

DTI of the Human Brain with Sub-millimeter Voxel Size: Clear Depiction of Fiber Decussation in the Optic Chiasm

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Introduction

There are numerous anatomical details in the brain that are undetectable at image resolutions typically used in diffusion tensor imaging (DTI), being 8mm^3 voxels, due to partial volume effects with surrounding tissue. In addition, the sequence used in the majority of DTI studies, single-shot EPI, is sensitive to magnetic field inhomogeneity near air/tissue interfaces. Because of these two factors, the optic nerves and optic chiasm have been a challenge to study with DTI. Recently, we developed a radial fast spin-echo (FSE) sequence for high-resolution DTI of *in vivo* brain that allows sub-millimeter isotropic voxels to be acquired in areas of magnetic field inhomogeneity [1]. In this work, the radial-FSE sequence was used to acquire DTI data of the optic nerve/chiasm. Being able to study these structures with DTI could provide clinically relevant information in a number of conditions affecting this region, such as optic pathway gliomas, pituitary tumors, and multiple sclerosis.

Methods

A diffusion-weighted radial-FSE sequence consisting of a Stejskal-Tanner diffusion preparation period followed by a train of 180° RF refocusing pulses with a mixed-CPMG phase cycling scheme [2] and a 300% wider refocusing than excitation slice, to improve B_1 -homogeneity [3], was used to collect data on a 3T GE Excite scanner, with gradients capable of 40mT/m . DTI data sets were acquired in an oblique plane aligned to the angle of the optic nerve/chiasm and contained a single non-diffusion-weighted image along with $b\text{-value}=1000\text{ s/mm}^2$ images in six non-collinear diffusion directions. Data was acquired of a healthy male volunteer at 0.8mm isotropic resolution with the following scan parameters: $\text{TE/TR} = 68/2000\text{ms}$, $\text{ETL} = 4$, and 512 radial lines. Data was also acquired of a second healthy male volunteer at 0.9mm isotropic resolution with similar scan parameters: $\text{TE/TR} = 68/2500\text{ms}$, $\text{ETL} = 4$, and 512 radial lines. In addition, a T1-FLAIR image of the same oblique slice was acquired at an equal 0.9mm isotropic resolution.

Results

Directionally encoded color (DEC) maps [4] calculated from the acquired DTI data sets with 0.8 and 0.9mm isotropic voxels are shown in **A** and **B**, respectively. Due to the ability to collect DTI data at sub-millimeter resolutions, partial volume effects are dramatically reduced and anatomical details, even within fiber tracts, can be revealed. White matter tracts running in the R/L direction are red, A/P direction are green, and the S/I direction are blue. In each image the white arrow points to the optic chiasm. The decussation of the fibers in the medial portion of the optic chiasm can be clearly seen in **A** as the red area in the middle of the chiasm, while the lateral fibers of the optic chiasm that don't cross can be seen in green continuing their antero-posterior trajectory and entering the ipsilateral optic tract. In **B** the partial decussation is also visible, although not as clearly. The voxel volume is 0.729mm^3 compared to 0.512mm^3 in **A**, a 42% increase, which may account for a loss of intravoxel orientational coherence of the fibers resulting in a less conspicuous appearance of the decussation. The image in **C** is the T1-FLAIR that corresponds to **B**. Due to the high-resolution obtained in **B**, several different bundles of fibers can be distinguished in white matter that appear homogeneous in **C**. For instance, superior-inferior intra-occipital association pathways can be detected as thin tracts (blue and purple) running adjacent to the optic radiation (green). Also, in subcortical areas very thin branches of U-fibers (red) can be detected with no partial volume contamination from adjacent structures. Unlike typical DTI images, collected with EPI, there is no distortion present in radial-FSE images and an ROI drawn on **C** can be directly overlaid on to **B**.

Conclusion

Using the modified radial-FSE sequence at 3T, images can be produced with a voxel size about 10 times smaller than that currently achievable with EPI-based DTI. This allows anatomical details in the brain to be studied with DTI, regardless of proximity to air/tissue interfaces. The DTI data sets in this work reveal fine details, even within fiber tracts, like the medial decussation in the optic chiasm. To our knowledge, these images are the first sub-millimeter isotropic voxel DTI of the optic nerve/chiasm to ever be presented.

References: [1] Sarlls *et al.*, ISMRM, 15: 1491, 2007. [2] Pipe *et al.*, MRM, 47: 42-52, 2002. [3] Pell *et al.*, JMRI, 23: 248-252, 2006. [4] Pajevic *et al.*, MRM, 42: 526-540, 1999.

