Flow analysis in patient specific lower airways using PIV

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In this study a novel method for creating airway models is described and the study aims to investigate the airflow in the lower airways experimentally with Particle Image Velocimetry (PIV). A qualitative and quantitative comparison to Computational Fluid Dynamics (CFD) simulations was made.

1. Introduction

Pulmonary diseases like Chronic Obstructive Pulmonary Disease (COPD) and Asthma are becoming more important and the number of people suffering from one of these diseases is increasing rapidly. In the case of severe hyperinflation in COPD patients, a possible treatments consists of volume reduction surgery where the inflated regions are removed to enhance the ventilator airflow towards better perfused regions (Tiong et. al.). An alternative technique is to place a one-way endobronchial valve causing a deflation of the lung region. (Strange et. al.). Considering the inherent variability in patients and outcome procedure it would be beneficial to improve our understanding of the airway mechanics using experiments and modeling. This study (i) describes the airway model manufacturing process and (ii) investigates the airflow into the lower airways.

2. Materials and methods

High resolution CT scans taken with a multi-slice scanner (GE VCT Lightspeed) were imported in a commercially available image segmentation software package (Mimics 10.0, Materialise, Leuven, Belgium). The trachea until the third bifurcation was extracted from the original STL file to develop the physical model. Using Fused Deposition Modeling (FDM, Stratasys Inc.) the kernel of the airway was printed in WaterWorks\textsuperscript{\textsc{TM}} and supported in Acrylonitrile Butadiene Styrene (ABS).

![Fig. 1 PIV model development cycle](image)

Using vacuum casting, transparent silicone (Dow Corning, Sylgard 184) was poured around the kernel. The silicone allows for optical access and matches the refractive index of the working fluid (water/glycerin mixture) (Hopkins et. al. 2000). The kernel was removed by washing it out in sodium hydroxide. Figure 1 shows the development cycle.

3. Results

2D PIV steady and oscillating flow experiments were performed for multiple Reynolds numbers based on the hydraulic diameter of the trachea. The velocity profile was measured in the midplane of the trachea. Figure 2 shows the in plane velocity at maximum inspiration during an oscillating flow of 0.2 Hz.

![Fig. 2 In plane flow velocities during inhalation. Reynolds number = 135, Womersley number = 2.58. Left: PIV result; right: CFD result](image)

4. Conclusion and future

An experimental platform for investigating the airflow in the lower airways was developed. A patient specific human airway model was designed and developed using an innovative technique for the kernel development. 2D PIV measurements were performed and the flow pattern was compared to CFD results for stationary and oscillating flow boundary conditions. Further investigations will be performed for a wider range of Womersley and Reynolds numbers. Afterwards 3D PIV measurements will be done to be able to compare velocity magnitudes instead of in plane velocity components. On a longer term this platform helps investigate the flow pattern in airways to predict the success of surgical interventions.

References