Camila del Mar Sánchez Sánchez, María Erika Molina-Peña, Claudia Yaneth Rodriguez-Triviño

Fundación Universitaria Navarra — Uninavarra, Neiva, Colombia

Comprehensive assessment of respiratory function, a step towards early weaning from the ventilator

Abstract

Methods for assessing diaphragmatic function can be useful in determining the functional status of the respiratory system and can contribute to determining an individual's prognosis, depending on their pathology. They can also be a useful tool for making objective decisions regarding mechanical ventilation weaning and extubation. Esophageal and transdiaphragmatic pressure measurement, diaphragm ultrasound, diaphragmatic excursion, surface electromyography (sEMG) and some serum biomarkers are of increasing interest and use in clinical and intensive care settings to offer a more objective process for withdrawing mechanical ventilation; especially in the situation that we are experiencing with the increased demand for mechanical ventilation to treat patients with Covid-19-associated viral pneumonia. In this literature review, we updated the clinical and physiological indicators with more evidence to improve ventilator withdrawal techniques. We concluded that, to ensure successful extubation in a way that is useful, cost-effective, practical for health personnel and non-invasive for the patient, further studies of novel techniques such as surface electromyography should be implemented.

Key words: airway extubation, COVID-19, ultrasonography, electromyography, diaphragm

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Introduction

The respiratory muscles are composed of contractile proteins which generate differences in pressure when they contract, thereby enabling the flow of air for gas exchange. Their most important functional characteristics are strength and endurance: their strength is related to the contractile proteins and is evaluated by maximum inspiratory pressures [1, 2]. Endurance is the capacity of the muscle to sustain contractile force and is connected with muscular blood flow, mitochondrial density and oxidative capacity [1]. During patients' stay in intensive care units (ICU), deleterious processes take place in the respiratory muscles which are related to factors that accelerate proteolysis, such as systemic inflammation, immobility, side effects of drugs (glucocorticoids) and the use of mechanical ventilation (MV) [3–5].

The use of MV generates side effects, such as diaphragm dysfunction (DD), volutrauma and barotrauma, among others; and these can make it difficult to withdraw , thereby prolonging hospital stay [3, 6]. Early ventilatory weaning (VW) strategies and timely use of partial and non-invasive modalities are the pillars of preventing complications [3]. Extubation failure is defined as the need to reintubate within 48 hours of removal of the tube, and success is the lack of mechanical support for 48 hours after extubation [7]. Extubation failure predictors that have been evidenced include arterial carbon dioxide tension ($PaCO_2$) > 5.99 kPa (45 mm Hg), prolongation of mechanical ventilation > 72 h, abundant secretions, upper airway disorders, and a prior frustrated weaning attempt [8].

Currently, methods such as the Yang Tobin index, T-tube test, measuring the minute ventilation, continuous positive airway pressure (CPAP), pressure support (PS) or synchronized intermittent mandatory ventilation (SIMV) are used, which, among others, seek to achieve successful VW [9].

Address for correspondence: Claudia Yaneth Rodriguez-Triviño, Fundación Universitaria Navarra-UNINAVARRA, English, Neiva, Colombia, e-mail: cy.rodriguez@uninavarra.edu.co

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However, there are difficulties in weaning from ventilatory support in approximately 20% of patients, and more than 40% of ICU time is spent in returning patients to non-assisted breathing [10], which is clinically challenging because the pathophysiology underlying the failure to wean is complex, multifactorial and not well established [11].

Choosing the MV withdrawal tool makes it possible to improve the possibility of weaning success and reduce the functional impact on the diaphragm [12]; different pathologies generate diaphragmatic fatigue or damage, as occurs during prolonged periods of ventilation (in viral pneumonias and acute respiratory distress syndrome (ARDS) associated with the COVID-19 virus, among others, disorders such as Parkinson's, carcinoma, myasthenia gravis, Guillain-Barré syndrome, malnutrition and immobilization). Therefore, diaphragmatic function analysis methods can complement the treatment of pathological conditions or impaired diaphragm states [13]. The most widely used methods include esophageal and transdiaphragmatic pressure measurement, diaphragmatic ultrasound, elastography, needle electromyography (EMG), surface electromyography (sEMG) and the use of diagnostic images to assess anatomical and/or functional conditions of the diaphragm, such as chest X-ray, fluoroscopy, computerized axial tomography and magnetic resonance imaging.

The aim of the review is to present the assessment methods for successful VW, using classical scales together with ventilatory monitoring to avoid reintubation.

