Respiratory impedance during weaning from mechanical ventilation in a mixed population of critically ill patients

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Background. Worsening of respiratory mechanics during a spontaneous breathing trial (SBT) has been traditionally associated with weaning failure, although this finding is based on studies with chronic obstructive pulmonary disease patients only. The aim of our study was to assess the course of respiratory impedance non-invasively measured by forced oscillation technique (FOT) during a successful and failed SBT in a mixed population.

Methods. Thirty-four weaning trials were reported in 29 consecutive mechanically ventilated patients with different causes of initiation of ventilation. During the SBT, the patient was breathing through a conventional T-piece connected to the tracheal tube. FOT (5 Hz, ±1 cm H2O, 30 s) was applied at 5, 10, 15, 20, 25, and 30 min. Respiratory resistance (Rrs) and reactance (Xrs) were computed from pressure and flow measurements. The frequency to tidal volume ratio f/Vt was obtained from the flow signal. At the end of the trial, patients were divided into two groups: SBT success and failure.

Results. Mixed model analysis showed no significant differences in Rrs and Xrs over the course of the SBT, or between the success (n=16) and the failure (n=18) groups. In contrast, f/Vt was significantly (P<0.001) higher in the failure group.

Conclusions. Worsening of respiratory impedance measured by FOT is not a common finding during a failed SBT in a typically heterogeneous intensive care unit population of mechanically ventilated patients.


Keywords: ventilation, high frequency oscillation; ventilation, mechanical; ventilation, respiratory impedance

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The process of care in mechanically ventilated patients is divided into several stages from intubation to successful extubation.1 Weaning represents 40–50% of the total duration of mechanical ventilation (MV).2 3 Although ~80% of the patients could be extubated in the first weaning attempt,1 20% require several attempts at weaning from MV, with the consequent prolongation of MV and increase in the mortality rate.3 Different respiratory and cardiovascular changes are associated with weaning failure.1 4 The progressive worsening of respiratory mechanics during the spontaneous breathing trial (SBT) has been traditionally regarded as a typical finding in weaning failure in ventilated patients.4 5 However, this assumption is based on cohorts that only included chronic obstructive pulmonary...
disease (COPD) patients and no studies in mixed populations are available.

The forced oscillation technique (FOT) is a method for non-invasively assessing respiratory mechanics and it is applicable to intubated patients. FOT is based on the application of small pressure oscillations at the airway opening by using an external generator and on recording the oscillatory pressure and flow signals. As explained elsewhere, the relationship between oscillation pressure and flow allows the quantification of the impedance of the respiratory system, which has two components: respiratory resistance (Rrs) and reactance (Xrs). Rrs is attributed to airways and tissue resistance, whereas Xrs is determined by the inertial and compliant properties of the respiratory system. The main benefits of FOT are the capacity of monitoring respiratory mechanics non-invasively (compared with invasive traditional methods in which an oesophageal catheter is necessary) and the relatively little cooperation needed from the patient to apply the technique. Although non-invasive measurement of respiratory mechanics using FOT has been successfully used in different clinical situations such as COPD, non-invasive ventilation, MV, and high-frequency oscillatory ventilation, its clinical use has not been previously tested during the weaning process. Accordingly, the aim of the study was to assess the changes of Rrs and Xrs measured by means of FOT during an SBT in a mixed population of ventilated patients, comparing patients who fail the trial (SBT failure) with those who tolerate spontaneous breathing (SBT success).

Methods

Patients

This prospective study was conducted from November 2005 to June 2008 in two intensive care units (ICUs) at the Hospital Clinic of Barcelona. All intubated and mechanically ventilated patients (≥48 h) were eligible for the study when the following criteria were fulfilled: improvement or resolution of the underlying causes of acute respiratory failure; no fever (≥38°C) or hypothermia (<36°C); haemoglobin ≥9 g d l⁻¹; absence of vasoactive drugs; normal consciousness after discontinuing sedation; and Pao₂ >8.0 kPa with fraction inspired oxygen (Fio₂) ≤0.4 and PEEP ≤5 cm H₂O. Patients who fulfilled the criteria and performed an SBT as a weaning technique were enrolled in the study. Exclusion criteria were: recent oesophageal, facial, or cranial trauma or surgery; tracheotomy or other upper airway disorders; active upper gastrointestinal bleeding; lack of cooperation; and decision to limit life-sustaining treatments. The study was approved by the Ethics Committee of the institution, and informed consent was obtained in all cases.

