

Refocusing Flip Angle Map Constrained Fitting for Indirect Echo Compensated T2 Mapping

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TARGET AUDIENCE Scientists interested in parameter mapping (e.g. T2 mapping.)

PURPOSE T2 mapping is a quantitative technique allowing direct assessment of the underlying parameter of T2 contrast. For spin-echo based T2 mapping, a *multiple spin-echo* (MSE) technique is generally used due to the long acquisition time required by single spin-echo T2 mapping strategies. However, because of pulse imperfection, the signal acquired by MSE sequences is generally contaminated by indirect echoes (including stimulated echo)^{1,2}. Several groups have investigated T2 fitting techniques incorporating the indirect echoes into the signal model to achieve accurate T2 mapping from MSE data. In 2010, Wilman and Lebel² proposed to use *slice-resolve extended phase graph* (SEPG) algorithm as the fitting model. Recently, a similar Block simulation based approach was presented by Ben-Eliezer, et al.³.

One common aspect of these model-based indirect echo compensated T2 estimation techniques is that the *flip angles of the refocusing pulses* (rFA) are also being fitted to the acquired TE images for each pixel along with T2 values. However, the smallest *root-mean-square error* (RMSE) of the fitting for all T2 values when rFA is fixed is not a convex function of rFA. As shown in **Figure 1**, the smallest RMSE as a function of rFA has two local minima. Due to the fact that these two local minima have very similar RMSE, the global minimum estimation is not stable when noise is present. This can be observed in **Figures 2a** and **2d**. In Ref. 2, this ambiguity was avoided by restricting $0 < rFA \leq 180^\circ$. Although the ambiguity is avoided by doing so, further investigation revealed⁴ this restriction can cause up to 5% underestimation of T2 values when the actual rFA is $>180^\circ$. Breikreutz et al.⁴ proposed to use a separately acquired rFA map to improve the accuracy. However, the additional acquisition time for rFA mapping is not desirable and the approach also suffers from subject motion between these two acquisitions.

In this work, we propose an iterative rFA map constrained T2 decay model fitting technique with indirect echo compensated to solve the ambiguity shown in Figure 1 without additional acquisition.

METHODS Under the assumption that the rFA map (similar to B1 map) is spatially smooth, we propose to use a Markov random field prior on the rFA map using the iterated conditional modes algorithm⁵:

$$\mathbf{T2}_{i,j}^{k+1}, \mathbf{rFA}_{i,j}^{k+1} = \arg \min_{\mathbf{T2}_{i,j}^{k+1}, \mathbf{rFA}_{i,j}^{k+1}} \{ \|F(\mathbf{T2}_{i,j}^k, \mathbf{rFA}_{i,j}^k) - D_{i,j}\|_2 + \mu \sum_{i',j'} w(i' - i, j' - j) |\mathbf{rFA}_{i,j}^k - \mathbf{rFA}_{i',j'}^k|^2 \},$$

where $\mathbf{T2}_{i,j}^{k+1}, \mathbf{rFA}_{i,j}^{k+1}$ are the (i,j)-entry of the estimated T2 and rFA maps after the k^{th} iteration, $F(\cdot)$ is the signal model, $D_{i,j}$ is decay data at (i,j) which is normalized such that its L_2 -norm=1 to avoid fitting of proton density, μ is the parameter to control the smoothness constraint, $w(\cdot)$ consists of weights of the smoothing window.

The proposed algorithm was performed on two brain dataset acquired on a young healthy subject using a 1.5T GE Signa HDxt MR scanner. The study was approved by local IRB and informed consent was obtained from the subject. The acquisitions were performed using a radial MSE sequence with acquisition parameters: slice thickness = 8 mm, receiver bandwidth = ± 15.63 kHz, TR = 4 s, FOV = 24 cm, 256 radial lines per echo, 16 equispaced echoes with 12.93 ms echo spacing. The two acquisitions were performed with two different nominal rFA: 180° and 120°.

