Combined Thoracic Ultrasound Assessment during a Successful Weaning Trial Predicts Postextubation Distress

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ABSTRACT

Background: Recent studies suggest that isolated sonographic assessment of the respiratory, cardiac, or neuromuscular functions in mechanically ventilated patients may assist in identifying patients at risk of postextubation distress. The aim of the present study was to prospectively investigate the value of an integrated thoracic ultrasound evaluation, encompassing bedside respiratory, cardiac, and diaphragm sonographic data in predicting postextubation distress.

Methods: Longitudinal ultrasound data from 136 patients who were extubated after passing a trial of pressure support ventilation were measured immediately after the start and at the end of this trial. In case of postextubation distress (31 of 136 patients), an additional combined ultrasound assessment was performed while the patient was still in acute respiratory failure. We applied machine-learning methods to improve the accuracy of the related predictive assessments.

Results: Overall, integrated thoracic ultrasound models accurately predict postextubation distress when applied to thoracic ultrasound data immediately recorded before the start and at the end of the trial of pressure support ventilation (learning sample area under the curve: start, 0.921; end, 0.951; test sample area under the curve: start, 0.972; end, 0.920). Among integrated thoracic ultrasound data, the recognition of lung interstitial edema and the increased telediastolic left ventricular pressure were the most relevant predictive factors. In addition, the use of thoracic ultrasound appeared to be highly accurate in identifying the causes of postextubation distress.

Conclusions: The decision to attempt extubation could be significantly assisted by an integrative, dynamic, and fully bedside ultrasonographic assessment of cardiac, lung, and diaphragm functions. **(ANESTHESIOLOGY 2017; 127:666–74)**

E STABLISHING the correct time to extubate mechanically ventilated patients is a crucial issue in the critical care practice.[1] Both premature and delayed extubation prolong the duration of mechanical ventilation and the intensive care unit (ICU) length of stay and increase morbidity and mortality.[2] Therefore, accurate prediction of postextubation distress and the early diagnosis of the causes responsible for failure of a trial of pressure support ventilation or a trial of totally unsupported respiration (T-tube)[3] are of paramount importance to improve the outcome of mechanically ventilated patients in the ICU. Nevertheless, identifying patients at risk for postextubation distress using the only available test we have, that is, a trial of spontaneous breathing, remains a challenging issue. Furthermore, the complementary tools that have been designed to assess readiness of weaning from mechanical ventilation are not able to entirely monitor the

> **What We Already Know about This Topic**
>
> - Distress after endotracheal extubation is associated with morbidity in recovering critically ill patients and can result from pulmonary, cardiac, and/or neuromuscular causes; predicting such distress is a major goal in critical care.
>
> **What This Article Tells Us That Is New**
>
> - Ultrasound examination was repeated before and after a pressure support trial (136 patients) and integrated models (lung, heart, and diaphragm) accurately predicted postextubation distress (area under the curve greater than 0.90); interstitial edema and elevated left ventricular diastolic pressure were most predictive. Integrated sonography might be valuable in assessing extubation readiness in the intensive care unit.

whole set of organ functions that are related to the weaning process and thus could fail to provide an integrative view of the processes underlying postextubation distress.

An accumulative body of evidence suggests that the decision to attempt extubation could be assisted by the use of thoracic ultrasounds. Actually, the sonographic assessment of the respiratory,[4] cardiac,[5] or neuromuscular[6] functions has been described in this clinically challenging setting. However, it could be argued that these studies, exclusively focused on isolated organ assessments, have merely explored single aspects of physiologic function that affect extubation outcome and crucially ignore the pivotal role of interorgan dynamics in pathologic conditions,[7] disregard the implication of mixed causes of postextubation distress,[8] and could lead to an oversimplified analysis of the sonographic semiotics observed in this setting.[9]

We hypothesized that the use of an integrative thoracic ultrasound assessment, encompassing bedside respiratory, cardiac, and diaphragm sonographic data, could accurately predict postextubation distress in patients who succeeded in a pressure support ventilation trial. In addition, we suggest that the use of appropriate analytical methods, that is, machine-learning methods, could permit the evaluation of the specific impact of respiratory, cardiac, and diaphragm sonographic data on the final estimation of a likelihood of postextubation distress. Finally, we hypothesized that an independent and fully bedside thoracic ultrasonographic assessment could accurately identify the causes of respiratory failure in case of postextubation distress.

