Respiratory-Gated 3D Fast Spin-Echo for Oxygen-Enhanced MR Imaging of Mice Lungs

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Introduction

Oxygen-enhanced magnetic resonance (MR) imaging has emerged as a technique to evaluate pulmonary ventilation. Inhaled paramagnetic molecular oxygen acts as a T1-shortening contrast agent[1] and ventilation is visualized as a signal intensity increase between images of lung parenchyma acquired in subjects breathing pure oxygen and room air. The technique is challenged, however, by the low proton density of lung tissue and cardiopulmonary physiology that result in reduced signal and increased motion artifacts in MR images. Cardiac and respiratory gating strategies have been applied to oxygen-enhanced imaging in humans to overcome these limitations[2]. With the growing interest in mouse models of pulmonary disease[3], such techniques are highly desirable since traditional breath-hold protocols cannot be used. This abstract presents an optimized cardiac-triggered respiratory-gated 3D fast spin-echo (FSE) sequence for oxygen-enhanced ventilation imaging in free-breathing mice.

Methods

All imaging was performed on a 7 T Varian INOVA scanner using a 3D-FSE sequence with 8 echoes (common scan parameters TE_{eff} = 2 ms, echo spacing of 2 ms, 234-µm isotropic voxels, FOV = (60 x 30 x 30) mm, NEX = 2). For live mouse protocols, wildtype C57BL/6 mice were anesthetized with 1.6% isoflurane and allowed to breathe spontaneously. Cardiac (ECG) and respiration (via pneumatic pillow) were monitored throughout imaging using commercial hardware (SA Instruments Inc.). All animal protocols were approved by the Hospital for Sick Children Animal Care Committee.

Fixed mouse imaging: In conventional thoracic imaging that combines cardiac triggering and respiratory gating, no imaging data are acquired during intervals of detectable respiratory motion (i.e. gasp periods). As a result of varying excitation periods, steady-state longitudinal magnetization is not maintained. To examine the effects of imaging with constant versus variable repetition times (TR), two 3D-FSE lung images were acquired of a fixed mouse[4]. The first data set was acquired with a constant TR of 200 ms and imaging time of 15 min. The second data set was acquired with a variable TR based on cardiac triggering and respiratory blanking (during gasp periods) as shown in Figure 1A. Physiological data was obtained from the real-time monitoring of an anesthetized mouse outside of the scanner. The TR was one cardiac R-R interval (~150 ms) and the imaging time was 22 min.

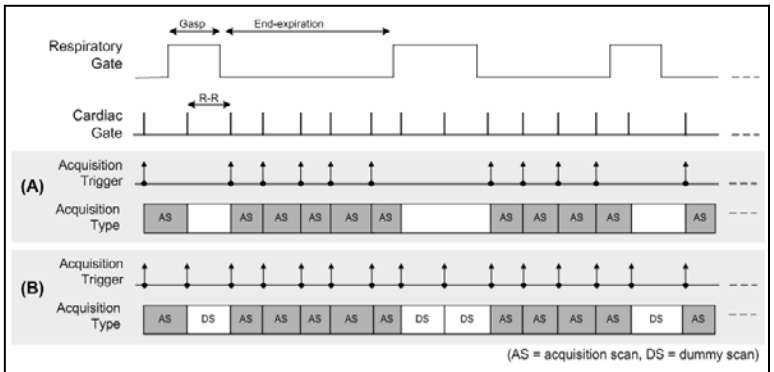

Figure 1. Fixed and live mouse image acquisition schemes: (A) cardiac-triggered, respiratory-blanked (during gasp periods) and (B) cardiac-triggered, respiratory-gated (with dummy scans).

Live mouse imaging: Oxygen-enhanced imaging was performed with the 3D-FSE sequence employing a cardiac-triggered respiratory-gated scheme shown in Figure 1B. Steady-state magnetization was maintained with application of dummy scans during the gasp periods of the respiratory cycle. Eight acquisition scans were obtained during every end-expiration period. 3D image sets were acquired with a mouse breathing 100% oxygen and then air both supplied at 1.1 L/min. A TR of two cardiac R-R intervals (~280 ms) was used to attain greater signal from the lung parenchyma and increase T_1-weighting. Imaging time for each scan was approximately 45 min.

Results and Discussion

Figure 2 demonstrates that ghosting artifacts are introduced when variations in cardiac and respiratory rates modulate recovery of the longitudinal magnetization of the MR signal. Since oxygen-enhanced imaging relies on the detection of small signal intensity differences in the lung parenchyma for the evaluation of ventilation defects, a gating strategy that preserves the steady-state magnetization throughout image acquisition is necessary to improve the sensitivity of the technique. Figure 3 shows images of a mouse breathing pure oxygen and air acquired using the cardiac-triggered respiratory-gated FSE sequence with maintenance of steady-state magnetization. For the coronal images at the same slice positions, a signal intensity increase of 20% (ROI in right lung) and 31% (ROI in left lung) is observed with pure oxygen inhalation. These increases are comparable to signal intensity changes reported in other animal studies[5].

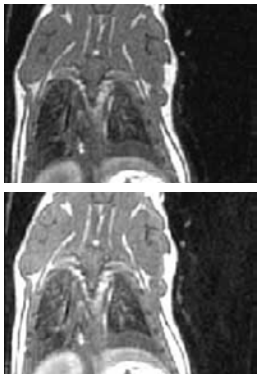

Figure 2. Images of a fixed wildtype mouse (21 g) acquired with a constant TR (top) and with a variable TR cardiac-triggered, respiratory-blanked (bottom) 3D-FSE sequence.

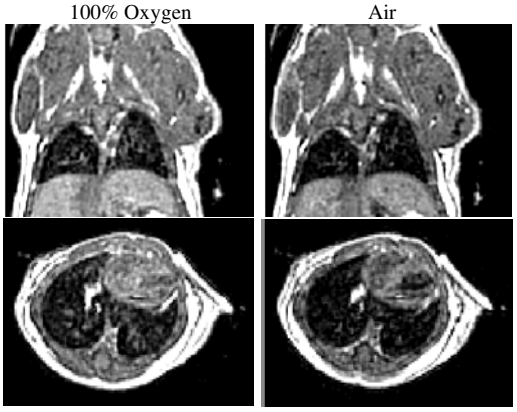

Figure 3. Oxygen-enhanced images of a live wildtype mouse (22 g) breathing 100% oxygen and air. Coronal (top) and axial (bottom) images were acquired using a cardiac-triggered respiratory-gated 3D-FSE sequence with dummy scans. Coronal images are shown at a slice position posterior to the heart.

Conclusions

Cardiac-triggered respiratory-gated 3D-FSE imaging with maintenance of steady-state magnetization offers high quality images for oxygen-enhanced imaging of free-breathing mice. The sequence gathers image data at similar positions in the cardiac and respiratory cycle and permits the non-invasive study of ventilation – without the need for mechanical ventilation. The sequence shows potential for future oxygen-enhanced imaging studies of normal and abnormal ventilation in wildtype and experimental mouse models.

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References

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