In vivo echo planar diffusion tensor imaging of the optic nerve in rats

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Introduction: Diffusion tensor imaging (DTI) is an increasingly important non-invasive clinical imaging technique. Since fast echo planar imaging technique (EPI) is sensitive to geometrical distortions because of susceptibility effects, most animal studies have so far have used a standard spin echo DTI sequence. With a spin-echo DTI sequence, acquisition times can be long, up to several hours, and most experiments have therefore been carried out ex vivo. Here, we have developed a protocol for in vivo imaging of the optic nerve in rats using fast echo planar diffusion tensor imaging (EPI-DTI). The results are confirmed with manganese-enhanced MRI (MEMRI), where the calcium analogue manganese, which is taken up and transported along axons, give contrast in MRI because of its paramagnetic properties (1).

Materials and Methods: In vivo MRI of the rat brain was obtained 24h after unilateral intravitreal injection of 150nmol $MnCl_2$ (3µl) in 10 rats (Sprague Dawley). MRI was performed at 7T using a Bruker Biospec Avance DBX-100 (Bruker Biospin, Ettlingen, Germany) with a 72 mm volume coil for transmission and an actively decoupled quadrature rat head surface coil for receive-only. Water-cooled BGA-12 (200 mT/m) gradients were used. For scanning, anesthetized animals lay prone in a dedicated animal bed within the magnet, heated with circulating air at 37ºC. Following the acquisition of scout images, a 3D data set was obtained using a T1-weighted 3D low flip angle gradient-echo sequence (FLASH) with TR=12 ms and TE=3.7 ms, and a flip angle of 30º. The acquisition matrix was 256×256×96 and the voxel resolution 195×195×208 μm^3. 4 averages were acquired and the acquisition time was 19 minutes. The appropriate oblique slice containing the optic nerve was chosen from the 3D volume using the 3D tool in ParaVision 3.0.2 (Bruker Biospin, Germany). Using this slice, with the animal in the same position, a multi-shot, single-slice EPI sequence with diffusion gradients was employed with TR=1500 ms, TE=31 ms, Δ=15 ms and δ=6 ms. A slice thickness of 0.85 mm and a matrix size of 160×160 (zero filled to 256×256) was used, giving an in-plane resolution of 0.313×0.313 mm^2. Diffusion sensitizing gradients were applied along 12 non-collinear directions with 8 b-values in the range of 0-3000 s/mm^2. The sequence was repeated 4 times, giving an acquisition time of 40 minutes. The DTI-EPI data was post-processed using in-house, custom developed software written in Matlab (Mathworks Inc, USA). The mean diffusivity, fractional anisotropy (FA) and axonal ($\lambda_\parallel$) and radial ($\lambda_\perp$) diffusivities ± standard deviation were calculated from the mean values in a region of interest (ROI) consisting of 26±4 pixels placed within the optic nerve 4 mm from the retina. The axial and radial diffusivities were compared using an independent samples t-test in SPSS (SPSS Inc, Chicago, USA).

Results and Discussion: We have developed a protocol for imaging the optic nerve using echo planar diffusion tensor imaging, where the DTI results are confirmed with MEMRI (figure 1). The results are high quality DTI-EPI images with few geometrical distortions. From the color coded FA-maps with the projection of the principal component of the eigenvector in each pixel, the optic nerves can be followed from the retina to the optic foramen (figure 1c, 1d). Additionally, the directions of the major eigenvectors align with the directions of the nerve (figure 1d). Within the optic nerve, the mean diffusivity and fractional anisotropy were 1.088±0.224 $\mu m^2/ms$ and 0.780±0.056, and the axial and radial diffusivities were 2.368±0.447$\mu m^2/ms$ and 0.449±0.148 $\mu m^2/ms$. These values are in agreement with previous findings (2), confirming the protocol. There was a statistical significant difference between the axial and radial diffusivity ($p<0.001$). The high-resolution diffusion tensor data obtained from the DTI-EPI sequence can allow for segmentation of the optic nerve either using fiber-tracking techniques or scalar indices of the diffusion tensor.

Conclusion: We have developed a protocol for in vivo echo planar diffusion tensor imaging of the optic nerve. With a scan time of 40 minutes, high quality DTI-EPI images with few geometrical distortions were obtained. Within the nerve, the axial and radial diffusivities were 2.368±0.447 $\mu m^2/ms$ and 0.449±0.148 $\mu m^2/ms$.

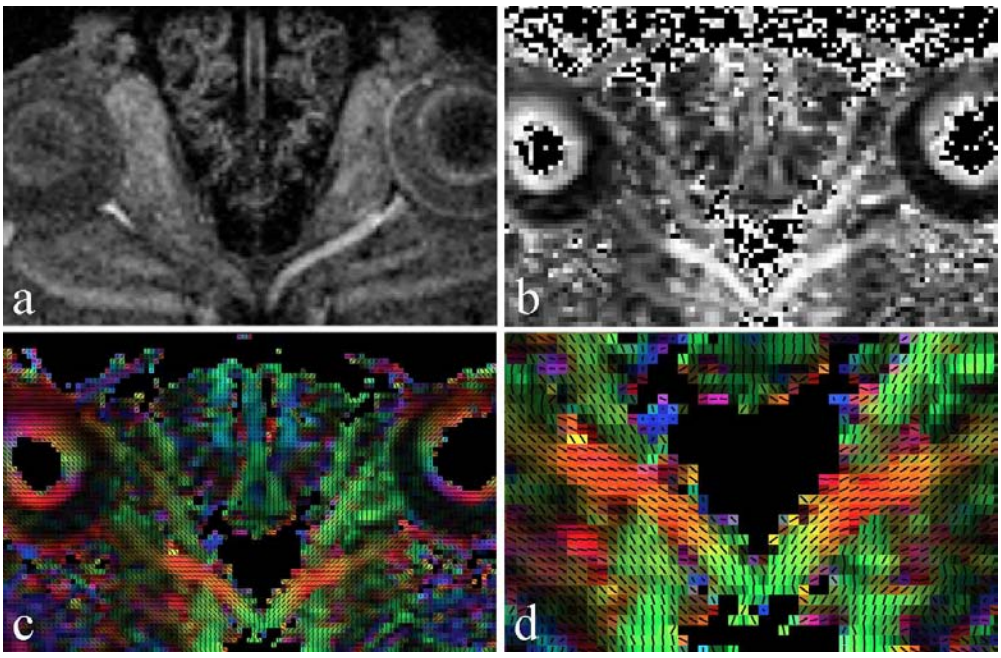

Figure 1: a) MEMRI of the enhanced (left) and non-enhanced (right) optic nerve. b) FA-map. c) Color coded FA-map with the major eigenvector projected in each pixel. d) A magnified color coded FA map where the direction of the major eigenvectors is shown.

References:

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