Materials and Methods

Population

We prospectively recruited consecutive patients from three ICUs of university teaching hospitals between January 2014 and January 2015. Inclusion criteria were age greater than 18 yr, mechanical ventilation for more than 48 h, and a successful pressure support ventilation trial (see Supplemental Digital Content 1, http://links.lww.com/ALN/B504, which is a table listing criteria for failure to sustain a pressure support ventilation trial), which was performed when the underlying disease that had required intubation was estimated by the attending physician as reversed. Exclusion criteria were patients with tracheostomy, paraplegia with medullar level more than T8, history of severe chronic obstructive pulmonary disease (COPD) with forced expiratory volume less than 50% of the theoretical predictive value, patients with planned prophylactic noninvasive ventilation after extubation, and patients who had previously failed a pressure support ventilation trial. The ethics committee of the University Hospital of Toulouse, Toulouse, France (Comité Consultatif pour la Protection des Personnes, Centre Hospitalier Universitaire Toulouse, Ref. 2014-A01225-48), approved the therapeutic and investigational procedures.

Pressure Support Ventilation Trial

Patients were considered ready for a pressure support ventilation trial in the presence of all of the following criteria, defined by clinical practice guidelines and recommendations[1]: adequate mental status, no subjective evidence of increased respiratory effort (dyspnea or increased accessory muscle activity); Pa_{O_2} at or more than 50 to 60 mmHg on fractional inspired oxygen tension at or less than 0.5 or peripheral capillary oxygen saturation at or more than 92%; Pa_{CO_2} less than 50 mmHg; pH more than 7.32; respiratory frequency/tidal volume less than 105 breaths $\cdot$ min^{-1} $\cdot$ l^{-1}; respiratory frequency less than 35 breaths/min; cardiac frequency less than 140 beats/min; and systolic blood pressure less than 180 mmHg and greater than 90 mmHg. Arterial blood gas samples were collected under full ventilator support.

The pressure support ventilation trial was defined as a 60-min test period, under low levels of pressure support (less than 7 cm H_2O) associated with a zero positive end-expiratory pressure level, as described previously.[10–12] Criteria defining failure to sustain a pressure support ventilation trial and postextubation distress are depicted in the Supplemental Digital Content (see Supplemental Digital Content 1, http://links.lww.com/ALN/B504, and 2, http://links.lww.com/ALN/B505, which are tables listing criteria for failure to sustain pressure support ventilation trial and postextubation distress, respectively). Patients who succeeded in a pressure support ventilation trial were extubated and followed up for 48 h aiming to detect postextubation distress. To further explore the value of the integrative models to detect patients at risk of postextubation distress, we conducted an additional pilot and prospective study in mechanically ventilated patients who underwent a trial of totally unsupported respiration (T-tube trial) while completely disconnected from the ventilator (see Supplemental Digital Content 3, http://links.lww.com/ALN/B506, which is a figure depicting predictive data obtained from an additional trial of totally unsupported respiration).

Routine Clinical Assessment

For every patient, standard medical care was provided by the senior ICU physician in charge. Experts were blinded to the ultrasound results. Thus, in the case of acute respiratory failure during the pressure support ventilation trial and subsequent extubation, and depending on the suspected diagnosis, initial treatment was decided by these members of the medical staff in accordance with normal practice and recommendations.[13,14]

Thoracic Ultrasound Assessment

All of the patients underwent a combined thoracic ultrasound test by investigators who did not participate in the patient management. Investigators used standardized criteria and followed a pattern analysis. Integrated thoracic ultrasound assessment encompassed transthoracic echocardiography and lung and diaphragm ultrasound evaluation and was performed with HP Sonos 5,500 (Hewlett-Packard Development Company, LP, USA) and a 2- to 4-MHz probe. All of the patients were studied in the semirecumbent position.

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The echocardiographic examination included left ventricular systolic function (visual estimation of the left ventricular ejection fraction at less than 50% or greater than 50%) and left ventricular end-diastolic pressure estimation (pulsed Doppler echocardiography-recorded mitral inflow and Doppler tissue imaging with the sample cursor placed in the lateral mitral annulus).[15] For the lung ultrasound examination, the anterior chest wall was delineated from the clavicles to the diaphragm and from the sternum to the anterior axillary lines.[16,17] The lateral chest was delineated from the axillary zone to the diaphragm and from the anterior to the posterior axillary line. Each chest wall was divided into three lung regions. Lung ultrasonograms were contemporaneously classified into a few categories according to previously described criteria.[7] The *pleural line* was defined as a horizontal hyperechoic line visible 0.5 cm below the rib line. A *normal pattern* was defined as the presence, in every lung region, of a lung sliding with A lines (A profile).[18] *Alveolar-interstitial syndrome* was defined as the presence of more of than two B lines in a given lung region (B profile).[19] In addition, moderate (multiple and well-defined B lines) and severe (multiple coalescent B lines) losses of aeration were described as B1 and B2 profiles, respectively.[20] *Alveolar consolidation* was defined as the presence of poorly defined, wedge-shaped hypoechoic tissue structures (C profile).[21] Each of the 12 lung regions examined per patient was classified in one of these profiles to define specific quadrants. The number of quadrants depicting analogous ultrasounds patterns was summed, and the total amount of each profile was computed to enable additional analysis (*i.e.*, SumA, number of lung quadrants with A profile; SumB1, number of lung quadrants with B1 profile; SumB2, number of lung quadrants with B2 profile; and SumC, number of lung quadrants with C profile).

