16-Channel Parallel DTI at 7T: Initial Experiments

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Introduction

Diffusion Tensor Imaging (DTI) is a powerful, non-invasive technique to study white matter in the human brain in vivo. Typically, image acquisition relies on single-shot EPI (sshEPI) due to its speed and its immunity to motion artifacts. Critical shortcomings of sshEPI are image blurring due to T2* decay and distortions related to B0 inhomogeneities, especially at high field strengths. Both problems can be addressed by parallel imaging which permits to reduce the echo train [1-4].

Recently, ultra-high field scanners with 7 T and beyond have been introduced to the scientific community. The related boost in potential SNR is promising, but on the other hand, diffusion-weighted imaging at 7 T is severely hampered by increased inhomogeneities of B1 and B0 as well as reduced T2 and T2*. In the present work, the use of a multi-channel head coil array in combination with parallel imaging at 7 T is investigated. In-vivo brain images using different SENSE reduction factors are presented and a high-resolution Fractional Anisotropy (FA) map with submilimeter resolution is shown.

Methods

Data sets of five healthy volunteers were acquired on a 7 T Philips Achieva whole body system (Philips Medical Systems, Cleveland, USA). For all acquisitions a transmit head volume coil and a 16-channel prototype receive-only head coil array (Philips Medical Systems, Cleveland, USA) was utilized (Fig. 1). Each session consisted of nine sshEPI whole brain scans (Fig. 2) with the following parameters: FOV = 200 mm, acquisition matrix = 124x124, reconstruction matrix = 128x128, 5 slices, slice thickness = 4 mm, slice gap = 4 mm, TR = 3 s, NSA = 1, total scan duration = 30 s, SENSE reduction factors of 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.0, 9.0 (TE = 67 ms, 62 ms, 59 ms, 58ms, 57ms, 56ms, 56ms, 55ms, 53ms) complemented with one high-resolution scan in the submillimeter realm (in-plane resolution 0.8x0.8 mm^2) (Fig. 3) with the following parameters: FOV = 200 mm, acquisition matrix = 224x224, reconstruction matrix = 240x240, 5 slices, slice thickness = 4 mm, slice gap = 4 mm, TR = 3 s, TE = 71 ms, NSA = 16, total scan duration = 342 s, and SENSE factor = 2.5. In order to limit T2 decay, partial Fourier encoding of 60 % was applied. Diffusion-weighting was carried out along 15 diffusion directions with b-factors of 0 and 900 s/mm^2. Retrospective interscan motion correction and a reduction of eddy current-induced image warping were achieved using a correlation-based 3D-affine registration algorithm. The independent elements of the tensor and the FA maps were computed with a dedicated software package developed in C++.

Results

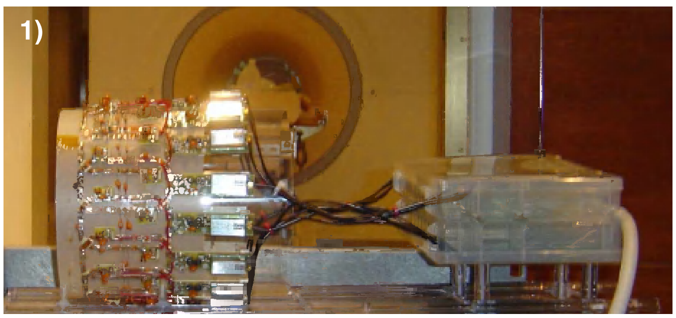

Fig. 1: 16-channel prototype receive-only head coil array.

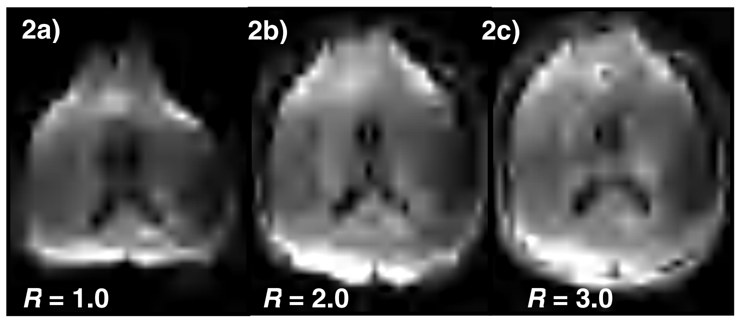

Fig. 2: Comparison of sshEPI SENSE-DTI axial images acquired with different SENSE reduction factors of R = 1.0, 2.0, and 3.0.

Fig. 2 illustrates the benefits of parallel imaging for sshEPI at high field on image quality. Susceptibility-related distortions and image blurring are significantly reduced. Visible improvements still occur at higher reduction factors. However, images with reduction factors of R = 4 and higher featured critically low SNR in the center due to combined acquisition time and g factor penalty. In the present work the optimal reduction factor was between 2 and 4. Inhomogeneous signal intensities due to susceptibility variations and non-uniform B1 excitation are visible in all images. Fig. 3 displays a typical example of a high-resolution color-coded FA map with a submillimeter in-plane resolution. Compared to Fig. 2 image distortions are slightly more pronounced. This is caused by a reduced pixel bandwidth due to longer readout lines. To emphasize the resolution Fig. 3b shows an enlarged section of Fig. 3a, exhibiting pixel-by-pixel the principal eigenvector of the diffusion tensor projected onto the color-coded FA map.

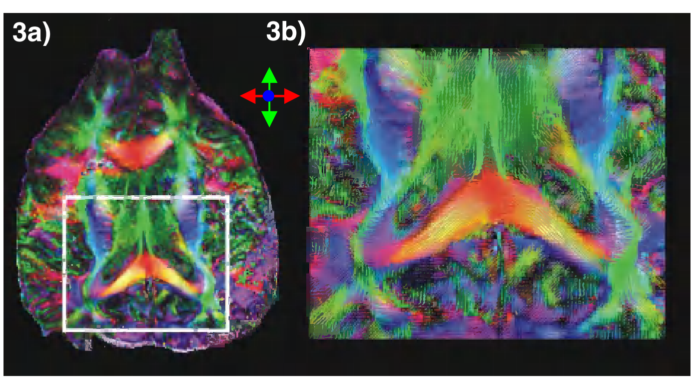

Fig. 3: Color-coded high-resolution FA map (in-plane resolution 0.8x0.8 mm^2) acquired using SENSE-sshEPI. SENSE reduction was 2.5. a) Example of an axial slice. b) Enlarged section showing the principal eigenvectors.

Discussion and Conclusion

This initial study confirms that ultra-high field poses serious challenges to diffusion imaging, particularly with respect to field inhomogeneity and T2 as well as T2* decay. However, it also illustrates that these challenges can be addressed quite effectively with parallel imaging. The main issues of susceptibility-induced distortion and T2*-related blurring were strongly mitigated with SENSE acceleration, indicating that the inherent sensitivity benefit of 7 T can actually be tapped for diffusion applications.

Recent theoretical work predicts a greater range of feasible acceleration factors at 7T than at lower field strengths, sufficiently large coils arrays provided [5]. The g factor behavior was not a focus of the present study. However, with a 16-channel array SENSE reconstruction was found to be robust up to 4-fold acceleration in one dimension without conspicuous regions of particular noise enhancement. Significant variations of signal intensity resulted from B1 inhomogeneity, which may be addressed by advances in array design and multiple-channel excitation in the future.

References

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