USING A MATHEMATICAL MODEL OF THE HUMAN RESPIRATORY SYSTEM TO CHOOSE BETTER STRATEGY FOR ARTIFICIAL LUNG VENTILATION

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Abstract

Different effects of artificial ventilation can be observed when conventional ventilation (CV) or high frequency ventilation (HFV) are used. The mathematical model of the respiratory system corresponding with its anatomical structure was developed. This model allows us to study total lung impedance, distribution of tidal volume among generations of alveoli, pressure inside lung structure, etc.

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

A morphology model of the human lung was developed [1, 2] 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. Generations 17-24 are predetermined to respiration, whereas generations 0-16 do not contain alveoli and these tubes are used for convection of the air mixture only.

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 [1, 2, 4].

An electro-acoustic [3] analogy was used to develop an electric model of the respiratory system respecting its exact anatomical structure. The final model has 23 airway generations and it employs 67 108 859 individual components. The structure of the model is shown in Fig. 1. The elements with index 1 represent the trachea. Other elements represent the next generations of the airways. Each index of these elements determines a generation of the airways.

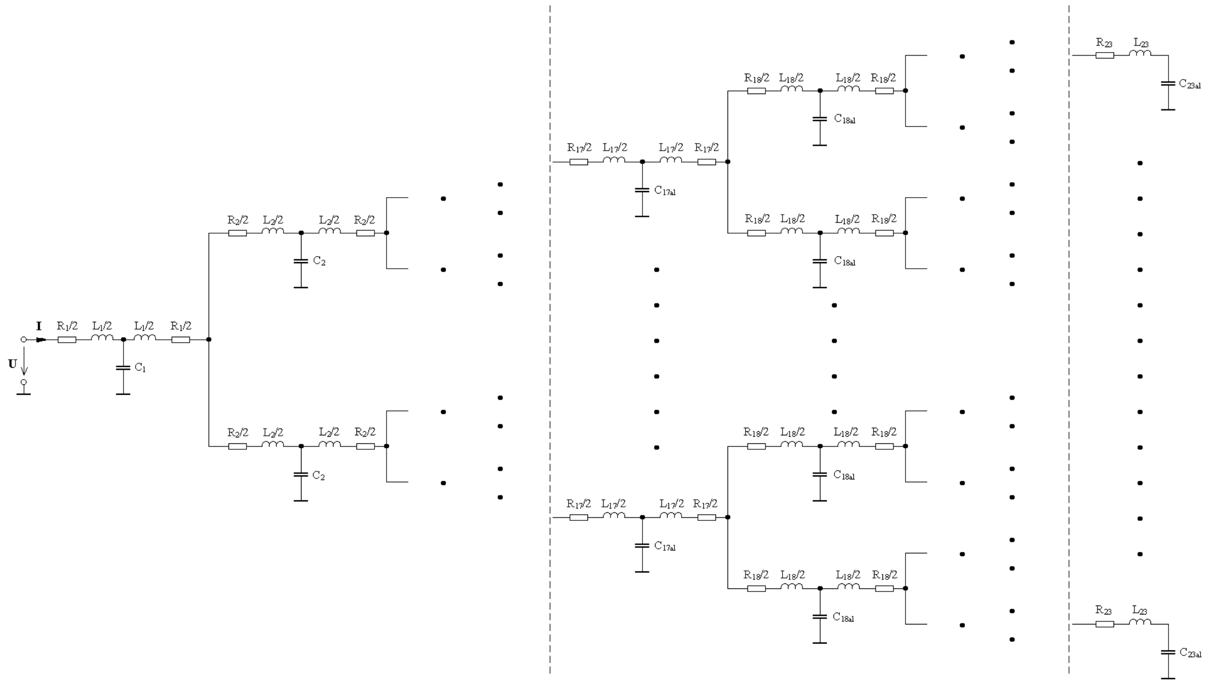
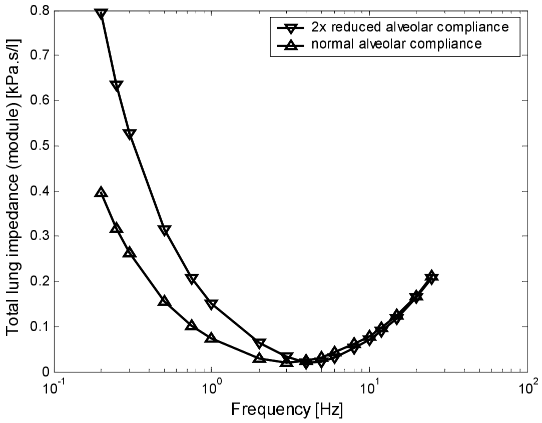


Fig. 1: Model of the respiratory system.

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.

Results

Changes of alveolar compliance have a significant effect on TLI during CV (Fig. 2) 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. 3). TLI is an essential variable for the pressure controlled ventilation modes. Results of simulations describe and explain some clinical experience.



