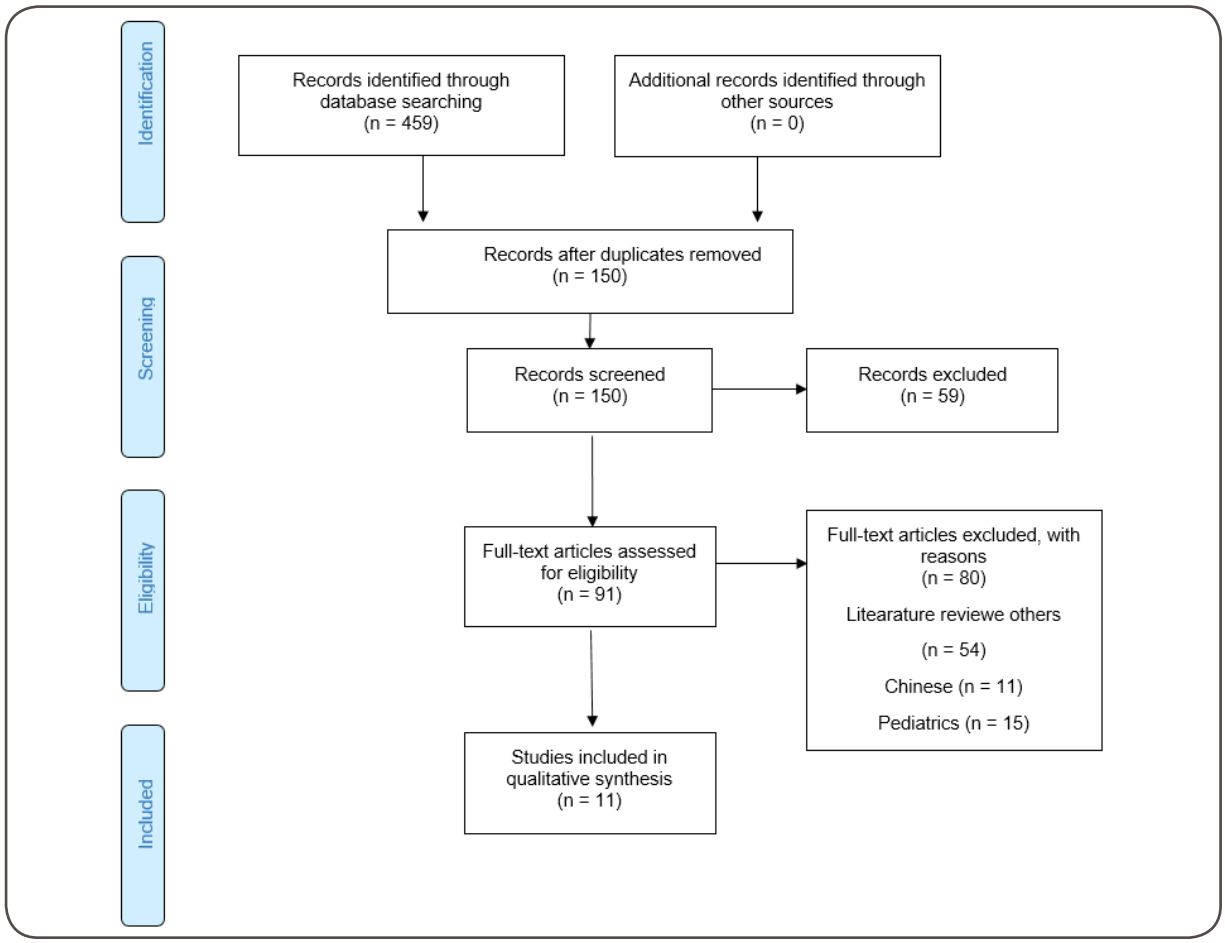

Figure 1 - Flowchart showing how the cohort studies that used ultrasound to obtain thickness and diaphragmatic excursion were obtained

Table I shows the general characteristics of the other studies. We can observe that some studies were carried out in more than one unit, among which are wards, general ICU and specialized ICU.

It is possible to verify that the authors used very similar criteria to determine the failure in the weaning / extubation process, showing that they all started from the same point to define the failure of the removal of artificial ventilation, such as re-connection in the mechanical ventilator, reintubation, use of NIV and tracheostomy within 48 hours after extubation. Table II shows the definitions of each author for failure in weaning / extubation.

