High Resolution SENSE-DTI at 3 Tesla using a High Performance Gradient System

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Introduction

Diffusion Tensor Imaging (DTI) has proved to be a useful tool for the in-vivo study of myeloarchitectonics in the human brain. However, limitations in imaging resolution prohibit the detailed study of white matter organization. A serious resolution limit stems from the strong link between voxel size and signal-to-noise ratio (SNR), the latter being inherently low due to extensive T2 decay and diffusion weighting. DTI using single-shot spin-echo EPI (sshSE-EPI) combined with the parallel imaging technique Sensitivity Encoding (SENSE) (1) is a promising method for overcoming this limitation. It has been shown (2, 3) that reducing the EPI train length with the parallel approach effectively mitigates blurring as well as susceptibility effects, and enhances SNR efficiency due to a reduced echo time (*TE*).

In the present work, we investigate SENSE-DTI at 3 Tesla using a high performance gradient system (80mT/m gradient coils). We argue that such a system improves the resolution of SENSE-DTI data significantly, because it reduces *TE* in order to obtain the required SNR for smaller voxels.

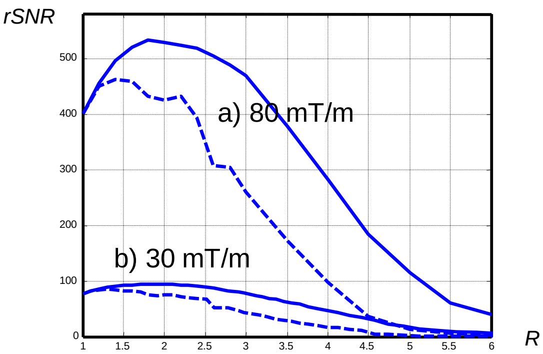

Fig.1: Relative SNR of DW-SENSE images for two different gradient systems as a function of SENSE reduction *R*. Mean (solid lines) and minimum SNR (dashed line) correspond to the mean and local maximum *g* factor in an image.

Methods

Data were acquired from 2 healthy volunteers and a 9 years old girl having a parieto-occipital cavernoma. All experiments were performed using a 3 T Philips Intera whole body system (Philips Medical Systems, Best, the Netherlands) equipped with new 80 mT/m, 100 mT/m/ms gradient coils and a 8-element receive head coil array (MRI Devices Corp., Waukesha, USA). Partial Fourier acquisition of 60% was applied in a diffusion-weighted sshSE-EPI scheme (matrix = 304 x 304 reconstructed to 512 x 512, *FOV* = 190 mm, SENSE *R* = 2.1, 5 slices, thickness = 4 mm, *TE* = 86 ms, *TR* = 2194 ms). The effective in-plane resolution thus achieved was 0.63 x 0.63 mm^2. Diffusion weighting with a *b*-factor of 1000 s/mm^2 was carried out along six directions, complemented by one scan with $b = 0$. A total of 12 averages were obtained, resulting in net scan times of 8 min 24 s. Eddy-current-induced image warping was removed with a 2D-registration algorithm (4) and the diffusion tensor's properties were derived by singular value decomposition.

For maximum SNR in diffusion weighted (DW) sshSE-EPI the echo time should be minimized within the constraints set by the required *b*-factor. TE determines the overall T2 weighting of the entire EPI train. Stronger gradients, partial Fourier acquisition and SENSE enable a shorter TE. The relative SNR yield was approximated as $rSNR = \exp(\Delta TE / T2) * \sqrt{f} / (g \sqrt{R})$ [1] with respect to a sshEPI sequence with full Fourier acquisition (256 x 256 matrix) using 30 mT/m gradients. ΔTE denotes the echo time reduction achieved with stronger gradients, partial Fourier acquisition and SENSE. *g* denotes the geometry factor, which expresses local noise enhancement specific to sensitivity encoding. For SNR estimation, actual *g* values were calculated from one volunteer data set and the white matter *T2* at 3 Tesla was approximated by 60 ms.

