Robust Fat Suppression for High-resolution Diffusion-weighted Imaging

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Introduction

The diffusion-weighted imaging techniques can greatly benefit from an increase in image resolution as smaller voxels reductes the effects of partial volume with surrounding tissue. By scanning in the 3T environment a significant gain in SNR is achieved which facilitates the ability for higher resolution scans. In diffusion tensor imaging (DTI) it is important to acquire data with isotropic voxels, thus the limiting factor in resolution may be the attainable slice thickness. In addition, for single-shot EPI (SSEPI) DTI acquisitions, a complete fat saturation is critical as any remaining fat signal will reconstruct as a shifted image within the brain tissue. At 3T, a spectral-spatial (SPSP) excitation pulse is often used to only obtain signal from water. However, the SPSP method has limits in the minimum slice thickness attainable, thus limiting overall DTI spatial resolution. Traditional fat saturation methods can be used, e.g. Chem Sat or SPIR, but are often incomplete in suppressing all fat signal at 3T as the RF pulse used to excite, or invert, fat is inhomogenious. In Fig. 1, images acquired with traditional fat saturation show that residual fat signal is present and has high intensity in diffusion-weighted images causing a reduced mean diffusion, <D>, and often spurious anisotropy. An alternative method for supressing fat is the slice-select gradient reversal method (SSGR) [1], which diminishes the fat signal by using opposite polarity slice select gradients during two consecutive RF pulses such that only the on-resonance water signal is refocused. In this work, several variations of the SSGR technique were tested and a robust strategy was determined.

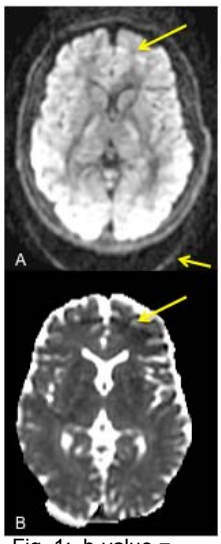


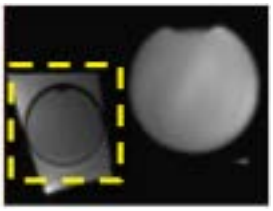
Fig. 1: b-value = 1100 s/mm^2 image (A) and <D> map (B). Arrows point to shifted fat image.

Methods

Data were collected on a 3T GE Excite scanner with gradients capable of 40 mT/m and an 8-channel phased-array coil. The SSGR method was incorporated into both a dual-spin-echo (DSE) [2] and single spin-echo (SE) [3] diffusion preparation period combined with an SSEPI readout. The DSE-SSGR method had opposite polarity slice select gradients for the two 180° pulses [4]. The SE-SSGR method had opposite polarity gradients for the 90° excitation and 180° refocusing pulses [5]. Both methods were acquired in combination w/ or w/o the default Chem Sat in the SSEPI sequence, in separate scan sesssions. Data was acquired of a ball phantom filled with 50% PVP [5] immersed in a container of vegetable oil, along side a large ball phantom filled with distilled water. The diffusion datasets consisted of 3 non-diffusion-weighted images and 17 diffusion directions with a b-value=1100 s/mm^2 with the following scan parameters: TE/TR=80ms/20s, slice=2.5mm, 96x96, FOV=24cm, sense factor=2. The DSE-SSGR method, plus Chem Sat, was used to acquire DTI data of a healthy volunteer at 1.7mm isotropic resolution. Data was also acquired with the original Chem Sat only sequence. In vivo data sets contained 5 non-diffusion-weighted images and 34 diffusion directions with b=1100s/mm.

Results

In Fig. 2, the effect of the shifted fat image can be easily seen as an increase in <D> and fractional anisotropy, FA, when data was collected without fat saturation (see arrows). The artifact is not present in the data acquired with the SPSP method, as expected., The fat artifact is diminished, but not removed, when Chem Sat only is used with a DSE prep. The DSE-SSGR method also diminishes the fat artifact, but is incomplete. When both the Chem Sat and DSE-SSGR method are combined the fat signal is completely suppressed. The Chem Sat only is also incomplete with an SE prep. When the SE-SSGR method is combined with Chem Sat, the fat artifact is still observable under close inspection; an overall increase in FA is also observed and needs to be further investigated. In Fig. 3, one can observe, in vivo, the ability of the DSE-SSGR method combined with Chem Sat to completely suppress the residual fat signal that is still present in the Chem Sat only image.



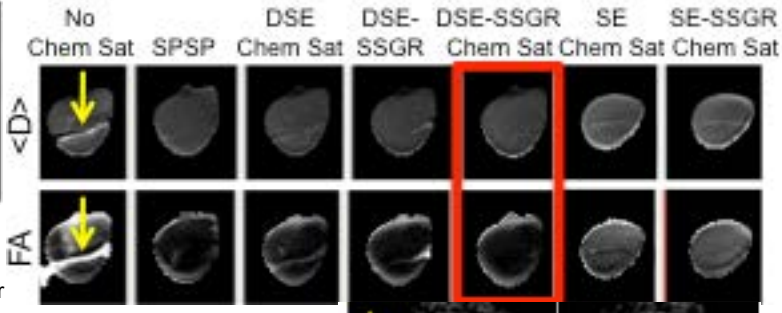


FIG. 2, Above: Reference image of the phantoms. Box shows cropped region. Right: <D> and FA maps for the various techniques.

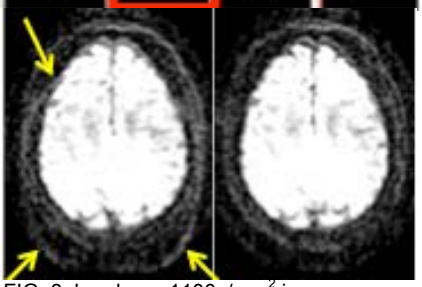


FIG. 3: b-value = 1100s/mm^2 images. Left: Chem sat only with DSE prep. Right: DSE-SSGR and Chem Sat.

Conclusions

Combining a traditional fat saturation technique with the DSE-SSGR method allows data to be acquired at 3T with high-resolution and without artifacts from fat. The combined approach is more effective than either alone, and more effective than the SE-SSGR diffusion prep version. The ability to collect high-resolution diffusion data in vivo will allow for less partial volume effects and ultimately lead to more accurate DTI measures.

References: [1] Gomori *et. al.*, Rad, 168:493-495, 1988. [2] Reese *et. al.,* MRM, 49:177-182, 2003. [3] Stejkal *et. al.,* JChemPhys, 41:288-292, 1965. [4] Nagy *et. al.,* MRM, 60:1256-1260, 2008. [5] Butts *et. al.,* MIA, 6:93-108, 200. [5] Pierpaoli *et. al.,* ISMRM, #, 2009.