The data presented below in Table III show the objectives and results found in each study using ultrasound to assess thickness and diaphragmatic excursion as a predictor of success in the weaning / extubation process. The authors identified that patients with thickness values < 1 cm, 20 < 2.20 + 0.69 mm [21] and < 10 mm [24] were associated with complications, prolonged MV and failure in weaning and extubation. Yoo *et al.* [26] found values of diaphragmatic thickness < 4 cm and 1.53 cm respectively are related to failure in weaning and extubation. These low values were also related to prolonged weaning, increased length of stay in the ICU, hospital mortality and after discharge from the unit.

Table I – General characteristics of the studies

Author/ Year	Patients	Average age	Hospital Unit	Inclusion
Sklar *et al.* [16] 2020	193	60	ICU	Invasively mechanically ventilated patients for less than 36 hours (initially, patients were eligible for enrollment within 72 hours after intubation; for the present analysis, patients were excluded if the first Tdi measurement was obtained > 36 hours after intubation). Also if they had been intubated for less than 36 hours because of acute brain injury, moderate or severe acute respiratory distress syndrome, septic shock, or pneumonia.
Vivier *et al.* [17], 2019	191	68	Three ICUs	Patients at high risk of reintubation (ie, aged > 65 years, with any underlying cardiac or chronic lung disease, or intubated > 7 days before extubation) were eligible for the study if they met all weaning criteria and had undergone successfully to a TRE.
Eltrabili *et al.* [18], 2019	35	52	Surgical ICU of a trauma and emergency department	Individuals on mechanical ventilation for 48 hours with intra-abdominal sepsis.
Zhang *et al.* [19], 2020	37	74	ICU	All patients with acute respiratory failure due to COPD and requiring MV.
Palkar *et al.* [20], 2018	73	72	Medical ICUs UTIs médica	The ICU team decided on the readiness of the patient to wean from MV, the moment of the beginning of the ERT and extubation based on the clinical evaluation.
Dres *et al.* [21], 2016	76	58	Medical ICU	Patients intubated and ventilated for up to at least 24 hours.
Khan *et al.* [22], 2018	90	55	Medical ICU	Patients on MV for more than 48 hours, without having tracheobronchial secretions and underlying disease (the reason for intubation) must have been resolved. All participants were alert, cooperative and hemodynamically stable.
Soliman *et al.* [23], 2019	100	57	ICU	Patients mechanically ventilated for more than 48 hours were included when the underlying cause that required intubation was resolved.
Huang *et al.* [24], 2017	40	84	Medical ICU	Patients were included when they met all of the following criteria: age ≥ 80 years, received mechanical ventilation for > 48 hours, suitable for an ERT, minimal doses of sedatives and analgesic drugs were allowed, but the patient should be easily aroused (score of Ramsay 3-4), and muscle paralyzing agents must have been discontinued ≥ 2 days prior to entry into the study and aminoglycosides were not allowed.

Table I – Continuation

Author/ Year	Patients	Average age	Hospital Unit	Inclusion
Pirompanich *et al.* [25], 2018	34	66	Medical wards and ICUs	Inclusion criteria were age ≥ 18 years, respiratory failure with MV for more than 24 hours, and the ability to tolerate ERT for 1 hour before ultrasound.
Yoo *et al.* [26], 2018	60	69	Medical or surgical ICU	Patients were included when they met all of the following criteria for the ERT: age ≥ 18 years, FiO_2 < 50%, positive ex-end expiratory pressure level ≤ 5 cmH_2O, respiratory rate (RR) ≤30 breaths / min, PaO_2 / FiO_2 > 200 mmHg, Glasgow coma score ≥14 and hemodynamic stability in the absence of vasopressors.

COPD = chronic obstructive pulmonary disease; FiO_2 = fraction of inspired oxygen; PaO_2: partial pressure of oxygen; Tdi: diaphragm thickness; TRE = spontaneous breathing test; ICU = intensive care unit; VM = mechanical ventilation.

