High Resolution T1 Mapping of the Full Brain with a Modified DESPOT1-HIFI Approach at 7T

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PURPOSE: T1 mapping has ever been a field of interest in MRI. Latest methods such as DESPOT1 [1] and MRF [2] offer efficient ways for fast 3D data acquisition and post-processing. In this work, a modification to the DESPOT1-HIFI [3] approach for applications at ultra-high magnetic field strengths is presented.

MATERIAL & METHODS: The DESPOT1-HIFI approach takes B1-field inhomogeneity into account by regarding a scaling of the readout flip angle in both 3D spoiled gradient echo (spgr) and magnetization prepared rapid acquisition gradient echo (mprage with adiabatic inversion) sequences:

$$S_{\mathrm{spgr}} = \frac{\rho(1-\exp(-TR/T1))\sin(\kappa\alpha)}{1-\exp(-TR/T1)\cos(\kappa\alpha)} \quad (1) \text{ and } \quad S_{\mathrm{mprage}} = \rho(1-(1+\frac{\rho'}{\rho})\exp(-TI'/T1))\sin(\kappa\alpha') \quad (2);$$

ρ' being proportional to the magnetization before inversion, κ a pixelwise readout flip angle scaling factor, other variables as common. In highly segmented mprage sequences ρ' cannot be approximated by a TD' (delay after readout) dependent term as in inversion recovery spin echo (IRse) sequences (Fig. 1, light blue curve), but by a free parameter ζ. A non-linear least squares minimization of the combined problem holds a target function with a number of four variables. Using only three (two spgr and one mprage) data sets might result in an under-determined problem:

$$f(\rho,\rho',\kappa,T1) = \sum_{n_{\mathrm{spgr}}}\left[S_{\mathrm{spgr}}(\rho,TR,\kappa,\alpha,T1) - M_{\mathrm{spgr}}\right]^2 + \sum_{n_{\mathrm{mprage}}}\left[S_{\mathrm{mprage}}(\rho,\rho',TI',\kappa,\alpha',T1) - M_{\mathrm{mprage}}\right]^2 \quad (3).$$

In this work it is shown that ρ' can be derived from a simulation of the Bloch equations for a specific set of sequence and tissue parameters (Fig. 1, red curve). After a transient response, the magnetization is driven into a steady state before inversion (Fig. 1, red dash-dot line):

$$\rho' = \zeta(n_{seg},\kappa,\alpha',TR',TD',T1)\rho \quad (4);$$

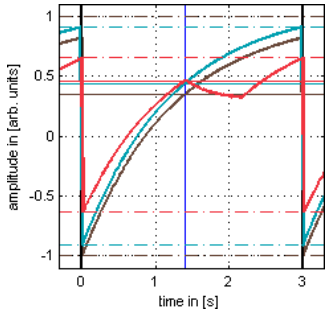

Fig. 1: Amplitude behavior of inversion recovery experiments for complete relaxation (brown), reduced TD' with a spin echo readout (light blue) and with a spgr readout train (red) in one TR interval; ρ' (dash-dot line), signal readout amplitude (solid line) at TI (blue line).

n_{seg} being the number of readout pulses per inversion. It is clear how the readout (Fig. 1, vertical blue line) distorts the prepared magnetization, as it leads to the spgr steady state, and conditions ρ'. Data acquisition was centrically-out reordered to capture the prepared magnetization state well in the contrast defining k-space center. The signal can be approximated by the first k-space line (Fig. 1, horizontal red line). With this strategy, a lookup table for ρ' can be calculated and accounted for inside the minimization routine, thus reducing the number of free variables by one and yielding higher estimation accuracy for the remaining parameters.

All measurements were performed at a 7T whole body MR system (Magnetom 7T, Siemens Healthcare, Erlangen, Germany) using a 24-channel coil (Nova Medical Inc., MA, USA). Computational processing was carried out on a standard desktop PC using MATLAB (MathWorks, MA, USA). The reference phantom houses 13 test tubes, 12 of which are filled with different concentrations of pure water and contrast agent (Gd-DTPA) and one with pure water only. Three individuals (2 male/1 female) were examined within a clinically reasonable timeframe of <25 minutes. Two spgr/mprage (for more robustness) contrasts each were acquired with the following sequence parameters: FOV: 256×256×192 mm^3, matrix: 256×256×192 px^3, n_{seg}: 192, α: 2°/17°, α': 7° (centrically reordered), TI': 1300 ms/1600 ms, BW: 490 Hz/px, TD': 900 ms/500 ms, GRAPPA R: 2/reference lines: 128, TA: 2:59 min, TA': 9:33 min. As a gold standard, an IRse experiment was additionally performed on the reference phantom as follows: FOV: 128×128 mm^2, matrix: 128×128 px^2, α: 90°, TI: 40-6090 ms, contrasts: 32, BW: 797 Hz/px, TD: 5000 ms.

