Chest Ultrasound in Prediction of Weaning Failure

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Abstract

Aim: Failure of weaning from mechanical ventilation (MV) is a common problem that faces the intensivist despite having some prediction indices. Application of chest ultrasonography (US) may help in weaning and prediction of its outcome.

Methods: 100 patients on invasive MV fulfilling criteria of weaning shifted to spontaneous breathing trial (SBT) (using PSV 8 cm H2O) for 1 hour. Weaning failure was defined as: Failed SBT, reintubation and/or ventilation or death within 48 hours. Echocardiography was used to get Ejection fraction, E/A ratio, Doppler tissue imaging (DTI) & lung ultrasound (LUS) was used to assess LUS score, diaphragm ultrasound was used to assess diaphragmatic thickening fraction (DTF).

Results: Mean age 57.1 ± 14.5, 62% were males. Weaning was successful in 80% of patients. LUS score was significantly higher in the failed weaning group: (10.8 ± 4.2) vs (16.5 ± 4.2 cm), (p: 0.001). (DTF) significantly higher in the successful weaning group: (43.0 ± 10.7) vs (28.9 ± 2.8 cm), (p: 0.001). DTF can predict successful weaning using Receiver operating characteristic (ROC) curves with the cutoff value: ≥ 29.5 with sensitivity 88.0% and specificity 80.0% with a p-value < 0.001. LUS score can predict weaning failure by using a ROC curve with cutoff value: ≥ 15.5 with sensitivity 70.0% and specificity 82.5 % with a p-value < 0.001.

Conclusion: The use of bedside chest US (to assess lung and diaphragm) of great benefit throughout the weaning process.

Introduction

Mechanical ventilation (MV) is one of the most common interventions in critical care. Weaning failure from MV occurred in 10-20% of patients [1], [2].

Timing is crucial when deciding if a patient can be successfully extubated. Both premature discontinuation and unnecessary delay of MV weaning have associated with poor outcome [3].

One of the major causes of weaning failure is the imbalance between the load on the diaphragm and its ability to cope with it [4], [5], [6], [7]. There is rising evidence that diaphragmatic dysfunction has a critical role in ventilator dependency. Diaphragm thickness calculated at end inspiration is related to maximal inspiratory pressure. Diaphragm US can be used to evaluate diaphragmatic dysfunction [7], [8], [9], [10]. Shifting a patient from MV to spontaneous breathing may be associated with lung aeration loss (derecruitment), which can cause weaning failure, [11], [12]. Lung ultrasound is an emerging and increasingly used tool to investigate both in a semi-quantitative and quantitative way lung aeration during MV [12].

Patients and Methods

A prospective observational study was conducted on one hundred patients admitted to the department of critical care medicine, faculty of medicine, Cairo University, from January 2016 to July 2017. The study was approved by the Ethical committee of Cairo University. Written informed consent was obtained by first degree relatives.
Patients

One hundred consecutive mechanically ventilated patients for more than 48 hours were included when the underlying cause that had required intubation was resolved, making the patient candidate to a first 1-hour SBT [10]. Exclusion criteria were patients aged < 18 years, patients with tracheostomy, cardiac arrhythmias. Left ventricular systolic dysfunction (LVEF < 50%) [22], diaphragmatic paralysis Neuromuscular disorders for example: Guillain barre syndrome and Myasthenia gravis, Severe ICU-acquired neuromyopathy, chronic obstructive pulmonary disease with forced expiratory volume < 50% of the predicted value and history of pneumonectomy or chronic lung disease

Methods

All patients were subjected to the following:

1-Detailed history is taking. Full physical examination and Laboratory investigations (Complete blood count, Coagulation profile, Arterial blood gases, Liver functions (ALT), Kidney functions (creatinine), blood glucose), bedside twelve leads ECG and chest x-ray.

2-Mechanical ventilation. All patients were intubated and mechanically ventilated under volume controlled ventilation using a Puritan Benett 840 ventilator, and they were observed till improvement of their conditions and became eligible to enter the SBT for weaning [23]. Patients were included in the weaning trial if they met the weaning criteria [11].

