"Rapid Magnetization Prepared Diffusion Weighted Imaging of Articular Cartilage in-vivo"

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Introduction and Motivation: The dynamic process of diffusion in cells provides insight into the tissue integrity and structure. Research has shown that DWI of knee has a strong potential as a biomarker and can act as a new and potent investigation tool for tissue integrity in meniscus and cartilage for early diagnosis of degeneration[1]. One limitation of diffusion imaging in knee is the long TE (40-60ms) in most sequences that have been used. This can be a problem in the knee where several tissues have short T2 relaxation times including the cartilage (32ms) and meniscus (11ms). Thus imaging of knee with a short TE diffusion sequence would substantially increase signal to noise ratio which in turn can be applied to improve diffusion measurements in meniscus and cartilage[2]. In this work, a new knee DWI sequence is proposed and evaluated. To our knowledge, this is first of its kind study at 3T. Our evaluated sequence is more signal efficient than the conventional spin echo (SE) sequence and can image whole knee volume.

Methods: The evaluated stimulated echo sequence is shown in the Figure 1. Since there number of interdependent variables diffusion preparation optimization, flip angle optimization, Monte Carlo analysis for noise preparation optimization was done followed by testing the sequence in phantoms, *ex-vivo* and *in-vivo*. For Monte Carlo analysis, matlab simulations were done using b-values: 100-2000 sec/mm^2 in 20 sec/mm^2 increments, ADC: 1.4 and 1.6(x10^{-3} mm^2/sec), T1: 900 and 1200 ms, T2: 11 and 3s ms (for cartilage and meniscus respectively), d: 3.2ms, M0 SNR was taken as 200, 20, 33.33 and 23. Agarose phantoms with varying concentrations (0%, 2%, 2.5%, 4% and 4.5%) in distilled water were placed inside head coil in a 7T GE scanner. Images were acquired by varying diffusion gradient duration: 2 to 4ms, or diffusion time: 75 to 350ms or both thus giving multiple b-values, the parameters used were 256x128, FOV: 16 cm, slice thickness: 3mm, VPS: 48 and TE: 12-15ms. Healthy volunteers (average age: 24-30 years) were scanned at 3T GE scanner. Scan parameters: 256x128, FOV: 14cm, slice thickness: 4mm, diffusion gradient duration: 4ms, diffusion time: 150ms, bandwidth: 62.5 KHz, VPS: 48, b-value: 310sec/mm^2 and T1 recovery time: 1200ms.

Results and Discussion: Figure 2 shows a 2D colormap showing the noise of ADC measurement with different b-values plotted against diffusion gradient duration for cartilage. The colorbar shows spectrum used in color coding to represent probability for highest signal, with lowest signal represented by red to highest indicated by blue. The wide blue area (high signal low noise shown with arrow) will allow for accurate measurement for a range of scan parameters. Figure 3 shows the signal efficiency of the evaluated sequence compared to conventional spin echo sequence. For b-value of 500mm^2/sec, the evaluated STE sequence signal is 20x higher than SE for meniscus and 1.5x more in cartilage. In phantoms measurements, the linear regression yields apparent diffusion coefficient (ADC) value as 1.6mm^2/sec; which is close to expected value (1.8-2mm^2/sec). The linearity of values obtained (R^2=0.99) suggests that proper scaling of the diffusion weighting is present in sequence. The representative *in-vivo* images obtained using the evaluated sequence is shown in Figure 4. The *in-vivo* ADC(1.5-2x10^{-3}mm^2/sec) and FA(~0.5) values obtained were little elevated compared to literature[3](1.27x10^{-3}mm^2/sec and 0.3 respectively) which may be due to the fact that the literature studies were done at 7T Siemens scanner, or may be due to presence of fluid and phase errors due to subject motion. The ADC values however validate the presence of a diffusion gradient that exists in the cartilage starting from high ADC low FA values in the superficial layer near the articular surface to low ADC high FA value in the deep zone near the subchondral bone. Future work will involve acquiring diffusion data in healthy volunteers and OA patient cohorts.

References: 1.Bihan et al. Artifacts and pitfalls in diffusion MRI. JMRI: 2006; 24:478-488; 2.Schick et al. Signal losses in diffusion preparation: comparison between spin-echo, stimulated-echo and SEASON. MAGMA 1998; 6:53-51; 3. Raya et al: Articular cartilage in-vivo tensor imaging. Radiology: 2012; 262:550-559

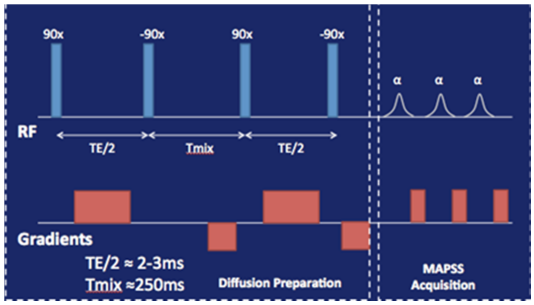

Figure 1: Evaluated stimulated echo sequence

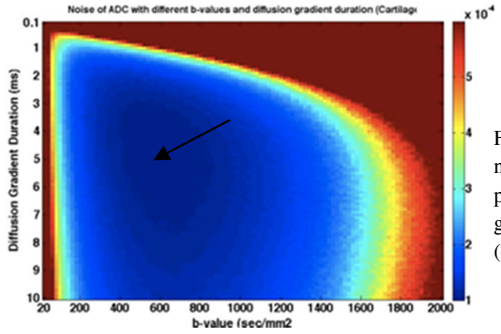

Figure 2: 2D colormap showing noise of ADC measurement plotted with different diffusion gradient duration values (cartilage)

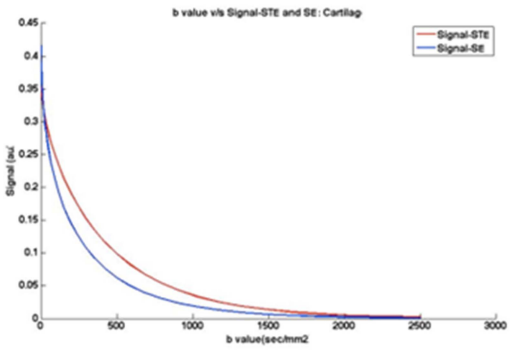

Figure 3: Plot showing signal comparison between STE and SE sequence (cartilage)

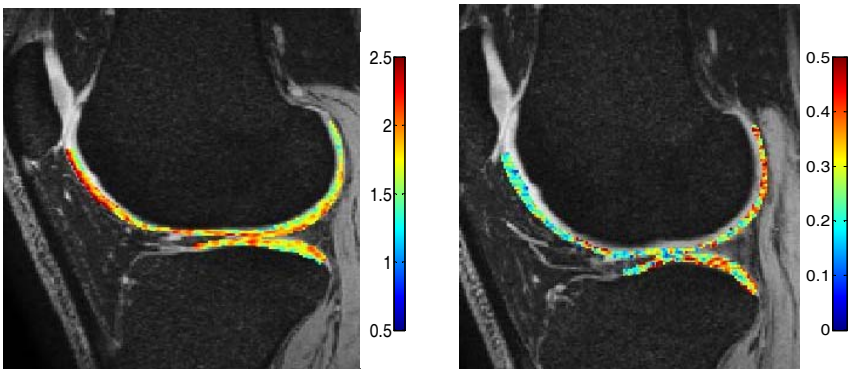

Figure 4: Lateral in-vivo knee images of a healthy volunteer knee with ADC (left) and FA (right) colormap overlaid