For diaphragm ultrasonographic study, we recorded changes in diaphragm vertical excursion using M-mode ultrasound, as reported previously.[6] Both left and right diaphragms were studied through spleen and liver ultrasonographic windows, respectively.[22] Values of three successive recordings per side were analyzed as a mean diaphragmatic dome excursion.

Final Diagnosis

As previously reported[8,14] and operationally defined, in case of postextubation distress, the final diagnosis of acute respiratory failure was determined by two independent senior experts from an examination of the complete medical chart, including all of the initial clinical findings; emergency laboratory tests, including plasma levels of cardiac troponin I and B-type natriuretic peptide; chest radiograph data; and the results of thoracic high-resolution computed tomography scans (performed in 35% of the patients). In addition, transthoracic Doppler echocardiography was performed in 40% of the patients by a senior cardiologist who was blinded to the ultrasound data to allow an independent comparison between the different diagnostic methods. Responses to treatments were specifically analyzed and were used as diagnosis criteria. In case of disagreement between the two experts, a consensus was reached with the help of a third expert.

Experimental Design

To dynamically evaluate the predictive value of ultrasound data, these parameters were measured immediately after the start and at the end of the pressure support ventilation trial (fig. 1). The attending physician remained blinded to ultrasound data. In case of postextubation distress (fig. 1), an additional combined ultrasound assessment was performed while the patient was experiencing postextubation distress, as soon as the diagnosis of acute respiratory failure was established by the physician in charge. The etiologic diagnosis obtained by this combined ultrasound approach was compared with the diagnosis of postextubation distress, determined by a panel of independent senior experts as described previously, that is, the final diagnosis.[14]

Statistical Analysis

Continuous data are expressed as mean ± SD and/or median (range) according their distribution (Kolmogorov–Smirnov test). Categorical variables were expressed as numbers and percentages. Two means were compared with Student's t test or Mann–Whitney U test and two proportions with a chi-square test. The Spearman rank test was used to test linear correlation. Sensitivity, specificity, and diagnostic accuracy were calculated using standard formulas.
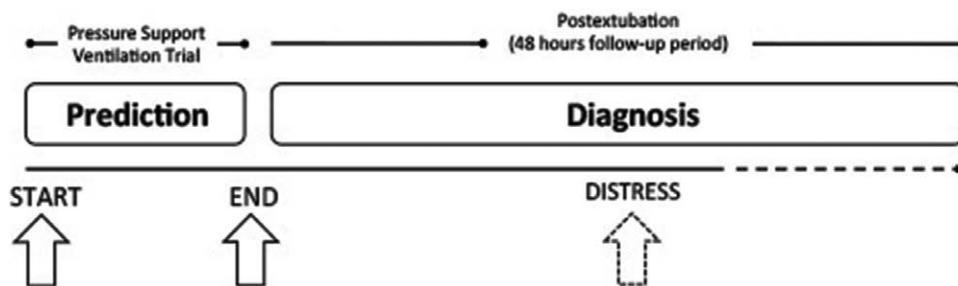
Fig. 1. Study design. To estimate the predictive value of ultrasound data over the risk of postextubation distress, these parameters were measured before (START) and at the end (END) of a pressure support ventilation trial. In case of postextubation distress, an additional combined thoracic ultrasound assessment was performed (DISTRESS), aiming at identifying the cause of respiratory failure.

To specifically address the predictive value of integrated thoracic ultrasound data, we used supervised learning machine techniques to elaborate and validate a mathematical model trained on labeled examples. To estimate how accurately the predictive integrated thoracic ultrasound model will perform in practice, we performed a twofold validation process: (1) a repeated tenfold cross-validation technique for assessing how the model created during the learning phase will generalize and (2) an additional validation procedure using an independent test sample.