3-SBT protocol. Patients were put on PS/CPAP trial (pressure support 8 cm H₂O, CPAP 5 cm H₂O for one hour and they were extubated if they have succeeded in the trial. Failure of the weaning process was defined as a failed SBT or the need for reintubation within 48 hours following extubation [11], [24], so all patients included in the study were observed for 48 hours after the SBT. The following weaning indices were recorded for all patients during the SBT: Tidal volume (TV), Respiratory rate (RR), ABG: Po₂, So₂ % and Po₂/FiO₂. Rapid shallow breathing index: (RSBI (f/VT) = Respiratory rate/tidal volume [25]. A threshold of ≤ 105 is a must to continue the SBT [25].

Indicators of weaning failure were recorded:

a) objective indices: tachycardia more than 140 beats/min, tachypnea more than 35 breaths/min, use of accessory respiratory muscles, systemic arterial pressure more than 200 or less than 80 mmHg, hypoxemia: SO₂ less than 90%, acidosis, Arrhythmia [11];

b) subjective indices: Agitation, disturbed conscious level, increased work of breathing. SBT without the presence of the above signs was considered successful, and patients were extubated

4-Echocardiographic study. Transthoracic Doppler echocardiographic examination was 30 minutes after the start of the SBT using TOSHIBA ACUSON X 300, with a probe 3.5 MHZ was used to assess the LV systolic function using 2D and modified Simpson’s method. LV diastolic function was assessed by measuring mitral inflow velocity E and A waves and velocities of mitral annulus (Ea) using Doppler tissue imaging.

5-Lung ultrasound. (LUS) Was performed using a 2- to 4-MHz convex probe [16]. LUS was performed by the same trained physician at the end of the SBT. An LUS score has been produced to provide quantifiable comparable measures of changes in aeration [17], [18]. This score originates from the conversion of LUS patterns into numeric values, Four aeration patterns by ultrasound were defined [17], [18]: 1) normal aeration (N); presence of lung sliding with A-lines or less than two isolated B lines; 2) moderate loss of lung aeration: multiple B lines (B1 lines); 3) severe loss of lung aeration: multiple fused B lines (B2 lines); and 4) lung consolidation (C), the presence of a dense air bronchograms and tissue pattern , N = 0, B1 lines = 1, B2 lines = 2, C = 3. The final score, ranging from 0 to 36, is the sum of the values, from 0 to 3, assigned to the LUS patterns visualised in each of the 12 regions examined.

6-Diaphragmatic ultrasound. Diaphragm ultrasound was performed using a 10 MHz linear probe; Each diaphragm was evaluated by B-mode and M-mode after 30 min of the SBT [26]. The diaphragm was seen by placing the transducer, in the eighth intercostal space, perpendicular to the chest wall between the anterior axillary and the mid axillary lines, to see the zone of apposition of the muscle below the costophrenic sinus [27], [28]. The diaphragm was imaged as a structure with three layers, including two parallel echoic lines (the peritoneal membrane and the diaphragmatic pleura ) and a hypo echoic structure between them (the muscle itself) [27], [28]. The patient was then instructed to perform maximum deep inspiration and then maximum exhalation [27], [28]. On each frozen B-mode image, the diaphragm thickness was measured from the middle of the pleural line to the middle of the peritoneal line. Then, the diaphragmatic thickening fraction (DTF) was calculated as a percentage from the following formula: Thickness at end inspiration – Thickness at end expiration/Thickness at end expiration [27], [28]. The same steps were done using the M mode.

Statistical methods

Data were coded and entered using the statistical package SPSS (Statistical Package for the Social Science; SPSS Inc., Chicago, IL, USA) version 22. Data were summarised using mean and standard
deviation in quantitative data and using frequency (count) and relative frequency (percentage) for categorical data. Comparisons between quantitative variables were made using the non-parametric Mann-Whitney tests. For comparing serial measurements within each patient in each group, the non-parametric Wilcoxon signed rank test was used. ROC curve was constructed with an area under curve analysis performed to detect the best cutoff value for detection of the success of 1st SBT. P-values less than 0.05 were considered as statistically significant.

Results

The studied patients were divided into two groups: group 1, 80 patients with successful weaning; group 2, 20 patients with failure of weaning.