Results

Figure 1 depicts two features: 1. The SNR gain of DW-sshSE-EPI (acquired with partial Fourier encoding) using 80 mT/m gradients is significantly higher than with 30 mT/m gradients due to a reduced echo time. 2. For both gradient systems SNR optima occur at $R \sim 1.9$. Figure 2A reveals only minor distortions related to susceptibility variations, especially at the anterior border of the lesion. The enlarged region of interest of Figure 2B allows detailed identification of cortical gray matter and subcortical white matter anatomy. Figure 2C and D show the detailed white matter arrangement from the subcortical level to the periphery of the cavernoma.

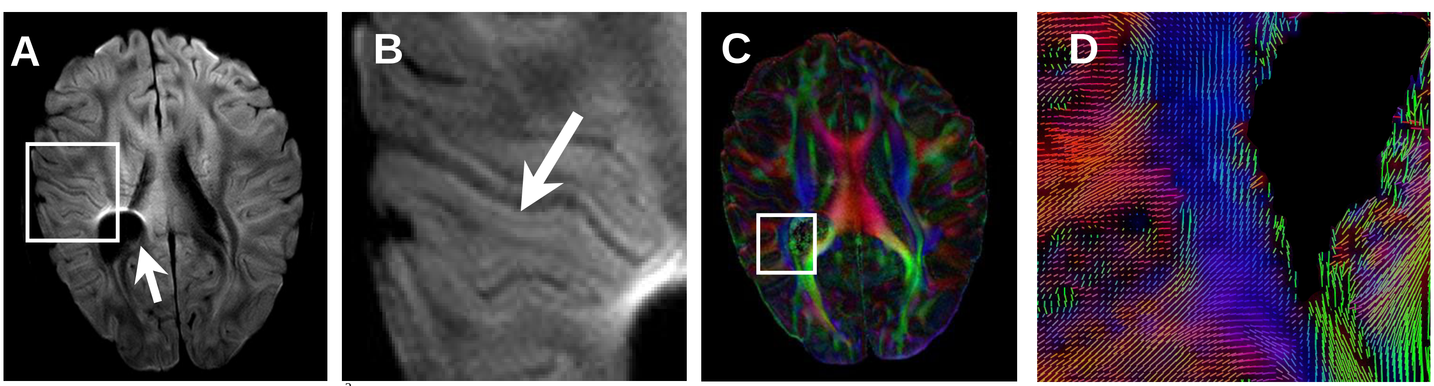

Fig.2: High resolution (0.63 x 0.63 mm^2 in plane) images obtained with SENSE-DTI using 80mT/m gradients. A: Diffusion weighted image acquired using sshSE-EPI with matrix of 304^2 and b = 1000 s/mm^2. The paraventricular hemorrhagic cavernoma is clearly visible (arrow). The white rectangle is zoomed in B. The arrow indicates cortical gray matter around an adjacent sulcus. C: Reconstructed color-coded fractional anisotropy map of the same axial slice as shown in A. The rectangle marks a 29 x 29 mm^2 region of interest, which is zoomed in D. D: Calculated main diffusion vectors superimposed on the FA data.

Discussion and Conclusion

In this study we have shown that sensitivity encoding using a MR system with 80 mT/m gradient coils permits sshSE-EPI with matrices larger than 256 x 256. The increased SNR due to a reduced *TE* yields DTI data with very high resolution in the sub-millimeter range. The combination with parallel imaging is essential, because it increases the *intrinsic* resolution: The faster travel trough k-space narrows the point spread function in phase encode direction. Finally, the presented patient results show that high resolution SENSE-DTI using a high performance gradient system is clinically feasible, permitting detailed depictions of diffusion anisotropy in a scan time as short as 8 minutes.

References

1. Pruessmann KP, et.al. Magn Reson Med 1999; 42: 952-962. 2. Jaermann T, et.al. *Proc Int Soc Magn Reson Med*: 64, 2003. 3. Bammer R, et.al. Magn Reson Med 2002; 48: 128-136. 4. Netsch T, et.al. *Proc. ICCV*: 718-725, 2001.