^{19}F Gas Flow Measurement of C_3F_7H during Constant Flow and High Frequency Oscillatory Ventilation

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Introduction

Gas flow measurements can help to understand the complex gas transport mechanisms under conditions of artificial ventilation methods. A protective artificial ventilation strategy that is widely used for patients with acute respiratory distress syndrome (ARDS) is high frequency oscillatory ventilation (HFOV). This ventilation method uses a constant distending airway pressure and a small oscillating tidal volume with frequencies between 3 and 12 Hz. Up to now the gas transport mechanisms during HFOV are not completely understood (1).

The aim of the current study is the development of MRI methods that enable the investigation of gas transport mechanisms during HFOV. This work includes measurements of constant gas flows in straight pipes, and the comparison of the MRI measurements with reference data obtained by direct numerical simulations (DNS), and with a gas flow meter. Further, time dependent velocity profiles are measured in an oscillatory pipe flow using MRI.

Material and Methods

All experiments were performed on a 1.5T MRI system (Siemens, Magnetom Sonata, Erlangen, Germany). A ^{19}F birdcage coil (RAPID Biomedical, Würzburg, Germany) was used for RF transmission and reception. The gas heptafluoropropane (C_3F_7H) was used as contrast gas for ^{19}F-MRI. It is a colorless gas that is already used as propellant for pharmaceutical aerosols. Two straight acrylic glass pipes with diameters (2.0 and 2.6 cm, respectively) that are comparable to the dimension of the human trachea were used as measurement phantoms. A velocity sensitive gradient echo sequence was utilized. Experiments using constant flow rates (19.9, 30.6 and 41.4 L min^{-1}) were performed and compared to DNS results obtained by integrating the Navier-Stokes equations using a finite volume method. In addition, flow rates were measured with a flow meter (VSM-02, Optiserve, Heilbronn, Germany). Subsequently, an HFOV device was modified in order to trigger the MRI system and to allow for a phase correct measurement during oscillatory flow in the second pipe. Thus, the axial velocity component of a 4-Hz-ventilation was determined pixel wise in a slice of 40 mm thickness at different ventilation phases of the oscillation period with an in plane resolution of 1 x 1 mm.

Results

The velocity profiles for constant flow rates are in good agreement with the DNS results (FIG.1). They are flattened in the bulk and exhibit steep gradients at the wall, as expected for a turbulent gas flow at a Reynolds number as high as 11,000. The flow rates determined by MRI agree with the acquisition of the flow meter (FIG.2). The implemented trigger regime allowed for the measurement of velocity profiles during HFOV and the tracking of these profiles over time (FIG.3).

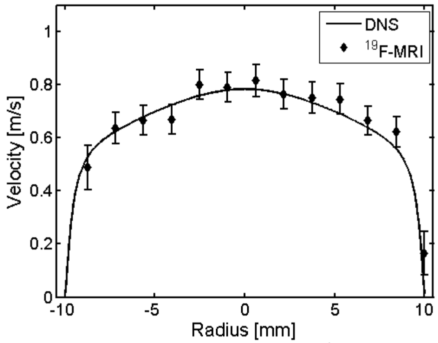

FIG.1: Velocity profile measured by ^{19}F-MRI compared to DNS results for a flow rate of 30.6 L/min.

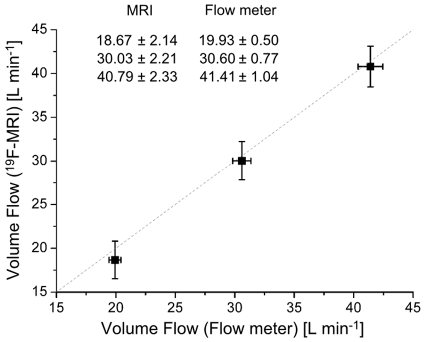

FIG.2: The volume flow measured utilizing a volume flow meter verifies the ^{19}F-MRI data.

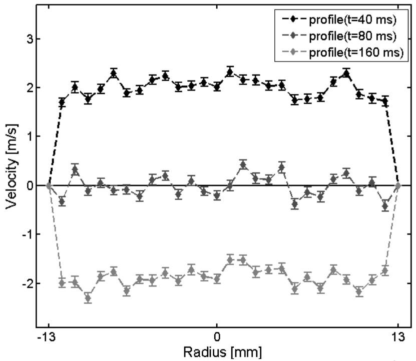

FIG.3: Three velocity profiles measured with ^{19}F-MRI at different phases of a HFOV cycle (f_{HFOV} = 4 Hz).

Discussion

The introduced results confirm the possibility of measuring turbulent gas flow using the fluorinated contrast gas C_3F_7H for ^{19}F-MRI. To overcome the relatively low signal intensity, a high number of averages was needed. This prolongs the measurement time substantially. The zig-zag-pattern that is adumbrated in the flow profiles may be attributed to small eddies that characterize turbulent flow and fluctuate with time and space. A higher number of averages may smooth the MRI flow profiles and they may align even more to the simulated data. A geometrical optimized RF coil as well as parallel imaging may help to reduce overall measurement time and/or allow for more averages.

In conclusion this work introduces a MRI method to measure gas flow during different ventilation strategies. This may help to understand complex gas transport mechanisms in large airways.

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References

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