Interleaved T1- and T2*-mapping for Dynamic Abdominal Tissue Oxygenation Applications

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Introduction: MR relaxation time mapping has been used for the assessment of oxygenation in brain [1], abdominal organs [2] and tumors [3] by measuring relaxation time changes due to paramagnetic T_1-shortening properties of molecular O_2 in tissue (TOLD) and susceptibility-related T_2^* increasing created by decreased concentration of deoxyhemoglobin (paramagnetic) in blood (BOLD) upon breathing 100% O_2. MR sequences for the simultaneous acquisition of T_1 and T_2^* maps were developed and applied for brain functional applications [4]. However, these techniques are severely hindered when used of assessment of abdominal organs due to respiration motion and severe local susceptibility in the dynamic abdominal organ oxygenation study. Therefore, a 2D, respiratory-triggered, free-breathing, dynamic, interleaved T_1 and T_2* mapping technique has been developed and tested in the present study.

Methods: Using PARADISE (Pulse programming environment for scientists) on a clinical 3T MRI system (Philips Achieva, Best, Netherlands), a dynamic multi-shot gradient echo EPI sequence (ms-GEPI) with presaturation pulse for fat-suppression was modified by adding a 180° adiabatic inversion recovery (IR) prepulse in even segments and four more EPI echoes in non-IR (odd) segments. The respiratory motion compensation was accomplished with standard bellows triggering and by acquiring all image data at the same phase of expiration. T_1 measurement was accomplished by using signals of the first echo in even and odd segments with constant TR and TE. The ratio of these two signal intensities is solely a function of T_1: $\frac{S_{IR,even}}{S_{GE,odd}} = \frac{1-2\cdot e^{-\frac{TI}{T_1}}+e^{-\frac{TR}{T_1}}}{1-e^{-\frac{TR}{T_1}}}$ (1), and T_1 value can be derived iteratively [5]. T_2^* was calculated by fitting five echo signals in the non-IR (odd) segment to an exponential decay: $\ln\frac{S_{GE}}{M_0} = -TE/T_2^*$ (2).

Gadolinium solution phantoms were used to compare T_1 and T_2^* values measured by the interleaved ms-GEPI-IREPI method and conventional IR-TSE and multi-echo GRE techniques. The interleaved ms-GEPI-IREPI technique was also applied to acquire human abdominal imaging data from 5 healthy volunteers in the coronal plane (2D, TR=3~5sec, TI=1.2sec, 5 echoes, matrix 128×128, spatial resolution 2.0×2.0×4 mm^3, temporal resolution ~24sec, SENSE 2.0, TE_1=7.4ms, ΔTE=9.5ms, ETL=9, SENSE Torso coil). All volunteers (N=5) breathed room air (4min) followed by 100% oxygen (8min). Dynamic T_1 and T_2^* values of abdominal organs were calculated pixel-by-pixel using equations 1 & 2.

Results and Discussion: The results of phantom experiments show good correlation of T_1 and T_2^* values measured by interleaved ms-GEPI-IREPI and conventional sequences (Table 1). For the volunteer study the relaxation times of abdominal organs were measured before and during oxygen inhalation (Table 2). To analyze the tissue oxygenation effect, regions of interest (ROI) in different organs were chosen and selected R_1 and R_2^* maps during air and oxygen inhalation are presented in Fig. 1. A significant decrease in T_1 was observed in spleen (*p= 0.004*) and renal cortex (*p = 0.07*) and no T_1 signal change was detected in paraspinal muscle and renal medulla when breathing 100% oxygen. Meanwhile, no significant change of T_2^* was seen for any organs in response to breathing oxygen.

Phantom	T_1 (IR-TSE) [ms]	T_1 (interleaved) [ms]	Diff. T_1 [%]	T_2* (multi-echo GRE) [ms]	T_2* (interleaved) [ms]	Diff. T_2* [%]
1	365±7	375±13	2.7	89±2	94±5	5.6
2	704±13	675±32	-4.1	113±3	109±7	-3.5
3	1089±19	1029±49	-5.5	131±3	141±9	7.6

Table 1: T_1 and T_2^* relaxation times measured in phantoms.

Organ	Mean T_1 (air)	Mean T_1 (O_2)	Mean T_2* (air)	Mean T_2* (O_2)
Spleen	1315 ± 42	1196 ± 38	39 ± 4	38 ± 5
R. cortex	1218 ± 65	1105 ± 59	63 ± 17	61 ± 15
R. medulla	1511 ± 72	1521 ± 75	38 ± 11	41 ± 12
Paraspinal m.	915 ± 26	902 ± 31	25 ±3	24 ± 4

Table 2: T_1 and T_2^* relaxation times of abdominal organs measured in air and O2 inhalation.

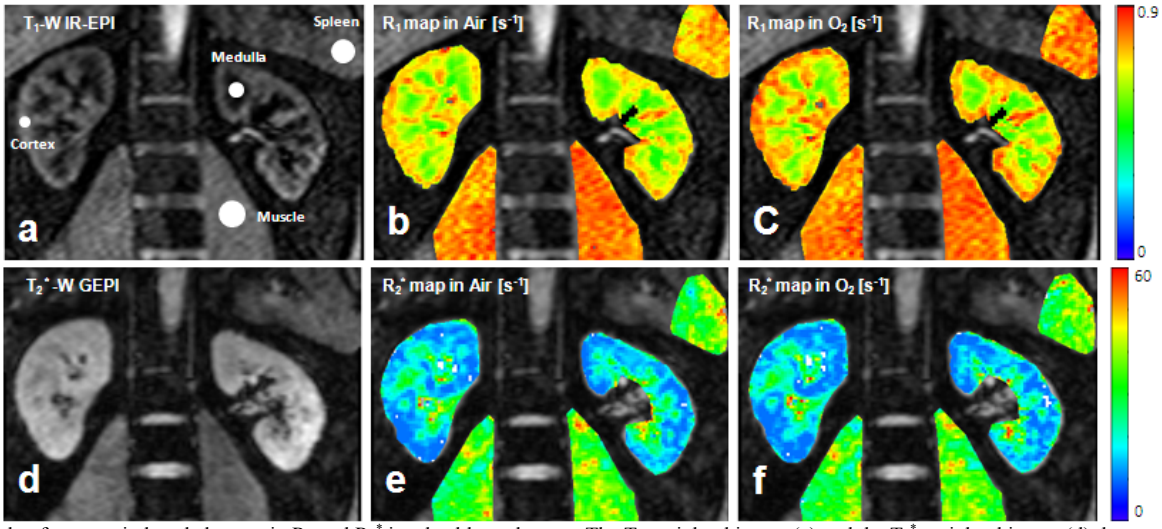

Figure 1: Example of oxygen-induced changes in R_1 and R_2^* in a healthy volunteer. The T_1-weighted image (a) and the T_2^*-weighted image (d) demonstrate the normal anatomy of the abdominal organs. Compared to the R_1 maps acquired while breathing air (b), a significant increase in R_1 value is seen in spleen and renal cortex when pure O_2 is inhaled (c). R_2^* maps appear near-identical when breathing air (e) and 100% O_2 (f).

Conclusion: The free breathing respiratory-triggered interleaved T1 and T2* mapping sequence was developed and applied to acquire quantitative relaxation time maps of abdominal organs in a dynamic scan without the need for image registration. Compared to traditional tissue oxygenation methods which only acquire one parameter in a dynamic study, this technique is a more efficient method which enables simultaneous monitoring of both tissue and blood dynamic oxygenation processes. While abdominal organs are used here as an example, this method can be more easily performed on oncology patients, many of whom have difficulty cooperating for long exams.

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