Oxygen-enhanced lung imaging using rapid acquisition of T1-maps during free breathing

J. F. Arnold[1], M. Kotas[2], E. D. Pracht[1], M. Flentje[2], and P. M. Jakob[1]

[1]Dept. of Experimental Physics 5, University of Würzburg, Würzburg, Germany, [2]Dept. of Radiation Oncology, University of Würzburg, Würzburg, Germany

Purpose/Objective: Oxygen-enhanced (OE) lung MRI was first proposed by Edelman et al. in 1996 [1] using a simple T_1-weighted approach. The main drawback of this method is its lack of quantification and the potential for misinterpretation [2]. As an alternative, Jakob et al. proposed the acquisition of quantitative T_1-maps [2]. Since T_1-mapping requires the acquisition of several images, all of which should be obtained during the same breathing cycle, the measurement is usually performed during a breath-hold of several seconds. Since several slices under various breathing gas compositions often have to be acquired more than once, repeated breath-holds are necessary, which can cause severe discomfort in some patients. Therefore, this study presents a technique for rapid acquisition of T_1-maps during free-breathing, suitable for quantitative OE lung imaging.

Materials/Methods: Seven 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 [2]. Imaging parameters were TE=1.4 ms, TR=3.5ms, FA= 7°, FOV=(400mm)^2, ST=15mm and an image matrix of 64x128, resulting in a total acquisition time of 4 seconds for all 16 images. The imaging protocol consisted of two phases: Firstly, 10 breath-hold T_1-maps were acquired as a reference for comparison with the new technique. Secondly, 15 T_1-map data sets were acquired during free breathing with a delay time of 3 seconds between consecutive T_1-maps. In a retrospective gating procedure, the diaphragm position in each image was assessed. Images showing identical diaphragm positions were selected out of the 15 data sets in order to obtain a single data set where all images are within the same respiratory cycle. This data set was used for T_1-map calculation. Because the short delay times used do not allow for full recovery of the magnetization between consecutive inversion pulses, the T_1-values were corrected using the post-processing technique described in [3]. To demonstrate the feasibility for OE lung imaging, the procedure described above was performed while the subjects were breathing room air and again during inhalation of carbogen (95% oxygen, 5% carbon dioxide).

Results: T_1-map acquisition during free breathing was better tolerated by the volunteers, especially when inhaling carbogen, where the diaphragm position in consecutive breath-holds varied substantially in some subjects. T_1-maps acquired during free breathing were in good agreement with breath-hold acquired T_1-maps in all cases (mean deviation of 1.5%). As an example, free-breathing T_1-maps and breath-hold T_1-maps of subject 1 are shown in Figure 1. In Figure 2, the feasibility of calculating T_1-maps in various respiratory phases by choosing different retrospective navigator positions is demonstrated. The results for all volunteers are depicted in Table 1.

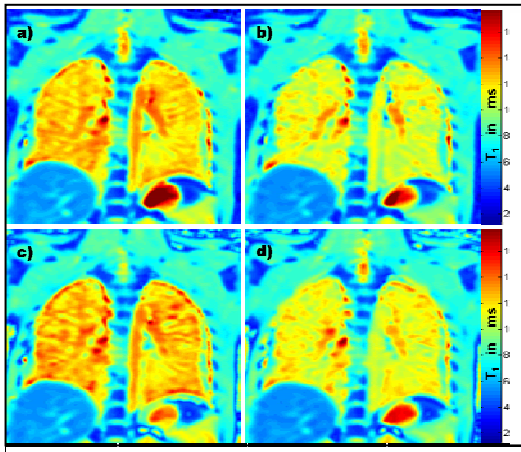

Figure 1: *Example of Volunteer 1: a) Breath-hold T_1-map with inhalation of room air and b) carbogen; c) Free breathing T_1-map with inhalation of room air and d) carbogen. Note the good agreement between T_1-maps acquired during free breathing and those acquired during a breath-hold.*

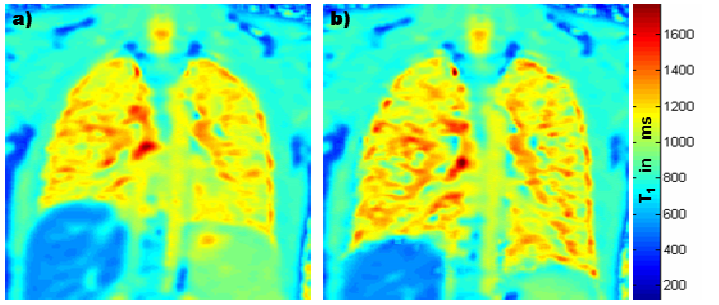

Figure 2: *Example of Volunteer 2: Two free breathing T_1-maps are shown. a) was calculated for a respiration cycle indicating expiration and b) for one indicating inspiration. T_1-maps acquired while inhaling carbogen are shown to demonstrate the feasibility of calculating T_1-maps of various respiratory phases because of the increased respiration depth when carbogen is inhaled.*

Volunteer	1		2		3		4		5		6		7	
	Air	Carb	Air	Carb	Air	Carb	Air	Carb	Air	Carb	Air	Carb	Air	Carb
T_1 BH	1213	1110	1240	1124	1214	1102	1231	1100	1339	1196	1234	1103	1182	1063
T_1 free	1253	1134	1220	1149	1217	1188	1225	1141	1373	1240	1237.0	1122	1172	1046
% deviation	3.2	2.1	-1.6	2.2	0.2	7.2	-0.5	3.6	2.4	3.6	0.2	1.6	-0.9	-1.7

Table 1: *T_1 values of the whole lung are shown for breath-hold T_1-maps and free breathing T_1-maps for all seven volunteers. The bottom row shows the mean deviation of the free breathing T_1-maps from the breath-hold T_1-maps in the lung.*

Conclusions: The technique described provides for rapid and accurate T_1-mapping during free breathing. T_1-maps can be calculated for various respiratory phases and the diaphragm positions of several T_1-maps, for instance acquired during the inhalation of room air and carbogen, are in good alignment as the same retrospective navigator placement is used. However, this can be problematic for different breath-hold acquired T_1-maps as they can vary substantially in diaphragm position [4]. Since various respiratory phases can be calculated using the same data set, changes in T_1 caused by respiration can be easily studied. The entire measurement, i.e. acquiring 15 data sets with a 3-second delay time, takes less than 2 minutes. However, the measurement time can be decreased even more by further reduction of the delay time and by using less than 15 data sets, for instance when only T_1-maps indicating expiration are needed. Thus, rapid free breathing quantitative OE T_1-mapping is perfectly suited for routine clinical use.

References:

1) Edelman RR, et al [1996] Nature Medicine 11:1236;
2) Jakob PM, et al [2001] JMRI 14:795;
3) Arnold JFT, et al [2004] MAGMA 16:246;
4) Molinari F, et al [2006] Invest Radiol 41 :476;