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Research paper

Diaphragm ultrasound as a new method to predict extubation outcome in mechanically ventilated patients

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ABSTRACT

Aim: To evaluate role of diaphragmatic thickening and excursion, assessed ultrasonographically, in predicting extubation outcome.

Methods: Fifty-four patients who successfully passed spontaneous breathing trial (SBT) were enrolled. They were assessed by ultrasound during SBT evaluating diaphragmatic excursion, diaphragmatic thickness (Tdi) at end inspiration, at end expiration and diaphragmatic thickness fraction (DTF%). Simultaneously traditional weaning parameters were recorded. Patients were followed up for 48 h after extubation.

Results: Out of 54 included patients, 14 (25.9%) failed extubation. Diaphragmatic excursion, Tdi at end inspiration, at end expiration and DTF% were significantly higher in the successful group compared to those who failed extubation ($p < 0.05$). Cutoff values of diaphragmatic measures associated with successful extubation were ≥10.5 mm for diaphragmatic excursion, ≥21 mm for Tdi at end inspiration, ≥10.5 mm for Tdi at end expiration, ≥34.2% for DTF% giving 87.5%, 77.5%, 80% and 90% sensitivity respectively and 71.5%, 86.6%, 50% and 64.3% specificity respectively. Combining diaphragmatic excursion ≥10.5 mm and Tdi at end inspiration ≥21 mm decreased sensitivity to 64.9% but increased specificity to 100%. Rapid shallow breathing index (RSBI) <105 had 90% sensitivity but 18.7% specificity.

Conclusion: Ultrasound evaluation of diaphragmatic excursion and thickness at end inspiration could be a good predictor of extubation outcome in patients who passed SBT. It is recommended to consider the use of these parameters with RSBI consequently to improve extubation outcome.

1. Introduction

The optimal time to discontinue patients from mechanical ventilation is critical as premature discontinuation may be followed by reinstitution of ventilator support in up to 25% of patients[1,2] and delayed weaning may be associated with ventilator induced diaphragm atrophy.[3–5] The respiratory muscle capacity and load imbalance (the common pathophysiology of weaning failure) can also contribute to extubation failure.[6,7] As spontaneous breathing trial (SBT) monitoring is insensitive to detect early signs of load-capacity imbalance,[8,9] several indexes have been developed to assess the patient's ability to breathe spontaneously. Variables such as minute ventilation, maximum inspiratory pressure, respiratory rate, rapid shallow breathing index (RSBI, i.e., respiratory frequency/tidal volume), airway occlusion pressure 0.1 s, and a combined index named CROP (compliance, rate, O_2, pressure index) have been used in common clinical practice, however these indices have done little to improve the timing of successful extubation.[10] More recently artificial neural network has been introduced to predict extubation outcome but its result varies in different studies.[11,12] Furthermore studies evaluating heart rate variability in predicting extubation outcome are few and single centred studies and can not be broadly applied.[13,14]

The diaphragm is a fundamental respiratory muscle whose dysfunction may be very common in patients undergoing mechanical ventilation.[6] Diaphragmatic fatigue has been observed even in patients successfully passed SBT.[15] The tools previously used in diaphragmatic function assessment can not be applied in the intensive care unit (ICU) either due to the risk of ionising radiation (as fluoroscopy, computed tomography) or due their need of a special skilled operator (as transdiaphragmatic pressure measurement, diaphragmatic electromyography, phrenic nerve stimulation).[16]

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Ultrasonography of the diaphragm allows for direct visualisation of the diaphragm muscle and assessment of its activity.[17–20] Ultrasonographic assessment of either motion of the diaphragm[21,22] or diaphragmatic thickness parameters can predict extubation outcome.[23] The evaluation of the diaphragmatic thickening fraction (DTF) may be also helpful to assess diaphragmatic function and its contribution to respiratory workload.[24] However these ultrasound indices of diaphragm function as predictors of extubation success or failure have not been extensively evaluated.

2. Aim of the study

The purpose of this study was to evaluate the role of diaphragm thickening and or excursion as assessed by ultrasound during a weaning trial to predict extubation outcomes. We also aimed to compare these parameters to other traditional weaning measures.

3. Materials and methods

This prospective study was carried out on mechanically ventilated patients at respiratory ICU of Assiut University Hospital, a tertiary care centre, during a period from April 2015 to November 2015. The ethics committee of the hospital approved the study and informed consent was obtained from the relatives of all enrolled patients.

All adult patients who had underlying pulmonary disease causing acute respiratory failure and necessitating MV were included in the study. We excluded patients with suspicious diaphragm paralysis (raised copula in chest X-ray) or known neuromuscular diseases (as Gillian Barre, myasthenia gravis), patients with pneumothorax or pleural effusion, patients with previous cardiothoracic surgery or pleurodesis and patients who presented with stridor (due to upper airway involvement) as a cause of extubation failure.

