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The Effect of Respiratory Manoeuvres for Patient-Specific Respiratory Mechanics Monitoring ⋆

Daniel P. Redmond * **Yeong Shiong Chiew** * **J. Geoffrey Chase** *

* *Department of Mechanical Engineering, University of Canterbury, Christchurch, New Zealand (e-mail: daniel.redmond@pg.canterbury.ac.nz)*

Abstract: Respiratory manoeuvres which from normal operation of the mechanical ventilator have been used to provide additional information to identify respiratory mechanics models, guide treatment, or provide more insight for clinicians. However, if the underlying respiratory mechanics are changed by a respiratory manoeuvre, then the application of respiratory manoeuvres may be significantly limited. This study identifies respiratory mechanics before and after super-syringe manoeuvres to investigate if the well-known super-syringe manouevre changes the underlying patient-specific respiratory mechanics. Thirty breaths before and after a super-syringe manouevre are analysed using a first order model for each of 16 patients. Median [IQR] absolute percentage changes in the median identified compliance and resistance distributions were 8.9% [2.1-16.8%] for compliance and 12.0% [3.5-19.3%] for resistance. 12 of 16 patients had significant changes in the distributions of compliance and 10 had significant changes in distribution of resistance (Wilcoxon ranksum test $p<0.05$). The magnitude and direction of the changes in parameters varied across patients. Some patients had very similar respiratory mechanics before and after the respiratory manouevre, others had large changes. Large changes in respiratory mechanics for some patients after a manoeuvre, limit the ability of using manoeuvres to guide treatment, as patients whose respiratory mechanics are greatly altered by respiratory manoeuvres cannot be known in advance. Therefore, consideration should be given to the potential clinical benefits and harms of respiratory manoeuvres before using them on patients.

Keywords: Mechanical ventilation, Respiratory mechanics, Positive end-expiratory pressure, Decision making support

1. INTRODUCTION

The identification of patient-specific respiratory mechanics is a useful tool for clinicians to diagnose obstructive and restrictive lung conditions (Broseghini et al., 1988; Bernasconi et al., 1988). In a critical care setting, respiratory mechanics can be used to guide clinicians selection of ventilator settings (Buehler et al., 2014; Sundaresan et al., 2011; Carvalho et al., 2007). Respiratory manoeuvres (RM) have been used in many clinical studies to provide additional information to enable or improve practical identifiability of the patient-specific respiratory mechanics models (Schranz et al., 2012a). These specific RM are unique and are different from the normal operation of the ventilator that supports the patients' breathing.

Some common RMs are the super syringe (Janney, 1959), low-flow manoeuvre (Schranz et al., 2012a), forced oscillation technique (Oostveen et al., 2003), and end-inspiratory pause (Servillo et al., 1997). End inspiratory pauses, during volume control ventilation, where the airway is occluded at the end of inspiration, have been used in the estimation of static resistance and elastance (Barberis et al., 2003). Super-Syringe (Janney, 1959) and low flow manoeuvres (Svantesson et al., 1999) can be used to obtain quasi-static pressure-volume curves (Schiller et al., 2003), from which positive end-expiratory pressure (PEEP) can be selected based on inflection points (Crotti et al., 2001; Villar et al., 2006). The forced oscillation technique superimposes a small amplitude external oscillation on the normal breathing cycle to calculate frequency dependent respiratory impedance (Oostveen et al., 2003).

In this study, the potential effects of a specific RM, the super-syringe, upon patient specific breathing mechanics are investigated. If the underlying respiratory mechanics are changed by the process of identifying parameters and the RM in specific, then the application of that RM may be significantly limited. As RMs may also have negative clinical effects, their use should be carefully considered if they cannot be used to guide treatment. For example, some manoeuvres require FiO_2=100% (Schiller et al., 2003; Stahl et al., 2006) to ensure adequate arterial oxygenation, which could cause harm due to oxygen toxicity (Jackson, 1985; Carvalho et al., 1998; Kazzaz et al., 1996). RMs that require reducing ventilation PEEP to zero end-

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expiratory pressure (ZEEP), or values lower than the clinical norm can cause further lung injury through cyclic de-recruitment/recruitment (Neumann et al., 1998; Ricard et al., 2003).

This study identifies and compares respiratory mechanics before and after the well-known super-syringe manoeuvre. A commonly used first order model (FOM), as well as viscoelastic model (VEM) are be used to identify the respiratory mechanics, and to assess if either, commonly used model is more, or less robust.

2. METHODS

2.1 Data

The clinical data used in this analysis comes from n=16 patients in intensive care units of 8 university hospitals. All patients had acute lung injury (ALI) or acute respiratory distress syndrome (ARDS), and had been ventilated for >24 hours prior to the study. A more detailed description of the clinical set up can be found in Stahl et al. (2006). Ethical approval was granted by local ethics committees of each participating institution.

