Oxygen enhanced lung MRI by simultaneous measurement of T_1 and T_2* during free breathing

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Introduction

Compared to hyperpolarised noble gas MRI, oxygen-enhanced (OE) functional lung MRI only requires widely available pure oxygen (O_2) rather than expensive gas isotopes and additional equipment. OE MRI exploits the known property that both T_1 and T_2* values in the lung change by about 10% when switching the breathing gas from room air (21%O_2) to pure oxygen in healthy subjects. Changes in T_1 depend on molecular O_2 dissolved in blood and thus can indicate both perfusion and ventilation defects[1]. In contrast, changes in T_2* reflect only ventilation, as it is determined by the susceptibility of gas in the alveoli[2]. Thus, to discern perfusion and ventilation defects, individual T_1 and T_2* measurements at room air and 100% O_2 conditions are required in the same respiratory state. For this purpose, we developed a self-gated simultaneous measurement of T_1 and T_2* with short echo-times and dc-gating to compensate for breathing motion. In this approach, T_1 is quantified using an Inversion Recovery (IR) Snapshot FLASH experiment that was expanded to a multi-gradient echo for T_2* quantification. In addition, a correction for the distortion of the dc-signal due to T_1 is described.

Method

All measurements were performed on a 1.5T clinical scanner. Following a global inversion pulse the magnetisation recovery was observed by a series of 680 radial projections arranged in an optimised golden angle[3] ordering. For each spoke (TR=4.25ms) 3 echoes with a readout asymmetry of 91.7% were acquired at $TE_{1,2,3}$= 0.57ms, 1.75ms and 2.95ms. This experiment was repeated for several inversions (typically more than 20) with a delay of 3s to allow for partial magnetisation recovery preceding each inversion pulse while also modifying the angle ordering in each inversion block. Radial spokes were then sorted according to their acquisition time since the last inversion pulse, mapping the data to a single inversion recovery. Individual contrasts were reconstructed using a sliding window 377 spokes wide (equivalent to 69.9ms) and a step width of 144 spokes (26.7ms). Quantitative T_1 parameter maps were fitted pixel-wise from these according to [4], correcting iteratively for limited relaxation during the delays. To quantify T_2*, all 3 echoes were used for a pixel-wise exponential fit, using echoes only from the steady state portion of the inversion recovery experiment.To compensate for motion dc-gating was employed[5]. Since each projection includes the k-space-centre, the dc-signal is available for each TR. However, as shown in fig. 1a, these signals are distorted by T_1 relaxation. In order to overcome this effect, the dc-signal in each inversion block was corrected using a respiratory-independent T_1 inversion recovery curve. This mean curve was generated by averaging the original dc-signal over all inversion blocks. Effectively, the correction separates motion and T_1 effects on the dc-signal, resulting in the gating signal shown in fig.1b. Projections were then assigned to respiratory states according to thresholds (dashed lines in fig. 1b), yielding parameter maps corresponding to expiration and inspiration, respectively.

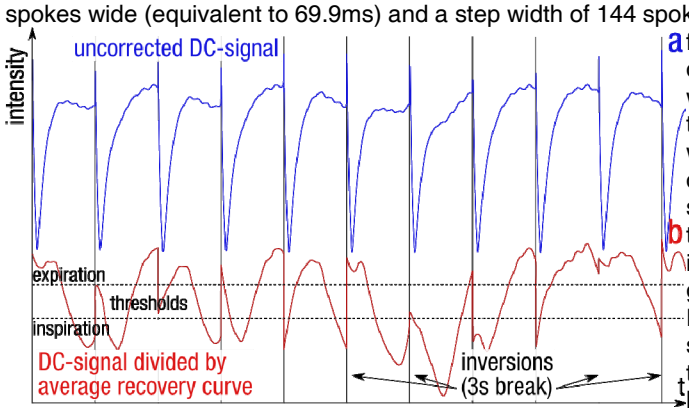

Figure 1: Original and corrected dc-signal during free breathing. Vertical black lines represent delays between inversion blocks.

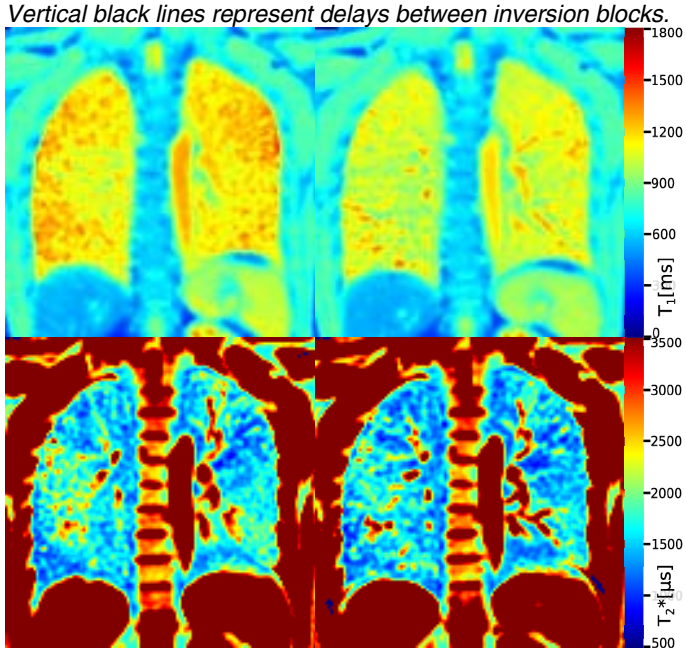

Figure 2: T_1 and T_2 maps of a healthy volunteer, gated for the expiration state and acquired while breathing room air (left) and pure O_2 (right). Matrix size: 192x192 Field of View: 50x50x1.5cm^3*

[4]Deichmann, R. et al.: JMR, 608-612 (1992)

Results

Fig. 2 shows T_1 and T_2* maps of one healthy volunteer acquired while breathing room air and 100% O_2, respectively. Maps for the expiration phase were calculated by using 33% of the total data. While not shown, parameter maps corresponding to inspiration are given by the same measurement. The relative reduction of relaxation times in the lung volume was found to be 8.8% for T_1 and 8.0% for T_2*, respectively. The total acquisition time was 73s for each of the breathing gases.

Conclusions

In this work we have successfully demonstrated that it is possible to acquire quantitative T_1 and T_2* maps in expiration and/or inspiration during free breathing. Self-gating allows for the reconstruction of co-registered parameter maps corresponding to room air and pure oxygen. Since both ΔT_1 and ΔT_2* are sensitive to different aspects of lung function, our approach has the potential to allow for the discrimination of perfusion and ventilation defects in patients. As the quasi-random angle distribution also allows for dynamic measurements, this method could also be well suited for monitoring oxygen-wash-in dynamically. In future work, this method will be applied in COPD patients.

Acknowledgements

This work was supported by the Kompetenznetz Asthma/COPD (Competence Network Asthma/COPD) funded by the Federal Ministry of Education and Research (FKZ(01GI0881-0888).

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