

# Turbo Spin Echo Diffusion Tensor Imaging (TSE-DTI) in the Brain at 3 T and 7 T

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## Background

Diffusion tensor imaging (DTI) is a powerful tool of modern neuroradiology(1). Based on the measurement of anisotropic diffusion in brain tissue, it provides both quantitative structural markers such as the mean diffusivity (MD) and fractional anisotropy (FA) as well as qualitative assessments of white matter organization provided by fiber tractography(2). The most common DTI pulse sequence is echo-planar imaging (EPI), which is fast and motion-insensitive, but suffers susceptibility artifacts at high field. Successful high field (7 T) EPI-DTI has been demonstrated(3-6) using high parallel imaging acceleration factors (R) to reduce these artifacts, but at significant cost in sensitivity, giving a resolution comparable to lower field standards. Other sequences have a different balance of image quality and resolution and may allow the high field sensitivity enhancement to be realized. The present work explores turbo spin echo DTI (TSE-DTI) at both 3 T and 7 T(7). Its high field limitations are high specific absorption rate (SAR) from its RF train, and blurring from T2 modulation in k-space(8).

## Methods

EPI-DTI and TSE-DTI scans were acquired in healthy volunteers in 3 T and 7 T Siemens clinical scanners, with 8-channel and 24-channel head coils, respectively. The TSE sequence used a centric, full-k-space trajectory. Both sequences employ a double-echo, bipolar gradient diffusion weighting segment. All scans used 6 gradient directions (dual-gradient scheme) ([1,0,1],[-1,0,1],[0,1,1],[0,1,-1],[1,1,0],[1,-1,0]) and three b-values ( $b = 0, 500, 1000 \text{ s/mm}^2$ , except TSE-DTI at 3 T, which used  $b = 0, 200, 700 \text{ s/mm}^2$ ). Other parameters: **3 T EPI:**  $2 \times 2 \times 3 \text{ mm}$  voxel,  $128 \times 128 \times 36$  matrix,  $TE = 72 \text{ ms}$ , 3 avgs.,  $R = 3$ . **7 T EPI:**  $1.3 \times 1.3 \times 3 \text{ mm}$ ,  $192 \times 192 \times 8$ ,  $TE = 83 \text{ ms}$ , 3 avgs.,  $R = 2$ . **3 T TSE:**  $2 \times 2 \times 3 \text{ mm}$ ,  $80 \times 128 \times 10$ ,  $TE = 100 \text{ ms}$ , 10 avgs.,  $R = 1$ . **7 T TSE:**  $1.3 \times 1.3 \times 3 \text{ mm}$ ,  $120 \times 192 \times 6$ ,  $TE = 110 \text{ ms}$ , 3 avgs.,  $R = 2$ . Additionally, a multi-contrast turbo-spin echo sequence ( $se_{mc}$ ) was used to acquire T2-weighted images at 10 echo times ( $TE = 15, 30, 45, \dots, 150 \text{ ms}$ ) for the same slices as the TSE-DTI acquisition, and T2 maps were calculated. For deconvolution, each TSE-DWI voxel was individually Fourier-transformed to k-space, where the T2 modulation was corrected using that voxel's T2 value in a Wiener filter(9). A parameter (K) in the Wiener filter prevents noise amplification and was chosen empirically to approximate the inverse white matter SNR. A composite k-space was accumulated from all such subspaces, and Fourier transformed to obtain the final image. DTI processing was performed with the corrected TSE-DWI. High resolution (1 mm) anatomical images were acquired with a spoiled gradient echo sequence (MPRAGE).

## Results

Figure 1 shows TSE-DWI with and without T2 deconvolution at 3 T and 7 T, using the T2 maps collected at each field. In both cases, the raw DWI suffer significant blurring in the phase encode direction (L-R). The deconvolved images show dramatic improvement, with better edge definition and white matter/grey matter/CSF differentiation. This improvement translated to higher FA contrast in the processed DTI images especially in A-P oriented fibers where blurring severely mixed white matter and grey matter, such as the optic radiation and forcepts. Figure 2 shows FA-directional-colormaps for EPI-DTI and TSE-DTI at 3 T and 7 T, overlaid on high resolution anatomical images. At 3 T the two sequences give comparable results both in contrast and resolution, and most of the same fiber groups are visualized (corpus callosum, corona radiata, and transverse fibers). At 7 T, however, the EPI acquisition suffers anterior anatomical distortion (see genu of the corpus callosum) and poor visualization of peripheral cortical fibers. In contrast, the TSE-DTI acquisition shows more complete white matter sensitivity and visualization and correct anatomical proportion throughout the brain.

