A Model-based Reconstruction Technique for Inversion Recovery Prepared Radially Acquired Data

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Introduction: MR parameter mapping is usually performed by tracking the evolution of the magnetization after a suitable preparation. Especially for short relaxation times, this can be difficult and measurements have to be performed in segmented fashion or with low spatial resolution. In [1], we proposed a Model-based Acceleration of Parameter mapping (MAP) algorithm in conjunction with radial data acquisition, capable of fully resolving an exponential signal evolution after saturation magnetization preparation. In this work, the MAP technique was extended for inversion recovery (IR) prepared datasets. This allows quantifying T_1 from a radial single-shot dataset using only one single magnetization preparation.

Materials and Methods: According to [2], the magnetization $M(TI)$ in an IR snapshot FLASH experiment can be modeled by the mono-exponential function

$$M(TI) = M_0^* - (M_0 + M_0^*) \cdot \exp(-TI/T_1^*) \quad (1)$$

(TI: inversion time, M_0: equilibrium magnetization, T_1^*: apparent relaxation time, M_0^*: steady-state magnetization of the tissue in presence of continuous RF excitation). Utilizing this model as prior knowledge allows characterizing $M(TI)$ by only the three parameters M_0, M_0^* and T_1^*. For small flip angles α, these parameters can be used to derive the actual longitudinal relaxation parameter

$$T_1 = T_1^* \cdot [(M_0 + M_0^*)/M_0^* - 1]. \quad (2)$$

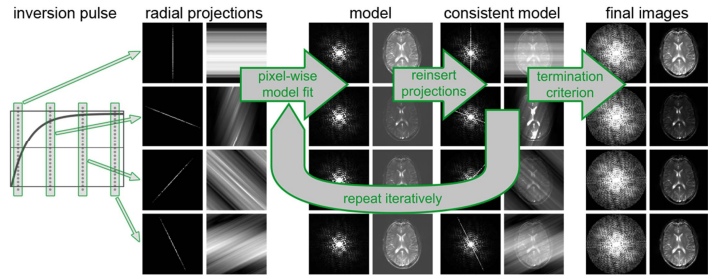

Fig. 1: *Basic IR-MAP reconstruction scheme.*

In this work, Eq. 1 was included in the MAP algorithm presented in [1] in order to fully resolve the evolution of the signal after IR magnetization preparation from only one single IR preparation. The proposed IR-MAP technique reconstructs one image for every acquired radial projection as well as an M_0, M_0^* and T_1^* map. It is initialized by separately gridding every single projection of the radially acquired k-space data using self-calibrating GROG [3] and Fourier transforming these k-spaces into image space. Subsequently, a least-squares fit of Eq. 1 is applied pixel by pixel, yielding a set of parameters $M_0(x,y)$, $M_0^*(x,y)$ and $T_1^*(x,y)$ for every pixel (x,y), corresponding to one model image for the contrast of every acquired projection. In order to ensure data consistency, every originally measured projection is substituted into the k-space of its model image. The consistent model images are then passed on to the subsequent iteration (Fig. 1). All reconstructions in this study were terminated after a fixed number of 500 iterations.

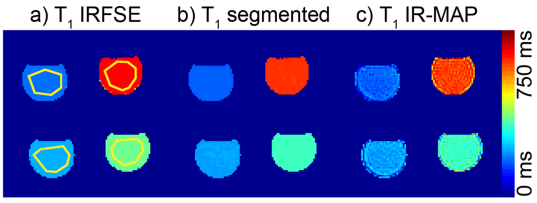

Fig. 2: *T1 maps of the phantom measurements.*

position	a) T1 IRFSE	b) T1 segmented	c) T1 IR-MAP
top left	173 ± 0	155 ± 1	156 ± 12
bottom left	216 ± 0	211 ± 1	205 ± 15
bottom right	361 ± 0	320 ± 2	318 ± 19
top right	649 ± 0	613 ± 3	603 ± 19