To do so, and based on previous experience,[14] ultrasound data were split into two time series: a learning sample (first 69 patients) was used to establish the best classification model and a test sample (last 67 patients), which had not been used during the previous phase, was used to test model's generalization and to avoid the risk of overfitting. Thoracic ultrasonographic data, used as independent variables, were used to estimate partial least-square regression (PLS)[23] to predict postextubation distress using linear multivariate models (see Supplemental Digital Content 4, http://links.lww.com/ALN/B507, which is text that contains additional information related to learning machine methods). No transformations were applied before analysis. Furthermore, the PLS model used a nonlinear iterative partial least-squares algorithm to implement missing data potentially encountered in this setting. The standardized coefficients and 95% CIs of each parameter were determined using a bootstrap procedure (1,000 permutations). A logistic regression was performed on the PLS component to convert PLS values of each observation into a probability score. Finally, receiver–operating characteristic[24] curves were calculated for each final diagnosis during each testing phase, and the highest sum of sensitivity and specificity was considered to be the optimal threshold. Positive and negative likelihood ratios were also estimated from this optimal threshold.

The level of agreement among observers for the ultrasound findings was evaluated in a previous study.[14] All of the statistical tests were two sided, and $P < 0.05$ was required to reject the null hypothesis. Statistical analysis was performed with Statistica 8.0 software (StatSoft, Inc., USA), R software (https://www.r-project.org), and Tanagra 1.4.50 (Rakotomalala, Lyon University, France).

Results

Patients

A total of 136 consecutive patients who successfully passed the pressure support ventilation were extubated and included in the study (table 1; fig. 2). Reasons for initiating invasive ventilation were severe hemodynamic instability (22%), respiratory failure (30%), multiple trauma (20%), nontraumatic coma (8%), and postoperative complication of abdominal surgery (20%). Among them, 31 patients developed postextubation distress within 48 h (20 of 69 and 11 of 67 for learning and test periods, respectively). Twenty patients were reintubated for seven additional days (range, four to eight days), and the remaining 11 patients were assisted by noninvasive mechanical ventilation for five days (range, three to six days). Five of the 11 patients who required noninvasive ventilation were finally reintubated and mechanically ventilated for six additional days (range, three to eight days). Patients with postextubation distress had significantly longer length of stay and greater mortality in the ICU (table 1). Furthermore, using the same recruitment criteria, we conducted an additional prospective pilot study in 17 mechanically ventilated patients who underwent a weaning trial while completely disconnected from ventilator (see

Table 1. Patient Characteristics

	Overall (n = 136)	Postextubation Success (n = 104)	Postextubation Distress (n = 32)	P Value
Causes of admission, n (%)				
Medical disease	69 (51)	53 (51)	16 (50)	0.924
Surgery	38 (28)	29 (28)	9 (28)	0.979
Multiple trauma	29 (21)	22 (21)	7 (22)	0.931
Clinical characteristics				
Age, mean ± SD, yr	57 ± 15	61 ± 16	56 ± 18	0.136
Sex ratio, men/women	81/55	60/44	21/11	0.424
Pulmonary disease, n (%)	18 (13)	13 (12)	5 (16)	0.648
Cardiovascular disease, n (%)	62 (46)	48 (46)	14 (44)	0.811
Weight balance since admission, mean (IQR)	+3 (0–7)	+2 (0–5)	+3 (1–6)	0.153
SAPS II, mean (IQR)	54 (45–64)	52 (44–62)	53 (45–61)	0.681
SOFA, mean (IQR)	10 (7–14)	9 (8–11)	10 (6–14)	0.131
ICU mortality, n (%)	10 (7)	3 (3)	7 (22)	0.0003
Length of stay in the ICU, mean (IQR)	14 (6–22)	11 (5–16)	24 (14–31)	0.002
Previous duration of MV, mean (IQR)	6 (3–9)	5 (2–7)	6 (3–8)	0.174

Pulmonary disease includes nonsevere chronic obstructive pulmonary disease with forced expiratory volume greater than 50%, asthma, and history of tuberculosis. Cardiovascular disease includes coronary heart disease and valvular heart disease.