Material and methods

A non-systematic search was conducted on MedLine, LILACS, Clinicalkey and Google Scholar. The terms used were: "Diaphragm", "Diaphragmatic Dysfunction", "Diaphragmatic Evaluation", "Extubation", "Intubation", "Electromyography", "Surface Electromyography", "Diaphragmatic ultrasound", "t-tube test", "Tobin and Yang index", "Pressure support", "Transdiaphragmatic pressure", "Synchronized intermittent mandatory ventilation" and "weaning intubation". The search was carried out both with individual terms and by combined terms using the search connectors "AND" and "OR". We obtained 134 articles from Medline, 16,700 from Google Scholar, 91 from LILACS and 925 from Clinicalkey and 413 results identified from other sources. Only original articles were reviewed so the final selection was 53 articles written between 2010 and 2020, plus 18 published in previous years, as seen in Figure 1.

Classical methods for evaluating ventilatory withdrawal

Yang Tobin index

The index proposed by Tobin and Yang (1991), also known as the "rapid shallow breathing index" (RSBI), is the ratio between respiratory

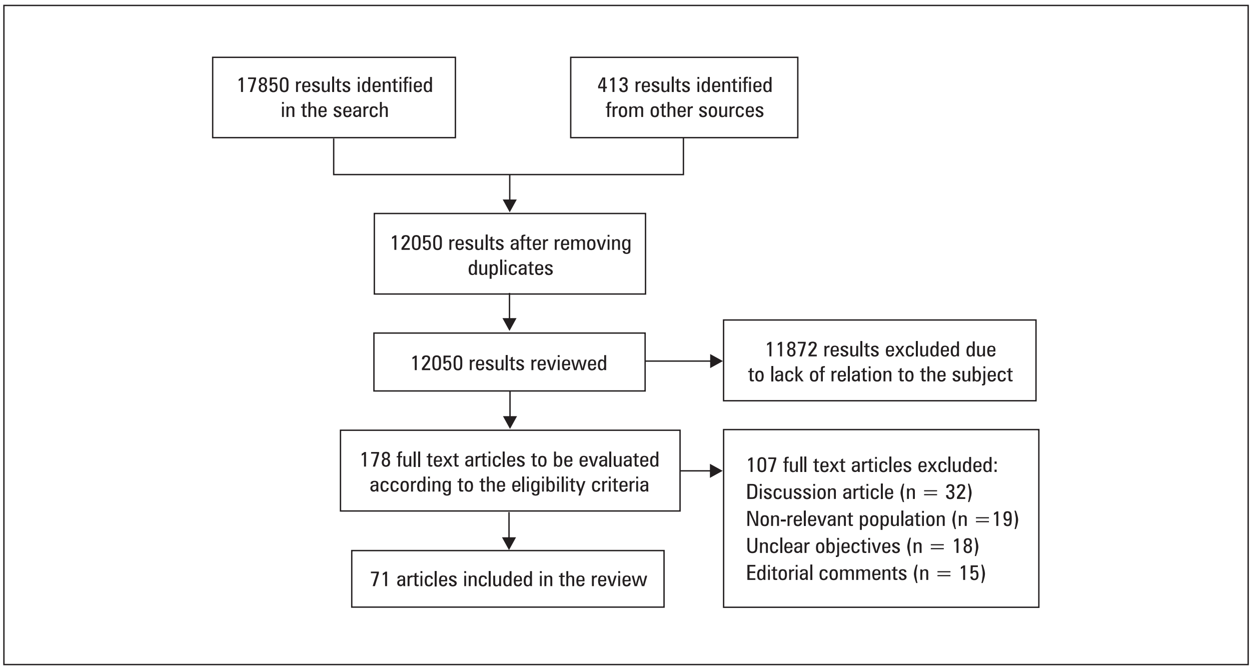

Figure 1. Methodology flowchart

frequency and tidal volume in liters (f/Vt). It evaluates respiratory function to predict successful withdrawal through a spontaneous ventilation test (SVT) [14]. In patients with preserved lung function, the f/Vt ratio is low (low respiratory frequency and high tidal volume), but in cases of impaired respiratory function, the ratio increases with a higher respiratory rate and lower tidal volume. The lower the f/Vt ratio, the lower the deterioration in respiratory function [15, 16]. However, this method could unnecessarily delay the extubation of patients who have recovered from ventilatory failure [17].

