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Assessing respiratory mechanics using pressure reconstruction method in mechanically ventilated spontaneous breathing patient

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ABSTRACT

Background: Respiratory system modelling can aid clinical decision making during mechanical ventilation (MV) in intensive care. However, spontaneous breathing (SB) efforts can produce entrained "M-wave" airway pressure waveforms that inhibit identification of accurate values for respiratory system elastance and airway resistance. A pressure wave reconstruction method is proposed to accurately identify respiratory mechanics, assess the level of SB effort, and quantify the incidence of SB effort without uncommon measuring devices or interruption to care.
Methods: Data from 275 breaths aggregated from all mechanically ventilated patients at Christchurch Hospital were used in this study. The breath specific respiratory elastance is calculated using a time-varying elastance model. A pressure reconstruction method is proposed to reconstruct pressure waves identified as being affected by SB effort. The area under the curve of the time-varying respiratory elastance (AUC E_{drs}) are calculated and compared, where unreconstructed waves yield lower AUC E_{drs}. The difference between the reconstructed and unreconstructed pressure is denoted as a surrogate measure of SB effort.
Results: The pressure reconstruction method yielded a median AUC E_{drs} of 19.21 [IQR: 16.30–22.47] cmH_2O s/l. In contrast, the median AUC E_{drs} for unreconstructed M-wave data was 20.41 [IQR: 16.68–22.81] cmH_2O s/l. The pressure reconstruction method had the least variability in AUC E_{drs} assessed by the robust coefficient of variation (RCV) = 0.04 versus 0.05 for unreconstructed data. Each patient exhibited different levels of SB effort, independent from MV setting, indicating the need for non-invasive, real time assessment of SB effort.

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Conclusion: A simple reconstruction method enables more consistent real-time estimation of the true, underlying respiratory system mechanics of a SB patient and provides the surrogate of SB effort, which may be clinically useful for clinicians in determining optimal ventilator settings to improve patient care.

1. Introduction

Estimation of respiratory mechanics can enable individualised mechanical ventilation (MV) therapy [1,2]. However, most mathematical lung models developed are only suitable for fully sedated patients [3–6] and/or are others are too complex for use at the bedside [7–10]. Thus, most respiratory models cannot be applied directly to spontaneously breathing (SB) patients who intermittently modify pressure and flow due to their own inspiratory effort [11] without added invasive measurements or manoeuvres.

A significant number of MV patients demonstrate intermittent spontaneous breathing effort while sedated [11,12]. To individualise MV therapy with model-based methods, it is essential to have a mathematical model that can be applied to analyse respiratory system mechanics in both sedated and partial SB patients that is suitable for real-time use at the bedside. However, the underlying pulmonary mechanics of SB patients cannot be estimated from pressure and flow data alone, as SB efforts are intermittent and highly variable.

In particular, one common case of this specific problem arises when a patient exhibits SB effort on top of a ventilator supported breathing cycle, resulting in ventilator dyssynchrony. This phenomenon is known as reverse triggering [13], which results in a consistent occurrence of 'entrainment' in observed airway pressure waveforms. This 'entrainment' can be described as an "M-wave" due to its shape [14], as shown in Fig. 1.

In essence, the patient's breath-specific inspiratory effort induces a reduction in airwave pressure that the model sees as reduced respiratory elastance due to the same volume being delivered for less pressure [12]. This M-wave pressure curve creates a significant problem in identifying accurate values for the true, underlying respiratory system elastance and airway resistance as this input is not known or modelled [15]. Hence, it is important to have a method to overcome the impact of these M-waves and provide a more consistent estimation of the underlying respiratory system mechanics for clinical monitoring especially for SB patients.

In addition to correcting for M-waves, it is essential to have a metric that detects the presence of these M-waves and provides an estimate of how much breathing effort is exerted by the patient during reverse triggering on top of ventilator-supported breathing. Hence, this paper presents a method of estimating the SB efforts through pressure reconstruction with a case example from spontaneously breathing patients.

Currently, there are no metrics for SB effort in fully controlled MV without using highly invasive oesophageal pressure catheter [16–18]. These SB efforts need to be assessed to determine if the MV mode needs to be adjusted or adapted to patient breathing effort for better patient–ventilator interaction [19]. Thus, from the proposed pressure reconstruction method, a complete objective surrogate of SB effort and its contribution in altering the airway pressure waveform can be calculated.

In this proof of concept study, a model-based method is introduced that reconstructs M-wave affected airway pressure curves that are free from reverse triggering effects. This method hypothesises that the true, underlying respiratory mechanics do not change significantly breath to breath at a given pressure level, as seen in sedated patients [6,20,21]. Thus, this method expects to provide more consistent respiratory mechanics values during spontaneous breathing through reconstruction of surrogates of the actual airway pressure curves. In addition, metrics to identify breath- and

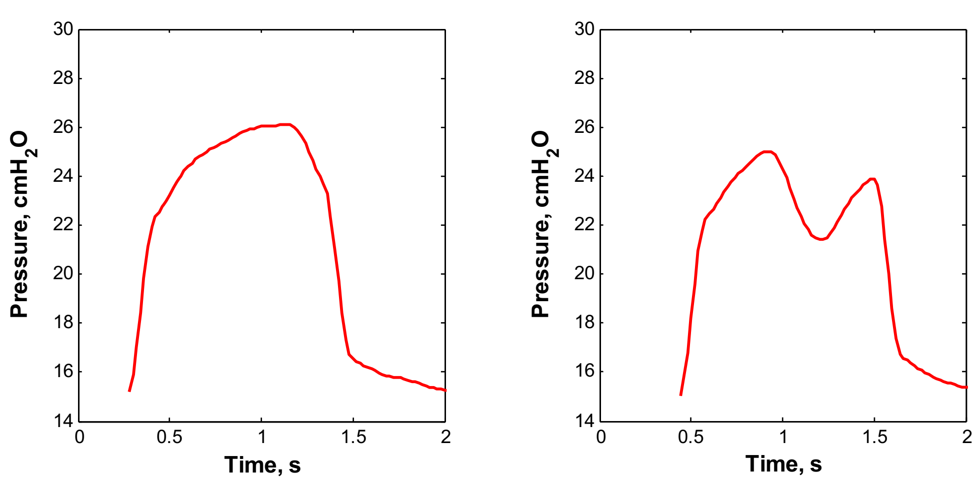

Fig. 1 – ***Left*: Normal airway pressure *Right*: M-wave airway pressure.**