Quantification Myelin Mapping Through Short T_1 Component Filtering Linear Combination Using Multi Flip Angle SPGR Data

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Introduction: The spoiled gradient echo (SPGR) has been widely used for T_1 quantification. A signal curve solely depending on T_1 will be generated after applying the SPGR sequence in a range of flip angles, which is easy to be linearized for single component [1] and multicomponent [2,3] T_1 analysis. Linear combination has been proved to be a high-efficient post-processing method, and was adopted for myelin mapping using T_2 decay data in previous literatures [4,5]. Myelin mapping was obtained through summing a 32-echo T_2 decay with weighted coefficients for images on each echo time (TE), where the coefficients were set by maximizing the SNR of short T_2 component (~15ms) [4]. Alternatively, the coefficients and the corresponding T_2 filter could be designed by suppressing signal from tissue water (T_2=75~85ms) and CSF (T_2=200~5000ms), and echo number in the acquired data could be further reduced to 3 ~ 5 [5]. Previously, Vidarsson et al. presented the work on myelin imaging using steady-state free precession (SSFP) sequence and linear combination [6], where high T_1 / T_2 ratio was used for myelin water characterization which, however, lacks further validation. So far there is no report on the application of T_1 filtering for quantitative myelin mapping, despite that short T_1 component (~118ms) has been suggested to be myelin [7]. In this preliminary study, we demonstrate the feasibility of myelin water fraction (MWF) mapping through short T_1 component filtering. The data are collected with multi flip angle SPGR sequence and post-processed by linear combination. This new approach provides a fast acquisition and post-processing alternative for quantitative myelin mapping.

Materials & Methods:

Data Acquisition: One healthy volunteer was scanned with a 3D SPGR sequence on GE 3T scanner using nine flip angles. The flip angles were 2°, 3°, 4°, 5°, 8°, 11°, 14°, 17°, 20°, repitition time (TR) = 5.9ms, echo time (TE) = 1.7ms, field of view = 240mm, slab thickness = 48mm, matrix size = 256×256×16, receive bandwidth = 50kHz. Total scan time of nine flip angles was 3 min 36 s.

Data Analysis: SPGR image containing multiple T_1 components could be represented following the well known SPGR signal equation:

$$I_n = \sum_{k=1}^{K} \frac{s_k(1-E_{1,k})\sin\theta_n}{1-E_{1,k}\cos\theta_n}, \text{ where } E_{1,k} = e^{-\frac{TR}{T_{1,k}}}, \; n = 1, 2... N$$

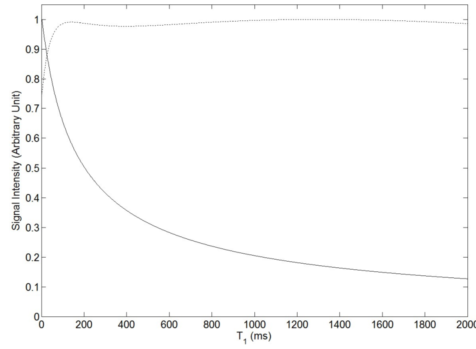

Fig. 1 Short T_1 component filter (F^M, solid line) and uniform filter (F^U, dotted line).

In this equation, n is the flip angle index, s_k represents the signal with $T_{1,k}$, and K is the number of T_1 components. Two sets of T_1 filter together with their linear combination coefficients c_n were designed: one set (denoted as F^M) was used for selecting signal from short T_1 component (around 118ms), which could be considered as myelin water [7], whose coefficients were denoted as c_n^M, and the filtered image I^M. The other set (denoted as F^U) is uniform filter to select the component of $T_1 > 80$ms, whose coefficients were denoted as c_n^U, and the filtered image I^U. The MWF map was calculated as $I = I^M / I^U$. Short T_1 component filter designing procedure was similar with ref [4], that is, to maximize the SNR (standard Levenburg- Marquardt algorithm in MATLAB) of selected T_1 range with nonlinear constrains. The SNR of the selected image was shown in following equation and the target function for minimization in MATLAB was set as the inverse of SNR:

$$SNR \propto \left(\sum_{n=1}^{N} \frac{c_n(1-E_{1,0})\sin\theta_n}{1-E_{1,0}\cos\theta_n} \right) \Bigg/ \sqrt{\sum_{n=1}^{N} c_n^2}, \text{ where } E_{1,0} = e^{-\frac{TR}{T_{1,0}}}$$

In the T_1 filter for short T_1 component, $T_{1,0}$ was set to be 130ms, a little bit larger than 118ms in order to increase the width of myelin peak. The short T_1 component filter and the uniform filter were shown in Fig 1.

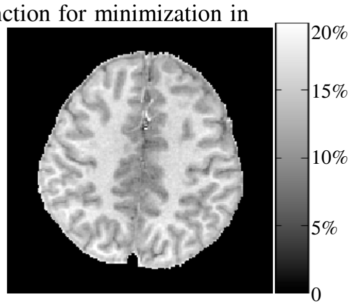

Fig. 2 MWF map of one axial slice.

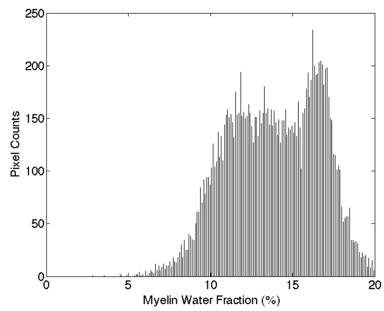

Fig. 3 Histogram of MWF map in the same slice with Fig 2.

Results: Fig 2 is the *in vivo* MWF map of one slice (with scalp manually removed), and the histogram of this slice is shown in Fig 3. The MWF map gives a good delineation between white matter and gray matter. Average MWF of white matter and gray matter was 16.6% and 8.48% in a 10-by-10 ROI, respectively. Thus signal peak between 15% < MWF < 18% in the histogram (Fig 3) was mainly representing the regions of white matter. The MWF value in white matter is consistent with previous literatures, demonstrating that this short T_1 component selection method is reasonable.

Discussion and Conclusion: A fast myelin imaging method using SPGR acquisition and linear combination post-processing is presented, and T_1 filtering method for obtaining MWF map is proposed for the first time. This method could be extended to the whole brain scanning, whose scan time is about 10 min by keeping the same resolution and TR/TE in this study. Moreover, myelin imaging using SPGR sequence is less sensitive to SNR fluctuation than that of multi-echo gradient echo. Additionally, for each set of scanning parameters, the linear combination coefficients and T_1 filter only need to be designed once. Besides, the calculation of the linear combined myelin image could be finished in less than one tenth of a second. However, the MWF appears too high in gray matter. Thus the optimization of the short T_1 component filter, especially the optimization of the flip angle is required. Furthermore, the investigation into less number of flip angles should be included for further reduction of scan time.

References

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