Indirect echo compensated model-based T2 fittings (SEPG model in this work) with and without the proposed rFA map constraint were performed on these two data sets. μ was used to $1e-7$; $w(\cdot)$ was a 23×23 window with weightings equal to the reciprocal of the distance of the two pixels in the unit of pixel; $\mathbf{rFA}_{i,j}^k$ was initialized by the nominal rFA. A threshold was used to remove pixels without signal from the fitting process. To reduce computation time, $F(\cdot)$ can be pre-computed as a dictionary given the range of T2 and rFA similar to the work by Ben-Eliezer et al.³. We used T2 = 50~2000 ms with step size = 1ms, B1 = 90°~270° with step size = 1.8° for the dictionary pre-computation. The fitting was stopped after 10 iterations.

RESULTS As shown in **Figure 2a** and **2d**, the conventional model-based fitting without rFA map constrained suffers from the rFA ambiguity problem. It can be seen that the values in the rFA maps obtained by conventional fitting jump between the two local minima (demonstrated in **Figure 1**) throughout the entire brain. However, the two corresponding rFA maps (**Figures 2b, 2e**)

obtained by the proposed rFA map constrained technique are uniform and the rFA values agree well with the nominal rFA. Also, the variation of the constrainedly fitted rFA maps visually agree with the reported maps in the literature^{2,4}. It can be seen that the T2 values obtained from data acquired with 120° nominal rFA are slightly higher. This overestimation for low rFA was expected due to the fact that T1 was fixed to infinity in the signal model². It has been reported that this overestimation can be alleviated by using an optimized T1 in the fitting¹.

CONCLUSION In this work, an rFA map constrained T2 fitting technique with indirect echo compensation was proposed and demonstrated using *in vivo* data. This approach is capable of solving the rFA ambiguity encountered by conventional algorithms and provides more accurate T2 maps.

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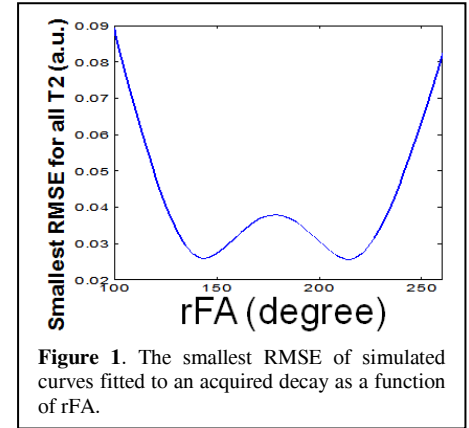


Figure 1. The smallest RMSE of simulated curves fitted to an acquired decay as a function of rFA.

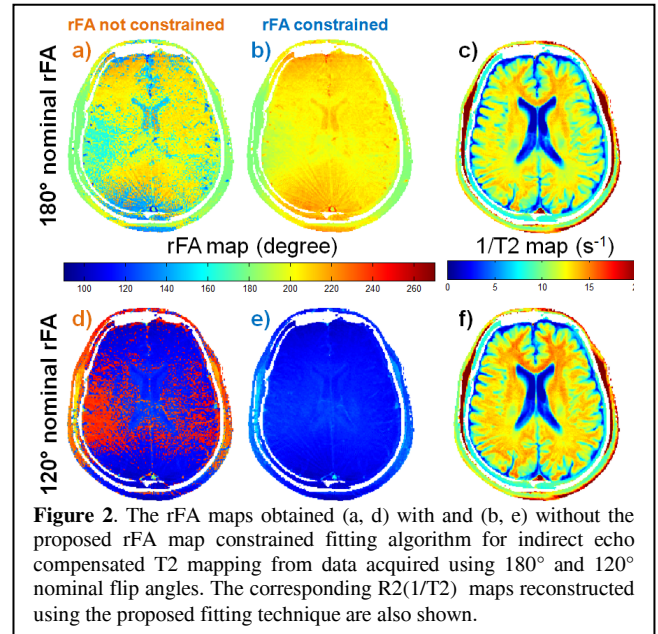


Figure 2. The rFA maps obtained (a, d) with and (b, e) without the proposed rFA map constrained fitting algorithm for indirect echo compensated T2 mapping from data acquired using 180° and 120° nominal flip angles. The corresponding R2(1/T2) maps reconstructed using the proposed fitting technique are also shown.