Table 1: Patients characteristics

| Demographic data         | Group 1 | Group 2 | P value |
|--------------------------|---------|---------|---------|
| Age (years)(mean)        | 56.4    | 59.9    | 0.383   |
| Sex (male/female)        | 80 (52/28) | 20 (10/10) | 0.301 |
| Causes of mechanical ventilation: | | | |
| Respiratory failure (82%) | 14     | 48     | 0.001   |
| Cardiac cause (12 %)     | 2       | 10     | 0.542   |
| DCL (16%)                | 4       | 12     | 0.001   |
| Hemodynamic support (10%)| 0       | 10     | 0.001   |
| 2D echocardiographic data: | | | |
| LVEDD (mm)(mean)         | 48.5    | 52.6    | 0.25    |
| LVEF (%) (mean)          | 38      | 39      | 0.82    |
| LVESD (mm)               | 38      | 39      | 0.82    |
| LVESD (mm)               | 48.5    | 52.6    | 0.25    |
| LVEF (%)                 | 38      | 39      | 0.82    |
| Ventilator parameters before the SBT in both groups: | | | |
| Frequency                | 20.7 ± 3.6 | 24 ± 3.9 | 0.012 |
| Tidal volume             | 484.2 ± 69.1 | 409.0 ± 82.7 | 0.005 |
| Ventilator parameters before the SBT in both groups: | | | |
| Frequency                | 25.4 ± 2.3 | 29.6 ± 3.6 | 0.001 |
| Tidal volume             | 416.4 ± 70 | 346 ± 76.9 | 0.008 |
| Minute ventilation       | 10387 ± 1479 | 9836 ± 1441 | 0.351 |
| Heart rate (beats/min)   | 123 ± 15.9 | 122.5 ± 30.4 | 0.934 |
| Systolic BP (mmHg)       | 123 ± 15.9 | 122.5 ± 30.4 | 0.934 |

LVEDD left ventricular end-diastolic diameter, LVEDD left ventricular end-systolic diameter, LVEF left ventricular ejection fraction.

LUS score was significantly lower in the group (1) than group (2) (10.8 ± 4.2 vs 16.5 ± 4.2 cm, P: 0.001). DTF was significantly higher in group (1) than group (2) (43.0 ± 10.7 vs 28.9 ± 2.8 cm, P: 0.001). Duration of mechanical ventilation was significantly higher in-group (2) than group (1) (8.8 ± 0.6 vs 6.0 ± 1.4 cm, P: 0.001).

Discussion

Weaning from MV is one of the most frequently encountered challenges in modern ICUs.

Tools available for determining the optimal timing of weaning and prediction of its outcome are limited. Subjective decisions are usually wrong. Stroetz and Hubmayr found that clinical prediction of extubation success or failure was often incorrect with the decision to extubate biased toward ventilator dependency [29]. The US is well established as a noninvasive widely available, and easy to use can be performed by the intensivist for evaluation and management of mechanically ventilated patients and guide weaning from it. Chest US should include the examinations of the lungs and diaphragm [14]. LUS can accurately detect extravascular lung water and also quantify the degree of regional lung aeration loss. Studies illustrate that LUS can detect extravascular lung water accurately since they compared LUS result with the result of pulse-induced contour cardiac output (PICCO) and pulmonary artery catheter and it was closely similar [30, 31]. An LUS score has been validated to provide quantifiable comparable measures of progressive changes in aeration [18]. This prospective observational study was conducted on one hundred patients underwent SBT weaning from MV shows several findings: SBT is correlated with significant lung derecruitment as assessed by LUS score that was significantly higher in the failed weaning group (P: 0.001), with cut-off value ≥ 15.5 predicted weaning failure with a sensitivity 70% and specificity 82.5%, AUC (0. 836) and P < 0.001. Soummer et al., in their study, concluded that, the lung derecruitment during SBT (assessed by lung u/s) is greater in patients who develop post-extubation distress (irrespective of its primary cause) than in patients who are definitively weaned (p < 0.001), they also concluded that LUS score > 17 (at the end of the SBT) is highly predictive of weaning failure and that derecruitment was made of partial loss of lung aeration rather than appearance of new consolidation [15].