An example of the patient data set is shown in Figure 1 This patient was first ventilated at PEEP 10 cmH_2O with constant square wave flow and an end inspiratory pause of approximately 0.6s, not shown in Figure 1. Immediately before the super-syringe manouevre, PEEP is decreased to ZEEP for 5 minutes. After the manoeuvre the patient is ventilated at the original PEEP. Each patient was ventilated at a different PEEP level between performing manoeuvres, but all were ventilated at ZEEP immediately prior to manoeuvres being performed.

A sample of 30 consecutive breaths immediately prior to the period of ZEEP and 30 breaths immediately after the super-syringe manoeuvres are used for comparison of respiratory mechanics parameters in each patient.

2.2 Respiratory Mechanics Models

First Order Model The linear first order model (FOM) (Bates, 2009) was used to analyse the breaths before and after the super syringe manoeuvre. The FOM is defined:

$$p_{aw} = \frac{V}{C} + R \times \dot{V} + p_0 \tag{1}$$

where p_{aw} is airway pressure, p_0 is the offset pressure, usually PEEP if there is no auto PEEP, V is the inspired volume, $\dot{V}$ is the inspiration flow rate, C is respiratory system compliance, and R is respiratory system resistance. As the FOM lacks the capability to model viscoelastic relaxation of the respiratory system, the model is only fitted to the part of inspiration prior to the end inspiratory pause.

Viscoelastic Model A viscoelastic model (VEM) (Bates, 2009) adds the capability to account for the stress relaxation of airway pressure during an end inspiratory pause. The state space representation of the VEM, where subscript 1 refers to the elastic compartment, and 2 refers to the viscoelastic compartment is defined:

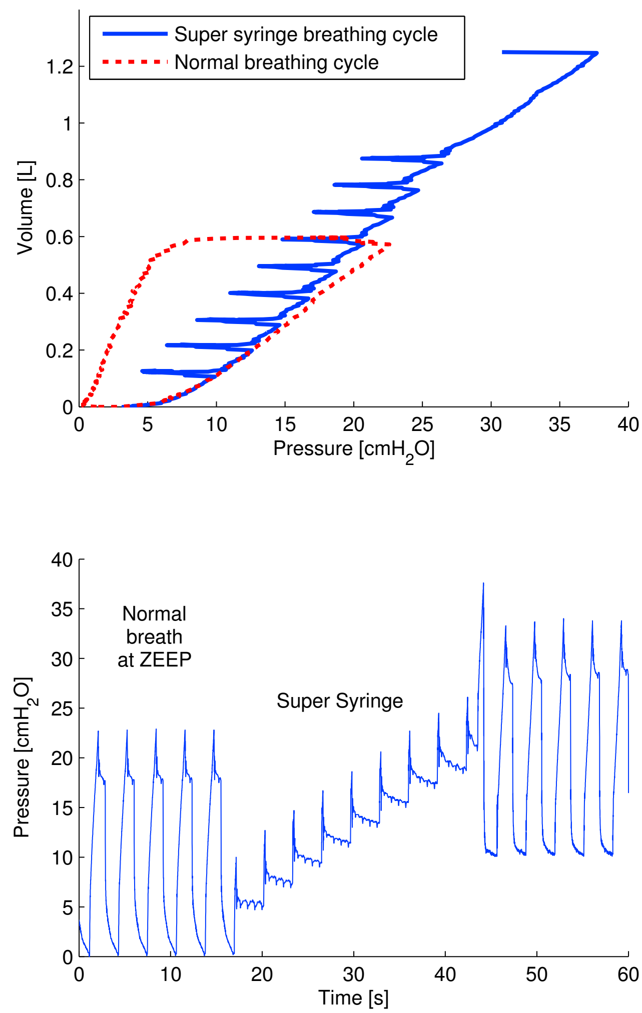

Fig. 1. Pressure-Volume and Pressure-Time curves of a super syringe manouevre and a normal breath at ZEEP with an end inspiratory pause for Patient 1.

$$\begin{bmatrix}\dot{p}_{C1}\\ \dot{p}_{C2}\end{bmatrix} = \begin{bmatrix}0 & 0\\ 0 & -1/(R_2C_2)\end{bmatrix}\begin{bmatrix}p_{C1}\\ p_{C2}\end{bmatrix} + \begin{bmatrix}1/C_1\\ 1/C_2\end{bmatrix}\dot{V} \tag{2a}$$

$$p_{aw} = [1\ 1]\begin{bmatrix}p_{C1}\\ p_{C2}\end{bmatrix} + R_1\dot{V} + p_0 \tag{2b}$$

where C_1 and C_2 are compliances and R_1 and R_2 are resistances.

2.3 Identification of respiratory mechanics

The FOM is identified for each breathing cycle using the data from the start to the end of inspiration. The data during the end-inspiratory pause is not used because the FOM cannot model the effects of the pressure decay due to viscoelastic effects. Integral-based linear regression (Hann et al., 2005) is used to identify the respiratory compliance and resistance of the FOM for each breath. The VEM is identified using the iterative integral method (Schranz et al., 2012b) to determine a resistance and compliance for both the elastic and viscoelastic compartments. This task involves rearranging Equation (2) to describe p_{aw} as