Romel *et al.* found that this ratio successfully predicts the withdrawal of MV in smokers. They determined a threshold of 105 breaths/min/L: if the value is lower than this threshold, VW is recommended; if it is higher, the recommendation is to maintain MV and carry out the SVT again. Furthermore, it predicts a successful SVT with a sensitivity of 0.97 and specificity of 0.65 [8, 18]. Patients could be classified according to the weaning process as simple (first attempt without difficulty), difficult (requiring up to three SVTs or as long as 7 days from the first attempt to achieve it) or requiring prolonged weaning (who fail at least three weaning attempts or require > 7 days of weaning after the first SVT) [8]. Rivas-Salazar *et al.* studied the f/Vt index for predicting successful weaning from mechanical ventilation in active smokers, obtaining a sensitivity of 76%, specificity 61%, positive predictive value 85%, negative predictive value 46%, false positives 38% and false negatives 23% for a value of 79.5, and found that patients with f/Vt ≤ 79.5 had successful weaning from mechanical ventilation in 86% of cases, whereas for patients with f/Vt > 79.5, the figure was only 46.4% 15. França *et al.* used RSBI, obtaining a sensibility of 66% and specificity of 80%, with a positive predictive value of 96%, and a negative predictive value of only 26% [19].

T-tube test

The T-tube test seeks to predict spontaneous breathing capacity, or determines responses to low levels of pressure support (PS) (5–10 cmH_2O) in the airways. When the endotracheal tube is removed, the patient is monitored for 48 hours and if during that time no breathing assistance is needed, VW is considered successful (with respiratory progression using T-tube for more than 30 minutes) [20, 21]. França *et al*. also performed extubation tests with a T-tube and achieved a 12.8% VW failure rate [19, 22]. Ladeira *et al.* made a meta-analysis in which, in nine trials, PS obtained a 76.93% (357/464) extubation success rate *vs* 73.03% (344/471) for T-tube SBT (RR 1.07, 95% CI 0.97 to 1.17, P = 0.16) [20].

Minute ventilation and determination of vital capacity

Minute ventilation measures the volume of gas inhaled or exhaled in a minute to determine the feasibility of extubation. Its shortcoming is the variability of results in the same patient, depending on the technique used. It is performed with or without oxygen, inside or outside a ventilator and/or with different devices, making it difficult to standardize. The minute volume estimates that a value of < 10 L/min would predict successful extubation; however, the evidence is poor [23, 24]. For its part, a normal vital capacity is 65–75 mL/kg and values of >10 mL/kg predict successful VW [22, 25].

Kirby index, oxygenation index and ventilation index

Gutiérrez *et al.* determined extubation failure predictors in neurosurgical patients using the Kirby index (PaO_2/FiO_2), the oxygenation index, the ventilation index and others, achieving successful extubation in 88.6% of cases, and failure in 11.4%; PaO_2/FiO_2 > 150 mm Hg predicts successful extubation. The abovementioned variables are summarized in Table 1 [26, 27].

Pressure support test (PS), synchronized intermittent mandatory ventilation (SIMV) and Continuous Positive Airway Pressure (CPAP)

The PS test determines whether the patient has overcome the resistance of the endotracheal tube by breathing spontaneously in order to initiate weaning; however, it generates discomfort and muscular strain [28]. Aguire-Bermeo *et al.* suggested a median support of 12 cm H_2O, which should also meet weaning criteria (positive end-expiratory pressure [PEEP] <10 cm H_2O with PaO_2 > 60 mm Hg, or SpO_2 > 90% with FiO_2 ≤ 50%). However, Brochard *et al*. said this value is for patients with chronic obstructive pulmonary disease, with 5 cm H_2O being the value for patients without underlying diseases [28, 29]. In weaning, PS levels should be decreased in steps of 2–4 cm H_2O depending on patient tolerance, requiring a good tolerance with a PS ≤ 7 cm H_2O to extubate [30, 31]. Robinder *et al.* found that the PS test significantly underestimated post-extubation effort by 126–147% compared to the CPAP and therefore, it should not be used [32].

