Adiabatic refocusing pulses in 3T and 7T diffusion imaging

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Introduction

Eddy currents and susceptibility effects are well known culprits contributing to image distortions in EPI-based diffusion tensor imaging. Nowadays, the use of the twice refocusing scheme (3) has proven quite proficient at diminishing eddy currents, leaving primarily the susceptibility distortions in the images. However, at higher fields (3T and above), the inhomogeneity of the transmit B_1 field is another source of artifact that has not been well addressed for diffusion imaging thus far. Aside from the signal modulations caused by the receive B_1 field, incomplete signal excitation and refocusing can occur in DWI as a direct result of the spatially varying transmit B_1 field. For quantitative diffusion parameters, such as ADC and FA - or even for fiber tracking - the variable flip angle (caused by the B_1 variation) will cause a spatially varying SNR and more pronounced additional coherences that require more efficient crusher regimes. Depending on the baseline SNR, type of transmit coil, and field strength, these B_1 inhomogeneities can potentially have impact on the overall quality of DTI and eventually offset (at least to some extent) the true benefit of migrating to higher magnetic field strengths. The purpose of this study was to combat the problem of B_1 sensitivity in DWI/DTI by the use of adiabatic refocusing pulses.

Materials & Methods

The two traditional 3.2 ms long sinc refocusing pulses in a diffusion-weighted single-shot EPI sequence were optionally replaced by two slice selective truncated hyperbolic secant pulses (4) of 10 ms in length. Here, the two adiabatic 180° pulses cancel their quadratic phase across the slice and yield a linear spin phase at the time when a spin echo is formed. The addition of the two adiabatic pulses led to an increased TE of ~13 ms. For the excitation, a standard spectral spatial (SPSP) 90° pulse was used, which has the fat saturation properties needed for EPI. In our first attempt towards B_1 insensitivity, we have not modified the SPSP 90° as no good fat-suppressed slice-selective adiabatic excitation alternative currently exists. Experiments were performed on phantoms at 3T and 7T GE whole body systems equipped with 40 mT/m gradients. The standard transmit/receive head coil was used on the 3T scanner and a volume/8-channel dual mode transmit/receive head coil was used in both modes on the 7T scanner. Image parameters were as follows: FOV = 24 cm, slice thickness = 4 mm, b-value 1000 s/mm^2, and 3 interleaves (to keep the phantom somewhat round). When the 8-channel coil was used, the inter-shot ghosting in the data was avoided by means of GRAPPA reconstruction of each shot. However, this has no impact on the transmit B_1-related intensity variations.

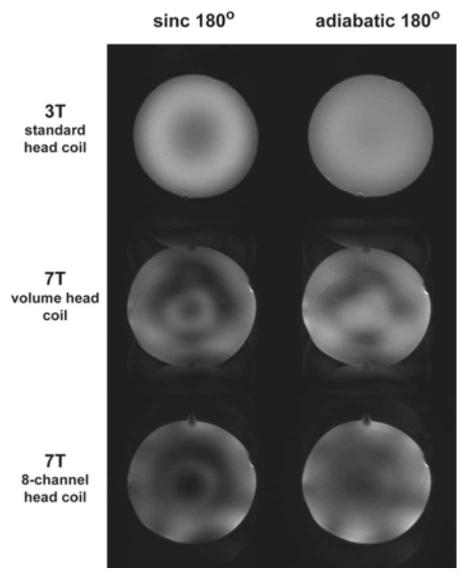

Figure 1. b=0 s/mm^2 images without (left) and with (right) the use of adiabatic refocusing pulses. At 3T, the signal variations are almost eliminated. At 7T,

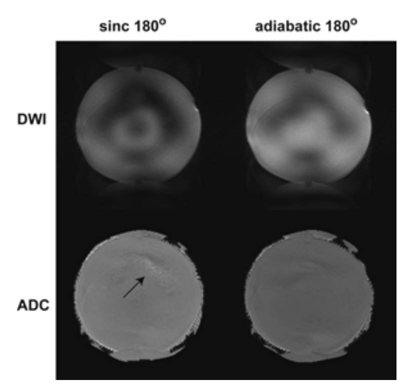

Figure 2. DWI (top) and ADC (bottom) images with and without adiabatic refocusing pulses

Results

Non-diffusion images on the gel phantom for different coils, field strengths, and refocusing pulses are presented in Figure 1. At 3T, the intensity profile due to the transmit side is clearly present although not extreme for the conventional sinc refocusing pulses. Using the adiabatic 180° pulses, this intensity modulation is almost gone. Since the standard head coil was used in this case, there is no sensitivity field on the receive end that produces signal variations. At 7T, the intensity variations due to the transmit field are much worse when the conventional refocusing pulses are used. With the adiabatic refocusing pulses (right), the situation is improved. The bottom panels of Fig. 1 shows 7T data with the receiver coil in 8-channel receiver mode, explaining the familiar signal variation due to the receive coils.

Figure 2 shows DWI and ADC maps with sinc and adiabatic 180° pulses. The black arrow in the ADC map (bottom-left) marks a region that has significantly lower SNR due to the very low signal intensities of the T2w (b=0 s/mm^2) and the diffusion weighted image. With the very low signal intensities, small B_1 field variations between the acquisition of the T2w and the DWI scan can also cause substantial bias in the ADC estimations.

Discussion & Conclusion

This is a first attempt to use adiabatic refocusing pulses for diffusion imaging. By using a twice refocused DWI sequence, the use of the two slice-selective hyperbolic secant refocusing pulses cancels the quadratic phase that is otherwise challenging for adiabatic refocusing pulses. The application of the adiabatic refocusing, the B_1-related signal variations were significantly reduced. Despite the non-adiabatic 90° excitation, this is not surprising because the two 180° pulses are responsible for "most of the flipping" in the sequence. The use of adiabatic refocusing pulses increased however TE, leading to extra T_2-related signal loss. But for many areas, this loss in signal is much less than the signal penalty resulting from incomplete refocusing due to undesired flip angle variations. Whether or not it is possible to reduce the duration of the adiabatic refocusing pulses and thus to diminish the TE penalty remains the subject of further investigation. Moreover, the RF transmit coils used in this work should be considered fairly homogeneous; and for other scenarios using e.g. a surface transmit coil or generally less circular symmetric coils, the non-adiabatic SPSP 90° may cause significant B_1-variation, even at 3T. A BIR-4 pulse can be used for phase coherent excitation; however this is neither spatially nor spectrally selective. An alternative approach may be to design a spectral-spatial slice-selective adiabatic 90° excitation. This is currently under investigation.

References

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