ICU = intensive care unit; IQR = interquartile range (first to third); MV = mechanical ventilation; SAPS = Simplified Acute Physiologic Score II; SOFA = Sequential Organ Failure Assessment.
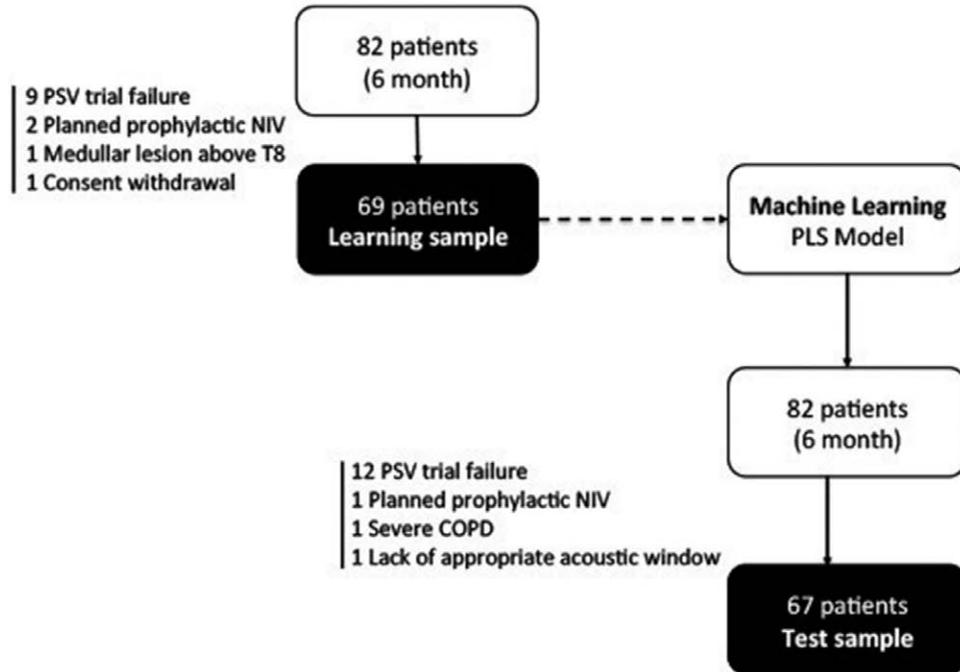
Fig. 2. Study flowchart. Longitudinal data from 136 consecutive patients were included in the study. Ultimately, the dataset was split into two time series to enable additional analysis: a learning sample (first 69 patients), which was used to establish the best predictive model, and a test sample (last 67 patients), which has not been used during the previous phase and was used to test model generalization. COPD = severe chronic pulmonary obstructive pulmonary disease with forced expiratory volume less than 50%; NIV = noninvasive ventilation; PLS = partial least-square regression; PSV = pressure support ventilation.

Supplemental Digital Content 3, http://links.lww.com/ALN/B506, which is a figure depicting predictive data obtained from an additional trial of totally unsupported respiration).

Modeling Multidimensional Data

Regarding the whole data set of ultrasonographic parameters that was used to generate the no *a priori* integrated thoracic ultrasound predictive model (fig. 3), the ultrasound semiotics related to the detection of lung interstitial water (B profile), or its absence (A profile), appeared to be the most relevant predictive factors. In addition, a significant difference was observed between the lung ultrasound profiles used to qualitatively estimate the total amount of interstitial lung water (B1 and B2 profiles). Focusing on the hemodynamic
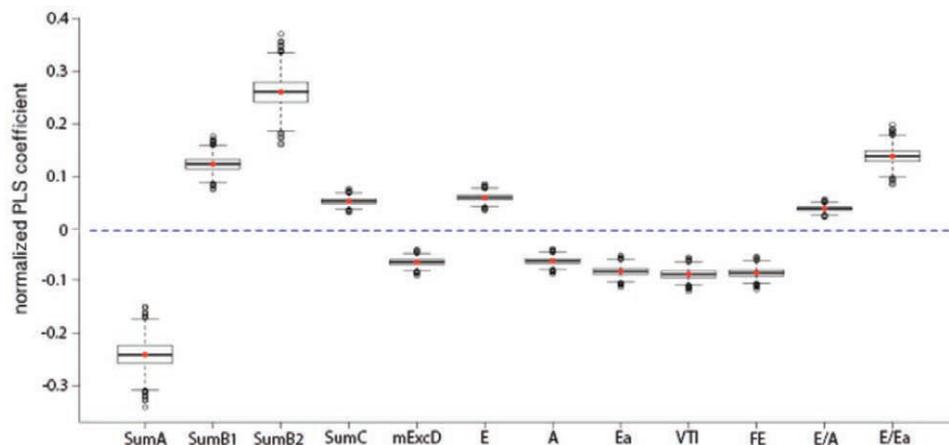
Fig. 3. Model components. One linear multivariate model was elaborated from ultrasound data. Normalized partial least-square regression (PLS) coefficients, obtained by a bootstrap procedure (1,000 permutations), are depicted as *whisker box plots* (median, 95% CI). A = A-wave velocity; E = E-wave velocity; Ea = Ea-wave velocity; E/A = E/A ratio; E/Ea = E/Ea ratio; FE = left ventricular ejection fraction; mExcD = mean diaphragm excursion (left and right); SumA = number of lung quadrants with A profile; SumB1 = number of lung quadrants with B1 profile; SumB2 = number of lung quadrants with B2 profile; SumC = number of lung quadrants with C profile; VTI = left ventricular outflow tract velocity time integral.

factors studied by echocardiography, the noninvasive estimation of the left ventricular telediastolic pressure appeared to have a significant predictive role compared with echocardiographic parameters used to assess left ventricular systolic function. Finally, it must be highlighted that the ultrasound assessment of diaphragm excursion had a poor impact over the final prediction of postextubation distress.