Table 1. Classical methods for evaluating ventilatory withdrawal

Authors and year	Predictive test and/or index	Definition	Values predicting success	Failure	Success	Sensitivity	Specificity
Yang and Tobin, 1991 França et al., 2013	Yang Tobin Index	Ratio between respiratory rate and tidal volume in liters (f/Vt)	< 105 breaths/min/L	68 breaths/min/L (± 24)[a]	56 breaths/min/L (± 17)[a]	66%	80 %
	And SVT			31.2%	68.8%	97%	64%
Bole et al., 2007		Spontaneous breathing trial or spontaneous ventilation test					
França et al., 2013	T-tube test	Predicts spontaneous breathing capacity after removing the tube	> 30 minutes -	12.8%	86%	—	—
Cortés-Román et al., 2018							
Teixeira et al., 2010			With PS 7 cmH_2O — 8 cmH_2O in adults or 10 cmH_2O in paediatric patients				
Ladeira et al., 2014	Support pressure (PS)	It is a form of assisted ventilation which the patient triggers the ventilator breath by breath and also allows to determine when to extubate	5–10 cmH_2O	23%	77%	—	—
Vats et al., 2012			7–8 cmH_2O				
Cortés-Román et al., 2018							
Nemer et al., 2009 **Gutiérrez L. et al. (2016)**	Kirby index	Arterial oxygen partial pressure (PaO_2) divided by fraction of inspired oxygen (FiO_2)	> 150 mm Hg	11.4%	88.6%	—	—
Gutiérrez. L et al. (2016)	Ventilation index	Volume exhaled per minute (VE) divided by Arterial carbon dioxide partial pressure ($PaCO_2$).	—	0.17–0.43[b]	0.20–0.37[b]	—	—
Hernández et al., 2017	Vital capacity	Combines the strength of the respiratory muscles and the impedance of the respiratory system	> 10 mL/kg	—	—	—	—
França et al., 2013	Maximal inspiratory pressure (Pimax)	Assesses the strength of the respiratory muscles, calculated based on an inspiratory effort made from the functional residual capacity	Pressure threshold between –20 and –30 cmH_2O	–22 (± 8) n = 10 (12.8)	–31 (± 10) n = 68 (87.2)	65%	70%
Guy Soo Hoo et al., 2005			–30 cmH_2O				

Guy Soo Hoo et al., 2005 Seymour et al., 2005 Yang and Tobin, 1991	Minute ventilation (VE)	Time required for minute ventilation to return to baseline following a successful SVT	< 10 L/min	---	---	78%	18%
Garcia et al., 2018 Nuñez et al., 2013	Continuous positive airway pressure (CPAP)	Mechanical method of constant delivery of airway pressure during inspiration and expiration, mimics gas distribution from spontaneous breaths	5–7 cmH_2O	13–15% 8,6% in neonates	--	--	--
Tanaka et al., 2017	Transdiaphragmatic pressure	Difference between pleural and abdominal pressure	< 4 cmH_2O > 10 cmH_2O	---	---	---	---
Amal Jubran et al., 2005	Esophageal pressure (Pes)	Substitutes for pleural pressure	Around 7.9 cmH_2O	58.3%	46.1%	91%	89%
García-Sánchez et al., 2020	Ultrasonography	It uses sound waves (ultrasound) to create images of tissues without radiation	7–27 mm for diaphragmatic excursion	52% with DD and 16% without DD	48% with DD and 84% without DD	68.4% 65.9% for DE	72.5% 64.3% for DE
Tanaka et al., 2017			TEE 0.28 ± 0.05 cm, right TEI 0.21 ± 0.05 cm, right TF 23.1 ± 10.7%, for TF	21.5% for TF	78.5% for TF	64%–78.3% for TF	84%–88% for TF

[a]Values given as mean (± 1 SD); [b]Used the Mann-Whitney U test

Synchronized intermittent mandatory ventilation (SIMV) is a volume control that provides fixed-volume breaths, allowing spontaneous breaths when the airway pressure is below the end-expiratory pressure, helping patients to come off the ventilator by trying to synchronize the delivery of forced breaths with spontaneous efforts [33]. Greenough *et al.* demonstrated its ineffectiveness with respect to other methods, and it is therefore not recommended [34].

Extubation of CPAP patients without additional tests is avoided due to the effort of using it alone, given the small diameter of the endotracheal tube which also decreases due to the resistance of the circuit and secretions or biofilms, thereby increasing the resistance of the airways [32]. In a systematic review, García *et al.* [31] showed a 13–15% CPAP weaning failure rate. Additionally, Fernández Nuñes *et al.* [35] applied CPAP in 70 patients at a neonatal care unit, obtaining a failure rate of 8.6%. Table 1 compares the different tests.

