Quantitative Free-Breathing Oxygen-Enhanced Imaging of the Lung

J. F. Arnold[1], F. Fidler[1], P. M. Jakob[1]

[1]Dept. of Experimental Physics 5, University of Würzburg, Würzburg, Bavaria, Germany

Purpose/Objective: Since oxygen-enhanced (OE) lung MRI was first proposed by Edelman et al in 1996 [1], many studies have been carried out using oxygen as a contrast agent. Two major kinds of approaches were established: A T_1-weighted approach [2] and a quantitative approach based on T_1-measurement [3]. Both methods have already proven their feasibility in dynamic OE lung MRI [4,5]. However, each approach has its specific advantages and disadvantages. T_1-weighted OE MRI has recently proven its multislice capability [6] and is favourable in terms of temporal and spatial resolution. On the other hand, since only relative signal changes are detected, various undesired dependencies arise, e.g. the method of data acquisition, the hardware used, etc. Comparisons of inter- and intrasubject findings, especially between diverse clinical groups, thus turn out to be difficult. In contrast, T_1-mapping would ease standardization for routine clinical OE lung MRI. Therefore, we propose a hybrid of the T_1-weighted and the T_1-mapping approach which makes use of the individual advantages of both techniques.

Materials/Methods: Five healthy volunteers were examined on a 1.5 T whole-body scanner (Vision, Siemens, Germany). Lung T_1-mapping was performed using a technique based on IR Snapshot FLASH [3]. Imaging parameters were TE=1.4 ms, TR=3.5ms, FA= 7°, FOV=$(400mm)^2$, ST=15mm and an image matrix of 64x128 zero-filled to 256x256. T_1-weighted imaging was performed using a single-shot inversion recovery HASTE (IR-HASTE) [7] sequence with an optimized inversion time of TI=1200ms [2]. Imaging parameters of HASTE readout were TE_{eff} =43ms, TE_{inter}=4.2ms and a matrix size of 128x256 zero filled to 256x256, where FOV, slice thickness and slice position were chosen as in T_1-mapping. T_1-maps were acquired in expiration breath-hold during breathing of room air and also during breathing of pure oxygen. 35 to 40 T_1-weighted images were dynamically acquired while the subjects were breathing freely with switching from room air to 100% oxygen after 10 to 13 images. To allow for relaxation, a delay time of 5 seconds in addition to the waiting time for the ECG-trigger signal before each new IR-HASTE acquisition was chosen. In a post-processing procedure, the diaphragm position of the T_1-weighted images was assessed. Using a single T_1-map, quantitative T_1-maps were calculated of all T_1-weighted images. The calculation procedure was as follows:

(1) With a scaling factor s, the Signal intensity SI_{cali} for an IR-HASTE experiment is given by: For calibration, SI_{cali} was calculated by averaging the signal of 3 IR-HASTE images which had identical diaphragm positions as in the T_1-map. Solving the equation for s and using the values of the T_1-map and SI_{cali}, s was calculated as for an IR experiment with TI = 1200 ms.

$$SI_{cali} = s * (1 - 2 * \exp(-TI / T_1))$$

(2) Now, as the scaling factor s is derived, Equation 1 can be remodelled and solved for T_1: A quantitative T_1-map ($T_{1,T1w}$) can thus be calculated of any T_1-weighted image (SI_{T1w}).

$$T_{1,T1w} = \frac{-TI}{\log[(1 - SI_{T1w}/s)/2]}$$

The assumption of a constant scaling factor implies a constant spin density. This is certainly not the case while the subject is breathing. Therefore, the respiratory phase of the T_1-weighted images must be considered. Only those images with similar diaphragm position as in the T_1-map result in quantitative $T_{1,T1w}$-maps.

Results: As an example, Figure 1 compares T_1-maps with $T_{1,T1w}$-maps. The $T_{1,T1w}$-maps shown consist of 3-times averaged $T_{1,T1w}$, calculated of T_1-weighted images which had similar diaphragm positions as was the case in the T_1-map. Figure 2 shows a difference image of two T_1-maps acquired under different breathing gas conditions as well as a subtraction map of thrice averaged $T_{1,T1w}$-maps also under these different breathing gas conditions. The $T_{1,T1w}$ subtraction map appears to be much more homogeneous, although both difference maps show similar values averaged over the whole right lung (219±132 ms and 201±69 ms, respectively). Figure 3 depicts a typical time course curve of T_1 values averaged over the whole right lung. The variation of $T_{1,T1w}$ calculated of images with diaphragm position indicating expiration is small and on average close to the T_1 measured in the T_1-maps.

