A Model-based Reconstruction Technique for Fast Dynamic T1 Mapping

Johannes Tran-Gia[1], Sotirios Bisdas[2], Herbert Köstler[1], and Uwe Klose[2]

[1]*Institute of Radiology, University of Würzburg, Würzburg, Germany,* [2]*Department of Diagnostic and Interventional Neuroradiology, University Hospital Tübingen, Tübingen, Germany*

Target Audience: Researchers & clinicians working in the field of quantitative MRI, MR relaxometry, dynamic T_1 mapping or brain MRI.

Purpose: To present a technique for dynamic T_1 mapping with a temporal resolution of up to one parameter map every 7.2 seconds for applications such as dynamic contrast enhanced (DCE) MRI.

Methods: The approach is illustrated in Fig. 1. It is based on the application of multiple global inversion pulses, each followed by a radial Look-Locker (LL) FLASH acquisition and a waiting period (i.e. 3s) to enable an additional T_1 relaxation before the next inversion. Each of these acquisitions will be referred to as one IR frame in the following. The signal during the IR LL FLASH acquisition follows a mono-exponential T_1^* relaxation $M(t) = M_0^* - (M_0 + M_0^*) \cdot \exp(-t/T_1^*)$. The previously proposed IR-MAP[1] technique uses this knowledge for a model-based reconstruction of the relaxation process of each individual IR frame, yielding M_0, M_0^* and T_1^* in every voxel and for every IR frame. If the magnetization equals $-M_0$ directly after inversion, T_1 can be calculated using $T_1 = T_1^* \cdot [(M_0 + M_0^*)/M_0^* - 1]$[2]. Although this might be the case for the first IR frame, short waiting periods of regular T_1 relaxation can result in an insufficient relaxation of voxels with larger T_1 in subsequent inversions, introducing systematic errors in the above T_1 calculation. Therefore, an iterative method had to be applied to correct these errors[3]. It uses the precisely known proportion of T_1^* and T_1 relaxation within each IR frame to find a set of underlying parameters M_0 and T_1 best modeling the observed relaxation. IR-MAP and T_1 correction are performed separately for each IR frame, delivering a dynamic series of T_1 maps.

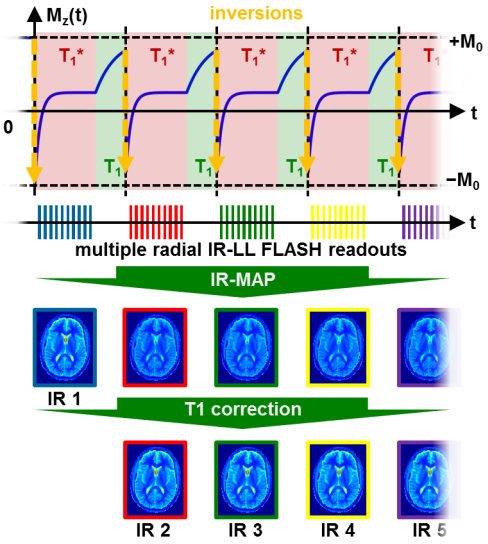

Fig. 1: Acquisition & reconstruction scheme.

All experiments were carried out on a 3T whole-body scanner (Magnetom Trio, Siemens AG, Germany). A validation study was performed using a phantom consisting of 7 vials with different contrast agent (Resovist®, Bayer Schering Pharma AG, Germany) concentrations. A set of 5 subsequent shots of an IR-LL FLASH sequence (FOV = 250×250mm^2, slice thickness = 10mm, TE = 1.89ms, TR = 4.24ms, α = 7°) with a Golden Ratio[4] radial k-space trajectory (1000 radial projections, 128 readout samples, total acquisition time = 4.2s) was applied for data acquisition, each followed by a waiting period of 3s. After data collection, 50 IR-MAP iterations, followed by 100 iterations of the T_1 relaxation correction were applied to obtain one T_1 map for each IR frame. The acquisition time of 4.2s combined with the T_1 relaxation delay of 3s resulted in a temporal resolution of one T_1 map every 7.2s. Additionally, the same setup was used on the brain of a healthy volunteer (HV). Finally, a slightly modified setup (FOV = 230×230mm^2, slice thickness = 3mm, TE = 2.5ms, TR = 6.0ms, α = 7°, 33 IR frames, 3s relaxation delay) was used to track T_1 changes after the injection of contrast agent (Gadovist®, Bayer Schering Pharma AG, Germany) in a patient with primary lymphoma.

