Optimal Filter Design for Linear Combination Filtering

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INTRODUCTION: Knowledge of a tissue's full T_2 spectrum may provide additional information on tissue pathology beyond current clinical techniques. For example, the white matter T_2 spectrum (Fig. 1) provides detailed information on demyelination and inflammation in diseases such as multiple sclerosis. Unfortunately, methods used to measure full T_2 spectra require impractically long scan times (~15-30 min.) [1]. As a possible alternative, linear combination filtering (LCF) provides information on a specified region of the T_2 spectrum (i.e. the passband of the filter, see Fig. 1) [2, 3]. LCF can be performed in clinically reasonable scan times (<10 min.). However, the effectiveness of LCF depends on the specific filter design. The purpose of this project is to optimize the LCF filter parameters for the white matter T_2 spectrum.

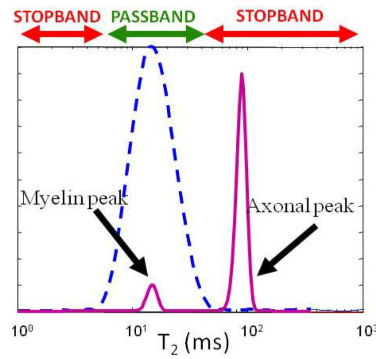

***Figure 1:** T_2 filter (dashed blue) and white matter T_2 spectrum (purple). Filter specifications include the passband size and location, as well as the stopband suppression factors.*

THEORY: LCF begins with a multi-echo acquisition. In each pixel, this produces a signal at *n* echo times: $S(TE_1), \ldots, S(TE_n)$. The signals are combined in a weighted sum with arbitrary weighting coefficients (a_i ; i=1,…,n) to produce a composite signal:

$$S_{composite}(T_2) = \sum_{i=1}^{n} a_i \cdot S(T_2, TE_i) \qquad (1)$$

With an appropriate choice of a_i's, the signal from one region of the T_2 spectrum can be highlighted, while signal from the rest of the spectrum is suppressed. The curve that defines the relative weighting of T_2 components can be considered a "T_2-filter" (Fig. 1). In previous LCF studies, filter specifications were defined arbitrarily based on an assumed T_2 spectrum distribution [2,3]. The objective of the present study is to identify systematically an *optimal* filter specification for characterizing the myelin component of the white matter T_2 spectrum.

METHODS: Four separate sixteen-echo brain scans were performed, each with different echo spacing (ΔTE=6, 7, 8, and 60ms). To provide a gold-standard reference, the full white matter T_2 spectrum was calculated from a composite data set containing all ΔTE's (total scan time ≈ 20 min) [4]. Next, a series of LCF's were performed using the ΔTE=7ms data alone (scan time ≈ 5 min). All LCF filters were designed to pass the myelin component of the spectrum (see Fig. 1). However, each filter was designed with a different specification (i.e. passband, stopband, and suppression factor). For each specification, the fraction of signal passed by the filter was compared to the true myelin water fraction (MWF) as determined from the full T_2 spectrum. The optimal filter design was defined as the one which provided the best match to the reference MWF derived from the full T_2 spectrum over the whole white matter region.

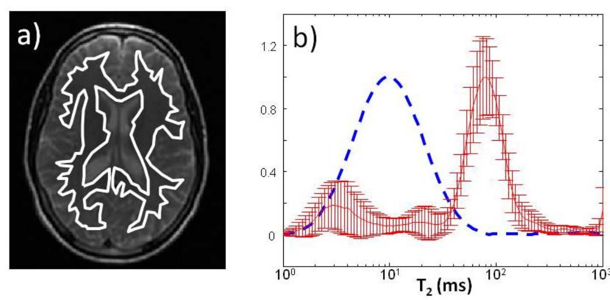

***Figure 2:** a) T_2–weighted image with white matter ROI overlay (white line). b) T_2-spectrum (red line) and optimal T_2-filter (dashed blue line). The T_2 spectrum represents mean +/- standard deviation over the whole white matter ROI.*

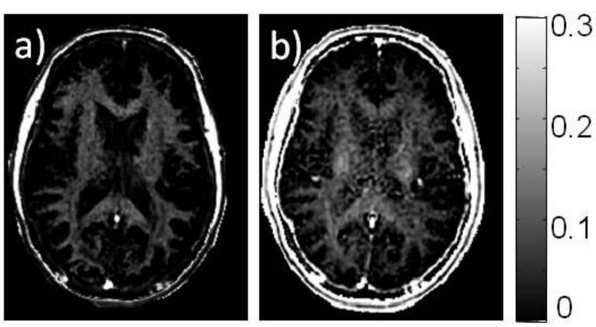

***Figure 3:** Myelin water fraction (MWF) images derived from the a) full T_2 spectrum and from b) LCF.*

RESULTS/DISCUSSION: Fig. 2 plots the optimal T_2 filter, together with the full white matter T_2 spectrum averaged over the entire white matter region. Fig. 3 illustrates MWF images produced by the optimized LCF, as well as the reference MWF image generated from the full T_2 spectrum. Qualitatively, the two images correlate closely. Quantitatively, Table 1 indicates a very close agreement between T_2-spectrum- and LCF-derived MWF's.

***Table 1:** Myelin water fraction (MWF) in various brain regions as determined from the optimal T_2 filter and reference full T_2-spectrum.*

Brain Region	Optimal T_2-Filter	T_2-Spectrum
Frontal	7 +/- 2 %	7 +/- 1 %
Genu	10 +/- 2 %	10 +/- 2 %
Cortical GM	1 +/- 2 %	1 +/- 1 %

[1] B Madler *et al.*, *MRI* 2008; 874-888,
[2] CK Jones *et al.*, *MRM* 2004; 495-502,
[3] L Vidarsson *et al.*, *MRM* 2005; 398-407.
[4] MS Sussman *et al.*, *ISMRM* 2011, p. 2752.