Oxygen-enhanced T1- and T2*-mapping of the human lung at 0.2 Tesla

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Introduction:

Oxygen-enhanced MRI was proposed for functional lung imaging, using the shortening of the relaxation time T_1 in the pulmonary blood in subjects breathing 100% oxygen (O_2) [1,2]. Another approach is the determination of T_2^* while breathing air or O_2 [3]. The relaxation times T_1 and T_2^* depend on the magnetic field strength as well as on the O_2 concentration of the respiratory gas. Breathing O_2 results in an increase of the physically dissolved O_2 in the pulmonary blood and thus shortens T_1 in the lung. Furthermore, breathing O_2 causes an increase of the magnetic susceptibility in the alveoli. This leads to stronger spin dephasing and thus reduces the relaxation time T_2^* [3]. At lower magnetic fields (0.2 T) the relaxation time T_1 is distinctly shorter [4], while T_2^* is much longer [5, 6] compared to 1.5 T. In this work, optimized sequences were implemented on a 0.2 Tesla scanner and oxygen-enhanced T_1 and T_2^* measurements were performed on healthy volunteers in expiratory breath-hold. Additionally, a navigator-echo based sequence was developed [7, 8] to acquire T_2^* maps during free respiration.

Methods:

All measurements were performed on an open 0.2 Tesla scanner (Siemens Magnetom Open, Erlangen, Germany). Five healthy volunteers were examined while breathing room air or O_2. Relaxation time T_1 was measured using an IR-Snapshot FLASH sequence [2] (TE/ TR/ α = 1.4ms/ 3.6ms/ 7°, 20mm slice thickness, coronary slices, matrix: 64 x 128, zero-filled to 256 x 256, centric reordered, FOV = 500 x 500 mm^2). A series of 14 Snapshot FLASH images was acquired after a non-selective inversion pulse. Including a short delay for relaxation, measurements were repeated three times and averaged, yielding a total acquisition time (TA) of ~ 18 s. To reduce Gibbs artifacts, data filtering was performed using a Hanning filter function. Relaxation time T_2^* was measured using a multi gradient-echo sequence (TE_{first}/ TE_{inter} / TR/ α = 2.6 ms/ 4.4 ms/ 24.0 ms/ 15°, 5 echoes, 15 mm slice thickness, sagittal slices, matrix: 64 x 128, zero-filled to 128 x 256, FOV = 250 x 500 mm^2). In total, ten measurements were performed in a single breath-hold and averaged, resulting in a TA of ~ 16 s. In order to acquire data during free respiration, a navigator-echo was implemented into the multi gradient-echo sequence (TE_{first}/ TE_{inter} / TR/ α = 2.6 ms/ 4.4 ms/ 41.0 ms/ 39°, 15mm slice thickness, matrix size: 64 x 128, zero-filled to 128 x 256, FOV = 250 x 500 mm^2). Five sagittal slices were recorded in an interleaved fashion including one non-phase encoded navigator-echo after each line in a separate slice [8]. The data was 25 times oversampled, resulting in a TA of 5.28 minutes. Using the navigator-echoes, the diaphragm position was evaluated retrospectively. Based on the most frequently occurring diaphragm position an accept/reject window of +/- 1 pixel was defined and data acquired within this window was applied for image reconstruction. All images were reconstructed for end-expiration, which was the most frequent diaphragm position. Data analysis was done using Matlab (the MathWorks, Inc., Natick, MA, USA). In order to calculate T_1 or T_2^* maps, least squares fitting was performed pixel by pixel. Difference maps were calculated between the images acquired under room air and pure oxygen.

Results:

Figure 1 shows T_1 maps of a volunteer, acquired while breathing room air or O_2. For all examined volunteers, mean T_1 values of 686 ms ± 61 ms (air) and 631 ms ± 46 ms (O_2) were determined. Calculated T_2^* maps under both respiratory environments are displayed in Fig. 2. Mean T_2^* values of 10.6 ms ± 0.9 ms (air) and 9.5 ms ± 0.8 ms (O_2) were measured in expiratory breath-hold. Using the navigator-echo technique, about 30% of all k-space lines were acquired in an identical inflation level in end-expiration and thus applied for image reconstruction. Under free respiration, T_2^* values of 10.1 ms ± 0.7 ms (air) and 8.8 ms ± 0.8 ms (O_2) were determined. Motion artifact free images were acquired in expiratory breath-hold as well as during free respiration. A good reproducibility of identical inflation levels between consecutive measurements was achieved resulting in accurate difference maps (Fig. 2).

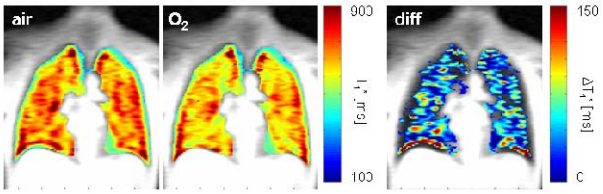

Fig. 1: T_1-maps, acquired in expiratory breath-hold

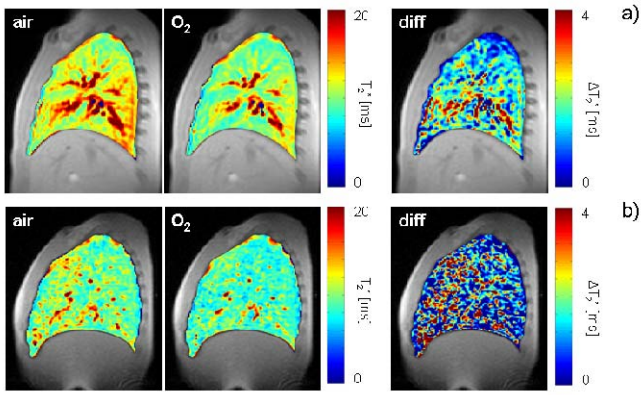

Fig. 2: T_2^*-maps, acquired during free respiration (a) and in expiratory breath-hold (b)

Discussion:

The presented sequences enable the performance of oxygen-enhanced functional lung imaging at 0.2 Tesla. A distinct reduction of both relaxation times (T_1 ~ 8%; T_2^* ~ 9%) was found when changing the respiratory gas to 100% oxygen. The measured T_1 and T_2^* values show good agreement to literature values [4-6]. Due to the longer T_2^* at 0.2 Tesla, an easier detection of the signal decay can be performed. In this work, artifact free T_2^* maps were acquired in expiratory breath-hold as well as during free respiration (Fig. 2). However, often the comparison of different breath-hold measurements poses a problem due to different diaphragm positions. The navigator-echo technique enables a high reproducibility of identical inflation levels between consecutive measurements and thus allows calculation of accurate difference maps. Furthermore, a higher SNR can be achieved due to averaging which improves significantly the accuracy of the fitted T_2^* values. All measurements were successfully performed in breath-hold or free respiration and are thus applicable for patient examinations. Using the navigator technique, even examinations of lung patients are possible who have only poor breath-holding abilities.

The next step will be lung examinations of children. Radiation free functional lung imaging in combination with an open scanner design is particularly suitable for these patients.

References

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