Probing restricted microcompartments with double PGSE

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Introduction

Most diffusion MR applications, including the more recent q-space diffusion MR (1-3) have used a single pair of diffusion sensitizing gradient pulses and can therefore be classified as single pulsed field gradients (s-PFG) experiments. In 2002, a double PFG (d-PFG or d-q-space, *Fig. 1*) has been shown to provide a means of probing local anisotropy in lyotropic liquid crystals (4). More recently, the d-PFG experiment was used to probe anisotropy in gray matter phantoms (5). Therefore, we decided to systematically study the water signal decay in d-PFG experiments in restricted compartments of micron dimensions.

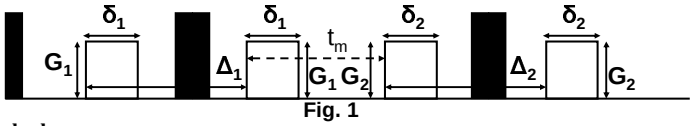

Fig. 1

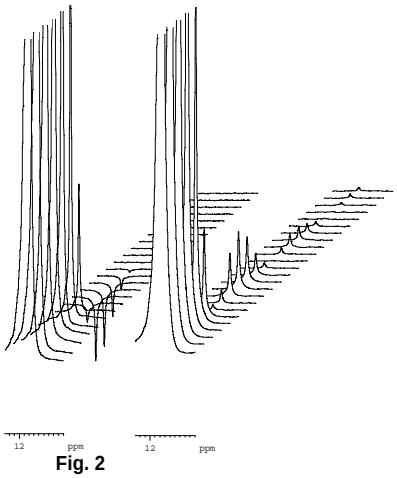

Fig. 2

Materials and Methods

Cylinders (20μm in diameter) were immersed in water for a period of several days prior to the experiments. The cylinders were packed into a 4mm glass sleeve and the sleeve was inserted into a 5mm NMR tube, aligned with the main axis parallel to the Z direction. All measurements were preformed on a Bruker 8.4T NMR with a micro5 imaging probe capable of producing pulsed gradients of 190G/cm in each direction. An in-house d-PGSE sequence was used with the following parameters: $\Delta_1 = \Delta_2$ = 5.5 to 100ms, (unless otherwise stated) in collinear (d-PGSE$_{xx}$) or orthogonal (d-PGSE$_{xz}$ or d-PGSE$_{ZX}$) directions, 24 or 32 points with G_{max}=120G/cm or 180G/cm resulting in q_{maz} of 1021 or 1532cm^{-1}, respectively. The mixing time (t_m) was varied between 5 and 50ms. For comparison an s-PGSE (Δ/δ=100/4ms) along the x-direction was collected (s-PGSE$_x$). The attenuation curves were magnitude calculated to overcome the negative diffractions. The data was then Fourier transformed, fitted to a Gaussian function and the full width at half height (FWHH) was used to extract the rms displacement (rmsd).

Results

Fig. 2 shows the comparison of the signal decay of the d-PGSE$_{xx}$ (left) with the s-PGSE$_x$ sequences (right). Clear diffractions are observed in both spectra at similar q values, from which compartment sizes of 17.9μm (d-PGSE$_{xx}$) and 22μm (s-PGSE$_x$) were extracted. The difference in sizes is probably due to the lengthening of the effective δ caused by the mixing period (5ms). This surprising negative diffraction was predicted by a very recent simulation (6) and is, to the best of our knowledge, shown here experimentally for the first time.

We tested the effect of applying orthogonal gradients with different diffusion times and different mixing times (*Fig. 3*). We first performed a d-PGSE$_{ZX}$ experiments with Δ_{1z}=5.5, 15 and 75ms (black, red and blue respectively) and Δ_{2x}=100ms with mixing times of 5 and 50ms. We then reversed the directions and performed the d-PGSE$_{xz}$ experiment with Δ_{1x}=100ms and Δ_{2z}=5.5, 15ms and 75ms. The results were identical for d-PGSE$_{zx}$ and d-PGSE$_{xz}$ in both mixing times (only data from the first experiment are shown). The results show an increase in the rmsd extracted from the FWHH that does not depend on the mixing time, this in contrast with the collinear directions. A plausible explanation for these findings is that the effective δ does not change because the Z direction does not contribute any restricting effect. *Fig 4* depicts the effect of lengthening the diffusion times in a collinear direction perpendicular to the main axis of the cylinders (d-PGSE$_{xx}$: $\Delta_{1x} = \Delta_{1x}$=10, 25, 50 and 100ms black, red, green and blue respectively) with a mixing time of 5ms. The compartment sizes that were extracted from the FWHH were 10.4, 15.1, 17.8 and 17.9μm respectively. This shows that varying Δs while keeping the mixing time constant (5ms) yielded results that are similar to the SE sequence in the way that an increase in diffusion time allows the boundaries to be explored and the diffractions to be observed.

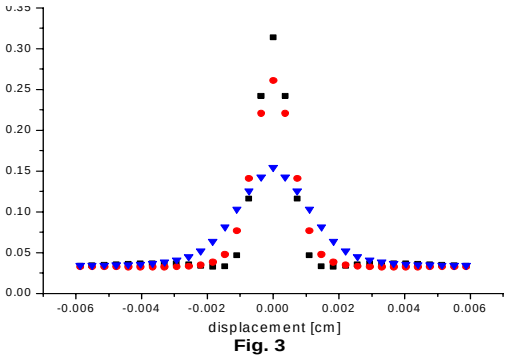

Fig. 3

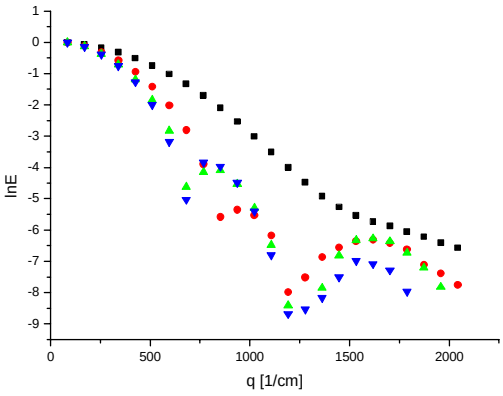

Fig. 4

Conclusions

We have explored the effect of changing different parameters on the signal decay and the information that can be obtained when d-PGSE experiments are preformed in restricted geometries. We showed that a negative diffraction is observed as predicted in the simulations and that the experiments carry information about the compartments in which diffusion occurs. Future work on this project will focus on neuronal tissue and the discrimination of gray matter and white matter, or small locally anisotropic lesions. Future studies will show whether the d-PGSE sequence can be manipulated to probe more difficult geometries, and perhaps provide a means of bypassing some of the difficulties of s-PGSE sequences.

References

[1] Cohen Y., Assaf Y., *NMR in Biomed.* **15**: 516-542 (2002). [2] Chin CL. et al., *MRM* **52**: 733-740 (2004). [3] Avram L. et al., *JMR* 169: 30-38 (2004). [4] Callaghan PT., Komlosh ME., *MRChem* **40**: S15-S19 (2002). [5] Komlosh ME. et al., *JMR* **189**:38–45 (2007), [6] Ozarslan E., Basser PJ., *JMR*, **188**: 285–294 (2007).