Improved Assessment of Degenerative Intervertebral Discs with a Novel Magic Echo Mapping Technique

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Introduction: The primary suspect of nonspecific lower back pain, degenerative disc disease (DDD), is a biochemical degeneration of the major subunits of the intervertebral disc (IVD): the nucleus pulposus (NP), surrounding annulus fibrosis (AF) and cartilaginous endplates. The primary objective of this research was to develop a novel, quantitative relaxation mapping technique for monitoring the biochemical and structural changes that occur in human IVDs during DDD. The long-term implications of this study are to provide a sensitive and non-invasive means for identifying biochemical changes that precede morphological changes *in vivo*. In particular, we show that the magic echo pulse sequence is more sensitive to the hypointense region of the IVD than standard spin echo imaging techniques.

Theory: The magic echo pulse sequence (Figure 1) refocuses the spin dephasing of dipolar coupled spin systems (1-3). The magnetization of a dipolar coupled spin system is modulated by the free precession secular dipolar Hamiltonian: $\hat{H}_{jk}^{DD} = b_{jk}(1/2)(3\cos^2\theta - 1)(3\hat{I}_{jz}\hat{I}_{kz} - \hat{I}_j \cdot \hat{I}_k)$ between nuclei j and k and incorporates the angle between the internuclear axis and the external magnetic field θ, the nuclear spin operators $\hat{I}$ and the dipole-dipole coupling constant b_{jk}. The magic echo cluster rotates water spins into the tilted rotating frame where the dipolar Hamiltonian has time reversal symmetry with the first τ period. In this way, the total spin phase dispersion due to the dipolar interaction at time 6τ is zero. For most tissues, however, the observed signal enhancement relative to the spin echo is likely a combination of both T2ρ relaxation effects (4) during the 4τ magic echo cluster and dipolar rephasing.

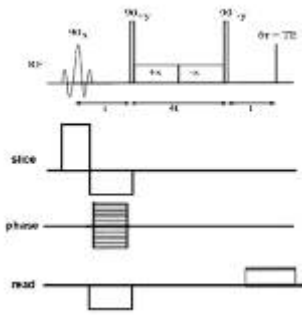

Figure 1: The pulse sequence for acquisition of magic echo images. The magnetization is refocused at a time 6τ during which the signal is acquired. Phase encoding for 2D imaging is performed by gradients applied during the first τ period.

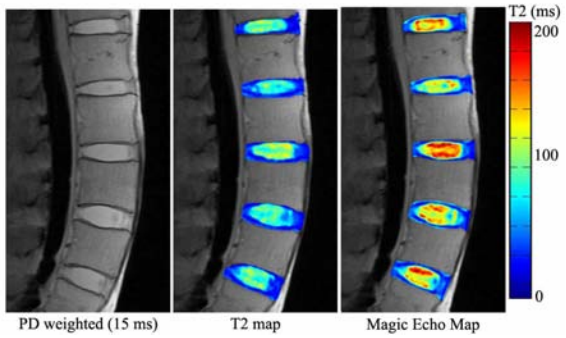

Figure 2: Cadaveric lower lumbar spine T2 and magic echo T2 relaxation maps from a 42 year old human male. A proton density weighted (TE/TR = 15/3000 ms) magic echo image is shown on the left and serves as reference for T2 (middle) and magic echo T2 (right) relaxation maps. The discs shown are L4/L5 through T12/L1. T2 and magic echo T2 maps were obtained using five identical echo times (15, 30, 45, 60 and 75 ms) as measured from the center of the slice selective sinc pulse to the zero readout gradient moment. Three additional ex vivo spines show similar T2 increases.

Methods: 4 cadaveric spines were obtained from NDRI and imaged using both standard spin echo and magic echo pulse sequences. T2 relaxation maps were generated from log linear least-squares fit to the signal decay equation $S(TE) = S_0 e^{-TE/T2}$ using Matlab 7.0 R14. T2 relaxation profiles shown in Figure 3 were obtained in ImageJ.

