Gas Flow Measurement using ^{19}F-MRI during Constant and Oscillating Flow

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Introduction

Protective ventilation strategies have an important function in intensive care medicine. Besides ensuring a sufficient gas exchange, a ventilator induced lung injury (VILI) needs to be prevented. A protective ventilation strategy mainly used for patients suffering from acute respiratory distress syndrome (ARDS) is the so called high frequency oscillatory ventilation (HFOV). Here, a constant distending pressure, that keeps the lungs open, is superposed by an oscillation with a frequency between 3.5 and 15 Hz. Up to now the gas transport mechanisms of this ventilation strategy are not completely understood. Thus, the aim of the present study was the flow measurement of Heptafluoropropane (C_3F_7H) using phase contrast MRI. Therefore, experiments for constant flows (*20, 30* and *40* L/min) and oscillating flow (4 Hz) were performed and compared to direct numerical simulations (DNS) and a reference flow measurement via flow meter.

Methods

All experiments have been performed on a 1.5T system (Siemens, Magnetom Sonata, Germany) using a ^{19}F birdcage coil for RF transmission and receiving. Using a flow sensitive gradient echo sequence, two dimensional maps of the axial velocity component were measured inside a straight acrylic glass pipe with clinically relevant diameter. Experiments were performed for constant flows with Reynolds numbers Re = {10254, 15744, 21306} and high frequency ventilation using a frequency $f = 4$ Hz. The measurements for constant flow were compared via descriptive statistics to DNS results that were obtained by integrating the Navier-Stokes equations using a finite volume method. In order to accomplish a phase correct measurement during oscillating flow the MRI system was triggered by the HFOV device. Thus, the axial velocity component of the 4-Hz-ventilation was determined pixel wise at 14 different time points of the oscillating ventilation.

Results

Axial velocity profiles for constant and oscillating ^{19}F gas flow were measured. The velocity profiles under constant flow (exemplarily shown for Re = 21 306 in Fig. 1) as well as the statistical results (Fig. 2) are in good agreement with the DNS results for all three Re. In Fig. 3, three of 14 profiles, each representing a different phase within the high frequency ventilation cycle, are shown. The so called Womersley number *Wo* is used to characterize oscillating flow [1].Womersley showed that for flows with *Wo >> 1* the profiles are flattened and a high velocity gradients close to the pipe wall occur [1]. This behavior could be reproduced in our ^{19}F measurements (Fig. 3).

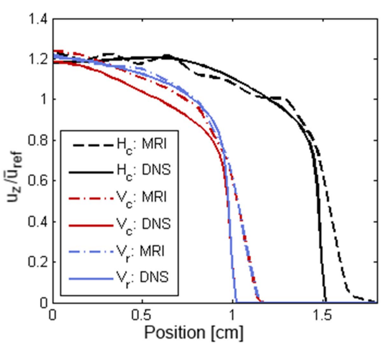

Fig. 1 Axial velocity profiles for *Re = 21 306* measured at the positions V_C, V_R and H_C in comparison with DNS profiles at the same positions.

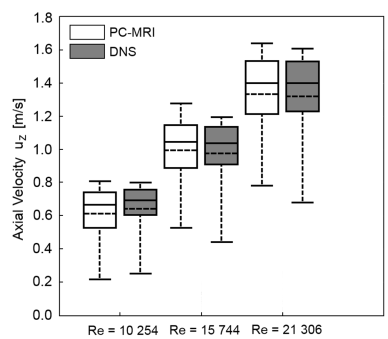

Fig. 2 Statistical comparison of the velocity distribution between PC-MRI and DNS for *Re = {10 254, 15 744, 21 306}*. The straight line represents the median while the dotted represents the mean value of the distributions.

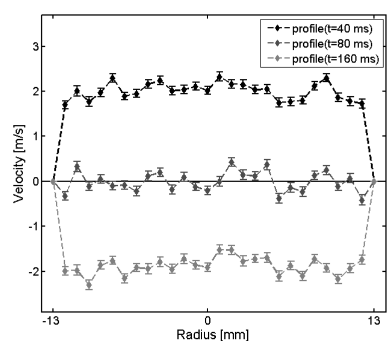

Fig. 3 Three of 14 velocity profiles measured at different phases of the high frequency ventilation cycle (f_{HFOV} = 4 Hz)

Discussion

Our results confirm the possibility of measuring turbulent gas flow using the contrast gas C_3F_7H for ^{19}F-MRI. The overall agreement with simulated DNS results was very good. Arising deviations are mainly located close to the wall, where low velocities and high velocity gradients occur. They are caused by partial volume effects as well as the larger relative error for low velocities due to the scaling velocity *venc* of the MR measurement.

Acknowledgement

This study was supported by: German research foundation, DFG (SCHR 687/5-1, SCHR 687/5-2 and WA 1510/8-2).

References

1. Womersley JR. Method for the Calculation of Velocity, Rate of Flow and Viscous Drag in Arteries When the Pressure Gradient Is Known. J Physiol-London 1955;127(3):553-563.