A REALISTIC ALVEOLAR DUCT MODEL FOR USE IN WHOLE-LUNG RESPIRATORY SIMULATIONS OF MECHANICAL VENTILATION

Sjeng Quicken (1), Eva Schuijt (1), Ruud Segers (2), Frans van de Vosse (1)

1.Department of Biomedical Engineering, Eindhoven University of Technology, the Netherlands;
2. Department of Intensive Care, Maastricht University Medical Center+, the Netherlands

Background

Mechanical ventilation (MV) is often applied on the intensive care unit (ICU). While essential for patient survival, MV can induce local lung tissue damage due to the highly heterogeneous mechanical response of the lung to MV. This phenomena is better known as "ventilator induced lung injury" (VILI) and can potentially be life-threatening. Reduced order computer modelling of lung response to MV has the potential to locally assess metrics related to VILI development. As such, these models can serve as a valuable tool to study the mechanisms responsible for VILI. However, most respiratory models assume relatively simple alveolar behavior. These models can therefore not be easily adapted to account for pathologies that affect alveolar mechanics. This greatly limits the usability of these models for evaluating lung mechanics in ICU patients, as these patients often do suffer from respiratory conditions that impact alveolar mechanics.
In this study, a 3D finite element alveolar model was developed that can be adapted to represent the effect of pathologies. We use this model to study the impact of lung emphysema and lung fibrosis on the pressure-volume behavior of the alveoli. Finally, we generalize these pathological alveolar pressure-volume relations to assess the impact of MV on pathological lungs.

Methods

A 3D alveolar-duct model consisting of 32 alveoli based on the geometry introduced by (*1*) was created using shell elements in LS-Dyna. Material behavior was described using a 5-parameter Mooney-Rivlin hyper elastic material model. Elastic material properties of the healthy alveolar duct were derived using an efficient inverse modeling approach that aimed to recover the pressure-volume curves published in (*1*).
Next, the alveolar model was adapted to model two common respiratory diseases: emphysema was modelled by removing all internal walls of the alveolar duct, whereas fibrosis was modelled by increasing alveolar wall thickness by a factor 1.7 (*2*). Subsequently, 3D duct behavior was generalized and implemented in a previously developed reduced order respiratory model. Finally, the reduced order model was used to evaluate the effect of MV on lung mechanics in the case of fibrosis or emphysema in the right upper lobe, assuming a tidal volume of 560 mL.

Results

Using the inverse modelling approach a set of material parameters where found that allowed to accurately reconstruct the data presented in (*1*) (Figure 1A). Furthermore, by adjusting model geometry, a stiffening behavior was observed for the fibrotic alveolar model, whereas more compliant behavior was observed for the emphysematous case (Figure 1A). Note that not only the magnitude, but also the shape of the emphysematous and fibrotic curves are different compared to the healthy alveolar model.
In the case of the fibrotic lung it was observed that stretch in the diseased lobe was reduced considerably with respect to the healthy simulation, whereas stretch in all other lobes increased (Figure 1B & C). In the case of the emphysematous lung, stretch in the pathological lobe increased, whereas stretch in all other lobes decreased (Figure 1B & D).

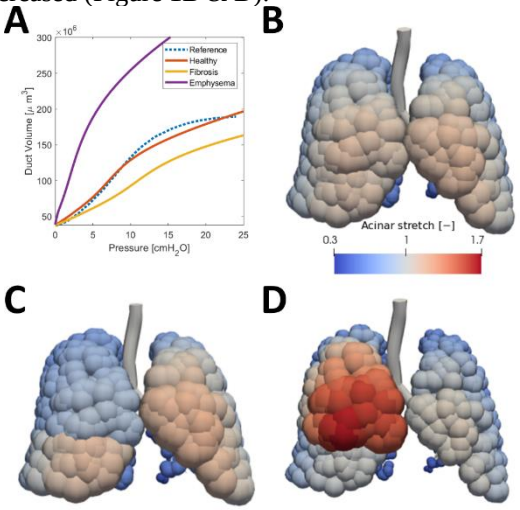

*Figure 1: Pressure-volume curves of the reference from (1) and the 3D models **(A)**. Resulting alveolar stretch distributions for the healthy model **(B)**, fibrosis model **(C)** and the emphysema model **(D)**.*

Discussion

In this study we created a 3D finite element model that allowed to investigate the effect of various pathologies on alveolar mechanics. FEM model response was successfully generalized and implemented in whole lung simulations of healthy, emphysematous and fibrotic lungs. Future research should however be performed to verify the obtained pressure-volume curves for the studied pathologies. The developed alveolar duct model is promising for the evaluation of alveolar mechanics in the presence of pathologies in ICU patients.

References

1. E. Denny *et al.*, *J. Biomech. Eng.* **122**, 143–151 (2000).
2. N. J. Stewart *et al.*, *Eur. Respir. J.* **44** (2014)