Table II – Characteristics of the included studies and definition of failure in weaning/extubation

Author / Year	Country	Study design	Cutoff values of DTF	Cutoff values of DE	Defining weaning / extubation failure
Sklar *et al.* [16], 2020	Canada	Cohort	≤ 2.3 mm		Complications of acute respiratory failure were defined as the occurrence of any of the following events: reintubation, tracheostomy, prolonged ventilation (> 14 days) or death.
Vivier *et al.* [17], 2019	France	Cohort	< 30%	< 10 mm	The definition of extubation failure was heterogeneous and included patients who failed the ERT and were not extubated, those extubated to the end of life or those who developed an episode of acute respiratory failure.
Eltrabili *et al.* [18], 2019	Egypt	Cohort	30.7%	10.4 mm	Weaning failure was defined as reintubation or use of non-invasive ventilation within 48 hours after extubation.
Zhang *et al.* [19], 2020	China	Cohort		DE > 1.72 cm; DE > 1.63 cm; ΔDE > 0.16 cm;	Extubation failure was defined as reconnection to the ventilator (invasive or non-invasive) within 48 hours due to respiratory failure or other reasons.
Palkar *et al.* [20], 2018	USA	Cohort		< 1 cm	Inability to maintain spontaneous breathing for at least 48 hours, without any form of ventilatory support. Patients who required reintubation or NIV within 48 hours after extubation were included in the "failure" group.
Dres *et al.* [21], 2016	France	Cohort	2.20 ± 0.60 mm	0.82 ± 0.42 cm	Weaning failure was defined as patients with failed ERT, requiring reintubation or any form of ventilatory support (including NIV for post-extubation acute respiratory failure, but not prophylactic NIV) during 48 hours after extubation.

Tabela II – Continuation

Author / Year	Country	Study design	Cutoff values of DTF	Cutoff values of DE	Defining weaning / extubation failure
Khan *et al.* [22], 2018	Pakistan	Cohort	1.35 cm		Failure to wean was considered if the patient required noninvasive or invasive ventilation within 48 hours after extubation.
Soliman *et al.* [23], 2019	Egypt	Cohort	29.5%		Weaning failure was defined as: ERT with failure, reintubation and / or ventilation or death within 48 hours.
Huang *et al.* [24], 2017	China	Cohort	10.7 mm	> 10 mm	Failure was considered: IRRS> 105, FR <10 and> 35 breaths / min, HR> 140 beats / min or altered < 20% compared to baseline or onset of new arrhythmia, tidal volume <4 mL / kg, SaO_2 < 90%.
Pirompanich *et al.* [25], 2018	Thailand	Cohort	3.4 ± 1.3 mm		Weaning failure was defined as the inability to maintain spontaneous breathing within 48 hours.
Yoo *et al.* [26], 2018	Korea	Cohort	1.4 cm	1.53 cm	Failure extubation was defined as reintubation and application of NIV within 48 hours or requiring tracheostomy.

DE = diaphragmatic excursion; DTF = Fraction of diaphragmatic thickening; IRRS = rapid and shallow breathing index; FR = respiratory rate; HR = heart rate; SaO_2 = arterial oxygen saturation; NIV = non-invasive ventilation; IMV = invasive mechanical ventilation; TRE = spontaneous breathing test; ΔDE = variation in diaphragmatic excursion

Table III - General data from cohort studies using diaphragmatic USG as a predictor of success in weaning and extubation

Author / Year	Study design	Objective	Results
Sklar *et al.* [16], 2020	Cohort	Determine whether lower Tdi is associated with delayed MV release and complications of acute respiratory failure (reintubation, tracheostomy, prolonged ventilation >14 days, or in-hospital death).	The reduction in baseline Tdi was associated with prolonged mechanical ventilation, an increased risk of complications and increased hospital mortality. And a higher baseline Tdi was associated with an increased risk of developing diaphragmatic atrophy.
Vivier *et al.* [17], 2019	Cohort	To evaluate whether the diaphragmatic dysfunction detected by ultrasound only at the time of extubation was associated with the failure of extubation in high-risk patients who underwent successful ERT.	After the success of an ERT, evaluation of diaphragm function by ultrasound before extubation did not allow prediction of extubation in patients at high risk of reintubation in the ICU. In contrast, clinical assessment of cough strength was found to be a strong predictor of extubation failure.

