Mapping of Microscopic Diffusion Anisotropy Measures in the living human brain

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Double-wave-vector diffusion-weighting (DWV) experiments [1] in which two diffusion weighting periods are applied successively (see Fig. 1), offer access to tissue properties on a microscopic level [1-3]. For instance, the diffusion anisotropy present on a microscopic scale in brain white matter could be detected even in a region-of-interest that appears isotropic in a DTI experiment (FA=0). Thus, DWV experiments may help to overcome confounds of conventional DTI, e.g. in white matter fibre crossings. But so far, only the angular signal modulation that reflects the presence of microscopic diffusion anisotropy has been detected in the living human brain [4].

The current study aims to extend these experiments to determine rotationally invariant measures of the microscopic diffusion anisotropy that have been introduced theoretically [5]. It is shown that with the dedicated direction combination schema experimental signal variations could be reduced which improves the reliability of the microscopic anisotropy measures. Additionally, the rotational invariance of these measures in brain white matter is demonstrated. Furthermore, it is shown that the measures can be mapped in the full brain white matter.

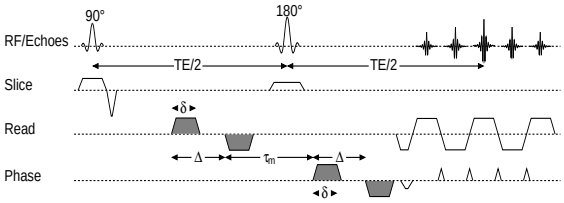

Fig. 1 Basic pulse sequence used in the present study.

Methods

Experiments were performed on a 3T whole-body MR system (Siemens Magnetom Trio) with a 32-channel head coil. Healthy volunteers were investigated after their informed consent was obtained. Measurements were performed with echo-planar imaging (Fig. 1) using an isotropic resolution of 3.0 mm (TE/TR = 155 ms/6 s) and covering 35 slices. The two diffusion-weighting periods were applied with a *b* value of 500 s mm^{-2} each, a diffusion time Δ of 31 ms, a mixing time τ_m of 48 ms and a gradient duration δ of 28 ms. For the derivation of the anisotropy measures I_{MA} and the normalized MA [5], two different direction combination schemes of the first and second wave vector were considered: the minimal schema consisting of 15 directions as proposed in [5] and an extended set to which antipodal combinations, spatially-rotated orthogonal combinations, and antiparallel combinations were added yielding 84 wave vector combinations in total. These additional direction combinations aimed to minimize the disturbing effects of, e.g., background gradients and eddy currents. The mean MR signal of about 400 voxels in the centrum semiovale was considered for a histogram analysis. To investigate the influence of the absolute wave vector orientations, in particular on the measures I_{MA} and MA, the 84 direction combinations were applied with all gradients rotated by the same absolute angle. Standard DTI experiments were performed for comparison by applying both diffusion weightings parallel in 60 directions (icosahedron). FA maps were calculated with the scanner software provided by the manufacturer.

Results and Discussion

Figure 2 demonstrates that the microscopic diffusion anisotropy measure I_{MA} in white matter of the living human brain can be observed with both – the minimal and the extended - schemas (Figs. 2a: 15 directions and 2b: 84 directions, respectively). But with less directions involved, the I_{MA} map shows a smaller signal-to-noise-ratio (SNR). Fig. 3 demonstrates the rotational invariance of the I_{MA} measure acquired with 84 wave vector combinations: Only minor deviations can be observed comparing the I_{MA} maps of the two acquisitions (a, b). In particular, the voxel-by-voxel comparison (I_{MA} difference map, c) shows only very few voxels with larger deviations possibly in gray matter voxels as observable in the image without diffusion weighting (d). In addition, the MA map in a representative slice of a healthy volunteer (Fig. 4) shows a more coherent appearance than the FA map which is consistent with the expected benefit of the method to be less confounded in voxels with different fiber orientations present. A map of the I_{MA} measure in ten slices demonstrates the whole brain applicability of the method (Fig. 5). Thus, DWV experiments may provide a reliable access to the diffusion anisotropy measures on the microscopic level and could be used to characterize white matter or neuronal integrity for whole-brain imaging also on clinical scanners.

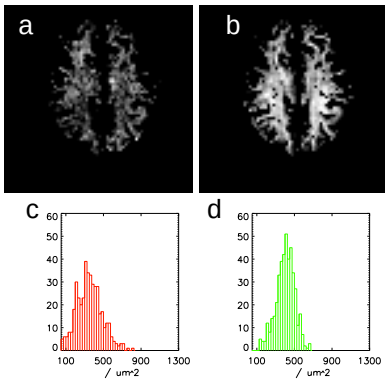

Fig. 2 I_{MA} measure detected with (a) 15 (three averages) and (b) 84 (one average) directional combinations and corresponding histograms (c) and (d), respectively for the ROI voxels (see Fig. 4b).

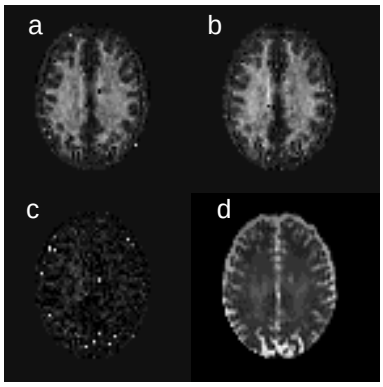

Fig 3. Rotational invariance of the I_{MA} acquisition schema: High similarity of the I_{MA} maps (a) and (b) in the centrum semiovale can be observed. The difference image (c) reveals only minor deviations in very few (possibly grey matter) voxels (compare image without diffusion weighting (d)).

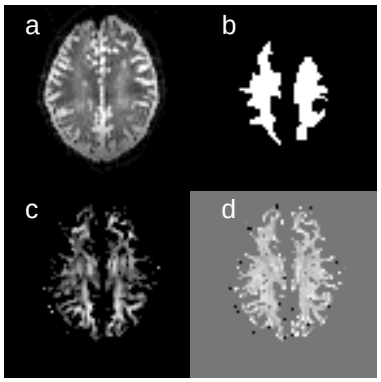

Fig. 4 (a) Image without diffusion weighting, (b) region-of-interest mask (as used for the histogram analysis, see Fig. 2). (c) The corresponding fractional anisotropy map (FA) shows less coherence than (d) the map for the microscopic anisotropy measure (MA) for the same slice of a young healthy volunteer.

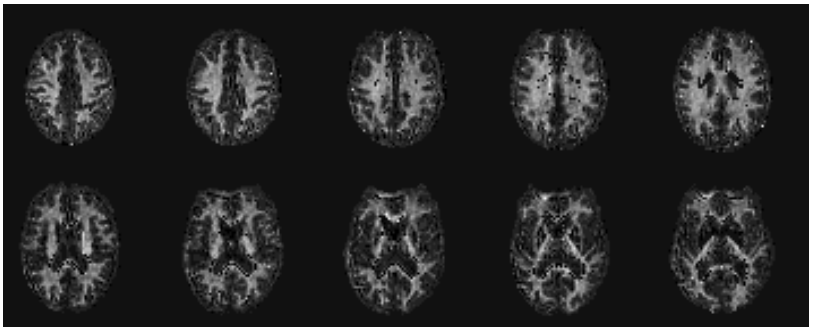

Fig. 5 Map of the IMA measure in ten slices of a healthy young volunteer.

References

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