Predictive Values

Overall, the integrated thoracic ultrasound model accurately predicts postextubation distress (table 2; fig. 4) during both the learning and test phases. It is worth noting that data obtained during the validation phase confirm the accuracy (fig. 4) and robustness of the cross-validated model (see Supplemental Digital Content 5, http://links.lww.com/ALN/B508, which is a figure representing model accuracy assessment) created during the learning phase (see Supplemental Digital Content 6, http://links.lww.com/ALN/B509, and 7, http://links.lww.com/ALN/B510, which are tables encompassing the whole clinical biologic and ultrasound data set and the ultrasound missing data, respectively).

It must be noted that receiver–operating characteristic analysis showed no differences when comparing ultrasound data between both testing sessions (*i.e.*, outset and conclusion of the pressure support ventilation trial) in both sampled groups ($P = 0.464$ and $P = 0.182$ for learning and test phases, respectively; see Supplemental Digital Content 8, http://links.lww.com/ALN/B511, which is a figure depicting data changes between integrated thoracic ultrasound assessments). Finally, data obtained from mechanically ventilated patients who underwent a T-tube trial confirmed these findings. The predictive value of integrated thoracic ultrasound was highly accurate during both the outset and the conclusion of the T-tube trial (see Supplemental Digital Content 3, http://links.lww.com/ALN/B506, which is a figure depicting predictive data obtained from an additional trial of totally unsupported respiration).

Characterizing Postextubation Distress

Thirty-one cases of failure of weaning from mechanical ventilation were observed within the 48h after extubation (see Supplemental Digital Content 9, http://links.lww.com/ALN/B512, which is a table that describes the final diagnosis of postextubation distress). With respect to the final diagnosis of the cause of postextubation distress, a combined thoracic[14] ultrasound approach encompassing echocardiography and lung and diaphragm ultrasound assessment was in agreement with the final diagnosis of postextubation distress provided by the panel of experts. To illustrate the contribution of ultrasound in this setting, we could highlight the specific report of four cases of severe mitral valve regurgitation and two unilateral diaphragm paralyzes, which were implicated on postextubation distress and were accurately identified only by an ultrasound evaluation.

Discussion

Unnecessary extubation delays can increase the morbidity and mortality associated with prolonged ventilation.[25] Nevertheless, trying to decide when to extubate patients from mechanical ventilation can be challenging for the clinician and has been reported by some to be more art than science.[26] In this prospective observational study of mechanically ventilated patients considered to be ready for extubation (*i.e.*, successful pressure support ventilation trial), our main finding is that the use of a new, easy-to-perform and totally bedside combined thoracic ultrasound assessment of the likelihood of successful extubation appears to accurately predict postextubation distress. We suggest that such findings may be explained by the fact that, unlike currently used clinical indices, which constitute indirect testimonies of related organ failure and mostly reflect complex compensatory mechanisms,[27,28] thoracic ultrasound assessment permits an accurate monitoring of some pivotal physiologic processes

Table 2. Predictive Classifiers Accuracy

Diagnosis and Sample	AUC	Cutoff	Se, %	Sp, %	PPV, %	NPV, %	Correctly Classified, %	LR+	LR–
T0									
Learning									
TUS	0.921	0.5	67	94	80	89	87	11.332	0.351
	(0.842–0.981)	0.5	(41–87)	(84–99)	(52–94)	(77–96)	(71–93)	(8.122–15.813)	(0.122–1.340)
Test									
TUS	0.972		85	96	85	96	94	22.854	0.164
	(0.90–1.000)		(55–98)	(87–99)	(55–98)	(87–99)	(86–98)	(18–29)	(0.021–1.000)
T1									
Learning									
TUS	0.951	0.5	72	96	87	91	90	18.421	0.294
	(0.881–0.991)	0.5	(47–90)	(87–99)	(60–98)	(80–97)	(81–95)	(14–25)	(0.112–1.401)
Test									
TUS	0.920		69	91	64	93	87	7.482	0.341
	(0.841–0.982)		(39–91)	(80–97)	(35–87)	(82–98)	(77–93)	(5.221–10.825)	(0.101–1.151)

