Rozanek, M., Roubik, K.: Influence of The Changes in Pulmonary Mechanics upon the Suitability of Artificial Lung Ventilation Strategy. In: Biomedical Engineering. Zürich: Acta Press, 2004, pp. 417 -132. ISBN 0-88986-379-2.

Influence of the Changes in Pulmonary Mechanics upon the Suitability of Artificial Lung Ventilation Strategy

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Abstract

This study deals with modelling of the human lung structure corresponding to its anatomical structure. An electro-acoustical analogy was used to model the respiratory system. The whole model is computed numerically for a vector of different frequencies, which are used in the clinical practice for artificial lung ventilation.

Key Words
Artificial Lung Ventilation, Lung impedance, Biomedical Computing

1. Introduction

Artificial lung ventilation is the most efficient method for treatment of acute respiratory failure. Despite the fact that artificial lung ventilation has been examined properly and new protective ventilatory modes have been introduced, there are still strong adverse effects of artificial ventilation upon patient's respiratory system. A quite new ventilatory strategy is called high frequency ventilation (HFV). HFV can be characterized by increased ventilatory frequency (up to 40 Hz) allowing a significant decrease in pressure amplitude and delivered tidal volume. Usage of the small pressure amplitudes in the airways and breathing with very low tidal volumes prevent the lungs from overdistension, barotrauma and volutrauma. These properties represent the most significant difference between HFV and conventional artificial lung ventilation (CV) and they identify unconventional ventilatory strategies. Different effects of artificial ventilation can be observed when conventional ventilation (CV) or high frequency ventilation (HFV) is used. Many parameters can influence the oxygenation, but their effect is mostly impossible to study directly in the human body. Therefore, deriving model of the respiratory system exactly corresponding with the reality can be the only possibility how to study influence of mechanical lung properties through the bronchial tree, distribution of tidal volume among generations of alveoli, etc. A unique modelling approach has been chosen in this study based on the respiratory system modelling according to its exact anatomical structure. Simulations using the model are used to describe unequal effects of both conventional and high frequency ventilation modes upon various parameters characterizing intrapulmonary conditions.

2. Methods

The aim of this work was to find the model of the human respiratory system, which can be used for explaining the difference between the use of CV and HFV. A very complex structure of the human respiratory system begins with trachea and divides with each generation of the structure by course of irregular dichotomy. Therefore

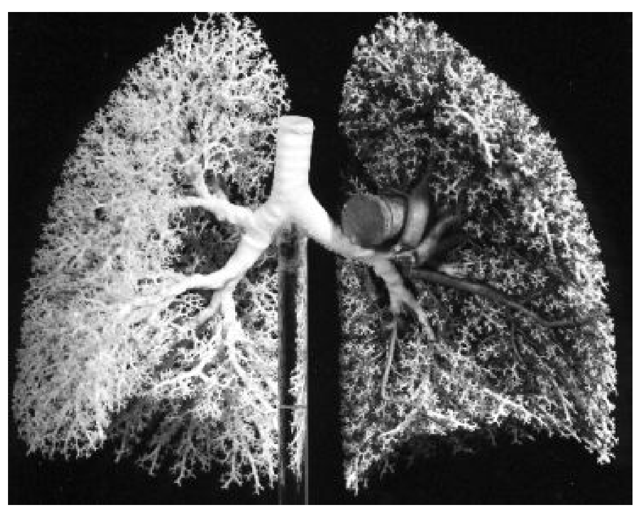

Fig. 1: Anatomical structure of the respiratory system. Reprinted from [1].

