THE IMPACT OF ALVEOLI RECRUITMENT AND DERECRUITMENT ON MODEL-BASED MECHANICAL VENTILATION OF THE LUNG

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Introduction: Approximately one third of all ICU patients require mechanical ventilation (MV). Hospital stay of mechanically ventilated patients is longer and twice as expensive as other critical care patients. In the intensive care unit (ICU), acute respiratory distress syndrome (ARDS) and acute lung injury (ALI) are common with mortality rates between 30 and 70%. Currently, there does not exist reliable MV treatment or protocols to treat acute respiratory diseases, and thus no proven way to optimise care to minimise the mortality, length of stay or cost. Often clinicians rely on experience and intuition for MV treatment, which can sometimes result in further damage to the lung units. The proposed research looks to change the current approach by creating patient specific models that can accurately predict lung response to various MV treatments. A critical part lung response is the distribution of recruited and derecruited alveoli, that can change significantly after MV. Previous work and limited clinical data in the literature has suggested that the distributions are normal. However, this paper shows from the results of 8 ICU patients, that a log-normal type distribution is more suitable. The overall result is an improved capturing of the pressure volume (PV) curves and better prediction of PEEP therapy response.

Methods: Groups of alveoli and the distal airways are modelled as lung units. The recruitment and derecruitment of the modelled lung units are controlled by the distribution of Threshold Opening Pressure (TOP) and Closing Pressure (TCP), respectively. A previously developed lung model is identified using clinical data without any assumption on the pressure distributions. The resulting distributions are denoted $N_{dea}(P)$ and are approximated by a log-normal type curves defined:

$$N(P) = N_0 e^{-\frac{1}{2}(\ln(x_3P) - x_4)^2} + x_5$$  \hspace{1cm} (1)

where $N$ describes the number of lung units open at a given ventilator pressure $P$. Let $P_{\text{peak}}$ denote the pressure at the peak of the experimentally derived $N_{dea}(P)$ curve and set $N_{\text{peak}} = N_{dea}(P_{\text{peak}})$. Differentiating Equation (1) and setting to zero, yields $x_4 = \ln(x_3P_{\text{peak}})$. Further analysis of the $N_{dea}(P)$ curve also yields analytical formulas for $x_1$ and $x_5$ in terms of the measured data (details not shown). Thus only two unknowns $x_2$ and $x_3$ which are analogous to the mean and standard deviation of a standard log normal distribution. The major advantage of Equation (1) is that the log normal distribution can be shifted to obtain more flexibility in fitting the model.

Eight ICU patients with several PEEP settings are chosen and the two unknowns $x_2$ and $x_3$ are determined to best fit the measured PV data. The resulting curve in Equation (1) represents the patient’s level of lung recruitment at the given PEEP. The lung model is then used to predictions lung response to changes in PEEP and the results are compared to a standard normal distribution which fits the mean and standard deviation.

Results: The log normal type distribution in Equation (1) enabled an accurate description of the entire PV curve, including the transition periods at the start of inflation and deflation. The normal distribution was only capable of matching the steady portion of the curve. Better prediction of the lung response to different PEEP changes was also obtained using Equation (1). This improvement was particularly significant in 4 of the 8 patients which had distributions quite different from a normal distribution.

Discussion: The results suggest that a log normal type curve is a better representation of the distribution of alveoli recruitment and derecruitment and warrants further clinical investigation in the future. In particular CT scans could be used to estimate how many alveoli are open or closed to better quantify how log normal the distributions actually are, as well as validating the current lung model. The significantly improved prediction of lung response to PEEP changes increases confidence that this overall minimal modelling approach to lung mechanics will result in improved MV protocols in the ICU.

Conclusion: A log normal type distribution is found to more accurately capture lung dynamics associated with PEEP changes in 8 ICU patients than a currently used normal distribution. This approach enables a wider range of patients to be modelled accurately, thus improving clinical utility.