In vivo high resolution, undistorted diffusion weighted imaging using DSDE-TFE

Tim Schakel[1], Hans Hoogduin[2], and Marielle Philippens[1]
[1]*Radiotherapy, UMC Utrecht, Utrecht, Netherlands,* [2]*Radiology, UMC Utrecht, Utrecht, Netherlands*

Purpose: to explore DSDE-TFE for in vivo high resolution, undistorted DWI and ADC calculation.

Background: Diffusion weighted MRI is commonly performed using a single shot spin echo EPI acquisition. EPI techniques, however, are very sensitive to B0 inhomogeneities due to susceptibility differences. This causes geometrical distortions.Because of the high sensitivity to motion, DW-EPI is mostly constrained to single shot MRI which limits the resolution. Diffusion Sensitized Driven Equilibrium (DSDE) has been proposed to overcome these limitations [1, 2]. This method is based on a diffusion preparation that restores diffusion weighted magnetization along the longitudinal axis which can be followed by an acquisition method of choice. This allows readout strategies which are less sensitive to distortion artifacts and allow for high resolution imaging.

Methods: Imaging was performed on a 3.0T Philips Achieva TX scanner using the 16 element NeuroVascular coil.<u>DSDE-TFE:</u>Diffusion weighting was applied along the 3 main orthogonal axes with b-values of 0, 100, 300, 800 s/mm^2.3D TFE was used for signal readout after preparation. TR/TE = 5.1/2.6 ms, FA = 10°, FOV 180x227x170 (FHxAPxRL) mm^3, acq voxel size 2x2x2 mm^3, rec voxel size 1x1x1 mm^3, SENSE 2/2 (AP/RL), TFE factor 48, shot interval 500 ms, total acquisition time 4m41s.

<u>DW-EPI:</u> TR/TE = 4284/92 ms, FOV 179x282x180 (FHxAPxRL) mm^3, acq voxel size 2x2 mm^2, rec voxel size 1x1 mm^2, 36 transverse slices of 4 mm, SENSE 2 (AP), EPI factor 73, b-values: 0, 100, 300, 500, 1000 s/mm^2 along the 3 main orthogonal axes, total acquisition time 1m04s.

<u>ADC calculation:</u> ADC values were calculated for a spherical agar phantom. For DSDE-TFE, ADC values were calculated using an adapted signal model: $S(b) = A(T_1,T_2)e^{-bADC} + B(T_1)$ [equation 1] according to [1]. Parameters A, B and ADC were fitted using a nonlinear least squares curvefit. For DW-EPI, the standard mono-exponential fit was done using the same algorithm: $S(b) = S_0 e^{-bADC}$ [equation 2]. All fits were performed in MATLAB.

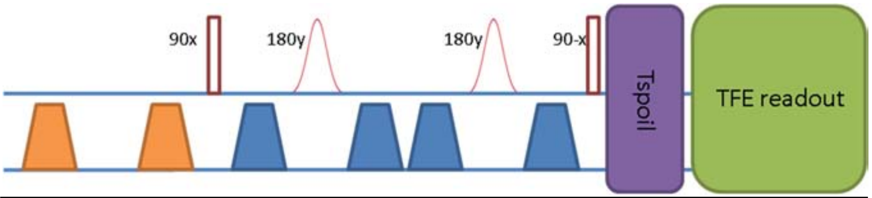

Figure 1: Schematic overview of the DSDE-TFE sequence. Orange: dummy gradients to compensate for eddy current effects. Blue: diffusion weighting gradients around adiabatic refocusing pulses. Excitation and tipup rf pulses are applied as hard pulses. Tipup is followed by subsequent spoiling gradients (purple) on the principal imaging axes.