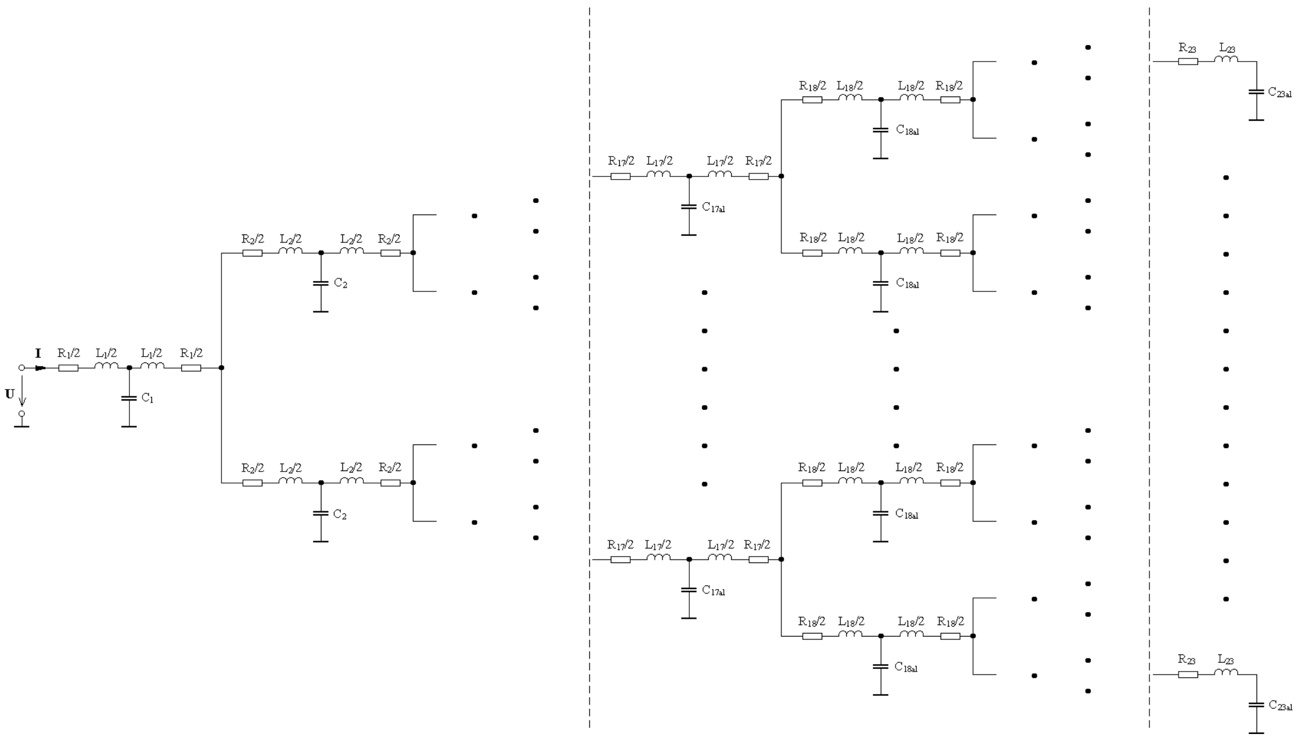

Fig. 2: Model of the respiratory system.

the tubes have various length and diameter in the same generation of the lung structure. Whole human lung structure can be seen in figure 1. It would be very difficult to describe this system mathematically.

A morphology model of the human lung was developed [2, 3] in which the irregular dichotomy was ignored so the tubes are dividing by course of regular dichotomy. Then the tubes have the same length and diameter in the same generation in this model. The number of generations in the model has been set to 23.

The model of the lung structure can be considered as an acoustic system. All individual airways are represented by short acoustic wave-guides with parameters computed using the common acoustic principles and published lung morphometry measurements [2, 3, 4, 5].

An electro-acoustic [4] analogy was used to develop an electric model of the respiratory system (Fig. 2) respecting its exact anatomical structure. The final model has 23 airway generations and it employs 67 108 859 individual components.

Ventilatory frequency of 0.25 Hz is considered for conventional ventilation (CV) and 5 Hz for high-frequency ventilation (HFV). A special method has been developed so that such a complicated model could be used for simulations of the real situations. Distribution of tidal volume V_T and pressure amplitude among generations of bronchial tree, total lung impedance (TLI) and other variables are studied under various conditions by modelling. The influence of respiratory mechanics upon the TLI was studied for frequencies that correspond with the ventilatory frequencies used during CV and HFV.

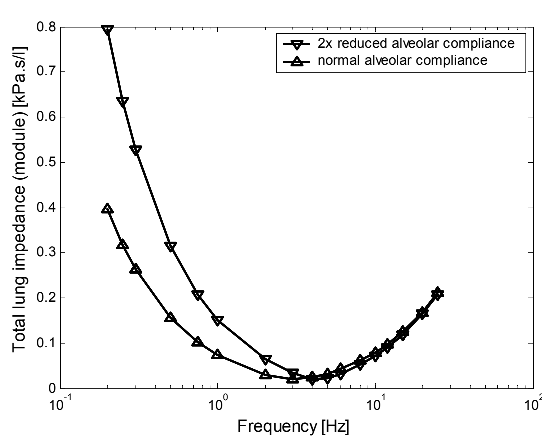

Fig. 3: Dependence of TLI upon frequency for normal and reduced alveolar compliance.

3. Results

Changes of alveolar compliance have a significant effect on TLI during CV (Fig. 3) while TLI changes during HFV are not essential (due to the effect of airway inertances). Contribution of airway resistance changes is significant mainly during HFV (Fig. 4). TLI is an essential variable for the pressure controlled ventilation modes. Results of simulations describe and explain some clinical experience.

