Parallel Line Scan Diffusion Tensor Imaging

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Introduction Diffusion tensor imaging (DTI)[1] is widely used in the study of white matter-related diseases. Single-shot echo-planar imaging (EPI) is usually the preferred technique to acquire diffusion tensor data because of motion robustness and rapid acquisition. However, EPI images show severe geometric distortions. As a consequence, image mapping methods based on DTI, such as fractional anisotropy maps or neural fiber tractograms, are inherently prone to errors in regions such as near the skull base and in the frontal lobe. Line scan diffusion imaging (LSDI)[1] is a one-dimensional Fourier encoding technique. The absence of phase encoding provides considerable robustness against motion and immunity to artifacts due to magnetic field inhomogeneities and susceptibility. Full volume acquisitions with LSDI are, however, time consuming. To address this limitation, we present parallel line scan diffusion tensor imaging with parallel coil acceleration along two dimensions, which increases acquisition by a factor of four with no loss in SNR.

Methods: The pulse sequence diagram for parallel line scan diffusion tensor imaging with 2D acceleration is shown in Fig. 1. Cosine-modulation for both 90° and 180° pulses, shown in the inserts, produce double slice excitation along y and z axes respectively, which eventually results in four simultaneously refocused columns. After 1D FFT, four overlapping lines of image data, each from individual quadrants of the FOV, are acquired. Whole 3D aliased image data is obtained with one-fourth the number of excitations and un-aliased 3D images are obtained using SENSE algorithm. To reduce saturation artifacts caused by adjacent voxel excitation, an interleaving scan scheme along the diagonal direction of the volume is performed (see Fig. 2). Here the interleaving scan step is four, meaning that all voxels along the diagonal direction have been excited after four sweeps. A dummy scan is performed for the first sweep to maintain steady state. To reduce cross-talk artifacts, a gradient-spoiling technique is employed. Images are acquired six times with diffusion weighting along non-collinear directions and two times without diffusion weighting. Diffusion-weighted raw data are sorted offline after the scan. A 1D-FFT along the frequency encoding direction is performed, and 3D aliased images are obtained. Un-aliased 3D images are obtained using a SENSE-like algorithm. Diffusion tensor images are calculated using an in-house program.

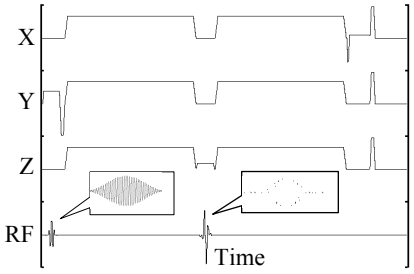

Fig. 1 Pulse sequence of parallel line scan diffusion imaging with 2D acceleration

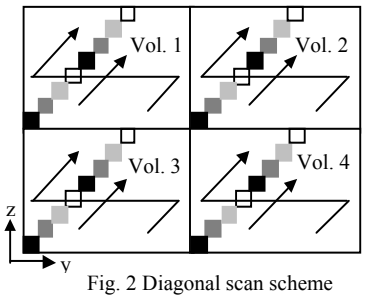

Fig. 2 Diagonal scan scheme

Results: The parallel line scan diffusion tensor pulse sequence was implemented on a 3T GE Signa EXCITE short bore scanner. Acquisition parameters are TE = 54.5 ms, TRc = 89 ms (column to column TR), TR_{eff}= 89 ms/column * 16 columns/sweep = 1424 ms, voxel size = 3 x 3 x 3 mm^3, FOV = 28.8 x 14.4 x 9.6 cm^3, matrix size for aliased data = 96 x 48 x 32, final unaliased matrix size = 96 x 96 x 64, 1D readout along the superior-inferior direction, 6 diffusion-weighted directions, b-value = 750 s/mm^2, 2 non-diffusion weighted. 2D acceleration was performed along the sagittal (z) and the coronal (y) direction. Total scan time for whole brain with 2D acceleration is around 22 minutes. This scan time can be reduced to 15 minutes, if more T1-weighting is acceptable. Fig. 3 shows one aliased diffusion-weighted image and reconstructed image. Fig. 4 shows three orthogonal slices through the reconstructed brain volume. Fig. 5(a) shows a mid-sagittal fiber tract image exhibiting through-plane fibers in the corpus callosum, and in-plane fibers in the cingulum and brain stem. Figure 5(b) is a lateral sagittal fiber tract image, showing fiber directions in the temporal lobe. Notice that both images, Fig. 5(a) and 5(b), feature very little geometric distortion even near the brain stem and temporal lobe, which would not have been the case, if an EPI sequence had been used instead.

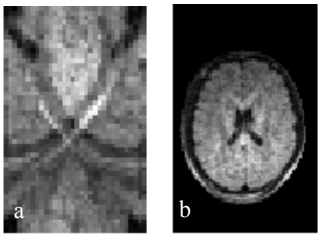

Fig.3 Aliased image (a) and reconstructed image (b). Frequency encoding is perpendicular to the image plane


Fig. 4 Orthogonal plane display of 3D reconstruction images

Discussion: Parallel line scan diffusion tensor imaging with 2D acceleration can not only reduce scan time to one fourth, but also maintain the same SNR (as demonstrated in[2]). Due to the absence of phase encoding in the line scan method, susceptibility induced signal loss and geometric image distortions are avoided, while motion robustness is maintained. Compared to a former proposed parallel line scan diffusion imaging technique[3], the addition of a gradient spoiler and a dummy scan dramatically reduces cross-talk artifacts[4] and steady state artifacts (banding).

Conclusion: We present a parallel line scan diffusion tensor imaging technique to reduce scan time by four-fold at no cost in SNR while maintaining immunity to the susceptibility-induced signal losses and geometric image distortions that often plague EPI.

[1] Basser *et al.* JMR B 1994;103:247 [2] Chu. ISMRM 2008:761 [3] Chu. ISMRM 2009:1376 [4] Gudbjartsson *et al.* MRM 1996;36:509

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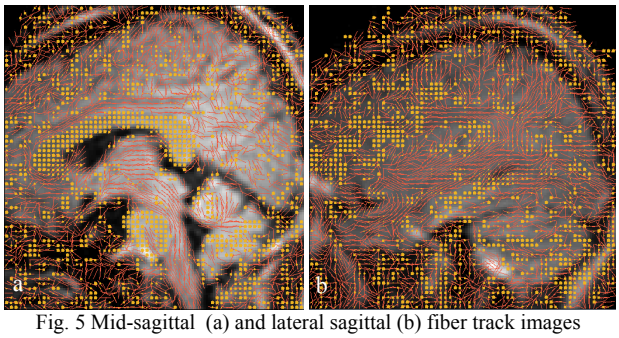

Fig. 5 Mid-sagittal (a) and lateral sagittal (b) fiber track images