Table III - Continuation

Author / Year	Study design	Objective	Results
Eltrabili *et al.* [18], 2019	Cohort	To evaluate the effectiveness of ultrasound-derived variables in predicting the success of mechanical ventilation release in patients who are seriously ill and with abdominal sepsis.	Both indexes of diaphragmatic ultrasound, that is, fraction of diaphragmatic thickening and diaphragmatic excursion, can be useful parameters for assessing the successful release of patients on MV with abdominal sepsis.
Zhang *et al.* [19], 2020	Cohort	Explore the value of right ND and its variation evaluated by ultrasound to predict the outcome of extubation in mechanically ventilated COPD patients.	This study demonstrated that DE 30 and ΔDE 30⁄5 can be used to predict the outcome of extubation in patients with COPD. The combination of two indicators can improve the predictive value.
Palkar *et al.* [20], 2018.	Cohort	Track the ED and the contraction speed using USG in order to correlate the change in ultrasound measurements during the weaning process with the result of extubation.	The results of this study demonstrate that during weaning from ventilatory support, ED is a better predictor of the outcome of extubation than the speed of contraction of the diaphragm. The ED in the extubation success group was significantly higher than the failed patients who had a value < 1 cm.
Dres *et al.* [21], 2016	Cohort	Quantify the prevalence and coexistence of these two forms of ICU-AW and their impact on the outcome.	DD was significantly associated with prolonged weaning, and DTF was an independent variable for weaning failure.
Khan *et al.* [22], 2018	Cohort	Comparar a DE com IRRS como preditores de desmame.	ED is a clinical predictor of the outcome of weaning and extubation, it is also a preventive factor for reintubation. Of the patients analyzed, 62 were successfully weaned (68.9%) and had an ED on average of 1.44 ± 0.26 cm. The difference between the failed and successful groups was statistically significant (p < 0.0001).
Soliman *et al.* [23], 2019	Cohort	A aplicação de USG de tórax pode ajudar no desmame e na previsão de seu resultado.	The DTF was significantly higher in the group successfully weaned (p 0.001) off value ≥ 29.5 and can predict the success of weaning with a sensitivity of 88.0% and specificity of 80.0%. The authors found that DTF was significantly higher in patients who were successfully weaned (43.0 ± 10.7 vs 28.9 ± 2.8 cm, P = 0.001) than in the group that failed. DTF can be effective to predict success in weaning, being reported by some authors as the best index representing diaphragmatic strength.
Huang *et al.* [24], 2017	Cohort	To evaluate the usefulness of M-mode USG in the results of ventilator weaning in elderly patients.	Patients with DD also had a higher incidence of weaning failure than patients without DD (24/30 vs. 4/10), P = 0.017.

Table III - Continuation

Author / Year	Study design	Objective	Results
Pirompanich *et al.* [25], 2018	Cohort	Evaluate the effectiveness of a combination of DTF and IRRS to predict successful weaning compared to IRRS alone.	The baseline characteristics were not significantly different between the successful and unsuccessful weaning groups, DTF on both sides were significantly different between the successful and failed TRE patients (right FTD: successful group 57.7 ± 21, 2%, failure group 22.9 ± 9.2%, p < 0.001 (Fig. 2); left DTF: success group 68.8 ± 41.2%, failure group 42.8 ± 18.5%, p = 0.017).
Yoo *et al.* [26], 2018	Cohort	Compare the clinical utility of these two diaphragmatic parameters to predict extubation success.	The average degree of diaphragmatic excursion was higher in patients with extubation success than in those with extubation failure. Successful extubation patients had a Δtdi% higher than those with extubation failure.

DE = diaphragmatic excursion; DTF = fraction of diaphragmatic thickening; COPD = chronic obstructive pulmonary disease; IRRS = rapid and shallow breathing index; MV = mechanical ventilation; NIV = non-invasive ventilation; Tdi = diaphragm thickness; DD = diaphragmatic dysfunction; TRE = spontaneous breathing test; ΔDE = variation in diaphragmatic excursion; Δtdi = variation in diaphragm thickness; USG = ultrasound; ICU = intensive care unit; ICU-AW = muscle weakness acquired in the intensive care unit

Discussion

Based on the findings of this review, we can evidence that the use of diaphragmatic ultrasound to assess the thickness and excursion of the diaphragm in patients undergoing invasive ventilatory support is effective in predicting success in the weaning and extubation process.

It is essential to evaluate and identify patients able to remove invasive ventilatory support. Some studies indicate that failure in this process increases the chance of mortality by 50%. Diaphragmatic USG is able to identify the result of this process through anatomical and biomechanical measurements such as thickness and its excursion during normal operation, with the result of this assessment it is possible to develop therapeutic strategies to minimize these risks.

