High-resolution Whole Brain Cardiac Gated Diffusion Tensor Imaging

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Introduction

While diffusion tensor imaging (DTI) has become a useful tool for investigating the integrity of white matter, its utility is somewhat limited by the low spatial resolution of current techniques. Ideally, DTI would be carried out with small isotropic voxels to increase voxel homogeneity and thus provide more accurate measures of anisotropy. In addition, there are numerous neuropathologies that effect temporal lobe structures and would be beneficial to study using DTI. Currently with single-shot techniques, high-resolution can only be obtained in-plane and there is signal drop out in areas of susceptibility near air/tissue interfaces, like the inferior temporal and anterior frontal lobes. In this work, a cardiac gated 3D diffusion-weighted radial fast spin-echo (FSE) sequence is demonstrated that combines the benefits of radial acquisition, i.e. insensitivity to rigid body motion and magnetic field inhomogeneity, with 3D MRI, i.e. improved SNR in small isotropic voxels.

Methods

The 3D diffusion-weighted radial-FSE sequence contains a dual spin-echo preparation period during which eddy-current compensated diffusion gradients are applied. This preparation period is followed by a FSE acquisition train, in which multiple radial lines of Fourier data (views) are collected. The number of views, their angular orientation and the order in which they are collected is completely flexible and has been shown to be critical to image quality in radial-FSE [1]. The number of views acquired is chosen to minimize undersampling artifacts while maximizing imaging speed. View orientations are chosen such that the angular spacing in θ and ϕ are equal. The collection order is chosen to coarsely sample the full volume of k-space within each TR period and to generate a high frequency angular variation in TE for adjacent views [1]. Imaging was carried out on a GE Signa 1.5T scanner with gradients capable of 22 mT/m. Seven datasets are collected in a DTI exam; one with b-value=0 s/mm^2, and six with b-value=1000 s/mm^2 in the following diffusion directions: (1,0.62, 0); (-1, 0.62,0); (0,1,0.62); (0,-1,0.62); (0.62,0,1); (-0.62,0,1) indicating fraction of maximum gradient strength on (X,Y,Z) gradients. Using a FOV=22 cm and 128 data points per radial line, images are reconstructed with 1.7 mm isotropic resolution. To suppress non-rigid body motion of the brain due to cardiac pulsation, the heart rate is monitored via ECG, and data was collected within each RxR interval with a post R wave delay time of 320 ms [2]. Individual 3D datasets were also aligned to each other using rigid body rotation and translation corrections in SPM2 to remove slow drift of the head during the exam.

Results and Discussion

An example high-resolution whole brain cardiac gated DTI dataset is shown in Figure 1. A cut-away of each 3D dataset are shown in panels with b = 0 s/mm^2 in a), the six diffusion-weighted images with b = 1000 s/mm^2 in b-g) and the calculated FA map in h). The splenium of the corpus callosum has an SNR = 51 in the b = 0 s/mm^2 image (Fig.1 a). The 3D dataset shown in Figure 1 indicates that all regions of the brain can be measured with high spatial resolution. High FA values are measured not only for major white matter tracts, like the internal capsule, but within smaller structures, such as the temporal stem. Furthermore, anisotropy values can also be measured in the region of the hippocampus and temporal pole, which are difficult to investigate using EPI methods. The 3D radial-FSE DTI dataset can also be mapped directly onto anatomical T1-weighted images for analysis without the need of unwarping the images. However, a major drawback of the current method is the long imaging time required; the volunteer shown had a heart rate of ~50 BPM which results in an ~2 hour exam. Because the scan time is directly related to heart rate, the total imaging time will greatly vary between subjects. The issue of long scan times can be addressed with several methods, including parallel imaging and/or vastly undersampled isotropic projection reconstruction (VIPR) techniques with bent trajectories [3]. The direction of diffusion weighting could also be altered within a single acquisition and the dataset post-processed into the six individual diffusion directions using a multi-tiered reconstruction [4]. Similarly, T2 maps can be calculated from the single b = 0 s/mm^2 radial-FSE dataset with a post-processing technique described previously [5]. The cardiac gated 3D diffusion-weighted radial-FSE sequence allows for maps of ADC, anisotropy, and T2 to be generated with small isotropic voxels and without sensitivity to magnetic field inhomogeneity and motion.

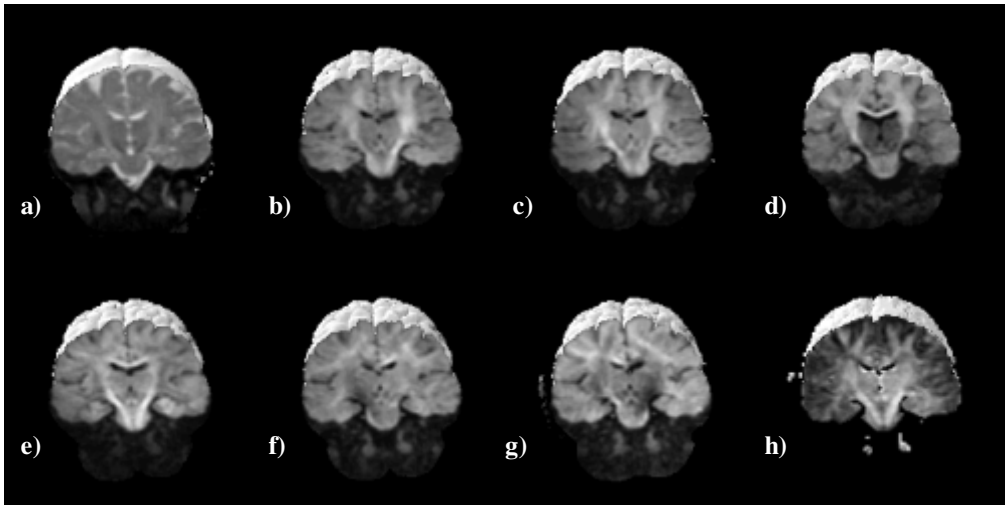

Figure 1. DTI dataset from a healthy volunteer. Scan parameters: TE_{eff} = 117ms, ETL = 8, FOV = 22cm, 128 points per view, 8192 views, cardiac gated with 320ms delay and 1 RxR. 1.71mm isotropic voxels. B-value = 0 s/mm^2 (a), and 1000 s/mm^2 in b-g) with diffusion directions XY, -XY, YZ, -YZ, XZ, -XZ, respectively. An FA map calculated from the DTI dataset is shown in panel h.

References: [1] Theilmann, *et al*., MRM, 51: 768-774, 2004. [2] Jones, *et al*., Proc. ISMRM 2005, P.222. [3] Barger, *et al*., MRM, 48: 297-305, 2002. [4] Newbould, *et al*., Proc. ISMRM 2004, P446. [5] Altbach, *et al*., JMRI, 16: 179-189. **Acknowledgements:** This work supported by NIH grant R21 AG021624.