Data include the 95% CI.
AUC = area under the receiver–operating curve; LR+ = positive likelihood ratio; LR– = negative likelihood ratio; NPV = negative predictive value; PPV = positive predictive value; Se = sensitivity; Sp = specificity; TUS = thoracic ultrasound assessment.
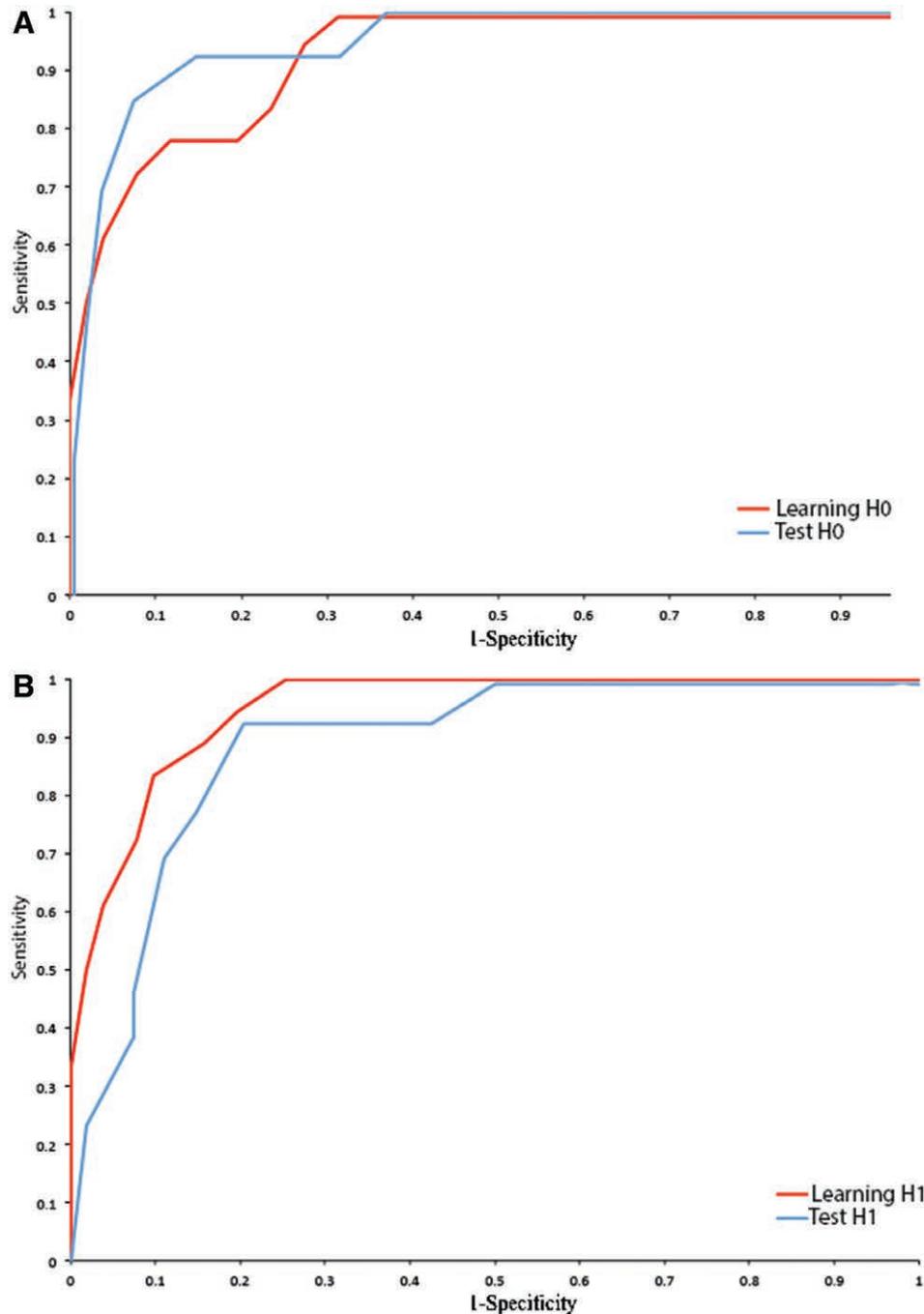
Fig. 4. Predictive values. Receiver–operating characteristic curves depicting the relationship between the proportion of true-positive findings and the proportion of false-positive findings. Estimation performances on prediction of likelihood of successful weaning from mechanical ventilation are represented as areas under the curve (AUC). Learning sample AUC: START, 0.921 (0.842 to 0.981); END, 0.951 (0.881 to 0.991). Test sample AUC: START, 0.972 (0.90 to 1.00); END, 0.920 (0.842 to 0.981).

