Diffusion weighted SSFSE with Dixon fat-water separation

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Introduction: The high signal and low diffusion coefficient of fat tissue makes it problematic for diffusion weighted imaging in areas such as breast, prostate, bone, or spine. Diffusion weighted EPI sequences typically use a spatial spectral excitation to suppress fat signal, but this technique suffers from geometric distortion and incomplete fat suppression in the presence of severe field inhomogeneity. Recently developed Dixon methods for fat/water separation [1,2] have been able to provide consistent water images despite variations in the background field. However, since geometric shift in EPI is a function of chemical shift, image-based Dixon methods are not directly compatible with these sequences. Diffusion weighted single shot fast spin echo (SSFSE) techniques [3-6] do not suffer from this problem, and some are even able to reconstruct the phase from time shifts or magnetization preparation [7]. This study examines the use of this phase information in a diffusion weighted SSFSE sequence with a previously developed Dixon algorithm, Multiple Echo Decomposition of Aqua and Liquid (MEDAL) [1], for fat suppressed diffusion weighted imaging in the cervical spine.

Theory: The sequence (figure 1) consists of a diffusion weighting magnetization preparation followed by a phase preserving SSFSE sequence as proposed by Alsop [5]. The sequence is shown with a single spin echo, though a dual spin echo preparation was used in this study. All refocused echoes in the echo train have the same phase information as that at the reference time, defined as the time half an echo spacing period (ESP) before the first refocusing pulse. Fast spin echo CPMG conditions are imposed at the reference time by using a dephasing gradient to spread the signal of each voxel in the transverse plane, followed by a 90 degree pulse centered at the reference time with the same phase as the refocusing pulses to tip all off-axis components into the longitudinal plane. A rephasing gradient before each refocused echo causes spins to realign to the phase they exhibited at the reference time, and a dephasing gradient likewise returns spins to their CPMG-compliant state. Shifting the echo train, along with the 90 degree conditioning pulse, will allow additional phase evolution due to chemical shift and background field variation. If phase errors due to diffusion weighting gradients are slowly varying in space, Dixon algorithms will still be able to distinguish fat from water signals based on this shift.

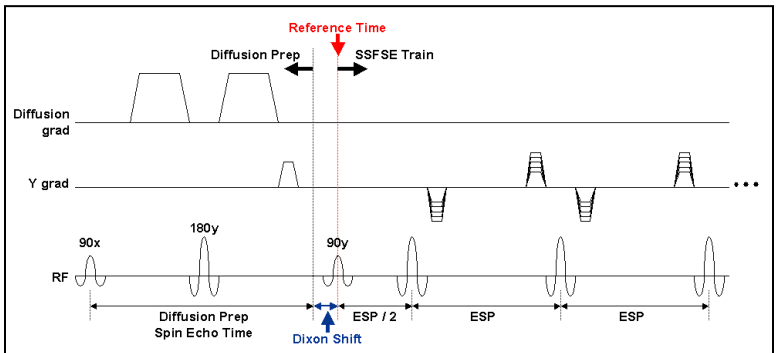

Figure 1. Diffusion weighted SSFSE sequence with Dixon echo shift.

Methods: Four repetitions were acquired of each slice and diffusion weighting, filling 5/8 k-space each time. For two of the repetitions, the echo train, including the 90 degree conditioning pulse, was shifted 2.2 ms relative to the diffusion preparation sequence to capture signal at a time when fat and water signals are out of phase. Sagittal images through the cervical spine of a healthy volunteer were acquired with the diffusion weighted SSFSE sequence on a 1.5T scanner (EXCITE HDx, General Electric Healthcare, Waukesha, WI) with an 8 channel neurovascular array coil (Medrad, Warrendale, PA). Imaging parameters were: TR = 4443 ms, TE = 78 ms, bandwidth = +/- 31.25 kHz, matrix = 96x128, FOV = 22.5 x 30.0cm, acceleration factor = 2, slice thickness = 6 mm, 6 slices, b-value = 0 and 500, diffusion axis = slice select direction, acquisition time = 3:43. After Fourier transform reconstruction, MEDAL fat-water separation was applied to the complex images to produce fat suppressed water images. Final images were produced by complex averaging water images from the same slice and diffusion weighting.