Methods for evaluating ventilatory weaning through diaphragmatic assessment

Measurement of transdiaphragmatic pressure

Transdiaphragmatic pressure (Pdi) is the difference between pleural and abdominal pressure (Pdi = Ppl – Pab), it is a type of transmural pressure to which the diaphragm is subjected during the ventilatory cycle [36]; it can be calculated for gentle or maximum effort breathing maneuvers. Pleural pressure can be replaced by esophageal pressure, while abdominal pressure is equivalent to gastric pressure and the difference between the two corresponds to Pdi [37, 38]. Calculating this figure allows us to understand, physiopathologically, acute lung injuries, the patient-ventilator interaction, VW failure, muscular work in MV [39], the estimated pressure calculated by the SVT, the quantification of lung cycles and to visualize ventilator asynchrony [9].

Supinkski *et al.* concluded that, in response to phrenic nerve stimulation (PdiTw), Pdi predicts extubation duration better than maximum inspiratory pressure (Pimax), which also anticipates successful extubation with a value of -30 cmH_2O [23]. Patients with PdiTw > 10 cmH_2O and < 4 cmH_2O were extubated in 5.5 and 10 days, respectively [40]. A Pdi of > 10 cmH_2O with unilateral phrenic nerve stimulation or > 20 cmH_2O with bilateral phrenic nerve stimulation rule out diaphragmatic dysfunction [41].

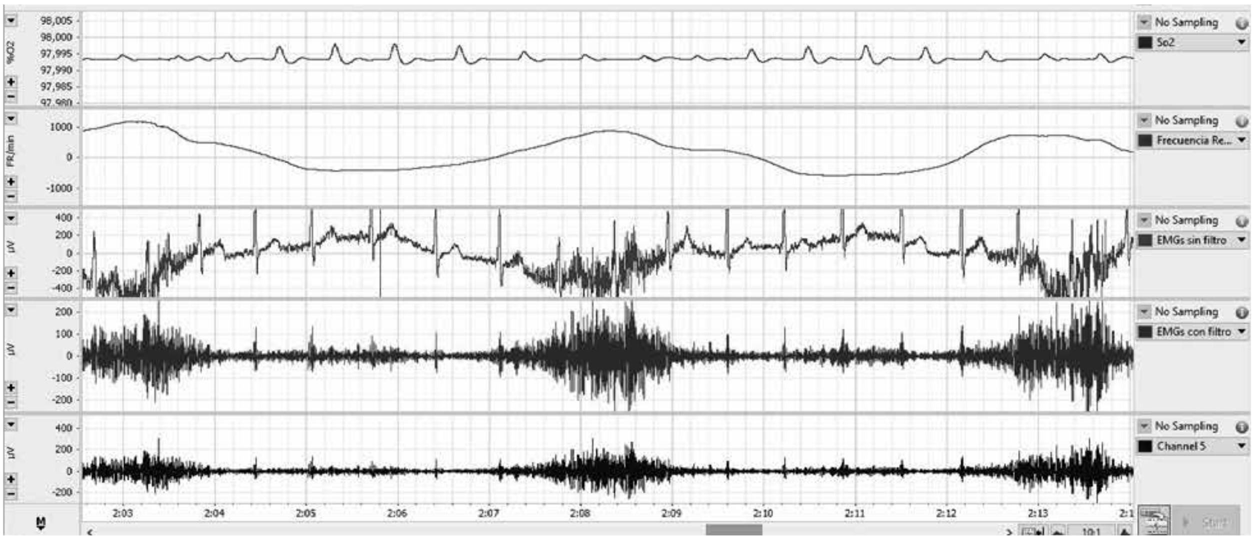

Figure 2. Surface electromyography

PdiTw estimates respiratory muscle strength, evaluating electromyographic signals and conduction velocity in each hemidiaphragm; its range of normality is 8.8–33 cm H_2O, but, having such a wide range, it would only be useful to identify severe muscle weakness [42]. It requires highly trained personnel because of its harmful results in terms of pain caused by electrical cervical stimulation, as it can overestimate muscular strength [42], as well as because it can be difficult to locate the phrenic nerve [38, 43].

Measurement of esophageal pressure (PES)

The measurement of Pes (a surrogate for pleural pressure) involves passing two 55 cm catheters up to the esophagus and stomach, each with a distal air-filled balloon (0.5–4 mL), under local anesthesia in the middle third, enabling the measurement of the pressure at different points, and lung volumes [39, 44]; its correct position is confirmed using the Baydur test; the optimal position is obtained when the ratio between the changes in Pes and the airway (ΔPes/ΔPaw) is 0.8–1.2 [37, 44].

