High Angular Resolution Diffusion Tensor Imaging with Sensitivity Encoding (SENSE) Accelerated Echo Planar Imaging (EPI)

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Introduction: The anisotropic nature of diffusion in structures such as white matter tracts measured using diffusion tensor imaging (DTI) can yield valuable clinical information [1,2]. Diffusion anisotropy can reveal anatomic and functional connectivity of white matter fiber tracts, and alterations in diffusion anisotropy can be indicative of underlying tissue pathology [3,4]. In DTI, it is desirable to measure diffusion along multiple directions to improve resolution of fiber orientations within a voxel. In addition, it is also desirable to acquire data over the entire brain with isotropic voxels to aid tracking of white matter fibers[3,4]. These two factors have tremendously increased the scan time required for a DTI experiment. As a result, despite its several limitations, echo planar imaging (EPI) is widely used for DTI, primarily to speed up data acquisition and to minimize the effect of bulk motion during data acquisition. Recenly, sensitivity encoding (SENSE) has been described as a means for more rapidly traversing *k*-space by using spatial variations in receiver coil sensitivities [5] for spatial encoding. The reduction in signal-to-noise ratio intrinsic to SENSE may be partly offset in the context of the single shot EPI technique in the form of reduced readout duration (and less T_2 blurring), and a modest reduction in effective TE for the same diffusion weighting [6,7]. The purpose of this study is to test the feasibility of combining SENSE with EPI to obtain high angular resolution DTI.

Materials and Methods: *Theory:* In single shot spin echo EPI, T_2 decay introduces blurring along the phase encoding direction (k_y), broadening the point-spread function (PSF) of the acquisition. This blurring, characterized by the increase in the full-width at half max (FWHM) of the PSF, is proportional to the acquisition duration. Using an EPI readout duration used in the study with and without SENSE (see below), the FWHM for a range of T_2 is shown theoretically in Figure 1. *MRI Acquisiton:* All experiments were done on a 1.5 T Philips Intera scanner using a 6-element phased array head coil. A low resolution gradient echo acquisition was acquired over the entire imaging volume using an interleaved body coil and synergy head coil acquisition to estimate the coil sensitivity information (scan time: 52 sec). *DTI SENSE and No SENSE protocol:* Two sets of DTI data with identical acquired voxel size (2.5 x 2.5 x 2.5 mm) and coverage (55 slices, 2.5 mm thick) were collected. The number of diffusion encoding directions (N_d=32), diffusion weighting ('b' value of 800 sec/mm^2), bandwidth per pixel along the read out direction (1866 Hz/pixel), and half scan factor (0.705) were all identical between the two acquisitions. The *only* differences between the two acquisitions were the use of SENSE (SENSE factor : 3 along the RL direction) in one acquisition to reduce the EPI readout duration from 37.7 msec to 13.5 msec, shorten effective TE from 92 msec to 84 msec, and the total scan time from 6:22 min to 5:12 min. *Phantom study:* Glycerol was diluted with water as a reference phantom to mimic the range of apparent diffusion coefficient (ADC) expected in vivo (0.8-3.0 mm^2/sec). Data using the DTI protocol described above with and without SENSE were collected. *In vivo Study*: In six adult, healthy normal volunteers (4 male, 2 female, age: 39.6 +/- 9.3 years) whole brain DTI data using the protocol described above were acquired with and without SENSE. *Data Analysis:* Parametric maps describing diffusion anisotropy were generated on an offline workstation. The differences in the estimated parameters in the SENSE and NoSENSE DTI in the phantom data was assessed using the method described by Bland and Altman [8]. For the in-vivo data acquisition, fractional anisotropy (FA), and ADC numbers from representative areas were measured.

Results: SENSE acquisition and reconstruction was successful in all cases with minimal residual foldover artifacts. Bland-Altman plots for FA maps obtained in the phantom are shown in Figure 2. Representative in-vivo results with and without SENSE are shown in Figure 3. Numerical values of FA and ADC at different anatomic locations are shown in Table 1.

Discussion: It should be noted that the noise in the SENSE technique depends on the coil geometry factor, and is spatially dependent. In this study, the effect of coil geometry factor was not quantitatively assessed.

Conclusions: Our results show that it is feasible to apply SENSE to minimize the EPI acquisition duration in DTI. The quantitative parametric maps (FA and ADC) characterizing anisotropy generated from SENSE EPI data are similar to those generated from EPI data without using SENSE. The addition of SENSE dramatically reduces the EPI readout duration (and resultant blurring), and the intrinsic SNR penalty associated with SENSE is partially offset with a shortened effective TE.

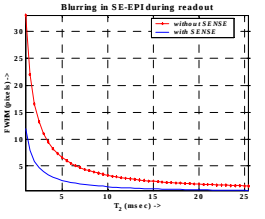

Fig1: Note diminished blurring using SENSE

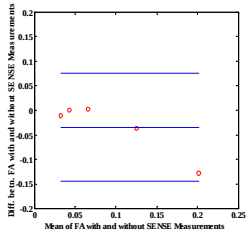

Fig 2: The lines mark +/-2 SD of the Bland-Altman plot. FA from phantom study.

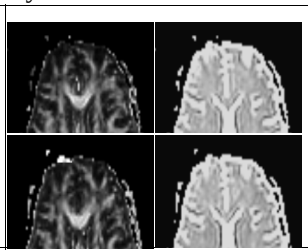

Fig 3: FA and ADC maps from a volunteer without (top row) and with SENSE (bottom row).

Location	FA NoSENSE/SENSE	ADC (mm^2/s) NoSENSE/SENSE
Genu	0.805/0.812	0.837/0.860
Splenium	0.777/0.786	0.843/0.828
R.Cent.Semiovale.	0.394/0.378	0.802/0.820
L.Cent.Semiovale.	0.368/0.365	0.824/0.839
R. Putamen	0.183/0.211	0.754/0.703
L. Putamen	0.235/0.235	0.733/0.761

Table 1: Representative mean values for FA and ADC in volunteers with and without SENSE EPI. Note close correspondence between the two measurements.

References: 1. Basser et al. Biophys. J. 1994;66:259-267; 2. Pierpaoli et al. Radiology 1996;201:637-648; 3. Sorensen et al. Radiology 1999; 212:785-792; 4. Bammer et al. MRM 2000;44:583-591; 5. Pruessman et al. MRM 1999; 42:952-962; 6. Bammer et al. MRM 2001;46:548-554; 7. Bammer et al. 2002;48:128-136; 8. Bland et al. Statistical Methods in Medical Research 1999; 8:135-60.