Results: A protocol analogous to T2 relaxation mapping, outlined in the methods section, corresponds with monoexponential decay for the magic echo signal in the disc as shown in Figure 2. Observed $T2_{ME}$ times in the IVD are significantly increased [$(T2_{ME} - T2_{SE}) / T2_{SE} \sim 35\%$] over $T2_{SE}$. Furthermore, Figure 3 shows $\Delta T2_{ME}$s between the NP and adjacent endplate for two separate L4/L5 discs of 92.0 ± 7.8 ms and 93.7 ± 1.0 ms compared to $\Delta T2_{SE}$s of 65.2 ± 5.3 ms and 71.5 ± 0.9 ms, respectively. The signal enhancement was also observed in two additional cadaveric spines as well as on human spines *in vivo*. In addition, $T2_{ME}$ maps reveal disc features not observed in $T2_{SE}$ maps. One example is the $\Delta T2_{ME}$ = 59.3 ± 2.5 ms difference between the hypointense region of the NP and the surrounding healthy NP observed in rostral portion of the L4/L5 disc shown in Figures 3A and B. This difference may reveal biochemical or water content differences that are not observable using standard spin echo imaging. Generally, the magic echo sequence provides greater dynamic range to T2 mapping studies and may eliminate artifacts from dipolar orientation effects or, conversely, to modulate these orientation effects. We are currently conducting experiments to isolate the T2ρ and dipolar enhancement contributions to T2 increases among the subunits of the disc.

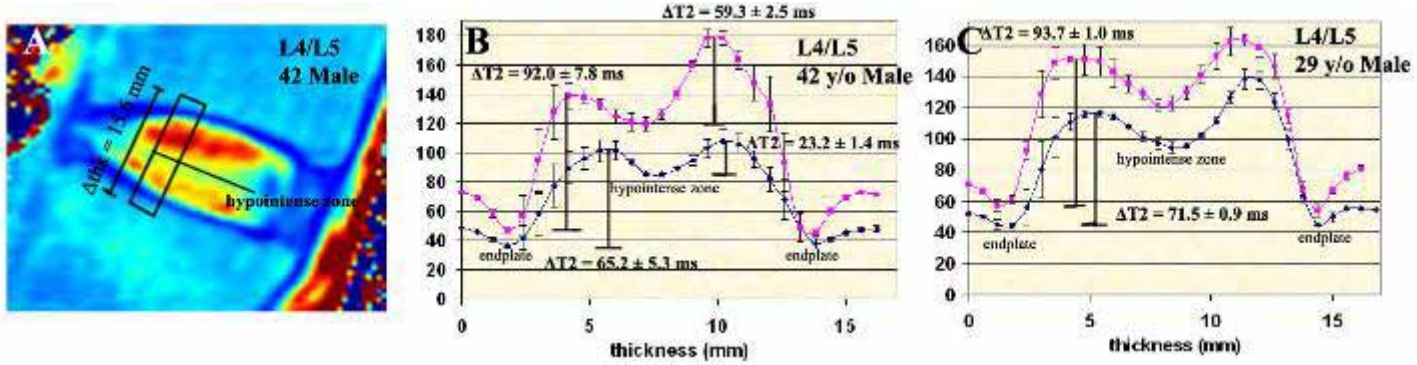

Figure 3: L4/L5 IVD ex vivo disc from a 42 y/o male (A) including labeled averaged disc profile (B) across the zone of hypointensity. (C) A similar T2 relaxation profile obtained from the L4/L5 disc of a 29 y/o male. The upper T2 profile (pink curve) was obtained with magic echo, while the lower T2 profile (purple) was obtained with spin echo.

References: (1) Rhim W, *Physical Review B* 1971;3(3):684-& (2) Hafner S, *Measurement Science & Technology* 1991;2(9):882-885. (3) Grenier D, *J. Mag. Res.* 2000;147(2):353-356. (4) Wheaton AJ, *Magn. Reson. Med.* 2004;52(6);1223-1227. (5) Antoniou J, *Magn. Reson. Med.* 1998;40(6):900-907.