Up till now, all indices that were used to predict extubation failure are indirect measurements of disorders of lung aeration, oxygen saturation defect, conscious level disturbances, hemodynamic instability, and physiological compensatory mechanisms, RSBI, and tachycardia that are patient-dependent [17]. The possibility of quantifying lung aeration directly at the end of an SBT offers an advantage for predicting weaning failure because decreased aeration is one of the critical pathophysiological factors [17].

DTF and weaning

DTF was significantly higher in the successfully weaned group (p 0.001), and with a cut-
The volume of diaphragm muscle mass is constant as it contracts. Therefore, as it shortens, it thickens, and measures of its thickening fraction are inversely related to changes in diaphragm length. In support of this concept, the absence of diaphragm thickening has been noted in patients with diaphragm paralysis [19]. Since the diaphragm is the major muscle of inspiration, the presence of diaphragm contraction and shortening should be a prerequisite for successful extubation. Diaphragm thickness may be estimated by B or M-mode [27], [32].

Similar to our results, Ayman I Baess et al., conducted a study on Thirty patients who were planned for weaning after MV, they concluded that diaphragmatic thickening was better than displacement in prediction of weaning outcome, and a cutoff value ≥ 30 can predict successful extubation with sensitivity (69%), specificity (71%) and AUC (0.65) [36]. One of the potential explanations that diaphragm thickening would be a more accurate index of diaphragm contractile activity than excursion during pressure-support ventilation, that thickening can only be influenced by active contraction [34].

DiNino et al. studied 63 intubated patients during the SBT and determined the DTF, They found that a DTF cutoff ≥ 30% was a good predictor for successful weaning with sensitivity and specificity, 88% and 71%, respectively and AUC (0.79) [21].

**Limitations:** The study is a single centre trial. US is an operator-dependent technique; however, in the current study, the only one trained intensive care physician performed the examination. We only assessed the right hemidiaphragm as it can be easily visualised compared to the left side where imaging is commonly impeded by gastrointestinal gases. However, this limitation is common in other studies on US assessment of diaphragmatic contractile function [33]. For the diaphragmatic us, we did not compare it with the gold standard methods (e.g. Trans-diaphragmatic pressure-time) because of the invasive nature of the procedure and relatively comparable results in previous studies [33], [35]. LUS couldn’t confirm the causes of lung derecruitment.

**Physiology, practice, and causes of weaning failure support the use of integrated US to predict weaning failure.** Chest ultrasound is an integrated bedside examination performed by the intensivist to assess the lung and diaphragm and help to understand the pathophysiological effects of weaning and help to optimise the clinical condition to improve the chances of successful weaning from ventilatory support.

