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Respiratory mechanics assessment for reverse-triggered breathing cycles using pressure reconstruction

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A B S T R A C T

Monitoring patient-specific respiratory mechanics can be used to guide mechanical ventilation (MV) therapy in critically ill patients. However, many patients can exhibit spontaneous breathing (SB) efforts during ventilator supported breaths, altering airway pressure waveforms and hindering model-based (or other) identification of the true, underlying respiratory mechanics necessary to guide MV. This study aims to accurately assess respiratory mechanics for breathing cycles masked by SB efforts.

A cumulative pressure reconstruction method is used to ameliorate SB by identifying SB affected waveforms and reconstructing unaffected pressure waveforms for respiratory mechanics identification using a single-compartment model. Performance is compared to conventional identification without reconstruction, where identified values from reconstructed waveforms should be less variable. Results are validated with 9485 breaths affected by SB, including periods of muscle paralysis that eliminates SB, as a validation test set where reconstruction should have no effect. In this analysis, the patients are their own control, with versus without reconstruction, as assessed by breath-to-breath variation using the non-parametric coefficient of variation (CV) of respiratory mechanics.

Pressure reconstruction successfully estimates more consistent respiratory mechanics. CV of estimated respiratory elastance is reduced up to 78% compared to conventional identification ($p < 0.05$). Pressure reconstruction is comparable ($p > 0.05$) to conventional identification during paralysis, and generally performs better as paralysis weakens, validating the algorithm's purpose.

Pressure reconstruction provides less-affected pressure waveforms, ameliorating the effect of SB, resulting in more accurate respiratory mechanics identification. Thus providing the opportunity to use respiratory mechanics to guide mechanical ventilation without additional muscle relaxants, simplifying clinical care and reducing risk.

Australian New Zealand Trial Registry Number: ACTRN12613001006730.

1. Introduction

Model-based methods to monitor respiratory mechanics for mechanical ventilation (MV) patients can assist clinicians to guide MV treatment [1–4]. However, true respiratory mechanics can be masked by spontaneous breathing (SB) efforts and cannot be estimated in these cases without the use of invasive measuring equipment or clinical protocols [5–7]. Since SB efforts can be common, the application of respiratory mechanics to guide MV remains limited [6].

Akoumianaki et al. [8] described a phenomenon where SB during volume controlled ventilation masks the true, measurable, respiratory system mechanics. This phenomenon is referred

Abbreviations: CV, coefficient of variation; MV, mechanical ventilation; PEEP, positive end-expiratory pressure; SB, spontaneous breathing.

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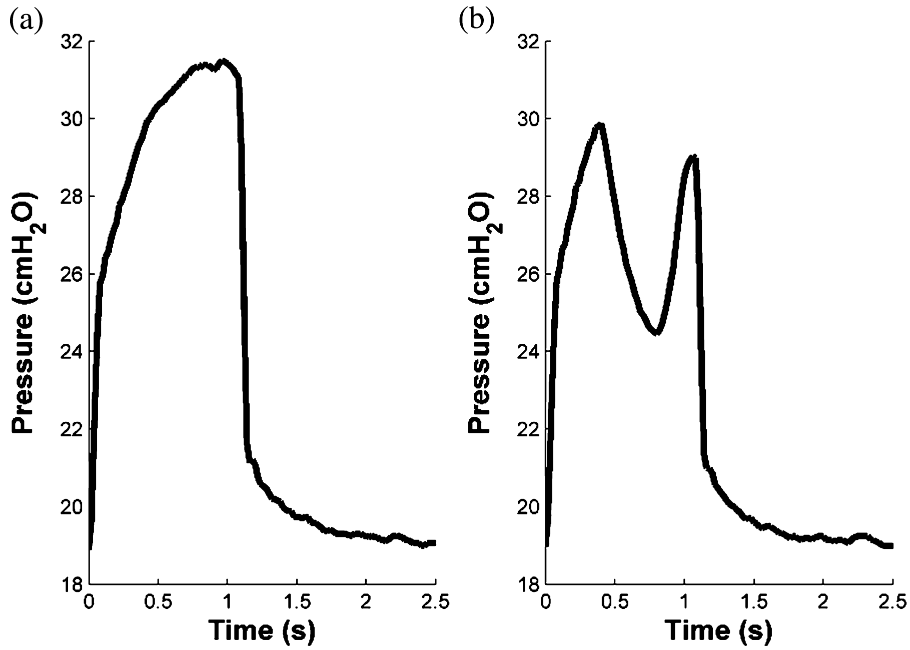