After evaluating Tdi, Sklar *et al.* [16] found that patients with values ≤ 2.3 mm were associated with prolonged weaning, longer on invasive ventilatory support and had a significantly greater difference in hospital mortality, especially after discharge from the ICU. It was identified with the USG that the Tdi obtained on the beginning of MV was independently associated with prolonged MV and higher mortality regardless of the severity of the underlying disease [16].

Corroborating with Sklar [16], Dres *et al.* [21] found that patients with higher DTF and ED values proved to be efficient as a predictor independently associated with failure in weaning and extubation. They found that in an unelected population of mecha-

nically ventilated patients considered ready to perform an ERT, the prevalence of DD was twice as high as the prevalence of ICU-AW, and that DD, not ICU-AW, influenced the outcome, being present in almost all patients who had failed weaning. This study served to highlight that DD should be the object of prevention and possible specific interventions [21].

Khan *et al*. [22] defined an IRRS cutoff point of 59 is 79% sensitive and 64% specific and 1.35 cm from DE, observed with ultrasound, a sensitivity of 74% and specificity of 75% to predict success in weaning, the greater the DE value the higher the success rate. In this study, they observed that IRRS better predicts the outcome of weaning, but that when associating the ND to the IRRS they are optimized in the classification of the outcome of weaning in guaranteeing extubation and prevention of reintubation [22].

In the intensive care setting, it becomes necessary to identify patients who are able to leave invasive ventilatory support and USG for diagnosing the patient's condition in real time, being low-cost, non-invasive and not emitting radiation is a useful tool and essential to evaluate these patients, its applicability is increasingly evident.

When using USG to assess DTF and DE in patients with abdominal sepsis Eltrabili *et al*. [17] found some results similar to Khan *et al*. [22], and they noticed a significant difference in patients who failed and those who were successful. The diaphragmatic parameters obtained with the USG, a DTF of 30.7%, with sensitivity of 94.1% and specificity of 100% and DE of 10.4 mm, with a sensitivity of 94% and specificity of 84% were values to predict successful withdrawal of mechanical ventilation. They observed that the best cutoff value to predict the success of weaning was 30.7%, because in other studies it varies from 20 to 36%, depending on the ventilatory support offered during the measurement [17].

ED has become a very relevant variable for the assessment of extubation. With that in mind, Zhang *et al*. [19] assessed DE with USG and found that patients who had extubation success had a higher value compared to those who failed, this value was significantly statistical. In the study, a cutoff value of DE of 1.72 cm was associated with success in extubation and observed that the combination of DE 30 and ΔDE 30-5 was more accurate in predicting extubation. Even if patients are successful in the ERT, they are still at risk of failing extubation, further proving the importance of looking for another indicator to predict the outcome of extubation and improve the survival of patients admitted to the ICU [19].

Many authors report the importance of an accurate evaluation of the diaphragm, especially of DE, which often appears as the main variable to be analyzed. Palkar *et al*. [20] were emphatic and said that DE is an imperfect predictor. Although the successful extubation group was significantly larger than the ones that failed, many complexity factors can interfere with the extubation result. They also observed that when measured between A / C and TRE they obtained a better result than only during the TRE.

Soliman *et al*. [23] found in patients with successful weaning a DTF significantly higher than in the group that failed, with a cutoff value ≥ 29.5, which can predict the success of weaning with a sensitivity of 88.0% and specificity of 80.0 %. The authors conclude the study by saying that they support the use of USG to predict weaning failure, to assess the lung and diaphragm, helping to understand the pathophysiological effects of weaning and to optimize the clinical condition, increasing the chances of successful weaning [23].

Using USG to assess the diaphragm of the elderly and the relationship between diaphragmatic dystrophy and weaning, Huang *et al*. [24] defined a cutoff value below 10 mm and used the M mode. They observed a 75% prevalence of DD in ventilated elderly people mechanically and 70% of weaning failure, having complex factors as reasons behind these weaning failures [24].

With similar results, Pirompanich and Romsaiyt [25] found a higher DTF in the successful group compared to the group that failed. The authors suggest that the right DTF greater than or equal to 26% is more accurate to predict success in weaning, being the best and most efficient predictor of success in ventilatory weaning. The reason the right side is more effective than the left can be a higher lung volume [25].

According to Yoo *et al*. [26] DE values are higher than Tdi in predicting extubation success, suggesting that DE may be more accurate than Tdi to predict weaning success. It is noteworthy that the values of the analyzed variables differ between studies, our findings demonstrate that regardless of the cutoff value established by the authors, the most relevant to be analyzed is the amount of loss of DTF, Tdi and DE from the beginning of mechanical ventilation.