Measuring Pes has been shown to be useful in monitoring patients in MV due to ARDS [37, 45]. Several studies used Pes, e.g. Sun *et al.* who computed ΔPes/ΔPaw during chest compression, finding that a volume of 0.6 mL corresponds to 7 cmH_2O, 0.8 mL to 6.7 cmH_2O and 1.0 mL to 6.8 cmH_2O [46].

Doorduin *et al.* [47] extubated patients in whom they calculated Pes and Pdi, resulting in failure in 9 patients and success in 11. Gareggnani *et al.* found that there is no certainty of its usefulness under MV, as there was little effect on mortality, ICU stay and adverse events [48].

The absolute values of Pes can be affected by technical as well as anatomical factors, due to respiratory mechanics, lung volume, mediastinum weight, posture, muscle reactivity and balloon characteristics [39, 48, 49]. Furthermore, if the ratio of the two pressures was positive, it would indicate diaphragmatic paralysis [36]. This value can increase progressively (up to 4 times) in patients with ARDS who are not successfully weaned, while successful weaning does not generate important changes [9].

Jubran *et al.* studied prognoses of VW in 60 patients by measuring first-minute swings in Pes and f/Vt. They did this initially with an SVT through a T-tube and began Pes measurements at the point of discontinuing MV and steadily measured this throughout SVT, with failure for 35 patients (58.3%) and success in 25 patients (41.6%). Moreover, there were swings in patients that suffered failure (14.5 cmH_2O; 95% confidence intervals, 18.9–11.2) but in success groups, there was no change in Pes over the first 9 minutes of the weaning trial (7.9 cmH_2O; 95% confidence intervals, 11.8–0.8). For f/Vt, the sensitivity was 0.82 and its specificity 0.67, with a positive predictive value of 0.60 and a negative predictive value of 0.86; on the other hand, Pes had a sensitivity of 0.91, specificity of 0.89, positive predictive value of 0.83 and negative predictive value of 0.94 [50].

An increase in Pes indicates failure in extubation [44]. Factors that can affect the results are sedation, neuromuscular blockade, the position

Table 2. Main advantages and disadvantages of different methods

Method	Advantages	Disadvantages
Yang Tobin index	Predicts a successful withdrawal in a simple way It's possible at almost all ICUs. It can be monitored by medical and paramedical personnel with successful results [17].	It could delay unnecessarily the extubation of patients who have recovered from ventilatory failure Requires high level of patient effort [17]
Kirby index or PaO_2/FiO_2	Predicts successful extubation [26]. Simple way to determine hypoxemia	It must be adjusted according to the height above sea level [79].
Ventilation index		
Vital capacity	Integrates respiratory muscle strength and the respiratory system impedance [22]	Depends on the patient effort and their collaboration [22]
Maximal inspiratory pressure (Pimax)	Simple test Noninvasive Performed quickly [80]	Difficult to understand it because of uncertainty of the most representative normative values [80]
Minute ventilation (VE)	Incorporates only measurement of VE prior to an SVT, or automated averaging of VE. As more ICUs gain data acquisition, future modifications may permit for more automated and exact measurement [22, 24]	Poor evidence Variability of results in the same patient, depending on the technique used [22, 24] Not recorded continually in all ICUs [24]
T-tube test	Easy to disconnect It doesn't need protocols like other methods such as PS Its tolerance can be clinically determined from 30 to 120 minutes [81]	Complications such as agitation and others [82]
Pressure support test	Allows a progressive transition from partial ventilation to extubation [81]	It requires a protocol for being disconnected [81] It generates discomfort and muscular strain [28] It underestimates post-extubation effort [32]
Synchronized intermittent mandatory ventilation	It has helped patients to come off the ventilator by trying to synchronize the delivery of forced breaths with spontaneous efforts [33] Prevention of respiratory muscle fatigue	Ineffective with respect to other methods [34]
CPAP	Variety of devices. Not necessarily extra material	It is avoided to use it without additional tests due to the effort of using it alone [32]
Transdiaphragmatic pressure	Allows to understand the injuries, the patient-ventilator interaction, VW failure and muscle work in MV [39]	It requires highly trained personnel It's difficult to locate the phrenic nerve [42]
Esophageal pressure (Pes)	Monitoring Pes activity offers the potential to monitor patient–ventilator interactions [39]	It is invasive Difficult technique Not routinely used Absolute values could be affected by technical as well as anatomical factors [39]
Ultrasonography	Non-invasive Cost-effective Safe Easy-to-perform Preferred method for extubation [1]	It requires highly-trained personnel Observer-dependent Poor acoustic window [51, 52]

of the patient and PEEP values. Furthermore, as it is invasive, it makes its routine use difficult due to technical issues in the insertion and positioning of the catheter, transducers and equipment, and ensuring accurate measurements [37–39, 42, 43, 49].