that are purportedly implicated in the postextubation distress, including loss of lung aeration,[29] pathologic increase of left telediastolic pressure,[15] and diaphragm dysfunction.[22]

Furthermore, in the present study, the use of artificial intelligence methods allowed the assessment of the specific impact of ultrasound parameters on the extubation outcome. First, we observed among the thoracic ultrasound data that the most powerful predictive factor was the detection

of reverberation artifacts through edematous interlobular septa within the lung. In fact, the presence (B lines) of lung interstitial edema was highly correlated with postextubation distress. In addition, we described for the first time to our knowledge that the qualitative estimation of lung interstitial edema was also a valuable predictor of respiratory failure after extubation, because the B2 profile was significantly associated with a greater likelihood of postextubation

distress compare with the B1 profile. It is worth noting that the detection of lung consolidation (C profile) was weakly associated with the rate of postextubation distress, emphasizing the still moot issue of the pathologic meaning of this lung ultrasound semiotic in mechanically ventilated patients. Frequently proposed as a pathognomonic indicator of pneumonia,[18,30] recent studies performed in patients with severe acute respiratory failure alternatively highlight the lack of specificity of this ultrasound pattern in mechanically ventilated patients and stress the need to combine echocardiography to avoid misdiagnosis in this setting.[7] In line with this important point, the present study also demonstrates that the echocardiographic parameter that permits the most accurate prediction of postextubation distress was the noninvasive estimation of left ventricular telediastolic pressure. Remarkably, this finding is coherent with the physiologic underpinning of hemodynamic pulmonary edema, because this pathologic process is specifically related to diastolic, and not systolic, left ventricular failure.[31]

Finally, our data suggest that the total amount of lung water and the estimated left ventricular telediastolic pressure[32] were kept constant between the outset and the conclusion of the pressure support ventilation trial (see Supplemental Digital Content 6, http://links.lww.com/ALN/B509, which is a figure depicting data changes between integrated thoracic ultrasound assessments). Future studies will need to specifically explore the impact of hemodynamic pulmonary edema during the weaning process. We suggest that those studies should confirm and further explore the diagnostic role of specific lung ultrasound patterns (B1 and B2 profiles)[33] to detect, monitor, and quantify interstitial lung water in pathologic conditions.

There are several limitations to the present study that should be mentioned. First, we tested patient readiness for extubation using low levels of pressure support without positive end-expiratory pressure. Although supplementary data obtained from mechanically ventilated patients who underwent a T-tube trial confirmed our findings obtained using low levels of pressure support, it could be argued that the use of a T-tube as a diagnostic test could be a more suitable procedure to analyze diaphragm excursion, because the presence of pressure support may result in diaphragm excursion even in cases of severe diaphragmatic paralysis[34] and T-tube trial could represent a more challenging test able to enhance the sensibility of the measurement realized during the testing period. In the current study, we decided to use pressure support instead of a T-tube to follow the standard of care recommendation[10–12] and to facilitate the replication of our results.

Second, specific groups of patients at risk of extubation difficulties, such as severe COPD, were excluded from the current study. In fact, we hypothesized that several etiologies of postextubation distress that are currently observed in patients with COPD cannot be correctly evaluated by an ultrasonography approach (*e.g.*, increased resistive load related to reversible airway bronchoconstriction) or need more complex and prolonged echocardiography assessments (*e.g.*, systolic and diastolic right ventricular function). Future studies encompassing tailored thoracic ultrasound assessments will need to specifically address the pathophysiologic underpinnings weaning from mechanical ventilation failure in patients with severe COPD. Finally, we must keep in mind that ultrasound has also intrinsic limitations and can be operator dependent; however, a high intraobserver and interobserver reproducibility has been reported.[35] In the present study, only a physician with advanced-level training and many years of experience in using and teaching ultrasonography in daily practice participated in ultrasound data recording.

Overall, our finding suggests that the prediction of postextubation distress could be significantly assisted by an integrative, dynamic, and fully bedside ultrasonographic concomitant assessment of cardiac, lung, and diaphragm functions. Among thoracic ultrasound data, the recognition of lung interstitial edema and the increased telediastolic left ventricular pressure appeared to be the most relevant predictive factors of successful extubation. Finally, in case of postextubation distress, an integrative use of thoracic ultrasound data accurately identified the causes of respiratory failure. This finding agrees with recent studies[7,14] emphasizing the usefulness of combining echocardiography and lung ultrasonography to diagnose severe acute respiratory failure. Future interventional studies are required to prospectively validate the impact of such predictive algorithms integrating thoracic ultrasound data on postextubation distress rate, length of stay, and mortality in this setting.

Research Support

Competing Interests

The authors declare no competing interests.

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