Measurement of residual dipolar oscillations in intervertebral disc by spin-lock method

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Introduction:

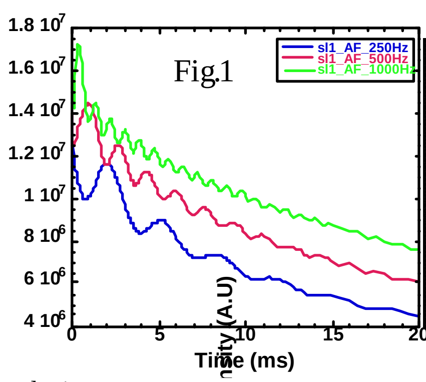
The intervertebral disc (IVD) consists of three anatomically distinct regions: the gelatinous nucleus pulposus (NP) in the center of the disc, the highly organized annulus fibrosus (AF) in the periphery, and cartilaginous end plates (EP). The water protons associated with ordered macromolecules (concentric layers of collagen fibers) experience residual dipolar interaction due to their anisotropic motion. Quantitative information about the residual dipolar coupling in AF and NP can be used to probe the structural integrity of the disc. Currently, multiple quantum filtered (MQF) NMR spectroscopy methods have been used to probe the order parameter in an anisotropic systems [1]. However, the MQF techniques have low signal-to-noise ratio (SNR) when compared to single quantum coherence, and requires signal averaging. Recently, it has been reported [2] that the spin-lattice relaxation time in the rotating frame ($T_{1\rho}$) can be used to quantify the residual dipolar oscillations (REDIOS) in an anisotropic liquid crystal containing dipolar coupled spins. It has been shown that $T_{1\rho}$ in the presence of residual dipolar interaction is no longer strictly mono-exponential [2]. The fast and slow components may provide unique information about residual dipolar coupling and chemical exchange respectively. Relaxation measurements on IVD using the slow decaying components in an imaging setting are presented elsewhere. In the present study, we quantified the fast decaying components and associated REDIOS in an isolated AF and NP specimens as a function of spin-lock frequency.

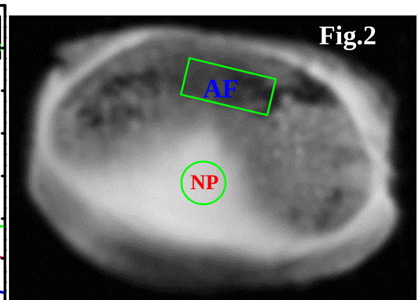
Materials and Methods:

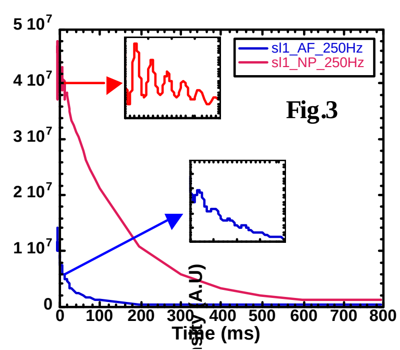
Fresh IVD specimens (n=3) from young cows (~6-12 months of age) were obtained from a slaughter-house within five hours of sacrifice. All the experiments were performed on an Oxford 4.7T horizontal bore magnet interfaced to a UNITY INOVA spectrometer equipped with 12-cm gradients having a maximum strength of 25 gauss/cm. A 5.0 cm custom-built, linear birdcage radio-frequency (RF) coil tuned to 200.78 MHz was employed. $T_{1\rho}$-spectroscopy experiments were performed on an isolated AF and NP plugs [3].

Results and Discussion:

Figure 1 shows a typical spin-locked signal intensity in AF as a function of spin-lock time for different spin-lock frequencies (γB_1=250Hz, 500Hz and 1000Hz). Although, the REDIOS increase with spin-lock frequency, the oscillations are rapidly damped. **Figure 2** shows a representative axial $T_{1\rho}$ image obtained with 100μs spin-lock length. The spin-locked signal intensity is lower in AF when compared to NP due to bundles of collagen fibers, which form concentric lamellae. Isolated sections from regions of interest (ROI) from AF and NP (Fig.2) are used and their corresponding spin-locked signal intensity plotted in **Figure 3**. The first 20ms of each curve is shown in the inset plots. The fast decay time constant ($T_{1\rho}$) is 15ms in AF and 74ms in NP. Relatively the amplitude of the oscillations in AF is smaller when compared to NP (Fig.3). The fast component frequency at low spin-lock frequency (250Hz) in AF and NP may be directly correlated to residual dipolar coupling. Furthermore, we also verified that no dipolar oscillations are observed in distilled water and 5% (wt./vol.) chondroitin sulfate phantom with identical experimental conditions (data not shown).







Conclusions:

The spectroscopy data obtained in disc shows that the REDIOS increase with spin-lock frequency. The preliminary results obtained from isolated NP and AF disc specimens demonstrate that the fast decay component of $T_{1\rho}$ is 15 ms in AF when compared to 74ms in NP. The shorter $T_{1\rho}$ of fast decaying component in AF is due to the highly ordered collagen structure in AF. Therefore, the REDIOS characteristics and time constants have potential to quantify the structural integrity of the disc. Currently, we are developing a model, which accounts for the damped dipolar oscillations in spin-lock experiments to quantify residual dipolar interaction in IVD.

References: 1) Navan G et al NMR in biomedicine 14 (2001) 112, 2). Chaumette H et al, Mol Phys 101 (2003) 1919, 3) Regatte RR et al JMRI 17(2003) 114.