DPIV measurements of dynamic flow patterns in a realistic model of the lung airways down to the 6th generation

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The objective of the study is a more detailed analysis of lung ventilation under normal breathing conditions and for artificial, respirator-assisted ventilation. Therefore a realistic 3D model of the lung down to the 6th generation was generated to investigate the oscillatory flow through the branching network by DPIV. A transparent model made of silicone is used in combination with a refractive index matching fluid (water/glycerin). The Measurements were carried out using hydrogen bubbles as tracer particles. The mass flow rate and the frequency were adapted to the characteristic flow parameters of the air flow in the human lung keeping the Reynolds- and Womersley-number constant. A first comparison of the results for the inspiration and expiration phase demonstrates the different nature of the flow. During inspiration one can see larger flow separation regions at the outer walls of the bifurcating channels which sometimes extend downstream to the next bifurcation. In contrast, the flow at expiration does not separate at all and shows the typical jet-like profile at the exit of the trachea. The complete cycle of inspiration and expiration suggests that due to the transformation of the velocity profiles and the generated separation regions a net mass flow is created into the model along the centerline and the inner walls of the bifurcations. This is compensated with a net mass outflow to the trachea along the outer walls of the branches along the separation regions which are washed upstream during expiration. At higher breathing frequencies this effect is enhanced which may help to remove deposited particles in the lung network.

1. Experimental set-up

Flow visualization and quantitative flow measurements were done using hydrogen bubbles as tracer particles which were recorded by a CCD camera. (PCO.1600, 1600x1200 pixels resolution, 15 fps at full resolution, 2GB camRAM). First results were obtained for stationary inflow conditions in the trachea.

The experiments with stationary inspiration flow were carried out at a Reynolds-number of Re = 1000 defined with the inlet tube diameter (∅ = 2 cm) which is approximately the diameter of the trachea and the mean bulk flow velocity for peak inspiration flow rate under normal breathing conditions at rest with a respiratory volume of . In addition to the stationary inflow conditions the measurements were carried out also for pulsating flow conditions at a physiological Strouhal-number of Sr = 0.01 and a Womersley-Number of Wo = 3.24 for breathing at rest conditions. To study the effect of clinical high-frequency ventilation support devices, higher frequencies were simulated, too. For all the above given cases, DPIV-measurements were taken in different light-sheet positions and for several regions of the branching network. The laser used for the measurements is a 120mJ Nd:YAG double pulse laser. The time delay between two subsequent pulses was 400µs. During stationary flow conditions pictures were taken at a frequency of 5Hz.

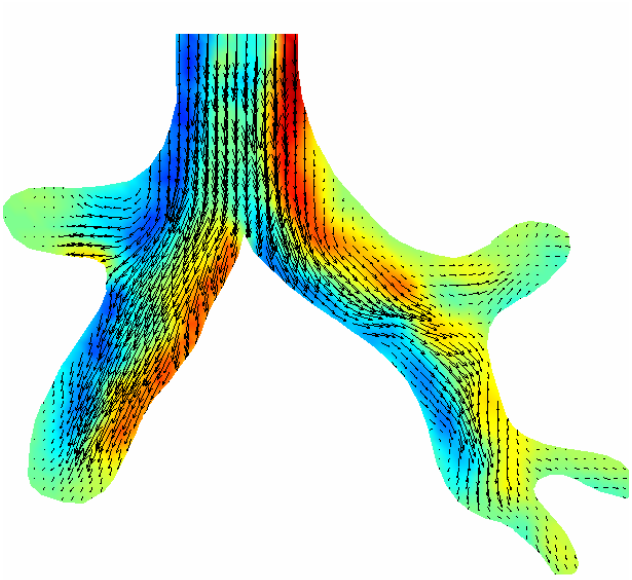

Fig. 1 Peak inspiration flow

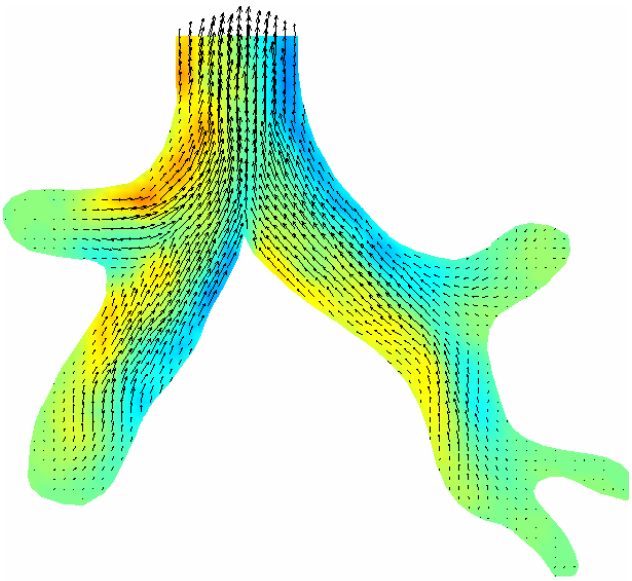

Fig. 2 Peak expiration flow