Fast T1 Mapping of the Brain at 7T with RF Calibration Using Three Point DESPOT1 Method

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Introduction: Rapid T_1-maping with high resolution that is better than 1 mm^3 voxel size has great potential for clinical applications. The recently developed DESPOT1 (driven equilibrium single pulse observation of T_1) approach allow accurate whole brain T_1 mapping within the clinical timeframe [1]. With DEPSOT1, T_1 is calculated from a set of spoiled gradient recalled-echo (SPGR) images acquired over at least two flip angles with constant repetition time (TR). However, the accuracy of this method is quite sensitive to B_1 inhomogeneity encountered at 7T. In this study, a modified approach based on 3 points DESPOT1 measurements is introduced, which allow rapid high resolution T_1 measurements with B_1 correction.

Materials and Methods: The study was conducted using a GE (General Electric) Signa 7T whole-body MRI scanner. The system is equipped with a Twin-Speed gradient system and a dynamically detunable birdcage transmitting coil. A whole-brain 16 channel receiver array coil (NOVA Medical Inc, MA) designed for brain imaging was used for receiving. A total of 6 healthy volunteers participated in the study. Quantitative T_1 measurements were made by acquiring DESPOT1 images at 3 different flip angles (5, 10, and 20). Typical acquisition parameters included the following: FOV=220 ×165 mm^2, matrix size=512×384, an axial 3D slab of 32 slices, slice thickness=1mm, and TE/TR=2.8/13ms. The DESPOT1 signal amplitude, $A(\alpha)$, can be written as a function of the flip angle, α, TR, longitudinal relaxation time, T_1, and the equilibrium longitudinal magnetization, M_0, as follow: $A(\alpha)=M_0(1-E_1)\sin(\alpha)/(1-E_1\cos(\alpha))$, where $E1=exp(-TR/T_1)$. When B_1 inhomogeneity is a severe issue as at 7T, the precise flip angle is unknown and T_1 cannot be accurately determined from the two point measurements. By performing the three point measurements at α, 2α, and 4α, T_1 can be evaluated with the corrected B_1, as long as the linear relationship between α, 2α, and 4α is valid. The procedure t is outlined below. Assuming the voxel intensities measured at α, 2α, and 4α are $A(\alpha)$, $A(2\alpha)$, and $A(4\alpha)$, respectively, the ratio between $A(\alpha)$ and $A(2\alpha)$ is a_1, the ratio between $A(2\alpha)$ and $A(4\alpha)$ is a_2, it is trivial to show that

$$a_1 = \frac{\sin(\alpha)(1-E_1\cos(2\alpha))}{(1-E_1\cos(\alpha))\sin(2\alpha)} = \frac{1-E_1(2\cos(\alpha)^2-1)}{2(1-E_1\cos(\alpha))\cos(\alpha)} \quad [1],$$

$$a_2 = \frac{\sin(2\alpha)(1-E_1\cos(4\alpha))}{(1-E_1\cos(2\alpha))\sin(4\alpha)} = \frac{1-E_1(2\cos(2\alpha)^2-1)}{2(1-E_1\cos(2\alpha))\cos(2\alpha)} \quad [2].$$

Let $x=\cos(\alpha)$ and $\cos(2\alpha)=2\cos(\alpha)^2-1=2x^2-1$, solving eqs. 1 and 2 for E_1, the following equation can be obtained:

$$-4a_2x^4 + (4a_1 + 4a_1^2)x^3 + (4a_1 + 4a_2 - 2a_1a_2 - 1)x^2 + (1 - a_1 - a_2) = 0 \quad [3]$$

Eq. 3 was solved numerically on a pixel by pixel basis using Matlab optimization toolbox. Once $x=\cos(\alpha)$ is known, T_1 and M_0 were extracted as detailed earlier in the reference [1].

Results: Fig. 1a shows a set of typical T_1 maps obtained by using the standard 2 point DESPOT1 method without B_1 calibration. As expected, the measured T_1 results were substantially affected by the B_1 inhomogeneity associated with the dielectric resonance effects at 7T. This is not surprising, because the actual flip angle in the central area of the images was about twice of that in the peripheral regions. With the proposed three point DESPOT1 method and B_1 correction, the center brightness is resolved, as demonstrated by the T_1 maps shown in Fig. 1b. The average T_1 values for grey and matter as measured by the three point DESPOT1 method are 2.0±0.1 and 1.5±0.1 sec, respectively, which agrees quite well with the previously reported literature results [2] based on other conventional T_1 measurement methods at 7T. Unlike the broad T_2 and T_2* distributions of the brain at 7T, the distribution of the T_1 in the brain is quite narrow as at the lower fields.

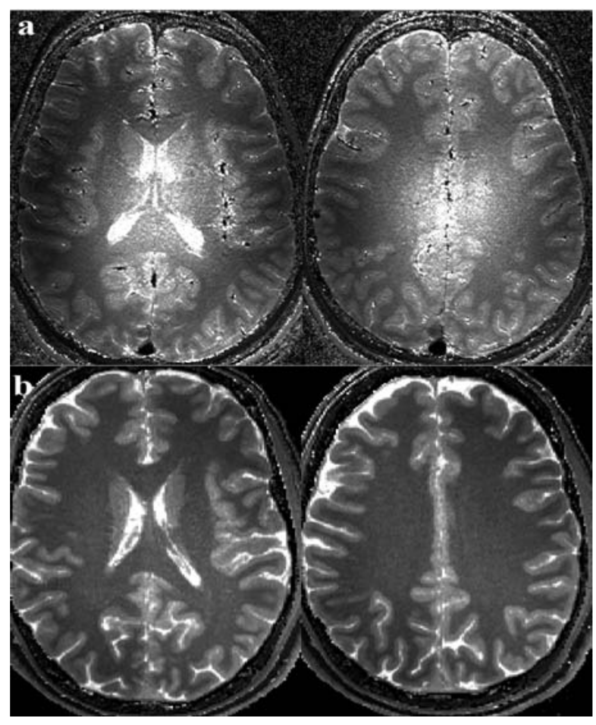

Fig. 1: T1 maps measured at 7T using the standard two point DESPOT1 method (a) and using the improved three point DESPOT1 method (b).

Discussion: In addition to the B_1 calibration capability, the time efficiency of the proposed three point DESPOT1 method is still quite high (30% lower that of the two point method). T_1 measurement of a slab with 32 slices lasts less than 2 min and the power deposition is still well below the SAR limit of the 7T. It should be pointed out that the DESPOT1 method is also sensitive B_0 inhomogeneity and using higher spatial resolution can reduce the banding artifacts. The banding artifacts can be diminished by using acquisitions based on 512x512 matrix size in stead of 256x256.

References:

1) S.C.L. Deoni et al. *Magn Reson. Med* **53**:237 (2005).
2). J. Pfeuffer et al. *Magn. Reson. Imaging* **22**:1343 (2004).