Conclusion

Based on the data found, we can conclude that diaphragmatic ultrasonography has great applicability to assess the ability to predict success or failure in removing invasive ventilatory support. Values of thickened fraction, excursion and diaphragmatic thickness differ between studies according to the authors and the population studied, but the main point of this review is to show that the loss of diaphragmatic function revealed by a decrease in the thickening, excursion and thickness fraction diaphragm in mechanically ventilated patients can predict success or failure in the weaning and extubation process.

Potential conflict of interest
No conflicts of interests have been reported for this article.

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Authors' contributions
Literature search, Data collection, Study design, Manuscript preparation and Review of manuscript: Cordeiro ALL, Soares LO, Oliveira KMV, Jesus AMGO.

References

1. Varón-Vega F, Hernández A, López M, Cáceres E, Giraldo-Cadavid LF, Uribe-Hernandez AM, Crevoisier S. Usefulness of diaphragmatic ultrasound in predicting extubation success. Med Intensiva (Engl Ed) 2021;45(4):226-33. doi: 10.1016/j.medin.2019.10.007

2. Girard TD, Alhazzani W, Kress JP, Ouellette DR, Schmidt GA, Truwit JD, *et al*. An Official American Thoracic Society/American College of Chest Physicians Clinical Practice Guideline: Liberation from mechanical ventilation in critically ill adult rehabilitation protocols, ventilator liberation protocols, and cuff leak tests. Am J Respir Crit Care Med 2017;195:120-33. doi: 10.1164/rccm.201610-2075ST

3. Grasse A, Ferlicca D, Lupieri E, Calcinati S, Francesconi S, Sala V, *et al*. Assisted mechanical ventilation promotes recovery of diaphragmatic thickness in critically ill patients: a prospective observational study. Critical Care 2020;24:85. doi: 10.1186/s13054-020-2761-6

4. Goligher EC, Dres M, Fan E, Rubenfeld GD, Scales DC, Herridge MS, *et al*. Mechanical ventilation-induced diaphragm atrophy strongly impacts clinical outcomes. Am J Respir Crit Care Med 2018;197(2):204-13. doi: 10.1164/rccm.201703-0536OC

5. Sklar MC, Dres M, Fan E, Rubenfeld GD, Scales DC, Herridge MS, *et al*. Association of low baseline diaphragm muscle mass with prolonged mechanical ventilation and mortality among critically ill adults. JAMA Network Open 2020;3(2):e1921520. doi: 10.1001/jamanetworkopen.2019.21520

6. Dres M, Dubé B-P, Mayaux J, Delemazure J, Reuter D, Brochard L, *et al*. Coexistence and impact of limb muscle and diaphragm weakness at time of liberation from mechanical ventilation in medical intensive care unit patients. Am J Respir Crit Care Med 2017;195(1):57-66. doi: 10.1164/rccm.201602-0367OC

7. Medrinal C, Prieur G, Frenoy E, Quesada AR, Poncet A, Bonnevie T, *et al*. Respiratory weakness after mechanical ventilation is associated with one-year mortality - a prospective study. Crit Care 2016;20(1):231. doi: 10.1186/s13054-016-1418-y

8. Geiseler J, Kelbe C. Weaning from mechanical ventilation. Weaning categories and weaning concepts. Med Klin Intensivmed Notfmed 2016;111:208-14. doi: 10.1007/s00063-016-0147-y

9. Goligher EC, Fan E, Herridge MS, Murray A, Vorona S, Brace D, *et al*. Evolution of diaphragm thickness during mechanical ventilation. Impact of inspiratory effort. Am J Respir Crit Care Med 2015;192(9):1080. doi: 10.1164/rccm.201503-0620OC

10. Palkar A, Mayo P, Singh K, Koenig S, Narasimhan M, Singh A, *et al*. Serial diaphragm ultrasonography to predict successful discontinuation of mechanical ventilation. Lung 2018;196:363-8. doi: 10.1007/s00408-018-0106-x

11. Öztürk E, Tanıdır İC, Yıldız O, Yükçü B, Ergün S, Haydın S, *et al*. Ultrasonographic postoperative evaluation of diaphragm function of patients with congenital heart defects. Turk Gogus Kalp Dama 2020;28(1):70-5. doi: 10.5606/tgkdc.dergisi.2020.18458