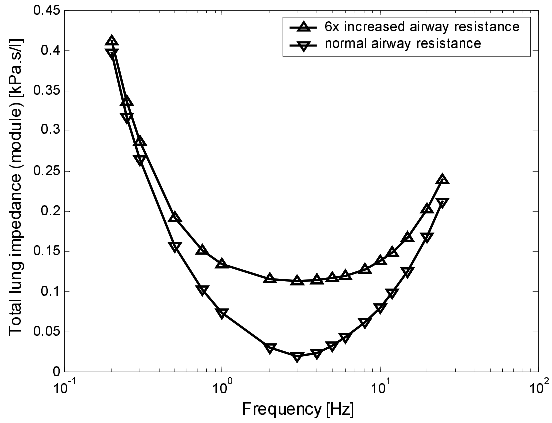


Fig. 2: Dependence of TLI upon frequency for normal and reduced alveolar compliance.

Fig. 3: Dependence of TLI upon frequency for normal and increased airway resistance.

The effect of ventilatory frequency (CV, HFV) upon the pressure inside lung structure is shown in Fig. 4. 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.

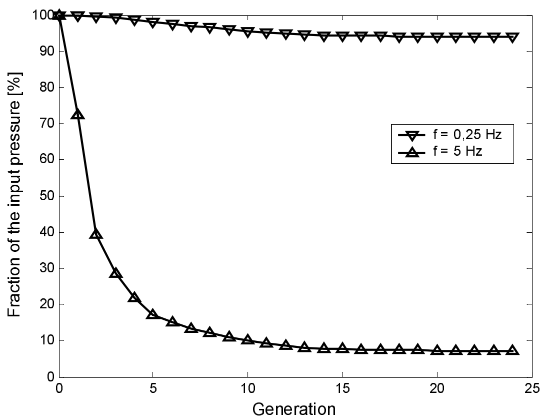


Fig. 4: The effect of frequency upon pressure inside the lung structure.

Reduced alveolar compliance causes a slight decrease in pressure inside the structure for CV (Fig. 5). While using higher frequencies, which correspond to HFV, the pressure inside the structure increases 4 times approximately (Fig. 6). It results in better functioning of HFV with a reduced alveolar compliance, which is the main symptom of adult respiratory distress syndrome (ARDS) [5, 6].

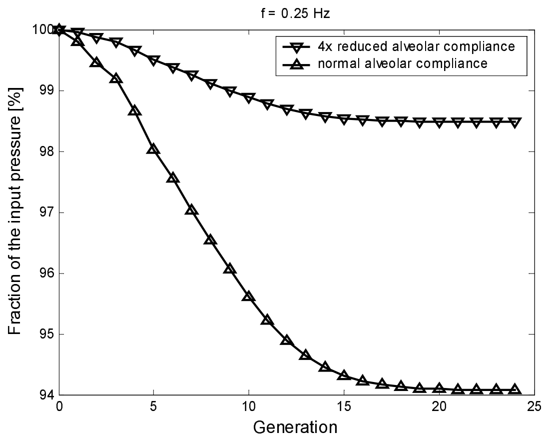


Fig. 5: The effect of reduced alveolar compliance upon pressure inside the lung structure for CV.

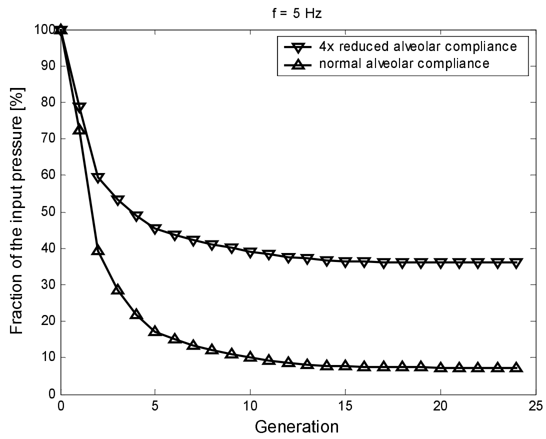


Fig. 6: The effect of reduced alveolar compliance upon pressure inside the lung structure for HFV.

Discussion

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.

Nevertheless, the developed algorithm and the model-based simulations have several restrictions. A harmonic signal of the ventilator is supposed to be applied in the airway opening. A Fourier analysis has to be implemented into the algorithm in order to cover all real ventilatory signal shapes. Another limitation is that the corresponding elements in each generation can not 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.

Acknowledgement

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References

[1] Weibel, E. R. Morphometry of the human lung. Berlin, Springer-Verlag, 1963. 175 p.

[2] Shields, T.W. – LoCicero, J – Ponn, R.B. General Thoracic Surgery. 5th edition, Philadelphia, Lippincott Williams & Wilkins, 2000. Chapter 3, Ultrastructure and morphometry of the human lung, pp. 31-49.

[3] Škvor, Zdeněk. Akustika a elektroakustika. 1. vyd. Praha, Akademie věd, 2001. 527 p. ISBN 80-200-0461-0.

[4] Jongh de F.H.C. Ventilation modelling of the human lung. Delft, Delft university of technology, 1995. 197 p. ISBN 90-5623-014-X.

[5] West, J.B. Pulmonary Pathophysiology – the essentials. 4th edition, Baltimore, Williams & Wilkins, 1992. 219 p. ISBN 0-683-08936-6.

[6] Milic-Emili, J., et al. Basics of respiratory mechanics and artificial ventilation. Milano, Springer-Verlag, 1999. 254 p. ISBN 88-470-0046-7.