Linear Combination Filtering in White Matter With Steady-State Free Precession (SSFP) Sequences

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Introduction: Myelin abnormalities have been reported in both MS and Schizophrenia (1-5). Recently a novel T_2 linear combination (LC) filtering method was proposed to measure in-vivo myelin content (3,4). However the required multi-echo acquisitions need long scan times (1,3,4). In this work we explore the use of LC filtering with multiple-flip angle fast (SSFP) sequences.

Theory: The SSFP signal is heavily dependent on tissue relaxation characteristics, in particular the ratio of T_1/T_2 (6,7). Myelin-water with its substantially shorter T_2 relaxation time has a different ratio than white matter water (1-5). From Schmitt *et al*. the SSFP response to a signal with a given $\tau = T_1/T_2$ value assuming TR << T_1,T_2 is given by:

$$S(\alpha,\tau) = \frac{M_0 \sin\alpha}{(\tau+1)-(\tau-1)\cos\alpha}$$

We will then form a linear combination filtering image, by linearly combining several SSFP images with different flip angles. The challenge is now to choose flip angles and weights such that the combined image highlights τ ratio's close to those of myelin, while suppressing other interfering tissues such as white matter water and cerebro-spinal fluid (CSF). We pose this as a τ-filter design problem. By expressing this as a convex optimization problem we choose weights that give maximum signal to noise ratio (SNR) for τ values of myelin, while arbitrarily suppressing τ values for interfering tissues. As with LC filtering we can find the weights for a fixed set of flip angles very efficiently by employing a so-called second order cone program (SOCP) solver (4). We can find the best set of flip angles by using our SOCP solver in an iterative fashion. Figure 1 shows the filtered signal vs. τ for our LC filter. For τ values close to myelin the signal is high, but low for interfering white matter water, and goes negative for CSF. To form a quantitative myelin fraction image, another uniform filter was designed, giving uniform signal to all τ ratios. The myelin-filtered image was then divided by the uniform image.

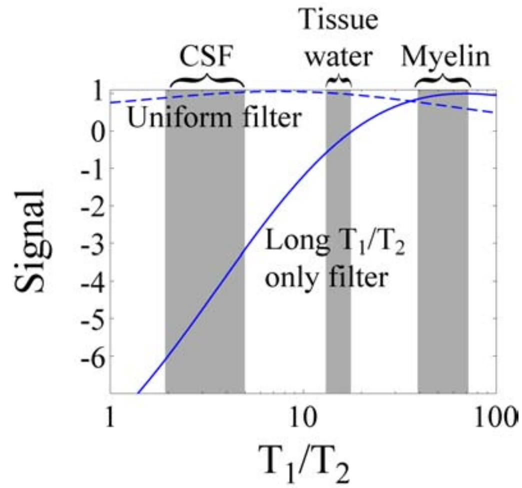

Figure 1: T_1/T_2 vs. Signal for our LC filter. We choose weights to expect good signal from myelin, while suppressing tissue water and cerebro-spinal fluid (CSF). Overlaid on the plot are literature values for T_1/T_2 for myelin, tissue water and CSF (1-4).

Methods: To study the use of LC filtering, an eight flip angle 3D-SSFP dataset was acquired of a healthy volunteer. The flip angles were logarithmically spaced from 10° to 68°; α=10°, 13°, 17°, 23°, 30°, 40°, 52°, 68°. Other parameters were: FOV=24cm^2 by 10 cm, 128 by 128 by 25 matrix, 2 averages, BW=62.5 kHz, TR/TE = 4/2 ms and phase cycling was used. Total scan time was 6 min 50 s. Images were processed using the method above to show only tissues with a high T_1/T_2 ratio, as expected for myelin (1-4), while suppressing interfering white matter water and CSF. Simulations were also performed where the theoretical SNR efficiency of the multi-echo approach was compared to that of our new multi-angle SSFP approach.

Results: *In-vivo* images are shown in Fig 2. High signal was seen from white matter which has high myelin content compared to gray matter and CSF. However, there was some edge enhancement due to motion as well as elevated signal in the frontal lobes due to off-resonance effects. Our theoretical simulations indicate that the multi-flip angle SSFP approach is 30% more SNR efficient, than the multi-echo approach.

Discussion: The high SNR efficiency of 3D-SSFP imaging yields higher theoretical SNR efficiency than that of multi-echo myelin imaging. However, SSFP sequences are more sensitive to off-resonance effects than spin-echo sequences (6).

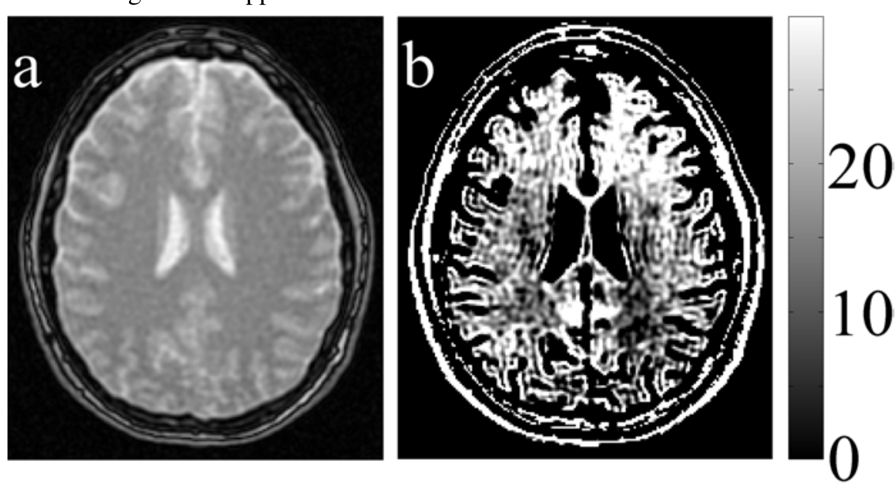

Figure 2: In-vivo images from a healthy volunteer. (a) Anatomic SSFP image (flip = 10°, TR/TE = 4/2 ms). (b) LC filtered image. The LC image is promising, showing good signal from white matter, which has high myelin content, while interfering gray matter and (CSF) are well suppressed. However, there is some edge enhancement due to motion, as well as elevated signal in the frontal lobes due to off-resonance effects.

References:
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