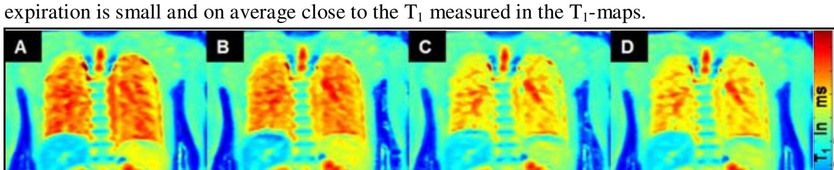

Figure 1: *Volunteer 1: A) T_1-map and B) averaged $T_{1,T1w}$-map calculated using 3 T_1-weighted HASTE images during breathing of room air. C) T_1-map and D) averaged $T_{1,T1w}$-map during breathing of 100% oxygen.*

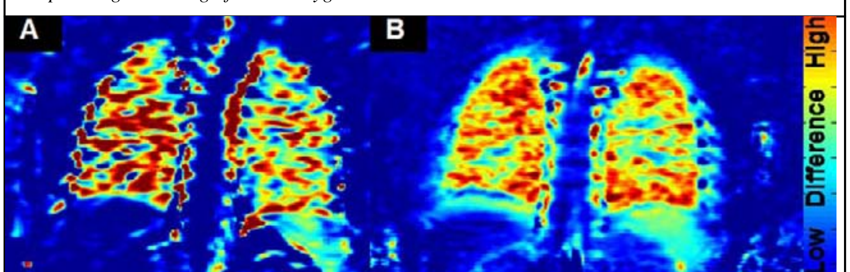

Figure 2: *Volunteer 2:* A) *Difference map (T_1-map_{air} – T_1-map_{O2}).* B) *Difference map from 3 averaged $T_{1,T1w}$-$maps_{air}$ and 3 averaged $T_{1,T1w}$-$maps_{O2}$.*

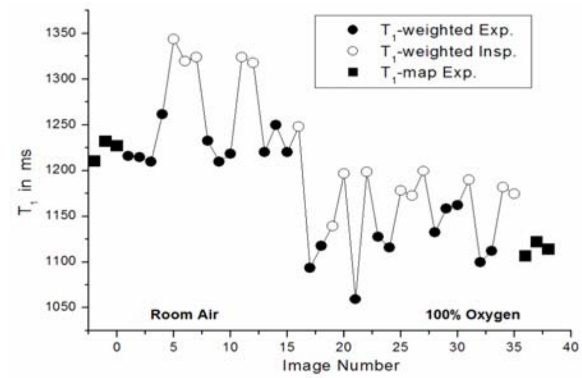

Figure 3: *Volunteer 3: Time course curve of T_1 values averaged over the whole right lung. The first images ($T_{1,T1w}$) were acquired during breathing of room air, the second part after switching to pure oxygen. Squares (■) denote values of the T_1-maps. (●) show T_1 values calculated in images with diaphragm position indicating expiration, whereas (○) show T_1 of images with the diaphragm closer to inspiration.*

Conclusions: Assuming a constant spin density for images having identical diaphragm position and acquired in identical cardiac cycles, those images with similar diaphragm position as in the breath-hold acquired T_1-map can be preselected for subtraction-map calculation. Using T_1-weighted imaging, a high number of $T_{1,T1w}$-maps can be obtained, resulting in better subtraction maps because of the averaging effect. In contrast to difference maps of solely T_1-weighted images, these subtraction maps are quantitative. In addition, breath-holds during image acquisition, as were used in dynamic T_1-mapping [5], are not necessary. In conclusion, with a single T_1-map acquisition for every slice, followed by a multislice T_1-weighted scheme, the oxygen transfer in the entire lung could be covered quantitatively in a short amount of time. Standardized OE lung MRI on patients should thus be feasible.

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References:

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