Magic Echo Imaging of the Brain at 1.5 T

W. R. Witschey II[1], B. K. Bronzo[2], A. Borthakur[2], R. Reddy[1]

[1]Biochemistry & Molecular Biophysics, University of Pennsylvania, Philadelphia, PA, United States, [2]Radiology, University of Pennsylvania, Philadelphia, PA, United States

Introduction: Magic echo imaging has recently been identified as a useful tool for generating dipolar contrast (1,2). Unlike traditional contrast mechanisms, such as T1-, T2- or diffusion weighted contrast, the tissue signal obtained with the magic echo is not attenuated by the dipole-dipole coupling between nuclei. This imaging technique, however, has never been employed in brain studies, where it is suspected that dipolar contrast may be more sensitive to the myelin water fraction, which may have significant non-zero averaged dipolar coupling. Here we show some practical aspects, restrictions and advantages to magic echo imaging of the brain.

Methods: The magic echo pulse sequence used for slice selective imaging of the brain is shown in Figure 1. The sequence consists of a slice selective pulse, followed by a free spin evolution period for duration τ, the 4τ magic echo cluster and finally another free evolution τ period where the echo is acquired. The magic echo cluster itself is composed of a ±x rotary echo sandwiched by $90_{\pm y}$ pulses. It is during the first 2τ period of the magic echo cluster that the dipolar Hamiltonian has time reversal symmetry with the first τ period (1). One can identify the source of this time reversal by considering the secular dipolar Hamiltonian in the tilted rotating

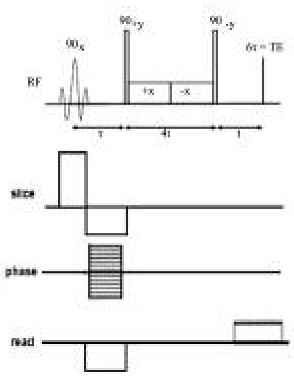

Figure 1: The pulse sequence for acquisition of magic echo images. The magnetization is refocused at a time 6τ during which the signal is acquired. Phase encoding for 2D imaging is performed by gradients applied during the first τ period.

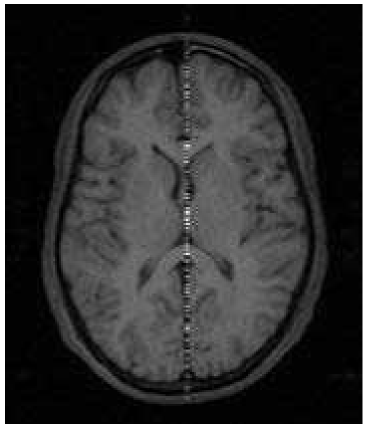

Figure 2: T1-weighted magic echo image (TE/TR = 15/500 ms) of the brain with a pair of bipolar crusher gradients applied during both τ periods. The presence of the zero-peak artifact vertically along the phase encoding direction (anterior -> posterior) may be eliminated entirely by zero gradient correction.

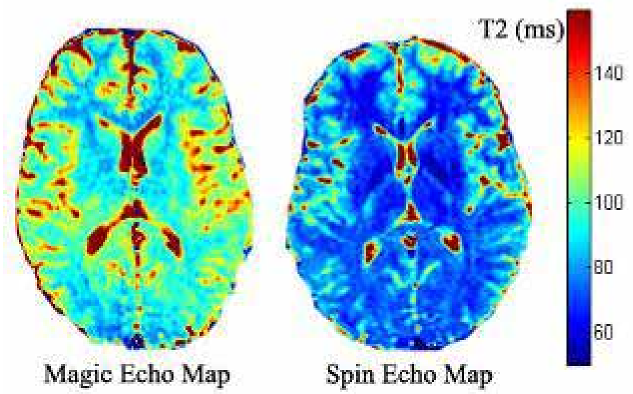

Figure 3: Magic echo and spin echo maps obtained using identical imaging parameters (TE/TR = 15, 25, 50, 75 / 3000 ms). This subject was scanned for the magic echo and spin echo map on two different occasions, accounting for slight differences in anatomy. $T2_{ME}$ is significantly increased over T_{SE}, increasing the dynamic range of T2 quantification in the brain. A polygonal ROI drawn in the left head of the caudate nucleus yields a grey matter $T2_{ME}$ = 115 ± 6.4 ms. Literature grey matter $T2_{SE}$ is typically quoted between 90 and 95 ms.

