3He and 19F MRI of High Frequency Oscillatory Ventilation (HFOV)

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Introduction:

HFOV is a protective ventilation strategy to prevent ventilator associated lung injury by repeated distension of alveoli during artificial ventilation. It comprises small tidal volumes (2mL/kg, pressure variation with 5-10 Hz and a constant distension pressure. Gas transport during HFOV is complex, the relative contribution of convective and diffusive motion, asymmetric velocity profiles, Pendelluft and Taylor dispersion are unknown [1]. Recently, 19F [2] and hyperpolarized 3He MRI [3] methods have been developed to analyse gas redistribution during normal breathing as well as during artificial ventilation. The aim of this study is to compare slow and fast gas redistribution during HFOV as measured with 19F and hyperpolarized 3He MRI in pig studies.

Methods:

An MRI compatible HFOV setup has been developed [2]. It comprised an HFO ventilator (Viasys, Germany), a trigger output to control the MRI acquisition and 4m tubes for gas supply. MRI was performed using a double resonant 19F/3He birdcage TX/RX coil (Rapid Biomedical, Rimpar, Germay). For 19F studies, C4F8 gas has been used (Air Liquide, Germany), for 3He MRI the gas has been polarized to approx. 60% polarization.

Slow gas redistribution was measured using both 19F and 3He MRI. For this purpose, a single 200 mL bolus of 3He was given ex-vivo during HFOV, and the temporal evolution of the signal intensity (SI) was observed using dynamic MRI with 1 image/sec. For 19F MRI in-vivo, the animal was first ventilated with a mixture of 80% C4F8 and 20% O2. Then the washout was observed with 1 image / 5 s by using ventilation with pure oxygen.

Rapid gas exchange was measured using the "burnt-slice technique" [3], where a slice perpendicular to the imaging plane was first saturated, i.e. the MRI signal from hyperpolarized 3He was removed. Rapid gas distribution was observed using dynamic imaging (10 images/s). It resulted in an initial signal increase in the previously saturated region, and in a subsequent signal decrease (gas elimination). All experiments were performed after approval of the local animal care committee in domestic pigs (24-26 kg)

Results:

Both, 19F and 3He MRI were feasible during HFOV. However, the continuous oscillatory motion of the lung induced a degradation of the image quality (e.g., 30% reduction of the signal-to-noise ratio (SNR) at 19F MRI of C4F8 in-vivo. T1 relaxation by paramagnetic oxygen was rapid because of effective gas mixing. Therefore, the 3He study was performed immediately after the animal's death, and using ventilation with N2 as a surrogate for ventilation with normal air.

3He wash-out was slower with 10 Hz ventilation as compared with 5Hz, and in non-dependent lung as compared with dependent lung. 19F MRI gave similar results: 53 ± 18s and 126 ± 39 s for 5 Hz and 10 Hz, respectively.

Rapid gas exchange measurements using hyperpolarized 3He gave gas redistribution time constants of 2.9±1.6s vs. 4.3±1.9s for 5 Hz and 10 Hz, respectively, and elimination time constants of 31 ± 7 s vs. 60 ± 17 s. The redistribution time constants increase by a factor of approx. 3 in non-dependent regions in comparison to dependent for both 5 Hz and 10 Hz HFOV.

Discussion and Conclusion

MRI during HFOV is feasible and provides insight into slow and rapid gas transfer processes in the lung. Gas transfer processes are less effective at 10 Hz than at 5 Hz. Results of measurements with hyperpolarized 3He and C4F8 gas give similar qualitative results. Quantitative results, however, differ somewhat, probably because of different type of experiments (single-bolus washout vs. continous washout measurements, "burnt-slice"). Moreover, differences between the physical characteristics (e.g., density, viscosity, diffusion coefficient) of the contrast gases 3He and C4F8, when compared with those of the respiratory gases O2 and CO2, need to be considered in the interopretation of the results

In conclusion, contrast gas based MRI is a new tool to visualize and analyze intrapulmonary gas transport processes during artifical ventilation.

References

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