RESULTS & DISCUSSION: Studies on the reference phantom show a good agreement between the IRse and modified DESPOT1-HIFI experiment (Fig. 2); correlation of 0.93 with R^2 of 0.999. One reason for the systematic deviation is presumably a temperature drift (≤ 1° C) and so caused changes in the relaxivity of Gd-DTPA [4] and $T1_0$ of pure water [5]. The modification allows magnetization prepared single shot scanning in higher spatial resolution, but without extending measurement time compared to the initial DESPOT1-HIFI approach, and reduces partial volume effects especially in gray matter regions.

method	$T1_{WM}$ in [ms]	$T1_{GM}$ in [ms]
this study	1246±43	1904±48
Look locker [6]	1220±36	2132±103
IR_EPI [7]	1357±22	2007±45
MPRAGE [8]	1130±100	1940±150

Tab. 1: Comparison of T1 values (B0: 7T).

In-vivo examinations allow for a clear discrimination between different compartments of the brain (Fig. 3). Averaged T1 values for white (WM) and gray (GM) matter at 7T fit into current literature references (Tab. 1). The method performs robust in the whole brain, even at very low B1 amplitudes (e.g. brain stem).

CONCLUSIONS: With a modification to the DESPOT1-HIFI method, three-dimensional T1 maps of the whole head with an isotropic resolution of 1 mm can be acquired within a 25 minute timeframe, revealing T1 values of 1246±43 ms (gray matter) and 1904±48 ms (white matter) at 7T.

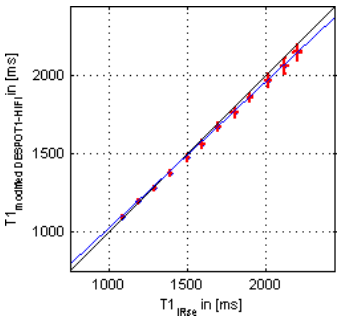

Fig. 2: Correlation of T1 values from IRse and modified DESPOT1-HIFI experiments (red marker): angle bisector (black), correlation (blue).

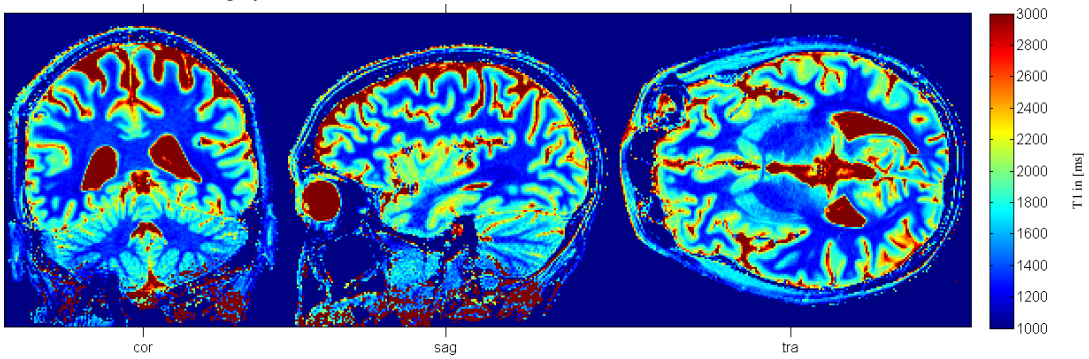

Fig. 3: T1 maps in milliseconds in coronal, sagittal and transversal view of a healthy volunteer: white and gray brain matter can clearly be discriminated. Regions in the brain stem offer a good contrast despite the low B1 amplitude. The method fails in regions of insufficient SNR. The color map clips at 3000 ms. Thus, CSF and eyes are not displayed correctly.

REFERENCES:

[1] S. C.L. Deoni et al., Magn Reson Med, 49, 515-526, 2003; [2] D. Ma et al., Nature, 495, 187-192, 2013; [3] S. C.L. Deoni, J Magn Reson Im, 26, 1106-1111, 2007; [4] I. M. Noebauer-Huhmann et al.. Invest Radiol, 45, 554-558, 2010; [5] K. Krynicki, Physica, 32, 167-178, 1966; [6] W. D. Rooney et al., Magn Reson Med, 57, 255-256, 2007; [7] V. Ikonomidou et al., Proc Intl Soc Mag Reson Med, 14, 920, 2006; [8] P. J. Wright et al., Magn Reson Mater Phy, 21, 121-130, 2008