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OPTIMIZATION OF ALVEOLAR RECRUITMENT BASED ON THE PULMONARY PRESSURE-VOLUME CURVE

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Abstract

Quasi-static pulmonary pressure - volume $(P - V)$ curves are used routinely to obtain quantitative information on the respiratory system that is important for both research and clinical guidances, as the conditions of gas (O_2-CO_2) exchange are related to the characteristics of the curve. During inflation (inspiration, inhalation) and deflation (expiration, exhalation) processes, the respiratory system changes its volume (measured in L $(= 10^{-3}\,m^3)$ or mL), the lung (airway, alveolar) pressure as well as the pleural pressure (the pressure of the thin liquid film that couples the lungs and the chest wall pleurae). The pressure, P, refers to the interpleural pressure difference (i.e. difference between the lung pressure and the pleural pressure) measured in water head $[cm \cdot H_2O]$ $(1\,cmH_2O\ =\ 98\,Pa)$. Clinical P-V curves are commonly obtained for an anesthetized human subject in supine position by sequentially adding (or withdrawing) incremental gas volumes ($\sim$ 50-100 mL) in a stepwise manner (with a duration of $\sim$ 5 seconds per step). A respiratory system model (RSM) is developed for analyses of P-V curves of both the inflation- and the deflation- process. In RSM, the respiratory system consists of a large population of basic alveolar elements, each consisting of a piston-spring-cylinder subsystem. The normal distribution of the basic elements are derived from Boltzmann statistical model with the alveolar opening (closing) pressure as the distribution parameter for the inflation (deflation) process. An error minimization by the method of least squares applied to existing P-V loop data from two different data sources confirms that a simultaneous inflation-deflation analysis is required for an accurate determination of RSM parameters. Commonly-used terms in interpreting clinical P-V curves are examined based on the RSM-based P-V equations, on the distribution function as well as on the geometric and physical properties of the basic alveolar element. Based on the results of the RSM analyses, a normalized P-V curve is proposed for quantitative comparisons of quasi-static P-V curves from different sources, including data from different investigators, normal vs injured respiratory system, animal tests vs clinical data, lung pressure-volume curves vs transpulmonary pressure-volume curves. Similarities and differences among five different data groups we analyzed are shown to be quantified through the magnitudes of the normalized -volume and -pressure range of the individual data set, and of two non-dimensional parameters of the inflation limb, derived from RSM.

The research is multidisciplinary in nature, requiring cooperation between (thermofluid and biomechanical) engineers and medical doctors (including anesthesiologists working in intensive care units where the optimization of artificial ventilation is an important issue for treatments of diseased respiratory systems). A unique feature of the present approach is an application of techniques in statistical mechanics and kinetic (molecular) theory to the biomedical field.