Results: Images are shown in figure 2. Consistent fat suppression was observed in all areas of the spine and brain.

Discussion: We have demonstrated the feasibility of diffusion weighted chemical shift imaging using an FSE based sequence. Without any modification of the MEDAL algorithm or phase correction of the base images, all areas of interest were accurately classified as water or fat. Removing fat signal allows a more accurate measurement of the diffusion of water. Due to the fast spin echo acquisition, the resulting images are also free of distortion effects often observed in EPI techniques. Cervical spine is particularly challenging for EPI acquisitions due to the severe field inhomogeneity from the sinuses and air passageways. Since Dixon algorithms assume that background phase differences between shifted echo times are slowly varying in image space, peripheral gating and/or low resolution phase correction may improve fat-water separation at higher b-values.

References: 1. Ma J, MRM 2004;52:415-419. 2. Reeder SB et al, MRM 2004; 51:35-45. 3. Norris DB et al, MRM 1992; 27:142-164. 4. Schick F, MRM 1997; 38:638-644. 5. Alsop DC, MRM 1997; 38:527-533. 6. Le Roux P, JMR 2002; 155:279-292. 7. Vogel MW et al, JMRI 2003;18:507-512.

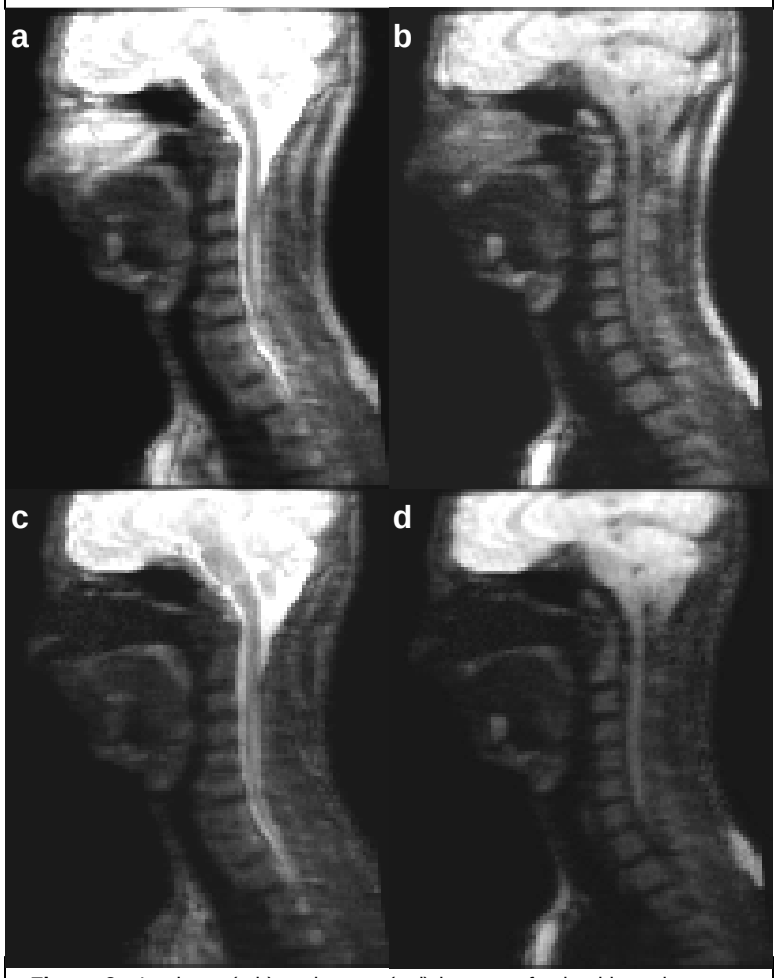

Figure 2. In-phase (a,b) and water (c,d) images of a healthy volunteer. Images were acquired with b-value = 0 (a,c) and 500 (b,d).