A MULTI-SCALE PHYSICS-BASED COMPUTATIONAL MODEL OF MECHANICAL VENTILATION IN COVID-19 PATIENTS

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INTRODUCTION

Coronavirus disease-2019 (COVID-19) is a severe respiratory illness that presents unprecedented challenges. COVID-19 acute respiratory distress syndrome (CARDS) differs significantly from typical ARDS, with increased mortality rate and occurrence of consolidation and ground glass opacities (GGOs). Mechanical ventilation (MV) is a common treatment to severe CARDS. MV has a high risk of ventilator-induced lung injury (VILI) and a consequently high mortality rate. Thus, this study aims to present a novel *in silico* coupled 3D/0D model capable of simulating patient-specific responses to MV based on clinically sourced CT images of four COVID-19-afflicted lungs, to improve the understanding of airflow dynamics in the lung during MV, and to provide new insights into risk factors of VILI.

METHODS

Four lung 4DCT scans obtained from patients hospitalized for COVID-19 are used. The geometry of the first airway generations, lung lobes, and COVID-19 damaged regions were segmented using Materialise Mimics 23.0 and the Chest Imaging Platform in 3D Slicer. The C++ simulation package CHASTE (Cardiac, Heart, and Soft Tissue Environment) was used to create conducting airways (Figure 1-top) and to establish multi-scale coupling of airways and a patient-specific sigmoidal acinar model [1]. Acini within segmented GGO and consolidated regions were modified with a surfactant loss to model damage. Airflow was presented with a modified Poiseuille flow profile with corrections to dynamic resistance and driven by a pressure-control ventilator waveform. Lung volume-based pleural pressure variation was modeled to simulate the weight of the chest cavity on a passive patient.

Results

Flow and volume over time from each simulation was analyzed in the full lung and within each lobe (Figure 1-bottom). Healthy and COVID-19 tidal volumes significantly differed in full lungs and between individual lobes. Lobar tidal volume was divided by total tidal volume to determine individual lobar share. Percent change in lobar share and relative COVID-19 damage, defined as the difference between lobar COVID-19 damage and average lung COVID-19 damage, had a strong negative correlation when all lobes are compared. Healthier lobes tended to increase their ventilation while more damaged lobes tended to decrease their share of ventilation in in these simulations.

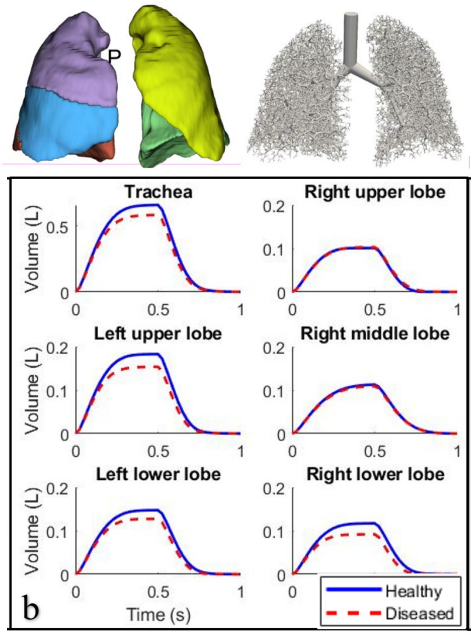

Figure 1: (top) Segmented lung and airway tree, (bottom) Evolution of lung volume over time for healthy and COVID-19 simulations for Subject 2.

Discussion

There is a need for high-fidelity physics-based, patient-specific models of COVID-19 lungs to understand better and potentially improve MV outcomes. In this research, we developed multi-scale physics-based computational models of MV in COVID-19 patients and compared the results to a hypothetical healthy lung subjected to MV for comparison. This study is important as a basis for physics-based simulation of heterogeneous, patient-specific COVID-19-induced damage in mechanically ventilated circumstances. Results showed proportional redistribution of ventilation from heavily damaged lung lobes to less damaged lobes, which can place additional mechanical strain in those regions, offering further insight into the airflow mechanics of mechanically ventilated COVID-19 patients.

References

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