Table 1: *Means & standard deviations of the phantom.*

All experiments were carried out on a 3T whole-body scanner (Magnetom TRIO, Siemens AG Healthcare Sector, Erlangen, Germany) employing a 12 channel phased-array head coil (Siemens AG Healthcare Sector, Erlangen, Germany) for signal reception. A validation study was performed using a phantom consisting of 4 compartments with different contrast agent (Gadovist, Bayer Schering Pharma, Berlin, Germany) concentrations and an IR snapshot FLASH sequence (FOV = 220×220 mm^2, slice thickness = 8 mm, TE = 3.07 ms, TR = 6.61 ms, α = 6°) with a Golden Ratio [4] radial k-space trajectory (512 radial projections, 128 readout samples, total scan time = 3.4 s). 500 iterations of the proposed IR-MAP algorithm were utilized for image reconstruction and quantification of M_0, M_0^* and T_1^*. To assess the functionality of the algorithm, a set of 512 Nyquist sampled IR snapshot FLASH contrasts was acquired in segmented fashion by a 202-fold repetition of the sequence with a varying order of the measured projections (total scan time > 3 h). In both cases, Eq. 2 was used to obtain a T_1 map out of the apparent relaxation parameters M_0, M_0^* and T_1^*. Additionally, a Cartesian IR fast spin echo (IRFSE) experiment (FOV = 220×220 mm^2, slice thickness = 8 mm, effective TE = 7.6 ms, α = 120°, echo train length 4, 128×128 matrix, total scan time > 3 h) of the same slice was acquired for 31 different contrasts with $TI \in [30\text{ ms}, 8000\text{ ms}]$ in order to determine a reference T_1 map. For comparison, a ROI analysis was performed for all T_1 maps.

Measurements of a human brain were carried out with the radial IR snapshot FLASH sequence described above (1024 radial projections, total scan time = 6.8 s) and again, the IR-MAP algorithm and Eq. 2 were used for image reconstruction and T_1 quantification. Due to the long scan time, a segmented IR snapshot FLASH measurement was not feasible for the in-vivo measurements. In consequence, the echo train length of the Cartesian IRFSE experiment was increased to 32 for a reduction in scan time to about 25 min for the acquisition of 24 contrasts with $TI \in [100\text{ ms}, 8000\text{ ms}]$ and a reference T_1 map was obtained.

Results & Discussion: Figure 2 shows T_1 maps obtained from the reference IRFSE dataset (a), the segmented radial IR snapshot FLASH dataset (b) and the IR-MAP reconstructed single preparation dataset (c). The ROIs used for the evaluation are indicated in yellow. Table 1 lists the mean T_1 values and their standard deviations (STD) within the compartments obtained in the ROI analysis. Results of the in-vivo measurements are depicted in Fig. 3. Shown are the IRFSE reference (a) as well as the IR-MAP reconstructed T_1 map obtained from only one single magnetization preparation (b).

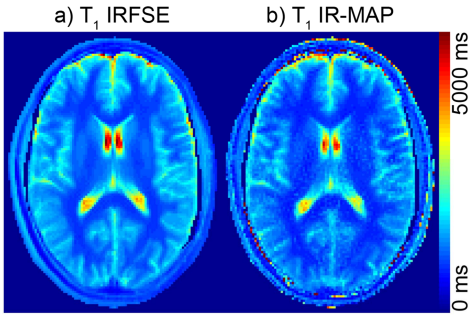

Fig. 3: *T1 maps of the in-vivo measurements.*

The T_1 values in Table 1 show a good agreement between the segmented (b) and the IR-MAP reconstructed (c) T_1 maps obtained with the IR snapshot FLASH acquisition. The increased STD within the ROIs of (c) are caused by the drastically reduced amount of preparations (1 vs. 202) used for the reconstruction. However, they are still acceptably small especially with respect to the acquisition time of more than 3 h for the segmented compared to 3.4 s for the single-preparation dataset and demonstrate the functionality of the IR-MAP algorithm. The IRFSE T_1 maps of the phantom and in-vivo measurements indicate a systematic underestimation of the T_1 maps obtained in the IR snapshot FLASH experiments. This might be a combination of inaccuracies in the IRFSE method on one side and limits of Eq. 2 in order to derive T_1 out of the apparent relaxation parameters time M_0, M_0^* and T_1^* on the other side.

In conclusion, the proposed IR-MAP reconstruction algorithm allows quantifying the longitudinal relaxation parameter T_1 from one single magnetization preparation, leading to extremely short acquisition times of about 7 s for a human brain. Compared to the SR preparation used in the first MAP implementation in [1], the signal-to-noise ratio is increased by a factor of approximately 2.

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References: [1] Tran-Gia et al., Proc ISMRM 20:359 (2012), [2] Deichmann et al., J Magn Reson 96:608-612 (1992), [3] Seiberlich et al., Magn Reson Med 59:930-935 (2008), [4] Winkelmann et al., IEEE T Med Imaging 16:68-76 (2007)