A Novel Fast and Robust T2* Mapping Algorithm Using the Definite Integral of the Signal Decay (DISC) Curve

Mengchao Pei[1,2], Thanh D. Nguyen[1], Lijia Wang[2], Tian Liu[1], Mitch Anthony Cooper[1], Jianqi Li[2], and Yi Wang[1,2]

[1]*Weill Cornell Medical College, New York, NY, United States,* [2]*Shanghai Key Laboratory of Magnetic Resonance, East China Normal University, Shanghai, Shanghai, China, People's Republic of*

INTRODUCTION

$T2^*$ as an important parameter characterizing tissue magnetic susceptibility properties has become increasingly used in clinical and preclinical research [1-4]. $T2^*$ values are commonly extracted from the multi-echo $T2^*$ decay curve using nonlinear least squares fitting methods such as the widely used Levenberg-Marquardt (LM) algorithm. This algorithm may become less robust for noisy data and its convergence is influenced by the initial guess. Here we propose a novel $T2^*$ mapping method based on the definite integral of the signal decay curve (DISC), which is fast, accurate and robust.

THEORY

Given the $T2^*$ signal decay curve (Fig.1) expressed mathematically as $S(t) = S_0 \exp(-t/T_2{}^*)$, the definite integral of this function over the range of acquired TE, which is the area under the curve over this interval, can be calculated as follows:

$$I = \int_{TE_1}^{TE_N} S(t)dt = -T_2{}^*[S_0 \exp\left(-\frac{TE_N}{T_2{}^*}\right) - S_0\exp(-\frac{TE_1}{T_2{}^*})] = -T_2{}^*[S(TE_N) - S(TE_1)]$$

Assuming that the decay curve is sampled with a sufficiently small TE step, the area can be approximated using the trapezoidal rule (Fig.1):

$$I \approx \sum_{i=1}^{N}\{[S(TE_i) + S(TE_{i+1})] * (TE_{i+1} - TE_i)/2\}$$

Correspondingly, $T2^*$ can be determined as $T_2{}^* = 1/[S(TE_1) - S(TE_N)]$. Due to the noise smoothing effect of the integration, we expect this method to be more robust at lower SNR.

METHODS

Numerical simulations were used to compare DISC and LM algorithms: 1) ΔTE=5ms, 10 TEs, SNR=40, and $T2^*$=10, 30, 60 ms; 2) ΔTE=5ms, 10 TEs, $T2^*$=20ms, and SNR=50, 20,10. For each parameter combination, 1000 datasets were generated by adding random Gaussian noise and $T2^*$ values were extracted with DISC and LM algorithms. A two-parameter exponential model was used for LM fitting [4]. Next, comparison was performed on healthy brain data acquired at 3T (3D multi-echo gradient echo sequence, TR=57ms, 11 echoes uniformly spaced between 4.3 to 52.4ms, ΔTE=4.8ms, flip angle=20°, matrix size=512×512×48, FOV=24 cm, slice thickness=3 mm). All processing was done in Matlab and processing times were recorded.

RESULTS

Figure 2 compares errors (the bias and standard deviation) of DISC and LM estimates obtained from numerical simulations for various $T2^*$ values (Fig.2a) and SNR values (Fig.2b). DISC consistently provided smaller biases, especially for larger $T2^*$ and lower SNR. While LM estimates have lower variability as measured by smaller standard deviations, the difference between the two methods is quite small. Figure 3 shows the $T2^*$ map of the human brain obtained with DISC and LM algorithms. While the maps and selective ROI measurements are very similar (Table 1), DISC reduced the processing time for a whole brain dataset from LM's 20 hr to 5 min, representing a 250 times reduction.

DISCUSSION

Our preliminary results have demonstrated that DISC is a fast, robust and accurate algorithm for $T2^*$ mapping, particularly at low SNR (less than 50). The improved robustness of the algorithm can be attributed to the noise smoothing effect of the integration. This method is easy to implement and does not require an initial guess as in LM. A drawback of DISC algorithm is the need to sample the $T2^*$ decay curve with sufficiently small TE step (around 5 ms); however, this can usually be achieved on modern scanners.

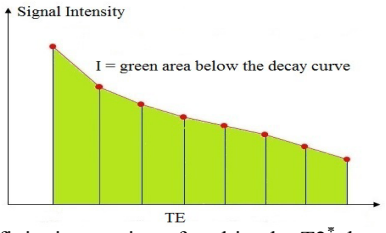

Fig.1. Definite integration of multi-echo $T2^*$ decay curve computed by the trapezoidal rule.

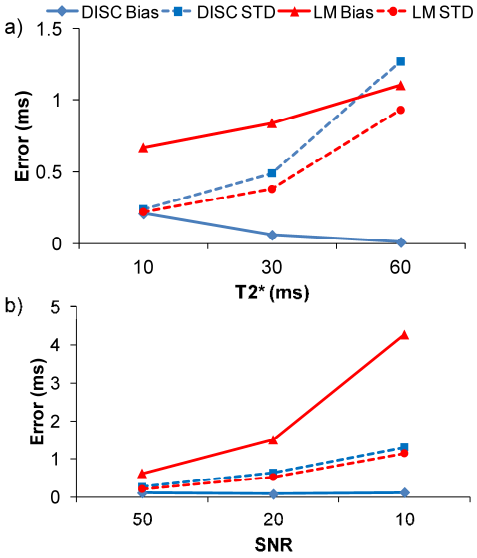

Fig.2. Comparison of errors (bias and standard deviation) of $T2^*$ estimates obtained with DISC and LM algorithms.

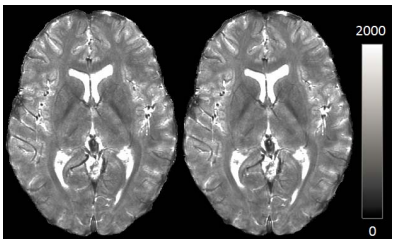

Fig.3. Human brain $T2^*$ map obtained with DISC (left) and LM (right) algorithms.

Table 1. Human brain $T2^*$ obtained with ROI analysis.

ROI	Caudate	Putamen	Thalamus
T2* DISC	46.3 ± 7.1	43.6 ± 5.3	49.2 ± 7.1
T2* LM	45.9 ± 7.2	42.7 ± 4.9	49.0 ± 7.4
SNR	61.5	61.2	57.7

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