Trace weighting in double wave vector diffusion experiments in vivo

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INTRODUCTION

Double wave vector (DWV) diffusion weighting [1] is anticipated to represent a new method for assessing the microscopic tissue structure [2, 3]. In particular, the difference between parallel and anti-parallel orientations of the gradients in two successive diffusion weighting preparations may be used to estimate the mean size of tissue pores with a uniform distribution of pore orientations. Theoretical investigations for infinitely sharp gradient pulses predict for a sample with an arbitrary orientation distribution that a rotation-invariant size estimate can be derived from the sum of (parallel and anti-parallel) measurements along three perpendicular orientations [4]. It is investigated whether the rotational invariance of this measure is observed in in vivo experiments on brain tissue using a whole body MR system with finite gradient pulse durations.

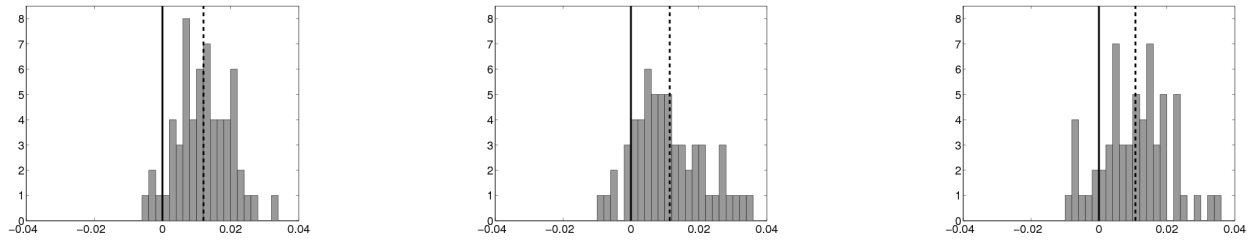
METHODS

The DWV-weighted signal from water in randomly oriented pores should depend on the angle θ subtended by the two diffusion gradients as $S(q,\theta) \propto 1 - \langle R^2 \rangle (q^2/3)(2+\cos\theta)$, if $q = \gamma\delta G$ is small and if the time lag τ_m between the onsets of the second and the third gradient pulse is negligible [1]. It is also assumed that $\delta << \tau_D << \Delta$ holds, with τ_D being the mean time required for diffusion across a pore. The "mean squared radius of gyration" $\langle R^2 \rangle$ increases with pore size. For complete restriction, the diffusion-induced signal loss should vary by a factor of 3 between parallel and anti-parallel gradient orientations.

DWV measurements were performed at 3 T magnetic field strength on a whole-body MR system (Magnetom Trio, Siemens, Erlangen, Germany). Axial slice images of the brain of a healthy volunteer were acquired, using spin-echo echo planar imaging with a multiple spin-echo diffusion preparation. One experiment (A) was performed with diffusion gradients along 60 directions distributed over a sphere (30 non-collinear directions), and two experiments with gradients along two different sets of three orthogonal directions (B: permutations of $(x, y, z)=(2/3, 2/3, -1/3)$, C: same with inverted y components). By using a different number of repetitions in the experiments A, B, and C (2, 35, 35 repetitions, respectively), the total acquisition time was adjusted to approx. 22 min in each experiment. The images were averaged over repetitions and gradient directions, separately for the parallel and anti-parallel cases. The signal difference between anti-parallel and parallel gradient orientations divided by the signal without diffusion weighting was determined in a region of interest in the upper right corticospinal tract. (25 slices, 3×3×3 mm^3 nominal resolution, gradient pulse duration δ = 10 ms, separation of de- and rephasing gradient pulses Δ = 75 ms, $\tau_m = \delta + 0.54$ ms, $q = 96.5 \cdot 10^3$ m^{-1}, TE = 186 ms, 6/8 partial Fourier acquisition, raw data filter applied to reduce ringing artefacts.)

RESULTS

Figure 1 shows the histograms for the evaluated region of interest. The mean value is positive in all three experiments, consistent with both theory and previous results using gradients perpendicular to the main fibre direction [5]. It corresponds to a nominal value of $(\langle R^2 \rangle)^{1/2} \approx 1.4$ μm. The mean values in the different direction schemes coincide reasonably well. These results suggest that with the given choice of experimental parameters the average of three orthogonal directions is rotationally invariant. Deviations might be due to the finite gradient pulse duration which leads to a violation of the conditions τ_m, $\delta << \tau_D$. They can also be related to the fact that some pores are not closed as assumed in the theoretical work, leading to violation of $\tau_D << \Delta$ along the fibre direction, e.g. It remains to be investigated how the results depend on experimental parameters.

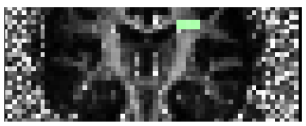


A: 60 directions
mean: 0.0120

B: 3 orthog. directions (1)
mean: 0.0114

C: 3 orthogonal directions (2)
mean: 0.0107

Fig. 1: Histograms of signal difference between anti-parallel and parallel gradient orientations, $(S(q,\pi)-S(q,0))/S_0$, in a region of interest in the upper corticospinal tract, averaged over measurements along a number of gradient directions. The average over the region of interest is shown by a dashed line. To the right: region of interest overlaid on a coronal view of the fractional anisotropy map calculated from all measurements in experiment A.



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