Measurements

Patient characteristics and clinical data were recorded on the day of the study. Maximal inspiratory (MIP) and expiratory (MEP) pressures were measured before the SBT, using a unidirectional valve. Respiratory flow (V) was measured by a Fleisch pneumotachograph (Sibel, Barcelona, Spain) placed between the tracheal tube and a conventional T-piece. The pressure decrease across the pneumotachograph was sensed by a differential pressure transducer (DP45, ±2.25 cm H₂O; Valydine, Northridge, CA, USA). During the forced oscillations measurement, the flow signal from the pneumotachograph was recorded with the FOT setup. The breathing frequency (f) was calculated from the flow signal. The tidal volume (Vt) was calculated by integrating the flow signal, breath by breath. The f/Vt was calculated as the ratio of the breathing frequency over the tidal volume. Pressure at the entrance of the tracheal tube was measured by a transducer (DP45, ±5.6 cm H₂O, Valydine) connected directly to the T-piece. During the weaning trial, a 5 Hz oscillation pressure (±1 cm H₂O) was applied at the T-piece. The time course of inspiratory and expiratory Rrs and Xrs was computed from pressure and flow signals. Rrs and Xrs data were corrected for the flow-dependent non-linearity of the tracheal tube.

Protocol

An SBT was performed in all patients of the study. Tracheal suctioning was performed before the SBT. As soon as the patient was disconnected from MV, the tracheal tube was connected through the pneumotachograph to the external oxygen supply and the FOT system using the T-piece. Then, FOT was applied for a period of 30 s. This procedure was repeated at 5, 10, 15, 20, 25, and 30 min. Flow measurements were recorded continuously during the weaning trial. The physician in charge of the patient was unaware of the FOT and f/Vt results. SBT failure was defined as the presence and persistence of one of the following criteria: respiratory frequency >35 bpm; arterial O₂ saturation by pulse oximetry <90% at Fio₂ ≥0.4; heart rate >140 or <50 beats min⁻¹, or increases or decreases more than 20% compared with MV; systolic arterial pressure >180 or <70 mm Hg, or increases or decreases more than 20% compared with MV; decreased consciousness, agitation, or diaphoresis; and paradoxical thoracic-abdominal movement. If no signs of SBT failure appeared within 30 min, the trial was considered successful and patients were extubated (SBT success). Alternatively, if signs of SBT failure appeared during this period, patients were reconnected to the ventilator (SBT failure). During the first 48 h after extubation, the patients were followed up for detecting respiratory failure after extubation.

Statistical analysis

Sample size estimation

As no previous data of Xrs changes during the SBT were available, the primary endpoint variable was centred in the
change of inspiratory Rrs during the trial in SBT failure. We expected a minimum increase of 5.8 cm H2O s litre\(^{-1}\) in SBT failure to obtain similar changes of Rrs as the previous study of Jubran and Tobin\(^6\) assuming a baseline Rrs of 9.6 (2.8) cm H2O s litre\(^{-1}\) [mean (SEM)]. Initial calculation revealed a minimal sample size of 15 patients in the SBT failure group [power analyses: 80%, \(\alpha=0.05\) (two-sided)].

Comparisons between the two groups
Data are presented as mean (SEM). Comparisons of MIP and MEP between the two outcome groups were carried out by \(t\)-tests. Dependence of Rrs, Xrs, and \(f/V_t\) on time and on weaning outcome was assessed by Mixed Effect Model Analysis (SPSS for Windows, Release 13.0 \(\copyright\) SPSS Inc., 1991–2000). The level of significance was set in all tests at 0.05 (all two-tailed).

Results
Table 1 shows the main characteristics of the 29 patients included in the study. Of the 34 trials assessed in this population, 16 (47%) were considered as SBT failure and 18 (53%) as SBT success. From the SBT failure group, only five patients were re-studied because it was not possible to repeat the study in the remaining patients, due to technical reasons (five cases) or worsening of the clinical status (five cases). One of the five patients who performed two consecutive SBT failed both trials, whereas the other four patients tolerated the SBT the second day and were extubated. From the SBT success group, three patients (17% of extubated patients) developed respiratory failure after extubation in the first 48 h (one was reintubated and two received non-invasive ventilation). There were no significant differences in MIP and MEP between the failure and success groups [42 (4.3) and 63 (6.1) cm H2O, respectively] and the success groups [52 (4.2) and 68 (5.4) cm H2O, respectively], although in patients with SBT success both pressures tended to be higher. Inspiratory Rrs, Xrs, and \(f/V_t\) variations during SBT are represented in Figures 1–3, respectively. Rrs and Xrs did not significantly change over the course of SBT, and no differences were observed between SBT failure and success. In contrast, \(f/V_t\) significantly (\(P<0.001\)) depended on the SBT outcome (although not on time). The analysis of expiratory Rrs and Xrs (data not shown) provided the same results as those obtained from inspiratory Rrs and Xrs: no significant dependence on time or on weaning outcome.

Discussion
In this study, we found that the course of Rrs and Xrs during a 30 min SBT, non-invasively measured by FOT, is
not significantly different between patients with successful and those with unsuccessful SBT in a mixed ICU population. Moreover, in line with earlier studies, we found that $f/V_t$ was significantly higher in patients who were unsuccessfully weaned.

