19F-MRI: Flow Measurement of Fluorinated Gases During High Frequency Oscillatory Ventilation

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Introduction

High frequency oscillatory ventilation (HFOV) is a protective ventilation method mainly used for patients with acute respiratory distress syndrome (ARDS). Contrary to conventional ventilation strategies it uses small tidal volumes, high breathing frequencies and a constant distending pressure in order to reduce ventilator associated lung injury (VALI). To investigate the complex gas stream behavior under HFOV new proceedings are required. The present work demonstrates how MRI of fluorinated gases (^{19}F-MRI) can help to explore these mechanisms.

Material and methods

All measurements were performed at field strength of 1.5T (Magnetom Sonata, Siemens Erlangen, Germany) with a double resonant ^{19}F/^{3}He coil (Rapid Biomedical, Würzburg, Germany) and with the fluorinated gases Heptafluoropropane (C_3F_7H) and Octafluorocyclobutane (C_4F_8). In comparison with other available fluorinated gases (C_2F_6, SF_6) they have relatively long relaxation times (C_3F_7H: T_1=19.9ms, T_2^*=14.7ms; C_4F_8: T_1=25ms, T_2^*=20ms) which offer enough time to perform a velocity encoding gradient. A straight acrylic glass pipe with a diameter comparable to human trachea was used as phantom. A velocity sensitive gradient-echo-(GRE)-sequence was utilized to determine the flow within the phantom. Preliminary experiments on constant flow were performed and compared to theoretical prospects to verify the reliability of gas flow information measured with ^{19}F-MRI. In a second step oscillated through-plane flow of two different frequencies (7 and 10Hz; slice thickness: 100mm) along scanners z-axis was explored in two different ways: First, flow was assessed by evaluation of acquired phase images of a 2D measurement. Second, flow was determined by projection measurement on readout direction by skipping the phase encoding gradient. In this manner 28 triggered velocity encoding steps with a temporal resolution of 10ms were performed for each method.

Results

The flow profile generated under constant flow conditions correlated with theoretical prospects determined by the 1/7 power law for turbulent flow as shown in figure 1.

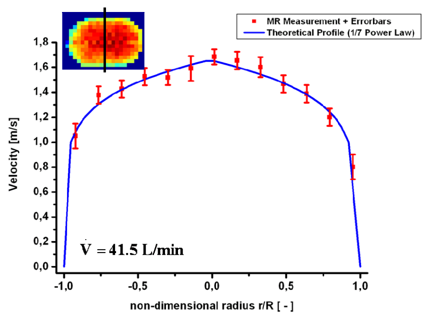

Figure 1: Flow profiles of C_4F_8 with error determined by ^{19}F-MRI (red) in comparison with theoretical velocity profile (blue) predicted by 1/7 power law for turbulent flow.

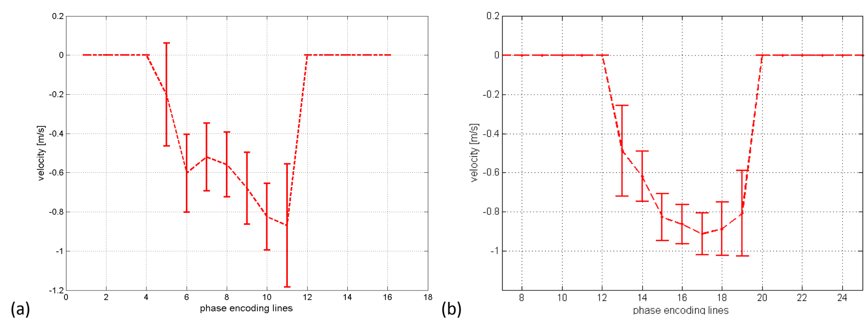

Figure 2: Flow profiles of C_3F_7H with error determined by ^{19}F-MRI during high frequency oscillated ventilation with 7 Hz. (a) Profile gained by 2D measurement and (b) by 1D measurement. The time span between trigger pulse and data acquisition was the same for both measurements.

Flow profiles could be recorded under HFOV conditions for two different frequencies (7 and 10 Hz). Additionally, an adequate trigger regime allowed for tracking these profiles over time with a temporal resolution of 10ms. The velocity error was determined by signal-to-noise ratio of the magnitude image. In comparison to constant flow the velocity errors for HFOV are much larger but could be reduced by using the 1D measurement. Flow profiles with error bars of 2D and 1D measurement are shown in figure 2.

Discussion

Experimental and theoretical data show good agreement for constant flow conditions. Under HFOV the signal-to-noise ratio was much lower than under constant flow. Especially at wall regions of the phantom partial volume and saturation effects occur due to reduced gas redistribution and low velocities. Hence, the velocity error for HFOV is greater than for constant flow. Here, the 1D method has shown obvious advantages. Measurement time could be reduced by a factor of approximately two while increasing the amount of averages by a factor of eight. Thus, SNR increases significantly.

Conclusion

Preliminary experiments on constant flow demonstrated that flow measurement with fluorinated contrast gases is feasible and correlates with theoretical considerations. First experiments under HFOV show that flow measurement of fluorinated gases can be done as well during HFOV.

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