Structural information of different nerve types from high b-value q-space diffusion MRS

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Synopsis

High b-value q-space diffusion MR were claimed to provide structural information under certain experimental conditions. Here, we use this methodology to examine the mean displacement in optic and sciatic nerves as a function of the diffusion time. The mean displacements of the sciatic nerves (both components) were found to be significantly larger than in the optic nerves. The slow diffusing component of the optic nerves was found to be the most restricted one. The extracted sizes were found to be comparable with those observed by microscope images suggesting that high-b value q-space diffusion MR can be regarded as "virtual histology".

Introduction

q-space diffusion NMR[1] was extended to imaging and used in recent years to obtain structural information in neuronal tissues.[2] For spins exhibiting restricted diffusion, diffraction patterns should be observed. However, clear diffractions were not previously observed in neuronal tissues and structural information was extracted from the displacement distribution profiles obtained by FT of the signal decay with respect to **q**. Recently, it was demonstrated that the two approaches give similar structural information using an ensemble of microtubes.[3] However, it is known that adequate structural information can be obtained only under certain experimental conditions.[3] In the present study we examined the structural information that can be extracted from high b-value q-space diffusion experiments on two different neuronal tissues of the same animal, i.e. the optic and sciatic nerves. We also tested the influence of the diffusion times (Δ-δ/3) on the extracted sizes for the two nerves and compared the results with light microscopy images of these nerves.

Methods

Experiments were performed on 4% formaldehyde fixed pig optic and sciatic nerves (N=4 in each group). Each nerve was placed in an NMR tube so that its fibers direction paralleling the gradient (z-direction). NMR diffusion experiments were acquired using an 8.4T NMR spectrometer (Bruker, Germany) equipped with a micro5 gradient probe capable of producing pulse gradients of up to 190 gauss/cm in each of the three dimensions. NMR diffusion experiments were conducted when the diffusion gradients were perpendicular to the fiber orientation of the nerve (x-direction) using the stimulated echo sequence with the following parameters: TR/TE/δ=3000ms/50ms/2ms. Pulsed gradient strength (g) was incremented from 0.5 to 160 Gcm^{-1} in 24 steps. The diffusion time was incremented from 4.35ms to 9.35ms in 1ms steps and then to 15ms, 30ms, 50ms and 100ms. A series of such experiments with δ=4ms were also performed but here the minimal diffusion time was 6.35ms. The displacement probability profiles that were obtained by performing a Fourier transformation on the signal decay with respect to **q** were fitted by bi-gaussiann functions.[2] From these profiles we extracted the compartment size of the investigated nerves by calculating the root mean square (rms) displacement from the full-width at half height of the displacement distribution profiles.

Results

Figure 1A shows the experimental water signal decay with respect to **q** at a diffusion time of 100ms for the optic and sciatic nerves. Figure 1B shows the displacement distribution profiles obtained by a Fourier transformation of the data shown in Figure 1A. Figures 1C and 1D depict the changes in the rms displacement as a function of the square root of the diffusion times for the slow and fast diffusing components, respectively. These results show the ability of this methodology to distinguish between the two different nerve types and reveal that the mean displacements are smaller in the optic nerves than the sciatic nerves. This is true for all diffusion times used for both the fast and the slow diffusing components. It was found that the mean displacement of the slow diffusing component of the optic nerves increase only slightly with an increase in the diffusion time. For diffusion times longer than 10ms, the mean displacement of this component is nearly constant. All other components seem to exhibit less dramatic restriction and their mean displacements increase with the increase in diffusion time. However, it should be noted that this increase in the mean displacement is much less than that expected from the Einstein equation. We found the mean displacement of the slow diffusing component of the optic and sciatic nerves to be 1.39μm and 2.17μm respectively at Δ=100ms. Indeed, light microscopy images of optic (Fig 2A) and sciatic (Fig 2B) nerves, after myelin staining, show that the sciatic nerve has bigger axons than the optic nerve. Interestingly, a clear change in the slope of the dependency of the mean displacement as a function of the diffusion time is observed only for the slow diffusing component of the optic nerve. From the bi-gaussian fits of the data shown in Figure 1B we determined the relative fraction of the fast and slow restricted components of the nerves. For example, at a diffusion time of 100ms we found the population of the fast diffusion component to be 64% for optic nerves and 73% for sciatic nerves. Figure 2A shows that, indeed, the optic nerve is denser than the sciatic nerve (Fig 2B). When the same set of experiments were performed with a longer δ of 4ms (data not shown), smallest rms values were extracted as expected for restricted diffusion indicating that more accurate structural information is to be expected when the pulsed gradient duration (δ) is smaller. This is especially true when compartments of a few microns are sampled.

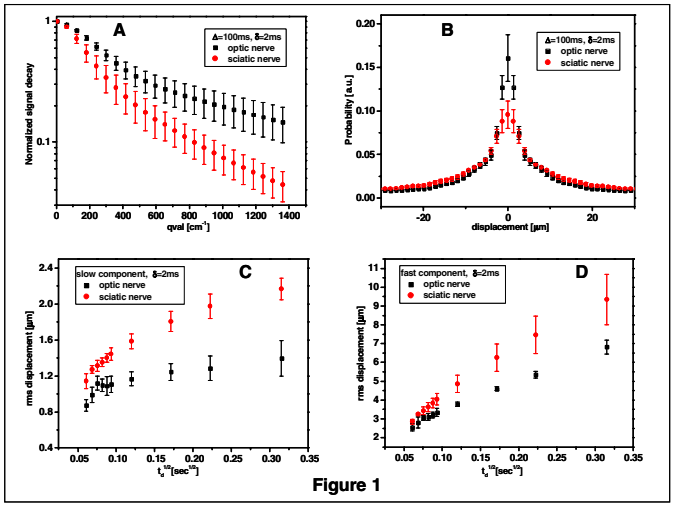

Figure 1

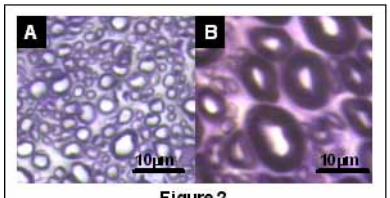

Figure 2

Discussion

This study demonstrates the ability of high b value q-space diffusion MR analysis to distinguish between the two different nerves. At high diffusion weighting, the differences in the diffusion characteristics are more pronounced. This study also demonstrates that accurate structural information for the different nerves can be obtained from such data. The extracted sizes are comparable with those obtained from light microscopy images demonstrating that this methodology provides structural information that can be regarded as "virtual histology".

References

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