PERSONALISED COMPUTATIONAL MODELS TO STUDY THE IMPACT OF COVID-19 LUNGS UNDER MECHANICAL VENTILATION

Dale Kernot (1), Jason Carson (1), Raoul van Loon (1), Hari Arora (1)

1. Department of Biomedical Engineering, Swansea University, UK

Introduction

COVID-19 has claimed millions of lives worldwide and the highly transmissible virus can cause devastating damage to organs, particularly affecting the lung. In some cases, COVID-19 pneumonia develops into acute respiratory distress syndrome (ARDS), a precursor to respiratory failure. If a patient fails to respond to non-invasive intervention, invasive mechanical ventilation (IMV) is required. IMV can save lives but can also lead to longer-term ventilator-induced lung damage.

This work proposes a modelling framework to analyse the lung function of mechanically ventilated COVID-19 patients to analyse flow and pressure distributions throughout the lung, using automated segmentation of patient pulmonary computed tomography (CT) scans to improve the practicality of modelling larger datasets.

Methods

From a selection of patient CTs, automated labelling of lung boundaries is carried out (Hofmanninger et al. [1]), along with the segmentation of airways, using existing trained machine learning models (Wang et al. [2]).

A volume-filling network generation algorithm, extended from Kitaoka et al, was used to fill the remaining lung volume with airways down to the 23rd generation. A reduced-order computational fluid dynamics simulation was then performed to study flow and pressure distributions throughout the lungs when under mechanical ventilation. This workflow is illustrated in figure 1.

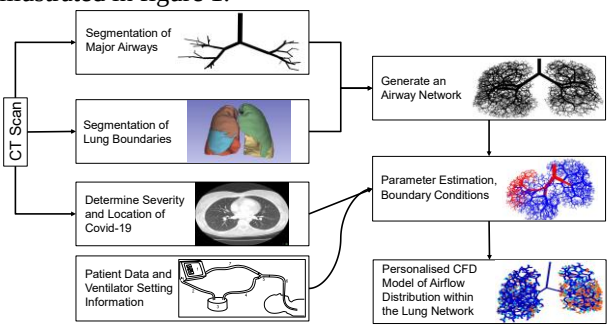

Figure 1 - An overview of the framework to progress from patient scan to personalised CFD model.

Results

During the network generation process over 900,000 airways are created down to the 23rd generation, this network shows similar statistical properties to that seen in other works such as Weibel et al. [4]

Model resistances and compliances were adapted to investigate the global effects of these parameters, which had the expected effect on the pressure-volume loop. Two cases are compared, one with mild disease and another with severe disease. Results show the severe case displays a significant increase in lung distention when compared to the mild case.

The speed of segmentation and time efficiency is increased by using the automated framework as opposed to the semi-automated techniques previously utilised within 3D slicer (https://www.slicer.org/ - Fedorov et al).

Discussion

Covid-19-induced lung damage can produce fibrosis-like (reduced compliance and increased resistance to airflow) and emphysema-like (increased compliance and reduced resistance to airflow) effects in different regions of the lung. The distribution of these can cause significant changes to the flow and pressure distributions, thus directly influencing alveolar distension. This is particularly apparent when neighbouring regions have an opposing effect, i.e. one region has a lot of fibrosis and a nearby region has a lot of emphysema.

In addition to the improved time efficiency, utilising a ML based automated segmentation tool for labelling of CTPAs provides a consistent standard, avoiding intra-person differences that may arise if manually segmented.

References

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