## Discussion

High field presents vast potential for increased resolution and sensitivity for most MRI techniques, including DTI. However, Figure 2 shows the difficulty for sequences like EPI in capturing this benefit; even with parallel imaging, susceptibility distortions limit the image quality. TSE-DTI is one potential alternative for high resolution, high field DTI. The aforementioned limitations of high SAR and T2 blurring are addressed in this case with coil acceleration to reduce echo train length and T2 deconvolution. The latter step is a known solution to TSE blurring, but full T2 mapping is sometimes too time-consuming to perform. In comparison to the acquisition times of full DTI scans, however, the T2 mapping sequence is quite acceptable considering its value. Future work will continue the development of TSE-DTI not only in the brain but in other problematic areas for EPI such as the spinal cord or optic nerve.

## References

1. Le Bihan, JMIRI 2001;13(4):534-546.
2. Bassler, MRM 2000;44(4):625-632.
3. Xu, ISMRM 2007 p 1466.
4. Reischauer, ISMRM 2007 p 3539.
5. Sammet, ISMRM 2007. p.1500.
6. Wiggins, ISMRM 2007 p 1497.
7. Norris, MRM 2001;45(5):729-733.
8. Zhou, JMIRI 1993;3(5):803-807.
9. Busse, MRM 2000;44(3):339-348.

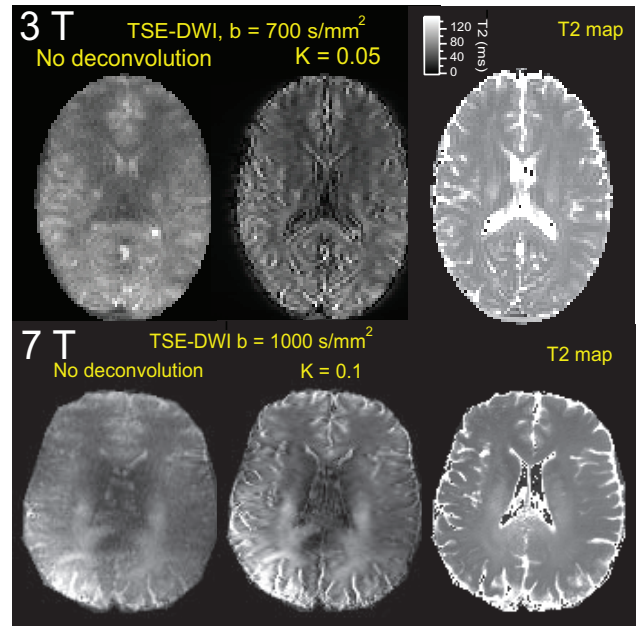


Figure 1: TSE-DTI T2 deconvolution processing for in vivo healthy volunteer brain imaging at 3 T and 7 T. For each field, a raw and deconvolved DWI is shown, using the separately measured T2 map for this slice.

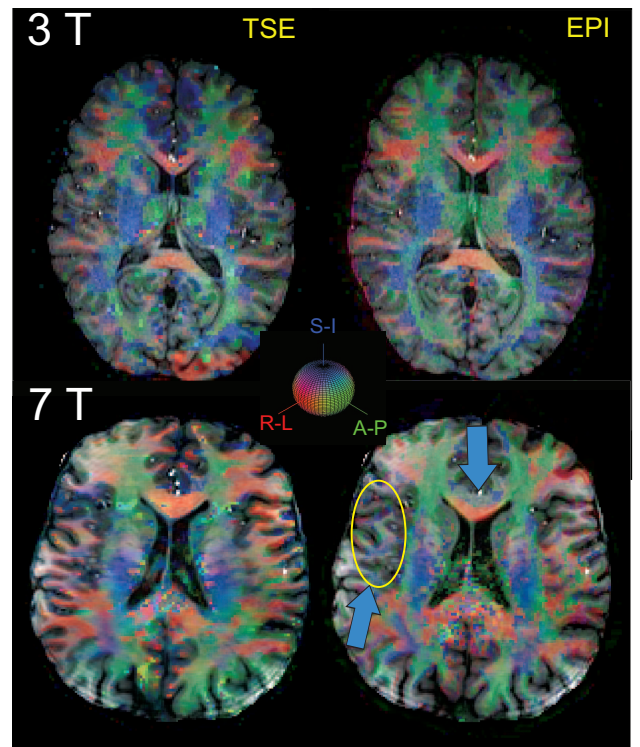


Figure 2: EPI-DTI and TSE-DTI results in healthy volunteers at 3 T and 7 T. FA colormaps are overlaid on anatomic images. At each field, the resolutions of each scan were the same ( $2 \times 2 \times 3 \text{ mm}$  at 3 T and  $1.3 \times 1.3 \times 3 \text{ mm}$  at 7 T).