Exploration of Gas Flow during High Frequency Oscillated Ventilation by ^{19}F-Gas-MRI

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Introduction

High frequency oscillated ventilation (HFOV) is a protective ventilation method used for patients with acute respiratory distress syndrome (ARDS). Compared to conventional ventilation it uses relatively high ventilation frequencies (5 – 10 Hz) and small tidal volumes (ca. 2 mL/kg) to reduce ventilator associated lung injury (VALI). The aim of this work is the development of new methods to measure gas flow in large airways during HFOV using ^{19}F MRI.

Materials and Methods

To detect convective flow inside a tube phantom representing the human trachea the fluorinated contrast gas C_3F_7H (Heptafluoropropane) was used. All experiments were performed on a Siemens Magnetom Sonata (1.5 T). In a first study of two experiments, measurements at a constant volume flow (20 l/min and 32.5 l/min) of fluorinated gas inside the tube was compared with results from Computational Fluid Dynamics (CDF) simulations. For flow detection a flow sensitive ^{19}F-gradient-echo-(GRE)-sequence was used (Larmor frequency = 59.9 MHz, slice thickness = 75 mm, TR/TE = 15/3.7 ms, FA = 35°, raw data matrix = 36x48). In the main experiment a mechanical lung model was built. Here, the trachea was represented by a pipe and its lung by an elastic ventilation bag (1.5 L). At ventilation frequencies of 5 and 10 Hz the MR-measurement was triggered by the ventilator. Similar to the clinical situation, the tube system was open und Heptafluoropropane was continuously applied. The adjusted parameters for the GRE-sequence were: slice thickness = 100 mm, TR/TE = 20/3.3 ms, FA = 40°, Matrix = 14x32, frequency = 59.9 MHz.

Results

Figure 1 demonstrates the good agreement between the 19F-MRI data and the CFD simulations. Furthermore, for the HFOV experiment it was possible to explore the applied pressure wave point-by-point and to determine the corresponding velocities. In figure 2, the development of velocity distribution inside the pipe is shown with a temporal resolution of 10 ms.
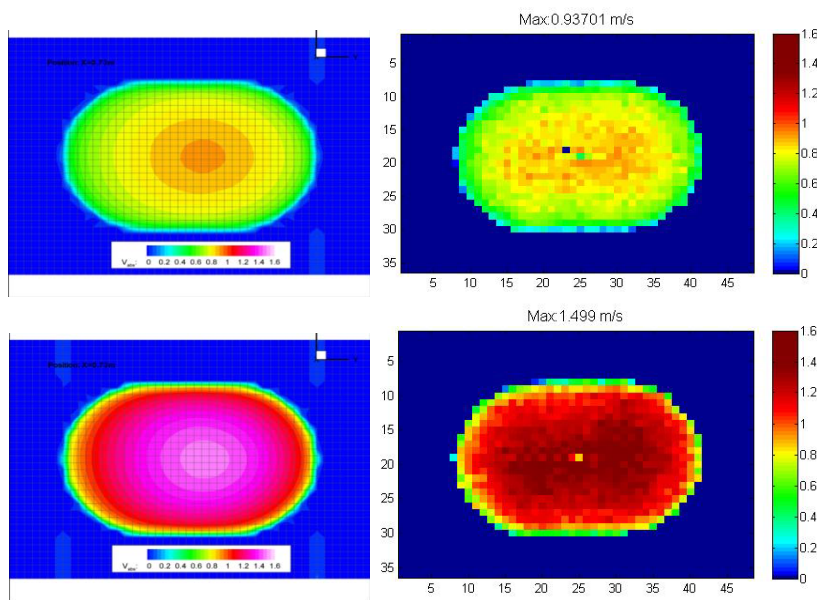

Fig.1: Comparison between simulation (500 Iterations) and measurement for constant flow 20 L/min and constant flow 32 L/min
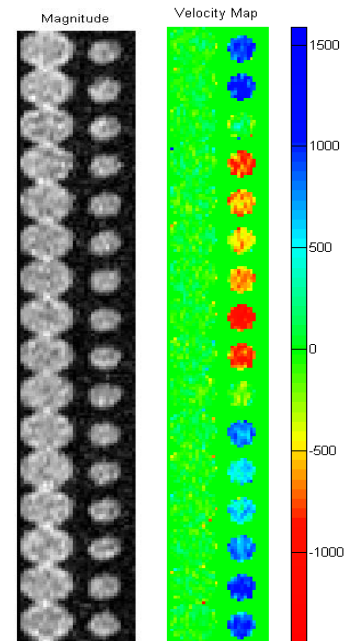

Fig.2: Magnitude images (left) and corresponding velocity images (right) with reference object

Discussion

The feasibility of flow measurement using fluorinated contrast gas during high frequency oscillated ventilation was shown for the first time. We observed a good agreement between MRI and CFD. Further work needs to include validation of the MR data, e.g. by particle image velocimetry. Then the new technique can be applied to HFOV measurements with a variation of breathing parameters like frequency, pressure amplitude and volume flow.

Acknowledgement: