A Novel Method for Characterizing T_2 Spectra

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INTRODUCTION: Tissue often contains a spectrum of T_2 values. Measurement of the full T_2 spectrum could potentially provide information on tissue composition and pathology that goes beyond what is available from methods used in current clinical practice. For example, the T_2 spectrum of white matter (Figure 1) provides detailed information on the processes of demyelination and inflammation in diseases such as multiple sclerosis. Despite its promise, T_2 spectrum analysis is rarely used clinically. This is because the current method used to measure T_2 spectra, multi-exponential fitting, requires very long scan times (~20-30 minutes) [1]. An alternate method for obtaining information from T_2 spectra is linear combination filtering (LCF) [2,3]. The advantage LCF is that it can be performed in clinically reasonable scan times. The disadvantage is that it only provides information on a single, extended region of the T_2 spectrum. In this project, we develop a novel technique that uses LCF to provide an estimate of the full T_2 spectrum in a clinically reasonable scan time.

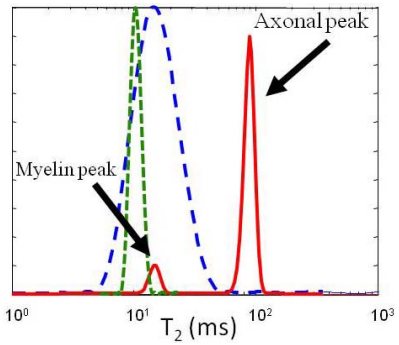

Figure 1: White matter T_2 spectrum (red) with axonal and myelin peaks indicated. Examples of wide (blue) and narrow (green) filter response functions are shown.

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 then linearly combined in a weighted sum with arbitrary weighting coefficients (a_i ; i=1,…,n) to produce a composite signal:

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

With an appropriate choice of a_i's, the signal from one part of the T_2 spectrum can be highlighted, while the signal from the rest of the spectrum is suppressed. The curve that defines the relative weighting of T_2 components is the "filter response function" (Fig. 1). Previous studies have designed filter response functions to isolate a single component of the spectrum (e.g. myelin, Fig. 1). In the present study, we develop a method using LCF to estimate the full T_2 spectrum. To accomplish this task, we employ two modifications (Fig. 2): First, a narrower-band filter response function is used. The purpose is to isolate signal from *within* a T_2 peak, as opposed to the *whole* peak as in conventional LCF. Second, a series of response functions centered at consecutive T_2 values, rather than just a single function centered about one specific T_2 value, is used. It can be shown that this provides an estimate of the T_2 spectrum ($\equiv \hat{\boldsymbol{m}}$) that is a convolution between the true T_2 spectrum ($\equiv \boldsymbol{m}$), and the filter response function:

$$\hat{\boldsymbol{m}}(\boldsymbol{T_{2_0}}) = \boldsymbol{m} * \boldsymbol{f} \qquad (2)$$

Thus, the effect of the filter response function is to generate a distorted estimate of the true T_2 spectrum. However, the distortion is fully controlled by the user-designed filter response function. This provides significant opportunity for optimization.

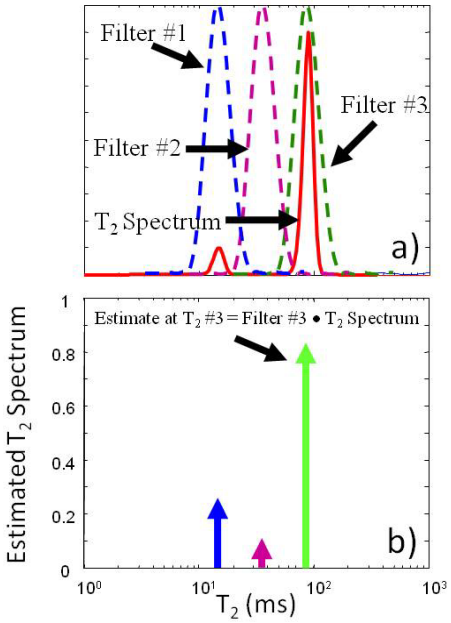

Figure 2: a) T_2 spectrum and three narrow filter responses at different T_2 values. b) The dot product of each filter response and T_2 spectrum provides an estimate of the T_2 spectrum at each T_2 value

METHODS AND RESULTS: Phantom and *in vivo* experiments were performed to validate the new technique. All data was acquired using a multi-echo spin echo pulse sequence (16 echoes, TE=8ms, matrix=128x128). Scan time was five minutes. The first experiment estimated the T_2 spectrum of a Gd phantom. Figure 3a indicates that the measured shape of the estimated T_2 spectrum corresponds very closely to theoretical predictions (Eq. 2). Note that due to the distortion inherent in the technique, the estimated T_2 spectrum is broadened relative to the true single, monoexponential T_2 value. A second experiment applied the technique *in vivo* to white matter. Figure 3b illustrates that the estimated T_2 spectrum contains two peaks in accordance with the known white matter T_2 spectrum (see Fig. 1). Unlike the expected true shape of the T_2 spectrum, however, the peaks overlap due to distortion in the estimate.

DISCUSSION AND CONCLUSIONS: A novel application of LCF for providing estimates of full T_2 spectra in a clinically reasonable scan time was shown. Although estimates had distortion relative to the true T_2 spectrum, the presence of peaks could still be detected. This may be sufficient for clinical purposes, where the presence of absence of peaks can provide information on pathology. In the future, it may be possible to reduce distortion through optimization of the filter response function. Alternately, since Eq. 2 indicates that distortion is caused by convolution, another possibility for reducing (or perhaps even eliminating) distortion is deconvolution.

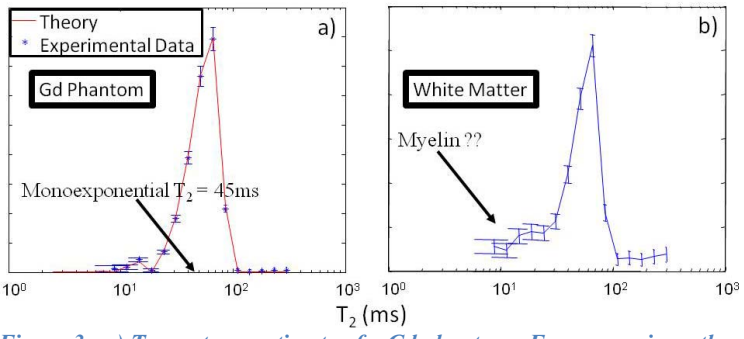

Figure 3: a) T_2 spectrum estimate of a Gd phantom. For comparison, the T_2 value derived from monoexponential fitting is indicated. b) T_2 spectrum estimate of white matter. The small peak may be myelin.

REFERENCES: [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.