Water Diffusion and Magnetization Transfer in normal and pathologic lumbar disc

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Introduction. Water diffusion is sensitive to intervertebral disc degeneration and pathologies (1). As a result, several techniques have been proposed to make diffusion weighted imaging of the spine more robust for use in the clinical setup (1,2). However, global motion and susceptibility differences still represent some of the major issues to yield high-quality diffusion weighted images (DWI) in the human spine. Differences in proton mobility are reflected by the diffusion constant (D), but likely also affect magnetization transfer (MT). In this work, we thus investigate possible correlations between the magnetization transfer ratio (MTR) imaging and apparent diffusion constants (ADC) to yield a possible alternative characterization of intervertebral disc diseases that relate to alterations in water diffusion. ADC and MTR were compared between normal appearing discs of young healthy volunteers and patients with lumbar disc herniations with or without signs of disc degeneration. High correlation between MTR and ADC values was found suggesting that changes in water diffusion for intervertebral discs are also reflected in MT measurements.

Methods. Six healthy volunteers (mean age: 29, (5f, 1m)) and six patients (mean age: 31, (2f, 4m)) with lumbar disc herniations and/or degeneration were prospectively investigated on a clinical 1.5T whole body system. The patients were divided into 2 groups: disc degeneration and combined herniation and degeneration. MT images were generated based on a SSFP-FID sequence (α=60°, TR=5.7ms) using RF-pulse modulation (Fig. 1a)(3), whereas a diffusion sensitive SSFP-echo sequence (DW-SSFP; TR=17ms, α=15°) (Fig. 1b) (4) was used to extract the trace of the diffusion tensor. Seven slices were acquired with 1.5x1.5x5mm resolution. For TR longer than T2 (TR>1.5·T2), DW-SSFP signal attenuation A_D is approximated as

$$A_D = \frac{S(bD)}{S(0)} = \frac{e^{-bD}(1+e^{-bD}E_1)(1-E_1\cos\alpha)}{(1+E_1)(1-e^{-bD}E_1\cos\alpha)}, \text{ where } E_1 = e^{-TR/T1} \qquad [1]$$

For spine imaging, short TRs (17ms) with DW-SSFP minimize motion related image degradation and the validity of Eq. [1] for diffusion analysis is restored by constraining the flip angle to α=15°, see Fig. 2. In this study, ADC estimation is based on a mean T1 of 1180ms (5).

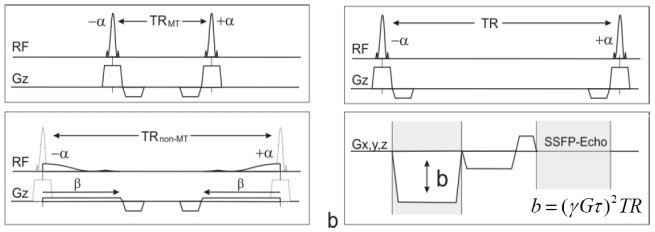

Fig.1 (a) MTR SSFP framework. RF Modulation is used to modulate MT effects (3). (b) DW-SSFP with diffusion sensitizing gradient pulse.

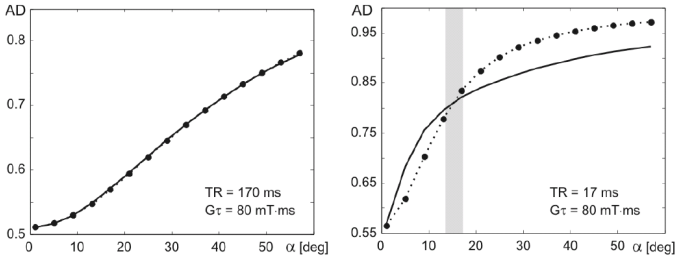

Fig.2: A_D as a function of α and TR for intervertebral discs (T1=1180ms) using DW-SSFP. For long TR (170ms), Eq. [1] (circles, dotted line) adequately describes DW-SSFP signal behavior (left). For short TRs (17ms), Eq. [1] describes the signal only in a small range of flip angles (α≈15°).