3.1. Study design

Subjects were assessed clinically, by acute physiology and chronic health evaluation II (APACHE II) score, Charlson comorbidity index (CCI) and by diaphragm ultrasound. When they were clinically stable and both biochemical and ventilator parameters were accepted by intensivist as ready for weaning, patients underwent SBT. Patients who successfully passed the SBT were included in data analysis and followed up for 48 h after extubation. Extubation was based on SBT results and on physicians' decision. The physicians who took the decision were blind of ultrasound results.

3.2. Charlson comorbidity index (CCI)

We applied CCI as an index of severity of co-morbidities.[25,26] It was formed of 19 co-morbid conditions: each condition took a score from 1 to 6, which was estimated from relative risk of this condition on mortality based on clinical studies. The total score was then calculated and recorded.[25]

3.3. Weaning trial

Patients were considered ready for weaning when they met all the following criteria: fraction of inspired oxygen (FiO_2) < 0.5, positive end expiratory pressure (PEEP) ≤ 5 cmH_2O, PaO_2/FiO_2 > 200, respiratory rate (RR) <30 breaths/min, alert and cooperative, and hemodynamically stable in the absence of any vaso-active therapy support.[9,27]

3.4. SBT

Patients underwent a SBT by putting the patient on spontaneous mode of weaning under low-level pressure support (8 cmH_2O) and zero PEEP using Puritan Bennett™ 840 ventilator and switch off ventilator rate. SBT was attempted for 2 h. If the patients passed the SBT without deterioration, they were extubated and received oxygen through Venturi mask from 28 to 40% and were followed up for 48 h after extubation. A successful extubation was defined as maintenance of spontaneous breathing for >48 h following extubation. Extubation failure was defined as the inability to maintain spontaneous breathing for at least 48 h, without any ventilatory support.[8,9] Criteria for failure to the SBT were the following: change in mental status, onset of discomfort, diaphoresis, RR > 35 breaths/min, haemodynamic instability (heart rate >140, systolic blood pressure >180 or <90 mmHg) or signs of increased work of breathing.[28]

3.5. Diaphragm ultrasound

All patients were evaluated in a semi-recumbent position. Ultrasound was performed by two pulmonologist expert in chest ultrasound using (Samsung Medison Sono Ace R3 ultrasound system; Samsung company, Seoul, South Korea). For evaluation of diaphragmatic thickness parameters, the diaphragm was visualised by placing the 7 MHz transducer at the zone of apposition perpendicular to the chest wall, in the eighth or ninth intercostal space, between the anterior axillary and the midaxillary lines. The diaphragm was imaged as a structure formed of two echoic lines (the diaphragmatic pleura and the peritoneal membrane) and a hypoechoic structure between them (the muscle itself)[13,29] (Fig. 1). Several images of the diaphragm were captured during quiet tidal breathing, including at least three at the point of end of inspiration and at least three at end of expiration. On each B-mode image, the diaphragm thickness (Tdi) was measured from the middle of the pleural line to the middle of the peritoneal line. The average of these three measures was taken, then the diaphragmatic thickness fraction (DTF) was calculated as percentage from the following formula: (Thickness at end inspiration − Thickness at end expiration)/Thickness at end expiration.[24]

For evaluation of diaphragmatic excursion, the 3.5 MHz probe was placed below the right subcostal margin in the mid-clavicular line and moved till better appearance of the posterior third of the right diaphragm. During tidal breathing, the M-mode was then used to display the diaphragmatic excursion along a selected line perpendicular to diaphragm (Fig. 2). Inspiration was considered as an upward motion in the M-mode tracing. The amplitude of diaphragmatic excursion was measured on the vertical axis of the

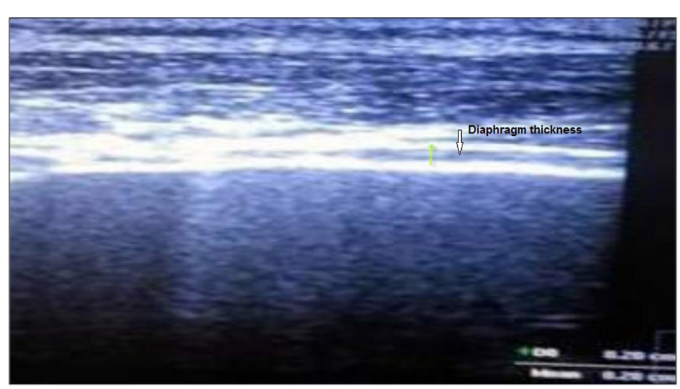

Fig. 1. Ultrasound B-mode using 7.5 MHz probe in the zone of apposition. The diaphragm muscle appeared as hypoechoic structure between the diaphragmatic pleura and peritoneal pleura (the two echoic lines) (arrow).