The dependency of the MR indices, observed by high b-value q-space diffusion MRS on fiber's orientation

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Introduction

Diffusion tensor imaging (DTI) exploits the observed anisotropy of water diffusion to tract fiber orientation by assuming that the fast-diffusing component coincides with the fiber's orientation.[1] Although conventional DTI is based on a single component analysis, it is well known that at sufficiently high diffusion weighting (high b- or high q-values), more than one diffusing component can be detected in neuronal tissues.[2,3] In addition, q-space analysis of NMR diffusion experiments performed on microtubes,[4] showed high sensitivity of the diffraction patterns and of the displacement distribution profiles obtained thereof, to the rotational angle, α (Figure 1). The present study examines the effect of α on the apparent diffusion coefficient (ADC), extracted from low b-values (b_{max}≈1200s/mm^2), and on the root mean square (rms) displacement of the fast and the slow-diffusing components extracted from high b-value q-space diffusion MR data in nerve tissues. In addition, the effect of both the diffusion time and myelination was evaluated.

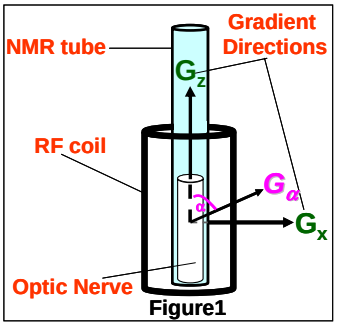

Figure1

Methods

Experiments were performed on formalin-fixed optic nerves of mature and newborn pigs (N=3 in each group). Each nerve was placed in an NMR tube so that its fibers direction was parallel to the z-direction (Figure 1). NMR diffusion measurements were acquired using an 8.4T NMR spectrometer (Bruker, Germany) equipped with a micro5 gradient probe capable of producing pulse gradients of up to 190Gcm^{-1} in each of the three dimensions. NMR diffusion experiments were conducted using the stimulated-echo diffusion sequence with the following parameters: TR/TE/δ=2500/12.3/2ms. Pulsed gradient strength (g) was incremented from 0 to 160Gcm^{-1} in 32 steps resulting in q_{max} of 1362cm^{-1}. The gradient pulses separation, Δ, was 7 or 100ms for each rotational angle. Diffusion was measured for the following rotational angles (αs): -10°, -5°, 0° (z-direction), 5°, 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80°, 85°, 90° (x-direction), 95°, 100°, 180° and 270°. Displacement probability profiles were obtained by performing a Fourier transformation on the signal decay with respect to **q** and then fitted with bi-Gaussian functions. From these profiles we extracted the rms displacement of each diffusion component in the investigated nerves as a function of the rotation angle α. The ADC values were extracted from each data set by linear fitting of the ln (I/I_0) curve as a function of the b-values. In this case, only 3 points were used with b_{max} of about 1200s/mm^2.

Results

Figure 2 shows the dependence of the rms displacement and ADC values, extracted from the NMR diffusion experiment, on the rotational angle α. Figures 2A and 2B depict the changes in the rms displacements of the slow- and fast-diffusing components, respectively, of mature optic nerves obtained from the q-space analysis of the diffusion NMR data while Figure 2C shows the dependence of the ADC values on the rotational angle α, which shows similar behavior to that depicted in Figure 2B. Interestingly, the behavior of the slow-diffusing component (Figure 2A) is different. There the rms displacement values were found to remain nearly constant for α in the range of -10° to +80° but to change drastically when diffusion was measured nearly perpendicular to the long axis of the fibers i.e., when α=90°±10°. In contrast, Figures 2B and 2C show that the rms displacement of the fast-diffusing component and the bulk ADC values change gradually with the change in α. Here the two indices do not change significantly when α is changed in the range of 90°±10°, i.e., when the diffusion is measured perpendicular to the main axis of the fibers.

Figure 2D presents the percentage changes in the extracted bulk ADC and in the rms displacement of the slow- and the fast-diffusing components, in purpose to quantify the sensitivity of different NMR diffusion indices to the rotational angle. Note that the percentage changes for 0°±5° and 0°±10° are relative to the values obtained for α=0° while the percentage changes for the 90°±5° and 90°±10° ranges are relative to the values of α=90°. From this figure, one can conclude that the most sensitive index for the fiber orientation near α=90° is the rms displacement of the slow-diffusing component extracted from the q-space diffusion NMR experiments. We also examined the effect of the diffusion time on the observed results and found the same pattern of behavior when Δ was set to 7ms (data not shown).

The same set of NMR experiments performed on newborn optic nerves and there, again, same trend was observed (data not shown) but the differences were less pronounced. It should be noted that the main difference between mature and newborn optic nerves is the lack of myelin in the latter (confirmed by histology).

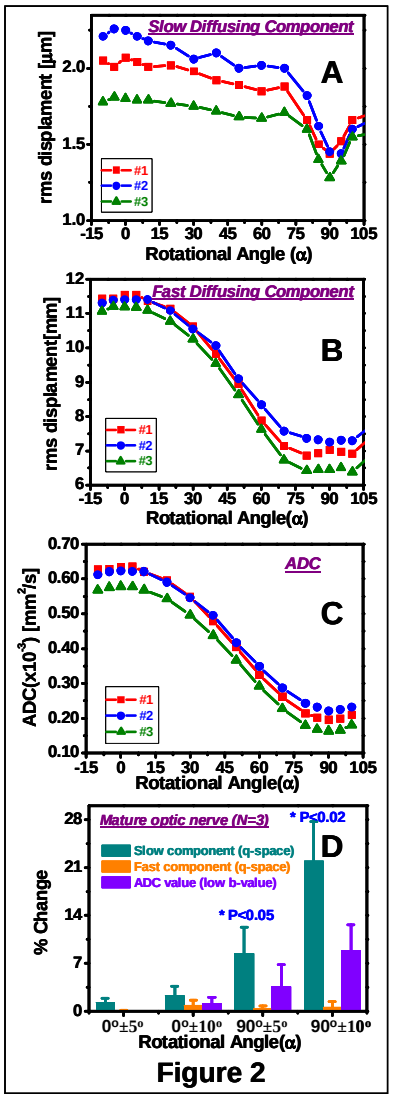

Figure 2

Conclusion

This study demonstrates that from all three indices investigated, the rms displacement of the slow-diffusing component extracted from q-space diffusion NMR, exhibits the most significant dependence on the rotational angle, α. This phenomenon was found for both mature (myelinated) and newborn (poorly myelinated) fixed optic nerves and for short (Δ=7ms) and long (Δ=100ms) diffusion times. Our findings imply that out of the studied indices the rms displacement of the slow-diffusing component, as extracted from q-space diffusion NMR, is the best predictor for restriction and fiber orientation and may have implications concerning determination of fiber orientation using diffusion NMR methodologies.

References

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