frame: $H^{dip}_{TR} = (1/2)(3\cos^2\theta - 1)H^{dip}_{R}$, where the dipolar Hamiltonian in the rotating frame H^{dip}_{RF} is modulated by a term dependent on the angle between the applied B_1 field vector and the off-resonance chemical shift. For *in vivo* imaging, we found that a field strength of 500 Hz was an ideal balance between SAR limitations and chemical shift artifacts. Phase encoding is performed during the first τ period and a full readout line is centered on the echo at time 6τ from slice selection. Three healthy volunteers were imaged during this study. $T2_{SE}$ and $T2_{ME}$ relaxation maps were obtained using a linear least-squares fit pixel by pixel to a single exponentially decaying signal $S = S_0 e^{-TE/T2}$ in Matlab. The presence of the zero-peak artifact along the zero gradient line in the readout direction (Figure 2) makes the sequence unsuitable for imaging without some modifications. This artifact is particularly severe in magic echo images, but can be reduced to a few phase encoding lines as shown in Figure 3 by phase cycling the magic echo cluster ($90_{y,y,-y,-y}$ > +x,+x,-x,-x > -x,-x,+x,+x > $90_{-y,-y,y,y}$) (4) or through the application of a bipolar gradient crusher pair during the two τ periods. To eliminate the artifact completely, the zero gradient line may be adjusted relative to the magnet isocenter or, conversely, the image plane of the subject may be obtained outside of the zero gradient line.

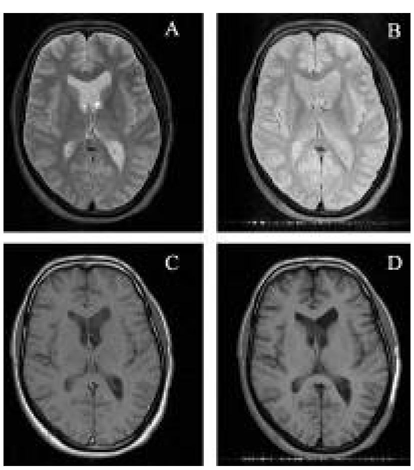

Figure 4: (A) T2-weighted spin echo image and magic echo image (B) obtained with the same imaging parameters (TE/TR = 73/2800 ms) from a single healthy volunteer. (C) T1-weighted spin echo image and magic echo image (D) obtained with the same imaging parameters (TE/TR = 14/500 ms, flip angle = 90°). Differences in contrast reflect a combination of $T_{2\rho}$- and dipolar-weighting in the spin echo images.

Results: In this work we were able to demonstrate slice selective magic echo imaging of the brain at 1.5 T. In addition, we showed the decay of magnetization has exponential behavior and is conducive to standard T2 spatial quantification techniques. The magic echo sequence significantly enhances the observed T2 compared to standard spin echo techniques in both grey and white matter. This T2 enhancement has a direct effect on image contrast as shown among T2-weighted (Figures 4A and B) and T1-weighted (Figures 4C and 2D) images. It is tempting to ascribe differences in T1- and T2- weighting as evidence of dipolar contrast, however, it appears that the contrast difference can be accounted for by differences in T2. For example, the magic echo image in Figure 3B has contrast similar to a spin echo image obtained at a shorter TE. On the other hand, magic echo grey and white matter contrast would be different from spin echo contrast if the T2 enhancement in the two tissues were dissimilar. This phenomenon has been observed previously during T2ρ relaxation, where apparent T2 increases are not the same among different tissues in the presence of a perpendicularly applied B_1 (5). Since dipolar coupled tissues are expected to have significantly shorter T2 values than bulk water it may still be possible to observe significant dipolar contrast at a shorter TE, however, ADC limitations restrict the minimum duration of the last τ period. For example, 256 readout points acquired at 50 kHz requires a τ period of at least 2.5 ms. While a minimum 6τ period of 14 ms has been achieved for a single 256 point readout, we are currently investigating options to shorten the minimum TE further.

References: (1) Rhim W, *Physical Review B* 1971;3(3):684-& (1) Hafner S, *Measurement Science & Technology* 1991;2(9):882-885. (2) Grenier D, *J. Mag. Res.* 2000;147(2):353-356. (4) Matsui S, *J. Mag. Res.* 1992;98(3):618-621. (5) Wheaton AJ, *Magn. Reson. Med.* 2004;52(6);1223-1227.