

Regional Analysis of Gas Elimination and Redistribution in Lungs during High Frequency Oscillatory Ventilation studied with hyperpolarized ^3He MRI

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Introduction

High-frequency oscillatory ventilation (HFOV) is a ventilation technique used in patients with acute respiratory distress syndrome (ARDS) in the field of critical care medicine. A number of fundamental question concerning HFOV gas transport mechanisms, such as type of flow pattern generated in airways, set of optimal ventilation parameters (mean flow, mean pressure, pressure amplitude) are still open. MRI with gaseous hyperpolarized ^3He is known to be a powerful tool to acquire information about lung functional properties providing direct visualization of both airways and gas distribution within the lung's parenchyma. The aim of the current work is to develop a method for characterizing gas elimination and redistribution effects in lung under HFOV conditions using hyperpolarized ^3He MRI.

Methods

With approval of the local animal care committee, four anesthetized domestic pigs (37 ± 3 kg) were investigated. Using prolonged (4m) pipes animals were ventilated by a HFOV-device. Respiratory frequencies of 5Hz and 10Hz were used with a gas flow of up to 30L/min and pressure amplitude $\Delta P=50$ mbar. MRI measurements were done immediately after killing animals by potassium chloride. Oxygen was pre-washed out by nitrogen to avoid paramagnetic depolarization of ^3He during HFOV. Boluses of 300ml 60% hyperpolarized ^3He were administered via a stop-cock into the lung. The HFOV elimination of ^3He was imaged using a 1.5T scanner (Sonata, Siemens, Erlangen, Germany) with double tune $^3\text{He}/^1\text{H}$ bird cage (Rapid Biomedical, Würzburg, Germany) The imaging parameters were: SGRE-sequence, no slice selection, TR/TE/FA=15ms/4.2ms/20°, matrix 64x64, FOV=300mm², time resolution of 1 fps.

The evaluation of data was done using MATLAB (Mathworks, USA). Reference series of images were measured at apnea to take RF and relaxation decay of ^3He signal into account. The decay of the ^3He signal intensity in corresponding lung regions were used to characterize the regional elimination and redistribution of gas. The temporal dependence of intensity was calculated on a ROI (average) and on a pixel-by-pixel basis. In the ROI approach the lung was segmented into a 3x3 ROI matrix (Fig 1). In the pixel-based analysis the next-neighbors averaging has been applied. The corrected ^3He signal intensities were calculated as $S(t)_{\text{(corrected)}} = S_{\text{HFOV}}(t) / S_{\text{apnoe}}(t)$. Thus, the influences of RF and T_1 -relaxation losses were excluded from further analysis. Because of the complex profile of $S(t)$ in different lung regions, using a common model function to fit the experimental data was not possible. Therefore, the elimination-redistribution dynamic was characterized by two parameters: (i) the time of $S(t)$ decay from initial to the level of 0.8 $\tau_{(0.8)}$ to describe mainly elimination, and (ii) the mean value of first derivative $M(0.25)=dS/dt$ within 25% of the total acquisition period which also depends on redistribution. The sign and value of the latter parameter allows for discrimination if wash-in or wash-out redistribution occurs in corresponding region.

Results and Discussion

The results of regional elimination and redistribution analysis are shown in Fig 1 and 2. Fig 1 represents the ROI based approach results. The profiles of non-corrected (HFOV), reference (apnea) and corrected signal intensities are shown. The 0.8 level used for time constant $\tau_{(0.8)}$ evaluation is shown. Fig 2 represents the results of pixel-based mapping of time constant and of mean redistribution flow $M(0.25)$.

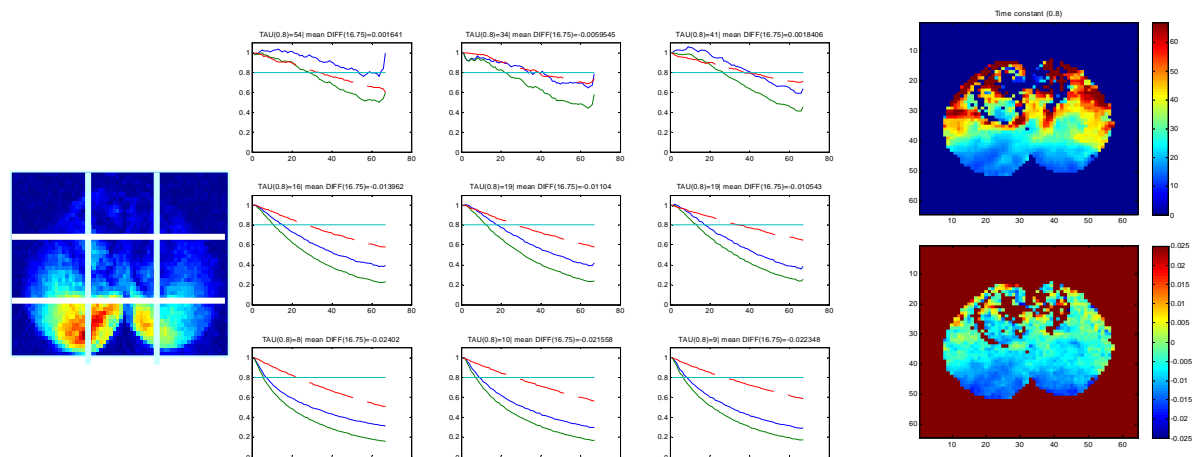


Fig 1. Temporal profiles of ^3He signal decay during 5Hz HFOV (green) in each ROI matrix element (see left). The profile of the apnea measurements are depicted in red and the corrected profiles $S(t)$ in blue. The plots position corresponds to the ROI allocation in matrix.

Fig2. Maps of elimination time constant (top) and mean flow (bottom) for at 5Hz HFOV frequency

Discussion

The elimination time constant and median flow show the tendency to increase in upwards direction both for 5 and 10 Hz HFOV frequency. During HFOV an active redistribution of gas from dependent to non-dependent (upper) lung regions was found. The intake of gas into non-dependent lung regions due to redistribution exceeds the losses due to wash-out within the first 10-15 seconds. This is reflected in both ROI profiles and pixel map (mean flow $M(0.25)$ value are positive). HFOV-stimulated redistributions increase with the frequency (probably due to smaller tidal volume and therefore slower wash out). On the contrary, the mean redistribution flow is nearly the same for both frequencies. During the 10 Hz HFOV the redistribution appears more accentuated since the wash-out is slower. In conclusion, ^3He MRI allows for characterization and visualization of complex ventilation effects which occurs in lung during HFOV. The regional analysis may provide both qualitative and quantitative information concerning the elimination and redistribution of gas, and may improve the understanding of the mechanisms of gas transport of HFOV and its efficiency for the patient care.

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