The normal values for Pes with maximum inspiratory effort with closed airway at functional residual capacity is 125 ± 20 cmH_2O and with magnetic stimulation 20.5 ± 2.2 cmH_2O [36]. According to Mauri *et al*'s review [44], esophageal normal values for the pressure–time product are close to 100 cmH_2O min−1.

Diaphragmatic ultrasound or ultrasonography

Diaphragmatic ultrasound or ultrasonography (DU) is a non-invasive, cost-effective, safe and easy-to-perform technique that overcomes several limitations of other techniques. Varón-Vega F *et al.* concluded that this is the preferred method for extubation [1, 51, 52]. It evaluates the diaphragmatic thickening fraction (TF) in three layers: a central non-echogenic layer (diaphragm) sandwiched by two echogenic layers (peritoneum and pleura) [1]. A phased array probe is positioned below the costal margin, perpendicular to the posterior third of the hemidiaphragm [53], which makes this technique more precise than a chest X-ray in the diagnosis of pulmonary deficiencies [54].

Boussuges *et al*. evaluated 210 people with normal spirometric values [53, 55]; average excursions were measured at 1.8 ± 0.3 cm on the right side and 1.8 ± 0.4 cm on the left [55]. This method assesses internal anatomy, diaphragmatic thickness (as a sign of atrophy), shortening fraction and diaphragmatic mobility (as a sign of diaphragmatic activity) [42]. García-Sánchez *et al.* made a meta-analysis acquiring diaphragmatic excursion values to predict weaning failure of between 7 mm and 27 mm [56].

The B-mode evaluates fiber morphometry in relaxation as well as in maneuvers; the M-mode quantifies the direction and amplitude of the diaphragm excursion during inhalation [57]. Thickness measurements are obtained at the end of inspiration (TEI), as well as at the end of expiration (TEE), to calculate the thickening fraction through the following formula TF = (TEI-TEE)/TEE, with a normal value of 2.6 [58].

In 2017, Tanaka *et al.* measured diaphragmatic thickness to predict successful weaning from mechanical ventilation. The thickening fraction was evaluated and multiplied by RSBI, obtaining a right TEE 0.28 ± 0.05 cm, right TEI 0.21 ± 0.05 cm, right TF 23.1 ± 10.7%, with a sensibility of 0.64 and specificity of 0.84. In addition, they wrote about chest radiography which offers very sensitive detection of unilateral diaphragmatic paralysis (90%), but its specificity is too low (44%) [41].

Currently, DU is used in COVID-19 patients as a prognostic measure of DD and a guide for ventilatory need and to determine the onset of interstitial syndrome [59]**.** Theerawit *et al.* concluded that DD is evidenced when diaphragm excursion < 10 mm or in cases of paradoxical movement and is related to extubation failure, a definition that is retained in the context of this pandemic [59, 60].

In 2017 Liu *et al.* concluded that this method is superior to others in predicting DD [61]. However, its limitation is the poor acoustic window (occurring in 2–10% of cases). In addition, it requires personnel that are highly trained in the technique and also qualitative and quantitative interpretation, making it observer-dependent [51, 52]. Carrie *et al.* determined that on its own it could not predict extubation and weaning failure from the bedside of patients who are undergoing spontaneous breathing tests, and does not provide any additional value compared to the Medical Research Council score, and is therefore not recommended [62].

Cutting edge methods for evaluating ventilator weaning

Diaphragmatic surface electromyography

The study of muscular activity by means of sEMG is used in investigations of the neuromuscular system through myoelectric signals by sensors located on the skin surface [63]. Although needle electromyography is still in use, it carries risks such as pneumothorax [64]. Diaphragmatic function has been assessed using sEMG in areas such as pediatrics, where it has been shown to be well tolerated by patients under two years of age and with reproducible results. Jeffreys E *et al*. determined its efficacy when following up the use of nasal cannulae [65].

