CHEST

Diaphragm Excursion-Time Index

A New Parameter Using Ultrasonography to Predict Extubation Outcome

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BACKGROUND: The diaphragmatic response to increased mechanical load following withdrawal of mechanical ventilation is critical in determining the outcome of extubation. Using ultrasonography, we aimed to evaluate the performance of the excursion-time (E-T) index—a product of diaphragm excursion and inspiratory time, to predict the outcome of extubation.

METHODS: Right hemidiaphragm excursion, inspiratory time, and E-T index were measured by ultrasonography during mechanical ventilation: (1) on assist-control (A/C) mode during consistent patient-triggered ventilation, (2) following 30 min during a spontaneous breathing trial (SBT), and (3) between 4 and 24 h following extubation. These measurements were correlated with the outcome of extubation. Patients in the "failure" group required reintubation or noninvasive ventilation within 48 h of extubation.

RESULTS: Of the 73 patients studied, 20 patients failed extubation. During SBT, diaphragm excursion was 1.65 ± 0.82 and 2.1 ± 0.9 cm ($P = .06$), inspiratory time was 0.89 ± 0.30 and 1.11 ± 0.39 s ($P = .03$), and the E-T index was 1.64 ± 1.19 and 2.42 ± 1.55 cm-s ($P < .03$) in the "failure" and "success" groups, respectively. The mean change in E-T index between A/C and SBT was –3.9 ± 57.8% in the failure group and 59.4 ± 74.6% in the success group ($P < .01$). A decrease in diaphragmatic E-T index less than 3.8% between A/C and SBT had a sensitivity of 79.2% and a specificity of 75%, to predict successful extubation.

CONCLUSIONS: Diaphragm E-T index measured during SBT may help predict the outcome of extubation. Maintenance or increase in diaphragm E-T index between A/C and SBT increases the likelihood of successful extubation. CHEST 2018; 153(5):1213-1220

KEY WORDS: diaphragm excursion; inspiratory time; mechanical ventilation; ultrasonography; weaning

ABBREVIATIONS: A/C = assist-control mode; AUC = area under the curve; E-T = excursion-time index; fR = respiratory rate; MV = mechanical ventilation; Pdi = transdiaphragmatic pressure; P_I = mean tidal pressure; P_{Imax} = maximum inspiratory pressure; ROC = receiver operating characteristics; RSBI = rapid shallow breathing index; SBT = spontaneous breathing trial; T_I = inspiratory time; $T_I/Ttot$ = duty cycle; Ttot = inspiratory duty cycle; V_T = tidal volume; W = work

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FUNDING/SUPPORT: The authors have reported to *CHEST* that no funding was received for this study.

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DOI: https://doi.org/10.1016/j.chest.2018.01.007

Difficulty in weaning from mechanical ventilation (MV) can be encountered in 20% to 25% of patients in the medical ICU.[1] Failure of extubation is associated with longer ICU stay, health care resource utilization, greater morbidity, and mortality.[2-6] The rapid shallow breathing index (RSBI), derived from respiratory rate divided by tidal volume, has variable predictive accuracy for extubation outcomes.[7-9]

Weaning failure is likely if the load on the inspiratory muscles is excessive relative to their neuromuscular capacity. The diaphragm is a muscle of fundamental importance for successful spontaneous ventilation. Increased respiratory load increases energy demands and is directly related to work. Work performed (W) by the diaphragm is directly proportional to the mean tidal pressure (P_I), expressed as a fraction of maximum inspiratory pressure (P_I/P_{Imax}), minute ventilation, inspiratory duty cycle (T_I/T_{tot}), and inspiratory flow rate (V_T/T_I) as given by Equation 1:

$$W = P_I \times V_T \times fR$$

where V_T is tidal volume, fR is respiratory rate, T_I is inspiratory time, and Ttot is total time required for inspiration and expiration in one breath.[10]

The above equation can be written as Equation 2:

$$W = P_I \times (V_T/T_I) \times T_I \times fR$$

$$= P_I \times (V_T/T_I) \times (T_I/T_{tot}) \times 60$$

Bellemare and Grassino[11] have suggested that the product of T_I/T_{tot} and the mean transdiaphragmatic pressure expressed as a fraction of maximal transdiaphragmatic pressure (Pdi/Pdi,max) defines a useful "tension time index" (TTIdi) that is related to the endurance time (ie, the time that the diaphragm can sustain the load imposed on it).

The diaphragm approaches the fatigue threshold when the TTIdi value is greater than 0.15.[11] It can occur when the inspiratory load is excessive (ie, P_I is high), the diaphragm is dysfunctional (ie, P_{Imax} is low), or the duty cycle (T_I/T_{tot}) is long. When the T_I is prolonged, however, the inspiratory flow (V_T/T_I) and hence diaphragm work (W) is reduced as per Equation above.

The ventilatory pattern can be altered by respiratory loading conditions. Mechanical load may be elastic or resistive. When healthy volunteers are subjected to inspiratory resistive loading during spontaneous breathing, the tidal volume, T_I, and Ttot are increased. The respiratory rate is decreased while diaphragm excursion remains nearly the same.[12] When an external elastic load is added in an incremental fashion in healthy volunteers, there is a progressive reduction in tidal volume and Ttot, with loading causing a rapid shallow breathing pattern.[13] The breathing pattern and adaptation of the diaphragm to increased mechanical loads during spontaneous breathing trials (SBTs) may be pivotal in determining the outcome of extubation.

Patients who are likely to be successfully extubated and able to overcome increased respiratory load during an SBT have a lower RSBI and are able to generate a higher V_T at a lower respiratory rate. The duration of T_I has a direct impact on work performed by the diaphragm through changes in inspiratory flow and the T_I/T_{tot} ratio as explained above.

We decided to use the diaphragm excursion (as measured by ultrasound) as a surrogate for P_I and V_T, and combine it with T_I as a proxy of the work performed by the diaphragm in response to inspiratory loading during weaning from MV. We devised the excursion-time (E-T) index given by the product of diaphragmatic excursion and T_I. We hypothesized that when measured during an SBT, patients successfully extubated would have a lower RSBI, a longer T_I, greater diaphragm excursion, and a higher E-T index.

We performed a prospective observational trial to study the utility of the E-T index during weaning from MV to predict extubation outcomes as compared with a traditional parameter, the RSBI.

Methods

Between June 2015 and February 2017, patients admitted to the medical ICUs of North Shore University Hospital (Manhasset, NY) and Long Island Jewish Medical Center (New Hyde Park, NY), both part of Northwell Health, were enrolled after informed consent was obtained. The institutional review board of Northwell Health approved the study (IRB protocol #15-049). Patients or their legal surrogates gave informed consent.

Inclusion Criteria

The ICU team decided about the readiness of a patient to wean from MV, the timing of initiation of an SBT, sedative dose, and extubation based on their clinical judgment. If the ICU team decided to extubate a patient, the primary investigator A. P. was informed. The patient was then enrolled in the study, following the obtaining of informed consent, unless the patient met any exclusion criteria.