Results & Discussion. Illustrative sample images of MTR and ADC images for normal and pathologic appearing discs are shown in Fig. 3. Generally, a highly significant correlation (R=–0.91, p<1E–7) between MTR and ADC values was observed (Fig. 4). For normal appearing discs, mean ADC values of D=1.3±0.1E-9 m^2/s and mean MTR values of 26.2±1.2% were found. For the group of patients with lumbar disc herniations and simultaneous degeneration, diffusion was reduced by 26.0% and MTR was increased by 29.3% as compared to normal appearing discs. In a comparison of degeneration only, diffusion was reduced only by 16.7% corresponding to an increase in MTR by 19.0%. Although, T1 effects on Eq. [1] were neglected in the overall ADC analysis, excellent correlation was found between MTR and ADC. The reduction in the ADC for pathologic discs, associated with a loss of free water content, is reflected by an increase in MTR, as expected from MT models. In summary, our findings indicate that MT can successfully be used as an indicator of changes in overall water diffusion.

Conclusion. ADC and MTR show an excellent negative correlation both in healthy as well as in pathologic lumbar discs. This might offer a new alternative for characterization of pathologies of intervertebral discs that are associated with changes in water diffusion. MTR SSFP spine protocols, offer decreased sensitivity to motion or susceptibility changes, high signal-to-noise and reduced acquisition times, as compared to standard DWI.

Refs. (1) Kealey SM et al. *Neuroradiology* **235** (2005). (2) Bammer R et al. *AJNR* **24** (2003). (3) Bieri O et al., *MRM* **58** (2007). (4) Buxton RB, *MRM* **29** (1993). (5) Boos N et al. *MRI* **12** (1994).

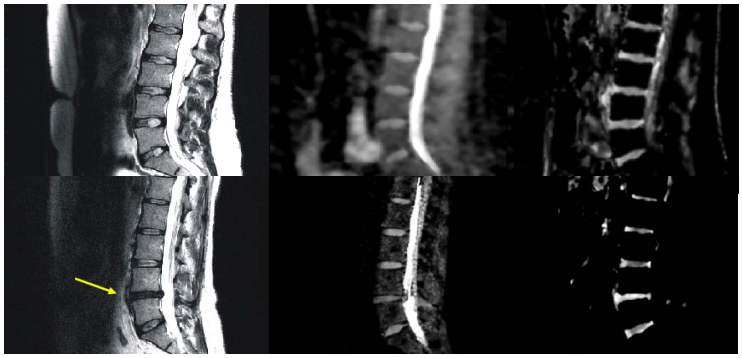

Fig.3: Sagittal images of a healthy volunteer (top row). T2w image (left), DW-SSFP trace image (middle, D_{app}=1.25E-9 m^2/s) and MTR image (right, MTR=27%). Sample images of a patient with lumbar disc herniation (yellow arrow) (bottom row). T2w image (left), DW-SSFP trace image (middle, D_{app}=1.31E-9 m^2/s (normal) & D_{app} = 0.93E-9 m^2/s (herniation)) and MTR image using MT-SSFP (right, MTR=28% (normal), MTR=37% (herniation)).

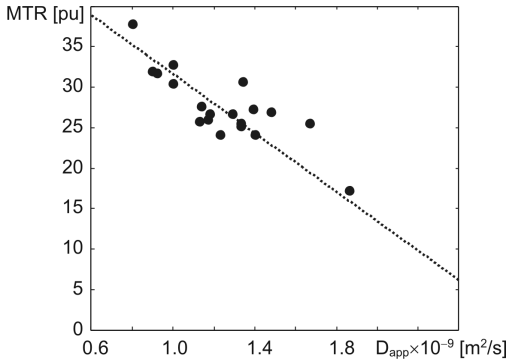

Fig.4: Mean apparent diffusion constants vs MTR for both healthy and pathologic discs. Correlation analysis of the data yields a highly significant (p<1E-7) negative correlation of 0.91.