Fig. 1. Comparison of a typical airway pressure waveform during volume control mode (a) to an airway pressure waveform with reverse-triggering effect (b) from the same patient at equal ventilator settings within three breaths. The reduced airway pressure is evident.

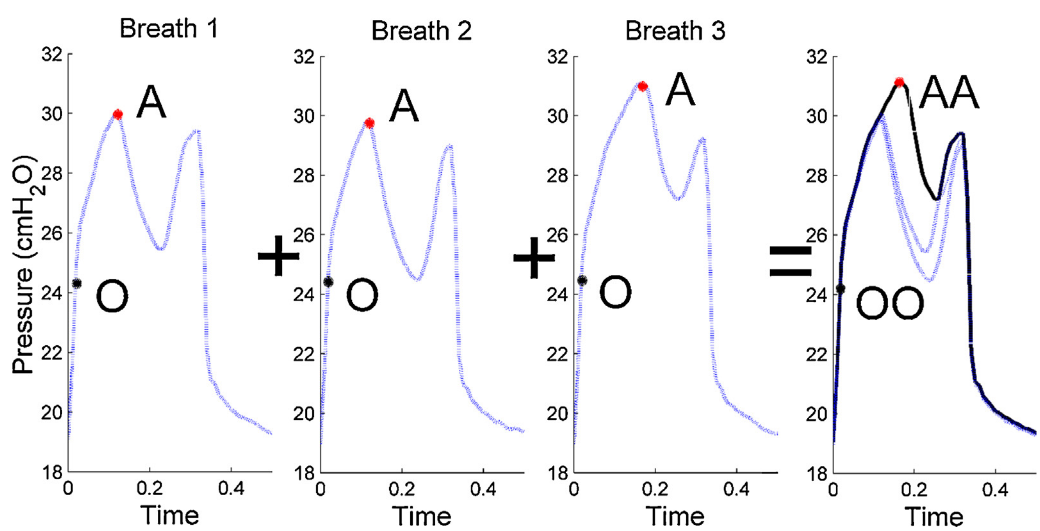

Fig. 2. How pressure waveform reconstruction is used to reconstruct a breathing cycle with more 'correct' data from three clinical breathing cycles affected by reverse-triggering.

to as ventilator-induced reverse-triggering of patient muscular breathing efforts. An example of the pressure waveform from a reverse-triggered breath is shown in Fig. 1. The reverse-triggering or patient effort creates anomalies in the patient airway pressure waveform, resulting in potential mis-identification of underlying respiratory mechanics if using simple models [6,9]. Specifically, patient effort reduces the net airway pressure for a given volume and leads to a lower calculated respiratory elastance due to the effective negative elastance component resulting from the patient's inspiratory effort [10]. Hence, the identified parameters do not represent the true underlying mechanics, as the patient-specific, variable inspiratory effort input was not accounted for in the model.

In addition, the level of SB effort can be highly variable. While none may occur in any given breath, other subsequent breaths may be heavily or only lightly affected, as shown in Fig. 1. Currently, modelling this input for real-time, breath-to-breath application is not possible, and direct measurements for later use, as with NAVA [11,12] for example, are additionally invasive and costly and thus infeasible. Hence, there is a need to more easily mitigate these effects with a cost effective method without inducing further stress to patients.

This study presents a simple model-based method capable of improving the consistency of identified respiratory mechanics in real-time. A pressure waveform reconstruction method was used to generate surrogates of SB 'unaffected' breathing cycles, to

Table 1
Primary cause of respiratory failure of each patient considered.

RM no.	Cause of respiratory failure	Age and sex
1	Faecal peritonitis	53 F
2	Cardiac surgery and contracted hospital acquired pneumonia	71 M
3	Pneumonia	60 M