RECONCILING THE MESO- AND MICRO-SCALE MECHANICAL PROPERTIES OF LUNG TISSUE USING COMPUTATIONAL MODELING

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INTRODUCTION

Many computational models have been developed for the lung at various spatial scales, while morphological studies combined with increased computing power have allowed for model expansion to smaller length scales. Yet, the wide range of experimental techniques and reported constitutive models for lung tissue at different length scales can lead to uncertainty when utilizing such material properties in computer modeling. Therefore, this study aims to use *in silico* modeling to compare, reconcile, and resolve the differences reported in lung tissue mechanics at different length scales. Specifically, this research aims to utilize computational modeling to study whether the emergent mechanical properties of lung tissue, based on microscale mechanical testing data, can be reconciled with the experimental data reported at the mesoscale.

METHODS

A finite element (FE) analysis was performed using COMSOL MultiPhysics at the mesoscale by assigning visco-hyperelastic microscale-based properties to alveolar septa based on previously reported *in vitro* and *in situ* experiments [1]. The 3D geometry comprised an array of approximately 10,000 alveoli represented by truncated octahedra and meshed using 2.2 million quadratic tetrahedral elements. The emergent properties from the FE analysis were then compared to mesoscale data from a study that utilized a comprehensive approach to determine the mechanical behavior of rat parenchyma [2]. The standard linear solid viscoelastic model was added to the microscale hyperelastic constitutive models to account for the effect of rate of loading [3]. The viscoelastic stress (σ_q) of the standard linear solid model was determined by the equation:

$$\sigma_q = 2n_1\dot{\gamma}_1 \qquad (1)$$

Where n_1 is the viscosity and is related to the stiffness (G_1) and relaxation time (τ_1) by $n_1 = G_1\,\tau_1$. Also, $\dot{\gamma}_1$ is the strain rate.

RESULTS

The tensile test simulation results (Figure 1) showed reasonable agreement with the reported mesoscale data [2] at strains between 0.0-0.3. Specifically, the simulated curve based on the work of Perlman and Wu [1] showed slightly lower stiffness compared to the reported mesoscale behavior model below ~28% strain. Above 30% strain, the disagreement between the simulated microscale-based curve and the mesoscale dataset increased. The mean error was determined for each simulated case concerning the reported mesoscale data to quantify the difference in the resulting stress-strain curves.

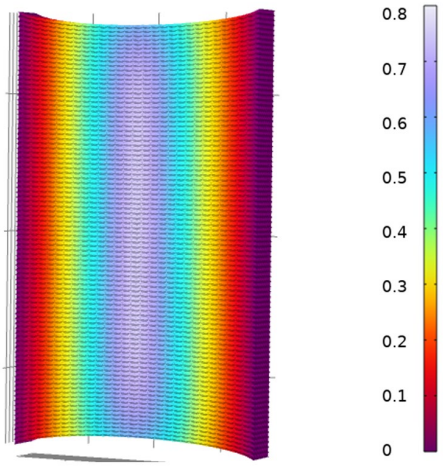

Figure 1: Strain distribution in the uniaxial tension model of 3D model at maximum displacement. The microscale constitutive models are applied to the walls of the truncated octahedra.

DISCUSSION

In this study, we analyzed two of the most comprehensive and high-fidelity mechanical testing datasets published by other researchers for the purpose of this study: the microscale data reported by [1] and the mesoscale multimodal data of [2]. Overall, the comparative research successfully reconciled the mechanical properties of lung tissue across micro- and mesoscales. In addition, this research further confirmed the reasonable accuracy of the mechanical behavior reported for lung tissue in both experimental studies. Furthermore, this study showed that FE modeling could be used as an informative and guiding tool to investigate and potentially resolve the differences in reported lung tissue mechanical properties across spatial scales.

References

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Acknowledgements

This material is based on the work supported by the National Science Foundation under award # 2034964.