References

1. Pinsky, M.R. and J.-F.o.A. Dhainaut, Pathophysiologic foundations of critical care. Williams & Wilkins, 1993.
2. MacIntyre NR, Cook DJ, Ely EW, Epstein SK, Fink JB, Hefnner JE. Evidence-based guidelines for weaning and discontinuing ventilatory support. Chest. 2001; 120(6):375S-95S. https://doi.org/10.1378/chest.120.6_suppl.375S PMid:11742959
3. Esteban A, Alia I, Gordo F, Fernandez R, Solsona JF, Valverdu I, Macias S, Allegue JM, Blanco J, Carriedo D, Leon M. Exubation outcome after spontaneous breathing trials with T-tube or pressure support ventilation. American journal of respiratory and critical care medicine. 1997; 156(2):459-65. https://doi.org/10.1164/ajccm.156.2.9610108 PMid:9279224
4. Spicher JE, White DP. Outcome and function following prolonged mechanical ventilation. Archives of internal medicine. 1987; 147(3):421-5. https://doi.org/10.1001/archinte.1987.00370030025005
5. Frazier SK, Stone KS, Moser D, Schlanger R, Carle C, Pender L, Widener J, Brom H. Hemodynamic changes during discontinuation of mechanical ventilation in medical intensive care unit patients. American Journal of Critical Care. 2006; 15(6):580-93. PMid:17053265
6. Papaioannou VE, Stakos DA, Dragoumanis CK, Pneumatikos IA. Relation of tricuspid annular displacement and tissue Doppler imaging velocities with the duration of weaning in mechanically ventilated patients with acute pulmonary edema. BMC cardiovascular disorders. 2010; 10(1):20. https://doi.org/10.1186/1471-2261-10-20 PMid:20478065 PMCID:PMC2880285
7. Vassilakopoulos T, Zakynthinos S, Roussos CH. Respiratory muscles and weaning failure. European Respiratory Journal. 1996; 9(11):2383-400. https://doi.org/10.1183/09031936.96.09112383 PMid:8947090
8. Heunks LM, van der Hoeven JG. Clinical review: The ABC of weaning failure—a structured approach. Critical Care. 2010; 14(6):245. https://doi.org/10.1186/cc9296 PMid:21143773 PMCID:PMC2220047
9. McCool FD, Tzelepis GE. Dysfunction of the diaphragm. New England Journal of Medicine. 2002; 366(10):932-42. https://doi.org/10.1056/NEJMra0070236 PMid:12397655
10. Jaber S, Petrof BJ, Jung B, Chanqures G, Berthet JP, Rabuel C, Bouyabrine H, Courouble P, Koechlin M, Similowski T. Rapidly progressive diaphragmatic weakness and injury during mechanical ventilation in humans. Am J Respir Crit Care Med. 2011; 183(3):364-71. https://doi.org/10.1164/rccm.201004-0670OC PMid:20813887
11. Boles JM, Bion J, Connors A, Henridge M, Marsh B, Melot C, Pearl R, Silverman H, Stanchina M, Veillard-Baron A, Welte T. Weaning from mechanical ventilation. European Respiratory Journal. 2007; 29(5):1033-56. https://doi.org/10.1183/09031936.00102006 PMid:17470624
12. Tobin MJ. Principles and practice of mechanical ventilation, LWL, 2006.
13. Grant BJ, Lieber BB. Compliance of the main pulmonary artery during the ventilatory cycle. Journal of Applied Physiology. 1992; 72(2):535S-42. https://doi.org/10.1152/jappl.1992.72.2.535 PMid:1559929
14. Lichtenstein DA. Lung ultrasound in the critically ill. Annals of Internal Medicine. 2014; 161(1):1. https://doi.org/10.15332/ajrccm.156.2.9610108 PMid:22584759
16. Bouhemad B, Zhang M, Lu Q, Rouby JJ. Clinical review: bedside lung ultrasound in critical care practice. Critical care. 2007; 11(1):205. https://doi.org/10.1186/cc5668 PMid:17316468 PMCID:PMC2151891

17. Bouhemad B, Brisson H, Le-Guen M, Arbelot C, Lu Q, Rouby JJ. Bedside ultrasound assessment of positive end-expiratory pressure-induced lung recruitment. American journal of respiratory and critical care medicine. 2011;183(3):341-7. https://doi.org/10.1164/ajrccm.201003-0369OC PMid:20851923

18. Bouhemad B, Liu ZH, Arbelot C, Zhang M, Ferarni F, Le-Guen M, Girard M, Lu Q, Rouby JJ. Ultrasound assessment of antibiotic-induced pulmonary reaeration in ventilator-associated pneumonia. Critical care medicine. 2010; 38(1):84-92. https://doi.org/10.1097/CCM.0b013e3181b08cd PMid:19633538

19. Gottesman E, McCool FD. Ultrasound evaluation of the paralyzed diaphragm. American journal of respiratory and critical care medicine. 1997; 155(5):1570-4. https://doi.org/10.1164/ajrccm.155.5.9154859 PMid:9154859

20. Matamis D, Soliemez E, Tsagourias M, Akoumianaki E, Dimassi S, Borili F, Richard JC, Brochard L. Sonographic evaluation of the diaphragm in critically ill patients. Technique and clinical applications. Intensive care medicine. 2013; 39(5):801-9. https://doi.org/10.1007/s00134-013-2823-1 PMid:23344890

21. DiNino E, Gartman EJ, Sethi JM, et al. Diaphragm ultrasound as a predictor of successful extubation from mechanical ventilation. Thorax. 2013; 2013:204111.