The mechanisms determining weaning outcome are complex with the result that prediction of successful weaning is a relevant clinical problem. Although a considerable number of earlier studies have focused on determining whether physiological variables, clinical indices, or both provide reliable predictors of weaning outcome, the problem remains unresolved. One approach to the problem is based on the fact that MV is applied when the breathing pump of the patient is unable to provide enough energy to ensure adequate alveolar ventilation. One potential reason for such patient limitation is that the respiratory system presents an increased mechanical load to breathe because of the patient’s pathology. Accordingly, indices directly or indirectly quantifying respiratory impedance could be helpful in improving weaning outcome.

Jubran and Tobin reported that the passive mechanical properties of the respiratory system measured before the SBT do not differ between patients who succeed from those who fail the SBT. However, the same group observed a higher increase in inspiratory effort, inspiratory resistance ($R_t$), and dynamic lung elastance during the SBT in the failure group than in the success group in a COPD population. In contrast, data in the present work show that $R_{rs}$ measured by FOT were not significantly different during the SBT in failure with respect to success. The fact that different techniques were used to assess the mechanical load to breathe probably does not account for the different results obtained. Indeed, it has been previously reported that $R_{rs}$ non-invasively measured by FOT is close to $R_t$ measured using an oesophageal balloon. The fact that the same results concerning dependence on time and on outcome were found when analysing resistance and reactivity both during inspiration and expiration indicates that, for the purpose of this study, all the investigated FOT indices are equally representative of the mechanical load of the patient’s respiratory system. A more plausible explanation for the different results described by Jubran and Tobin compared with the data in the present work is that different populations were investigated. All subjects studied by Jubran and Tobin suffered from COPD, whereas the proportion of COPD patients in the present study was lower. In fact, only nine (31%) patients had a diagnosis of COPD. In addition, the proportion of our patients that initiated MV due to an exacerbation of a chronic respiratory disorder represented only 31% of our population. COPD has been described as an independent risk factor for longer duration of weaning and weaning failure. Moreover, COPD patients present more unfavourable reserve conditions to cope with cardiopulmonary stress during the SBT than non-COPD patients. So the increase of respiratory impedance during an unsuccessful SBT might probably be more frequent in COPD (due to an impaired cardiopulmonary capacity to cope an increased respiratory load) than in a mixed ICU population.

As $f/V_t$ is an index that reflects the balance between respiratory loads and capacities to perform an SBT, its usefulness in differentiating SBT success or failure is probably independent of the characteristics of the population studied. In fact, $f/V_t$ is the most important weaning predictor and is commonly applied in weaning protocols. The most important advantages of $f/V_t$ are that it is easy to measure and not dependent on patient cooperation and effort. Using a threshold of 105, Yang and Tobin found that this ratio had a positive-predictive value of 0.78 and a negative predictive value of 0.95 in predicting weaning outcome.

In our study, we observed a relatively high rate of respiratory failure after extubation (17%), although only one patient was reintubated. An explanation of this finding could be that although the reasons of initiating MV were diverse, there was a relatively high rate of patients with chronic respiratory disorders (62%), in which 50% of them were non-COPD patients (Table 1). We have recently reported that in hypercapnic chronic respiratory patients, the rate of respiratory failure after extubation could be as high as 48% if non-invasive ventilation is not applied immediately after extubation to prevent respiratory failure. In the present study, none of the three patients who went back into respiratory failure received non-invasive ventilation after extubation, and all of them had chronic respiratory disorders.

Although in the current study we did not find significant changes in respiratory impedance between SBT failure and success in a mixed population, these findings may be taken cautiously as the heterogeneity of the population could have played a role in the negative results. FOT monitoring can be useful in particular population subsets (e.g. heart failure, lung fibrosis, and COPD). However, the
objective of our study was to determine the pattern of respiratory impedance in a mixed population as a first general approach using FOT during weaning. Although in this population FOT monitoring does not seem useful, the potential role in subsets of ventilated patients must be elucidated. For instance, FOT might be useful in identifying reversible causes of weaning failure. As respiratory overload is a frequent cause of weaning failure, FOT monitoring during SBT could help in detecting an increased airway resistance as a cause of persistent weaning failure. One example could be the detection of bronchoconstriction during a failed SBT in chronic obstructive patients, which could be easily solved with bronchodilators and corticosteroids. Another application might be in patients who develop acute cardiac dysfunction during the SBT. This population typically develops increased airway resistance during the SBT, so, FOT might early detect cardiac dysfunction and the correspondent inotropic and diuretic therapy could be initiated to avoid weaning failure.

In conclusion, this study indicates that although easily and non-invasively applicable in the weaning setting, FOT does not provide additional information to improve the process of weaning in a typically heterogeneous ICU population. However, future studies are warranted to assess the usefulness of this non-invasive technique in subpopulations of patients in whom an increased mechanical load to breathe could play a major role. In this direction, an attractive and useful application of FOT could be in detecting reversible causes of weaning failure.

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