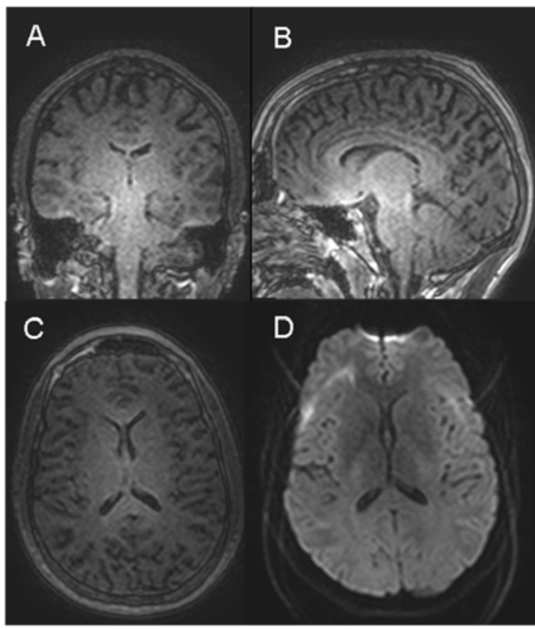

Figure 2. Coronal (a), sagittal (b) and transverse (c) b800 DSDE-TFE images of a volunteer. d: DW-EPI at the same slice as c.

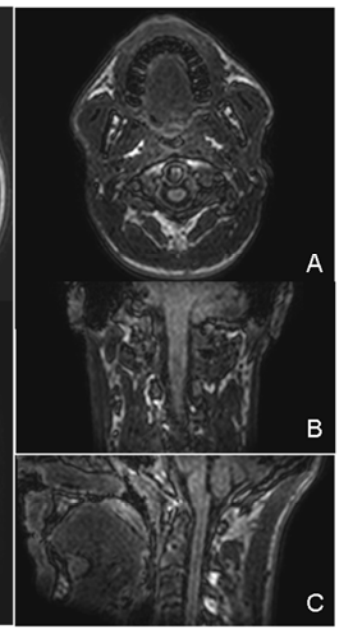

Figure 3. Transverse (a), coronal (b) and sagittal (c) b800 DSDE-TFE images of a volunteer.

Results: Volunteer brain and neck results are shown in figures 2 and 3. DSDE-TFE images showed undistorted high resolution isotropic images with a mixed contrast of T_1, T_2 and diffusion (figure 2a-c). Even at high b-values, signal to noise is sufficient. DW-EPI showed distorted images with a mixed T_2 and diffusion contrast (figure 2d). The comparison between figure 2c (DSDE-TFE) and 2d (DW-EPI) shows the improved geometrical accuracy especially in the area around the frontal sinus. The results from the neck region in figure 3 also demonstrate the geometrical robustness of DSDE-TFE in an otherwise very difficult anatomical region to perform DWI.

ADC values for the phantom were 2.1x10^{-3} and 2.4x10^{-3} mm^2/s for DW-EPI using equation 2 and DSDE-TFE using equation 1 respectively.

Discussion: The difference in image contrast between the 2 techniques is due to the differences in signal dependence. The signal in DSDE-TFE is also influenced by T_1 and T_1 related sequence parameters. ADC values are now overestimated due to the effect of shot interval which is not yet taken into account [3]. To eliminate the diffusion independent signal, B in equation 1, phase cycling of the rf pulses can be applied [1]. Generally, fat suppression is necessary to avoid large water fat shifts in the DW-EPI scan. In the case of DSDE-TFE, no fat suppression is required as the fat shift is negligible when using TFE. This fat shift artifact is still visible in the fat suppressed DW-EPI (figure 2d). Fat suppression can still be included, for applications in the neck such as cranial nerve and plexus visualization and tumor detection.

Conclusion: DSDE-TFE can produce high resolution, distortion free, diffusion weighted images. It is a promising technique which can be used in various applications of diffusion weighted images in areas which otherwise suffer greatly from EPI-related artifacts. Further optimization of the sequence should further improve image quality and diffusion quantification.

References: [1] Coremans J et al. A comparison between different imaging strategies for diffusion measurements with centric phase-encoded turboFLASHsequence.J.Magn.Reson 1997;124:323-342. [2] Obara M et al. Diffusion weighted MR nerve sheath imaging (DW-NSI) using diffusion-sensitized driven-equiliblium (DSDE). Proceedings ISMRM 2011: 4023. [3] Thomas DL et al. A quantitative method for fast diffusion imaging using magnetization prepared turboFLASH. MRM 1998;39(6):950-60.