22. Lindenfeld J, Albert NM, Boehmer JP, Collins SP, Ezekowitz JA, Givertz MM, Katz SD, Klapholz M, Moser DK, Rogers JG, K. Decision-making processes of weaning patients from the ventilator. New England Journal of Medicine. 2012; 367(23):2233-9. https://doi.org/10.1056/NEJMoa1203367 PMid:23215550

25. Yang KL, Tobin MJ. A prospective study of indexes predicting the outcome of trials of weaning from mechanical ventilation. New England Journal of Medicine. 1991; 324(21):1445-50. https://doi.org/10.1056/NEJM199105233242101 PMid:2023603

26. Ueki J, De Bruin PF, Pride NB. In vivo assessment of diaphragm contraction by ultrasound in normal subjects. Thorax. 1995; 50(11):1157-61. https://doi.org/10.1136/thx.50.11.1157 PMid:8533271 PMCID:PMC475087

27. Wail JL, Johnson RL. Patterns of shortening and thickening of the human diaphragm. Journal of Applied Physiology. 1997; 83(4):1123-32. https://doi.org/10.1152/jappl.1997.83.4.1123 PMid:9338420

28. Boon AJ, Harper CJ, Ghahfarokhi LS, Strommen JA, Watson JC, Sorensen EJ. Two-dimensional ultrasound imaging of the diaphragm: Quantitative values in normal subjects. Muscle & nerve. 2013; 47(6):884-9. https://doi.org/10.1002/mus.23702 PMid:23625789

29. Stroetz RW, Hubmayr RD. Tidal volume maintenance during weaning with pressure support. American journal of respiratory and critical care medicine. 1995; 152(3):1034-40. https://doi.org/10.1164/ajrccm.152.3.7663780 PMid:7663780

30. Lichtenstein DA, Meziere GA, Lagoueyte JF, Biderman P, Goldstein I, Gepner A. A-lines and B-lines: lung ultrasound as a bedside tool for predicting pulmonary artery occlusion pressure in the critically ill. Chest. 2009; 136(4):1014-20. https://doi.org/10.1378/chest.09-0001 PMid:19809049

31. Enghard P, Radermacher S, Nee J, Hasper D, Engert U, Jörres A, Kruse JM. Simplified lung ultrasound protocol shows excellent prediction of extravascular lung water in ventilated intensive care patients. Critical Care. 2015; 19(1):36. https://doi.org/10.1186/s13054-015-0756-5 PMid:25656060 PMCID:PMC4335373

32. Cohn D, Benditt JO, Eveloff S, McCool FD. Diaphragm/thickening during inspiration. Journal of Applied Physiology. 1997; 83(1):291-6. https://doi.org/10.1152/jappl.1997.83.1.291 PMid:9216975

33. Vivier E, Dessap AM, Dimassi S, Vargas F, Lyazidi A, Thille AW, Brochard L. Diaphragm ultrasonography to estimate the work of breathing during non-invasive ventilation. Intensive care medicine. 2012; 38(5):796-803. https://doi.org/10.1007/s00134-012-2547-7 PMid:22476448

34. Umbrello M, Formenti P, Longhi D, Galimberti A, Piva I, Pezzi A, Mistaletti G, Marini JJ, Iapichino G. Diaphragm ultrasound as indicator of respiratory effort in critically ill patients undergoing assisted mechanical ventilation: a pilot clinical study. Critical Care. 2015; 19(1):161. https://doi.org/10.1186/s13054-015-0894-9 PMid:25886857 PMCID:PMC4403842

35. Summerrill EM, El-Sameed YA, Glidden TJ, McCool FD. Monitoring recovery from diaphragm paralysis with ultrasound. Chest. 2008; 133(3):737-43. https://doi.org/10.1378/chest.07-2200 PMid:18198248

36. Baess AI, Abdallah TH, Emara DM, Hassan M. Diaphragmatic ultrasound as a predictor of successful extubation from mechanical ventilation: thickness, displacement, or both? Egyptian Journal of Bronchology. 2016 May 1;10(2):162. https://doi.org/10.4103/1687-8426.184370