Fast Quantitative T_2^* Mapping with Elimination of Macroscopic Susceptibility Artifacts

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Introduction One well-known problem associated with T_2^*-weighted imaging/T_2^* mapping is that physiology-relevant or contrast agent-induced changes in T_2^*-weighted signal intensity is masked by macroscopic susceptibility artifacts originated from magnet imperfection, poor shimming and tissue-air interfaces. Various so-called z-shimming methods have been developed to deal with this problem (1-4). In this work, a novel fast z-shimming method was proposed to acquire quantitative T_2^* maps in the presence of macroscopic susceptibility artifacts. The feasibility of the method was demonstrated in vivo.

Materials and Methods The method is based on acquisition of two gradient-echo images to calculate T_2^* map. The pulse sequence is shown in Fig. 1. The first gradient echo (S_1) is acquired at a very short echo time (TE_1) so that the dephasing effect of the in-slice macroscopic field gradient (G_m) is only minimal. After acquiring the first echo, a large compensation gradient ($G_{c,max}$) of a length Δ is applied, followed by a number (N) of smaller gradients (G_s), having a length of δ each, that explore the k space of the in-slice direction, and $G_{c,max}\Delta=(N/2)G_s\delta$. k space shift increment in the in-slice direction is $\Delta k=\gamma G_s\delta=2\pi v/z_0$ (i.e., v is the over-sampling factor). TE_2 is the echo time of an echo in the echo train when the total phase disperse generated by the compensation gradients reaches zero. The gradient echoes acquired after each G_s were Fourier-transformed (FT) first in the in-plane directions and then in the slice direction to obtain magnitude images which are then summed to form an effective gradient echo (S_2), which is nearly artifact-free and has an effective echo time (TE_{2eff}) [4]. $TE_{2eff}=TE_2+n_c\tau$, where n_c (i.e., $-N/2\le n_c\le N/2-1$) is the number of the echo whose signal intensity is the highest among all the echoes in the echo train.

The signal intensity of the first gradient echo is $S_1=M_0\exp(-TE_1/T_2^*)\mathrm{sinc}(\gamma G_m TE_1 z_0/2)$, where M_0 is the slice selective excitation profile magnetization, γ is the gyromagnetic ratio, and z_0 is the imaging slice thickness. It can be shown that, as long as the amplitude of Δk (or v) is sufficiently large (here we chose v=0.67), $S_2\approx M_0\exp(-TE_{2eff}/T_2^*)$. Define $S_1^*=S_1/\mathrm{sinc}(\gamma G_m TE_1 z_0/2)$, where G_m is calculated as $(TE_2-TE_{2eff})G_s\delta/(TE_{2eff}\tau)$. It can be shown that $T_2^*=(TE_{2eff}-TE_1)/\ln(S_1^*/S_2)$.

The method was implemented on a Bruker Biospec 4.7 T/30 cm spectrometer. A 12-cm diameter Helmholtz coil was used for RF excitation and a 2.5-cm diameter single loop surface coil for signal reception. T_2^* mapping of the brain was performed on 5 Sprague-Dawley rats (250-300 g, n=5) with FOV 4 cm × 4 cm, matrix size 128 × 128, slice thickness 2.5 mm and TR 500 ms. The T_2^* maps obtained with the proposed method (v 0.67, TE_1 3.5 ms, TE_2 50 ms, τ 2.6 ms and N=32) were compared to those obtained a conventional FLASH sequence (i.e., 10 echoes with TE of the first echo 3.5 ms and inter-echo space 5 ms).

Results and Discussions Figure 2 shows the two gradient-echo images (a and b) acquired with the proposed method, the calculated T_2^* map (c) based on (a) and (b) and a T_2^* map measured with the conventional FLASH method (d). Table 1 lists T_2^* measured from different brain regions with different methods. With the proposed method, the two gradient-echo images used to calculate T_2^* map were both nearly artifact-free. In clear contrast to the T_2^* map acquired with the conventional FLASH sequence, the T_2^* map obtained with the proposed method showed only minimal macroscopic susceptibility-induced artifacts. The T_2^* values measured with the proposed method had lower inter-subject variations and were significantly longer relative to those measured with FLASH ($p<0.05$), suggesting good compensation of the macroscopic in-slice field inhomogeneities.

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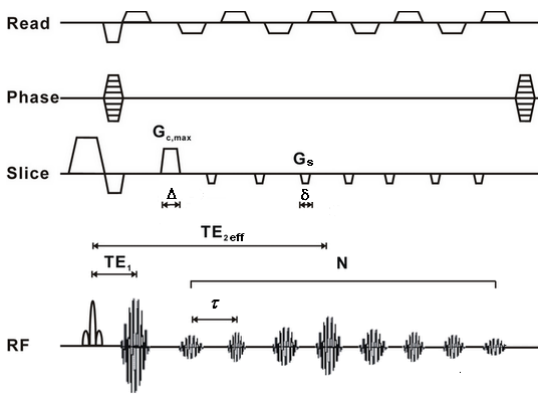

Figure 1. Pulse sequence for the method proposed.

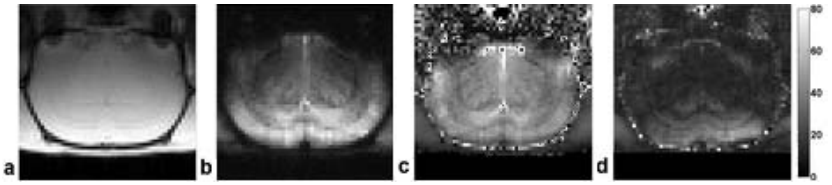

Figure 2. The first gradient-echo image (a, TE_1=3.5 ms) and the second effective gradient-echo (b, TE_{2eff}=44.8~86.4 ms) image acquired with the proposed method. The T_2^* map (c) calculated based on (a) and (b) was compared to the T_2^* map measured with the conventional FLASH (d).

Table 1. T_2^* (n=5, in ms) in different brain regions measured with different methods

	Cortex	Hippocampus	Thalamus
FLASH	33.4 ± 6.3	24.8 ± 7.0	17.6 ± 4.8
Proposed	41.4 ± 2.1*	46.1 ± 2.9*	35.6 ± 0.9*

* $p<0.05$ compared to the values obtained with the FLASH method