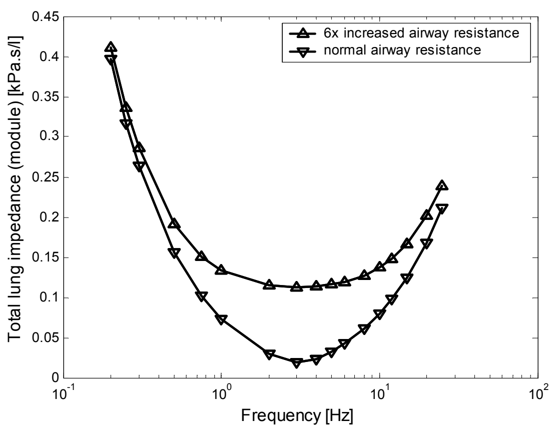

Fig. 4: Dependence of TLI upon frequency for normal and increased airway resistance.

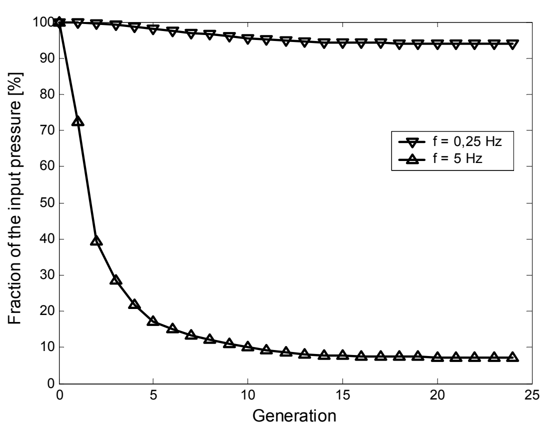

Fig. 5: The effect of frequency upon pressure inside the lung structure.

The effect of ventilatory frequency (CV, HFV) upon the pressure inside lung structure is shown in Fig. 5. Nearly 95% of input pressure is present inside the lung structure if using CV. On the other hand about 5% of the input pressure amplitude is transferred deep inside the structure of the respiratory system during HFV. It suggests that HFV is protective ventilatory strategy contrary to CV.
Reduced alveolar compliance causes a slight decrease in pressure inside the structure for CV (Fig. 6). While using higher frequencies, which correspond to HFV, the pressure inside the structure increases 4 times approximately (Fig. 7). It results in better functioning of HFV with a reduced alveolar compliance, which is the main symptom of adult respiratory distress syndrome (ARDS) [6, 7].

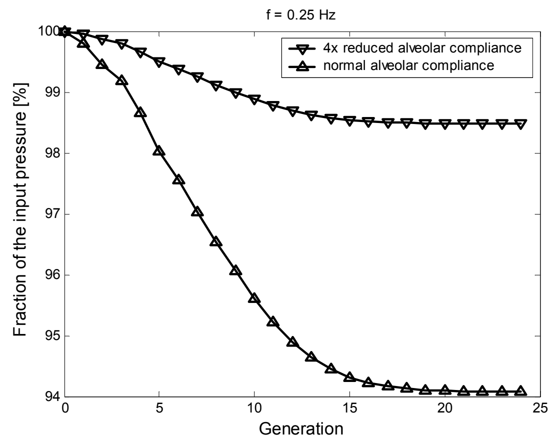

Fig. 6: The effect of reduced alveolar compliance upon pressure inside the lung structure for CV.

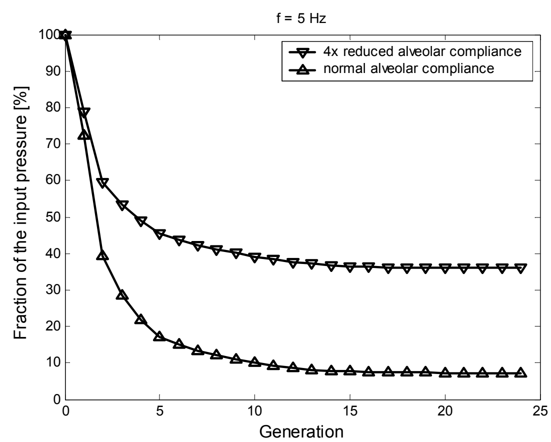

Fig. 7: The effect of reduced alveolar compliance upon pressure inside the lung structure for HFV.

4. Conclusion

It is possible to use the simulation results to explain the differences between CV and HFV usage. Therefore some essential effects observed in the clinical practice can be studied and explained by this modelling technique.
The corresponding elements in each generation cannot have different values. Therefore, only homogeneous changes in lung mechanics can be simulated. Subdivision of the model into the compartments that will be computed independently will be necessary for more detailed simulations.

5. Acknowledgement

The work has been supported by grant MSMT CR No. VZ:J04/98:210000012 and GA CR 305/00/0651.

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