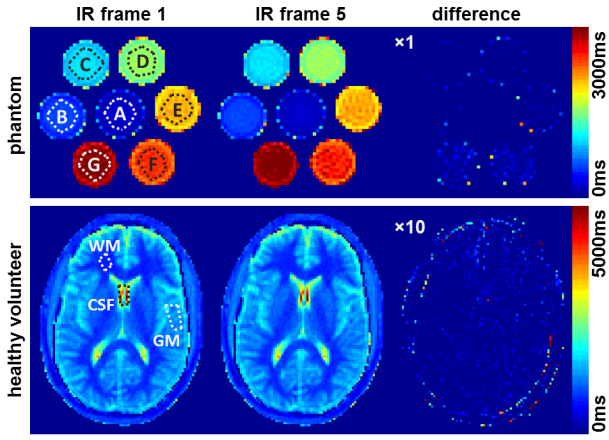

Fig. 2: T1 maps of phantom and HV measurements.

vial	IR frame 1 (ms)	IR frame 5 (ms)
A	184 ± 10	186 ± 9
B	544 ± 24	546 ± 22
C	1015 ± 32	1022 ± 33
D	1553 ± 31	1562 ± 36
E	2067 ± 49	2102 ± 68
F	2469 ± 54	2543 ± 114
G	2990 ± 68	3062 ± 142
WM	725 ± 26	735 ± 25
GM	1323 ± 191	1324 ± 190
CSF	2847 ± 976	2858 ± 987

Table 1: Means and standard deviations of ROI analysis.

Results & Discussion: Figure 2 shows T_1 maps of the 1st and 5th IR frames as well as their differences for the phantom (top) and the HV measurement (bottom). Even at a 10-fold magnification, differences in the HV T_1 maps remain negligible. The results of the ROI analysis listed in Table 1 quantitatively underline this consistency. For the HV measurement, values of white matter (WM), gray matter (GM) and in the cerebrospinal fluid (CSF) are in a very good agreement for both IR frames. The first 12 T_1 maps of the DCE MRI experiment are shown in Fig. 3. The functionality of the T_1 correction is indicated by the fact that areas with large T_1 values (such as the CSF in the ventricles) where an insufficient relaxation period would usually lead to errors in T_1 remain unchanged throughout the time series. As expected, T_1 in areas where the contrast agent accumulates (such as the lymphoma in our patient) is significantly lowered after the contrast agent injection.

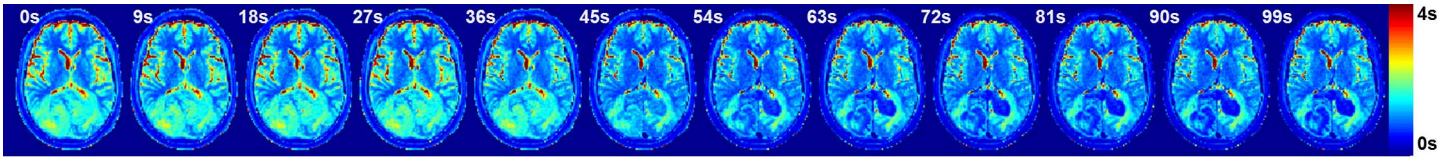

Fig. 3: T1 dynamic after contrast agent injection in a patient with brain tumor.

Conclusion: A setup for dynamic parameter mapping with a temporal resolution of up to 7.2s is presented. It uses the previously presented IR-MAP technique[1] to reconstruct relaxation curves for successive inversions, each followed by a radial Look-Locker FLASH acquisition and a waiting time of 3s for relaxation. After a correction of T_1 errors caused by an insufficient relaxation between successive inversions[3], this allows monitoring T_1 variations over time, which is desirable in many applications such as dynamic contrast enhanced MRI.

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References: [1] Tran-Gia et al., Proc ISMRM 21:2454 (2013), [2] Deichmann et al., J Magn Reson 96:608-612 (1992), [3] Siversson et al., J Magn Reson 30:834-841 (2009), [4] Winkelmann et al., IEEE T Med Imaging 16:68-76 (2007).