12. Abbas A, Embarak S, Walaa M, Lutfy SM. Role of diaphragmatic rapid shallow breathing index in predicting weaning outcome in patients with acute exacerbation of COPD. Int J COPD 2018;13:1655-61. doi: 10.2147/COPD.S161691

13. Carrie C, Gisbert-Morae C, Bonnardel E, Gauche B, Matthieu B, Vargas F, *et al*. Ultrasonographic diaphragmatic excursion is inaccurate and not better than the MRC score for predicting weaning--failure in mechanically ventilated patients. Anaesth Crit Care Pain Med 2016:1-27. doi: 10.1016/j.accpm.2016.05.009

14. Llamas-Álvarez AM, Tenza-Lozano EM, Latour-Pérez J. Diaphragm and lung ultrasound to predict weaning outcome: systematic review and meta-analysis. Chest 2017;1 52 (6):1140-50. doi.org/10.1016/j.chest.2017.08.028

15. Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med.2009;6(7):e1000097

16. Sklar MC, Dres M, Fan E, Rubenfeld GD, Scales DC, Herridge MS, *et al*. Association of low baseline diaphragm muscle mass with prolonged mechanical ventilation and mortality among critically Ill Adults. JAMA Network Open. 2020;3(2):e1921520. doi: 10.1001/jamanetworkopen.2019.21520

17. Viver E, Muller M, Putegnat Jean-Baptiste, Steyer J, Barrau S, Boissier F, *et al*. Inability of diaphragm ultrasound to predict extubation failure a multicenter study. Chest 2019;155(6):1131-9. doi: 10.1016/j.chest.2019.03.004

18. Eltrabili HH, Hasanin AM, Soliman MS, Lofty AM, Hamimy WI, Mukhtar AM. Evaluation of dia-

phragmatic ultrasound indices as predictors of successful liberation from mechanical ventilation in subjects with abdominal sepsis. Respir Care 2019;64(5):564-9. doi: 10.4187/respcare.06391

19. Zhang X, Yuan J, Zhan Y, Wu J, Liu B, Zhand P, Yu T, *et al*. Evaluation of diaphragm ultrasound in predicting extubation outcome in mechanically ventilated patients with COPD. Ir J Med Sci 2020;189(2):661-8. doi: 10.1007/s11845-019-02117-1

20. Palkar A, Mayo P, Singh K, Koenig S, Narasimhan, Singh A, *et al*. Serial diaphragm ultrasonography to predict successful discontinuation of mechanical ventilation. Lung 2018;196(3):363-8. doi: 10.1007/s00408-018-0106-x

21. Dres M, Dube Bruno-Pierre, Mayaux J, Delemazure J, Reuter D, Brochard L, *et al*. Coexistence and impact of limb muscle and diaphragm weakness at time of liberation from mechanical ventilation in medical intensive care unit patients. Am J Respir Crit Care Med 2017;195(1):57-66. doi: 10.1164/rccm.201602-0367OC

22. Khan M, Munawar K, Hussain S, Qadeer A, Saeed ML, Shad ZS, *et al*. Comparing ultrasound-based diaphragmatic excursion with rapid shallow breathing index as a weaning predictor. Cureus 2018;10(12):3710. doi: 10.7759/cureus.3710

23. Soliman SB, Ragab F, Soliman RA, Gaber A, Kamal A. Chest Ultrasound in predication of weaning failure. Open Access Maced J Med Sci 2019;7(7):1143-47. doi: 10.3889/oamjms.2019.277

24. Huang D, Ma H, Zhong W, Wang X, Wu Y, Qin T, *et al*. Using M-mode ultrasonography to assess diaphragm dysfunction and predict the success of mechanical ventilation weaning in elderly patients. J Thorac Dis 2017;9(9):3177-86. doi: 10.21037/jtd.2017.08.16

25. Pirompanich P, Romsaiyut S. Use of diaphragm thickening fraction combined with rapid shallow breathing index for predicting success of weaning from mechanical ventilator in medical patients. J Intensive Care 2018;6:6. https://10.1186/s40560-018-0277-9

26. Yoo Jung-Wan, Lee SJ, Lee JD, Kim HC. Comparison of clinical utility between diaphragm excursion and thickening change using ultrasonography to predict extubation success. Korean J Intern Med 2018;33:331-9. doi: 10.3904/kjim.2016.152.e1