Focused High Resolution SENSE-DTI at 3 Tesla using a Micro Coil Array

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Introduction

Diffusion Tensor Imaging (DTI) is a promising non-invasive method for studying white matter structure of the human brain in-vivo. However, detailed study of different brain structures is seriously hampered by the current resolution limits of the technique. Single-shot spin-echo EPI (sshSE-EPI) is the most commonly used sequence for DTI due to its motion robustness. Critical shortcomings of sshSE-EPI are image blurring and its sensitivity to field inhomogeneity, especially at high B_0 field strengths. Recently, the potential of the parallel imaging technique Sensitivity Encoding (SENSE) (1) was demonstrated in combination with DTI using sshEPI at 3 Tesla (2). SENSE was shown to mitigate effectively both susceptibility artifacts and blurring by shortening the EPI train. While reducing blurring, SENSE confers DTI an increased intrinsic resolution. Another serious resolution limit stems from the strong link between voxel size and SNR, the latter being inherently low due to extensive T2 decay and diffusion weighting. To overcome these limitations, the use of receiver coils with very high sensitivities and a high B_0 are required.

In the present work, we explore the use of a micro coil array for SENSE-DTI. We hypothesize that the spatially narrow coil sensitivities represent an ideal basis for sensitivity encoded DTI. In addition to the advantages of parallel imaging with respect to artifacts and blurring, SENSE-DTI using a micro coil array is expected to push the resolution beyond previous limitations, potentially enabling to follow white matter tracts at the intracortical level, an area with known low anisotropy.

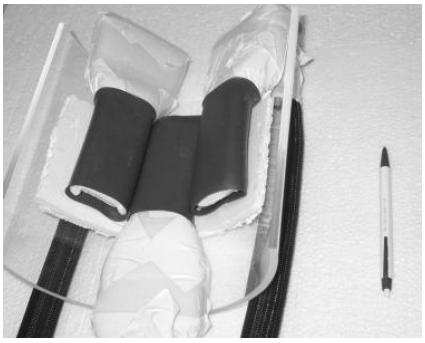

Fig.1: Coil array consisting of three singe coils placed parallel to each other. Each coil was wrapped with foam and shrinkable tubing. The coil configuration was fixed on an arced plate of 200 mm diameter made of Plexiglas. The loop dimension of each coil element is 35 x 70 mm. In comparison to the setup a regular pen.

Methods

DTI data were acquired from 6 healthy volunteers using a 3 T Philips Intera whole-body system (Philips Medical Systems, Best, the Netherlands) equipped with 80 mT/m, 200 mT/m/ms gradient coils. A receive head coil array was assembled using custom-made micro coils placed on an arced Plexiglas plate whose curvature permitted an optimal fit to the back of the volunteer's head (Fig. 1). Depending on the desired field of view either three or five coils were attached. For maximum spatial resolution, R = 2.4-fold SENSE reduction was combined with 60 % partial Fourier acquisition in a diffusion-weighted (DW) single-shot SE-EPI scheme (matrix = 256 x 256, FOV = 150 mm, 5 slices, thickness = 2.5 mm, TE = 67 ms, TR = 2140 ms). The effective in-plane resolution thus achieved was 0.58 x 0.58 mm^2. Diffusion weighting with a b-factor of 1400 s/mm^2 was carried out along six directions, complemented by one scan with b = 0. A total of 34 averages were obtained, subdivided in two identical scans, resulting in net scan times of 22 min. Eddy-current-induced image warping was removed with a 2D-registration algorithm (3) and the diffusion tensor's properties were derived by singular value decomposition. Compared to Ref. (4), where the cat visual cortex was investigated using a biexponential diffusion model, data were fitted to a single-compartment diffusion model. Fibers were reconstructed using a custom-made line propagation tracking algorithm.

Results

Figure 2 shows DTI data free of residual aliasing artifacts and reveal only minor distortions related to susceptibility variations. A sensitivity encoded base DW image is shown in A). The image is hyperintense at the anterior border due to the restricted penetration depth of the coils: the SENSE algorithm attempts to even out the inhomogeneity of the coil array, which leads to an increase in the signal where the coil's sensitivity is low. The image allows a good distinction between gray and white matter. Figure 2B) illustrates an area of 62 x 62 mm. The top left corner reveals lower SNR compared to the region around the sulcus (arrow). This implies an optimal penetration depth of the coils of about 40 mm. Fiber reconstructions in C) and D) allow following of the fiber trajectories within the cortical gray matter.

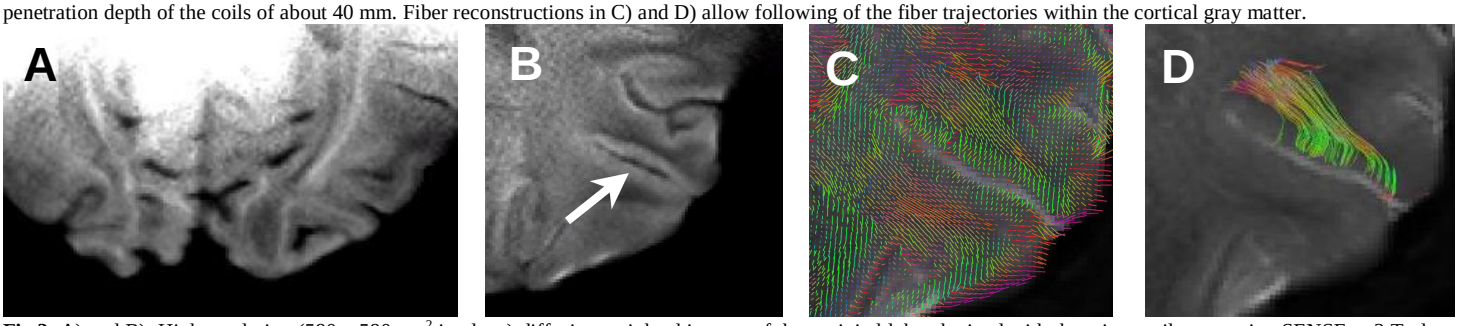

Fig.2: A) and B): High resolution (580 x 580 µm^2 in plane) diffusion weighted images of the occipital lobe obtained with the micro-coil array using SENSE at 3 Tesla. The diffusion weighting was b = 1400 s/mm^2 in A and b = 1000 s/mm^2 in B, respectively. C): Color-coded main diffusion vectors superimposed on T2-weighted (b = 0) image. D): Reconstructed fibers of a seed area located anterior to the sulcus. C, D reflect the same (magnified) sulcus as shown in B (arrow).

Discussion and Conclusion

In this study we have shown that parallel acquisition using an array of micro coils permits DTI with very high resolution in the sub-millimeter range. It seems that DTI and fiber tracking become feasible in regions which have been precluded so far due to inadequate image resolution and low fractional anisotropy values, such as cortical gray matter, where diffusion is dominated by a more isotropic component and the fiber density is low compared to white matter. The ability to follow white matter tracks to the cortical level is crucial for the non-invasive investigation of connectivity in the human brain. This can only be provided by further progresses in the spatial resolution and sensitivity of the technique.

References

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