Electromyographic signals result from the recruitment of fast-twitch fibers, the diameter of the muscle fiber, the recruitment of non-linear motor units (MU) and muscle synchronization [66]. The electrodes allow the study of surface musculature, present an overview of the muscle without any limitations regarding the surface studied or the recording time [67], and non-invasively depict voluntary muscle activity, collecting the electrical signal from the muscle in movement, at rest or active (maximum voluntary contraction and static) [10]. It is useful in evaluating the role and interactions of the muscles during functional tasks, sport and exercise [68], and also in studying, among others, muscle maladaptations and dysfunctions in musculoskeletal injuries [66, 69].

In 2017, Duarte *et al.* studied liver transplant patients receiving MV. They were positioned with the heads of their beds raised by 35° and two adhesive electrodes were placed 5 cm below the xiphoid process, while two others were positioned in the region of the bilateral costal margin with a distance of approximately 16 cm between them [68].

Interpreting an EMG requires amplitude descriptors which consist of the average rectified or squared signal of the raw sEMG during a motor task and which are the average rectified value (ARV) and root mean square (RMS) and are defined as follows [70]:

$$ARV\ [d] = \frac{1}{N} \sum_{n=1+N(d-1)}^{Nd} (EMG[n])$$

$$RMS\ [d] = \sqrt{\frac{1}{N}} \sum_{n=1+N(d-1)}^{Nd} (EMG[n])^2$$

d corresponds to the moment in which the ARV or RMS amplitude is calculated

The root mean square (RMS) is used to quantify the EMG signal and its values increase when the patients tense their muscles [67, 63]. It consists of a group of mathematical and statistical techniques to analyze problems that are based on adjusting a linear or quadratic polynomial function (f) to the experimental data [73].

When RMS is used, variations in EMG amplitude, estimated with ARV, are related to the degree of myoelectric activity; however, RMS is preferred because it gives more direct results by measuring EMG power, while ARV measures the area under the curve. To obtain the signal, it is necessary to filter out waves that could be picked up from other sources, including cardiac electrical activity. Other features are the mean and median frequencies which indicate the frequency with which the wave is distributed. To study these, the frequency and time domains are observed to determine if there is muscular fatigue represented by low conduction and therefore, low speed in the motor unit action potential (MUAP) [70].

Lozano-García *et al.* placed the electrodes in the seventh intercostal space, between the mid and anterior axillary lines, with a ground electrode in the clavicle [74, 75]; and converted crural diaphragm electromyography to RMS, finding a correlation between invasive and non-invasive measurements, concluding that sEMG is a novel non-invasive measure that provides information about the physiological and physiopathological study of respiratory function in health and disease conditions [74]. Fernandes *et al.* [76] studied the influence of inter-electrode distance and cadence of movement on the frequency domain of the EMG signal. One of the relationships was expressed with the following formula:

$$\int_{0}^{fm} Sm(f)df = \int_{fm}^{\infty} Sm(f)df$$

— S_m is the power spectrum of the EMG signal
— f_m is the mean frequency

To interpret the electromyographic wave, a reduced MUAP amplitude may indicate atrophy of muscle fibers or an increase in connective tissue; while a reduced duration may represent fiber atrophy or loss, but if the duration is increased, it would suggest increased fiber recruitment [76].

Biomarkers

The concentration of fast troponin-I (fsTnI) in peripheral blood increases when the fast-twitch fibers are damaged [77]. The release of fsTnI is consistent with load-induced injury of the fast-glycolytic fibers of inspiratory muscles, probably the diaphragm, precisely the mechanical stress associated with the high pressures generated against the load and the local metabolic conditions in the inspiratory muscles. This means that troponin-I levels could indicate diaphragmatic injury, and this is measurable at serum levels. Further studies are required to determine the sensibility and specificity in relation with the damage by mechanical ventilation [78].

Conclusions

Techniques for measuring diaphragmatic function to predict extubation have limited usefulness and several limitations. In the case of diaphragmatic ultrasound, although it is a reliable method, it requires highly trained personnel in addition to being observer-dependent. It is necessary to search for new cost-effective techniques that can be used simply on the patient, are minimally invasive, and are also easy for health personnel to use. Among the tools that should be investigated is surface electromyography which, being easy and comfortable to use, not only reduces costs, but also facilitates the determination of extubation readiness without the need for invasive maneuvers, thereby increasing the possibility of having personnel trained to use it. In the context of the Covid-19 pandemic, successful ventilatory support with the least possible impact must be guaranteed.

Conflict of interest

All authors declare that they have no conflict of interest.

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