

Observation of microscopic diffusion anisotropy in the spinal cord using double-pulsed gradient spin echo MRI

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Introduction: Multiple scattering NMR sequences¹⁻⁴ can be used to detect local anisotropy in macroscopically isotropic, microscopically anisotropic materials. These techniques rely on the principle that the echo attenuation resulting from a series of sequential Pulse Gradient Spin Echo (PGSE) blocks will depend on the combination of gradient directions of those blocks if local anisotropy is present. For example, for a double PGSE (d-PGSE) sequence, the echo attenuation resulting from two sequential PGSE blocks with the same gradient direction (collinear) will differ from the echo attenuation resulting from two PGSE blocks with orthogonal gradient directions (orthogonal). However, since all the above techniques lack spatial encoding, only homogeneous media can be investigated. To examine heterogeneous media, like CNS tissue, multiple scattering MRI is required. In this study d-PGSE NMR sequences were conjoined to an MRI block to map the local anisotropy of a “gray matter” phantom and fixed porcine spinal cord specimen. We call this *d-PGSE filtered MRI*.

Material and Methods: The “gray matter” phantom consists of 0.5mm long fused silica tubes (ID=20 μ m; OD=90 μ m) filled with water and randomly immerse in deuterated dichlorobenzene. A fixed porcine spinal cord was rehydrated and then immersed in Fomblin. d-PGSE filtered MRI experiments were performed on a 7T vertical bore AVANCE system using nine combinations of *x, y, z* gradient direction combinations on the “gray matter” phantom ($\delta=3$ ms, $\Delta=40$ ms, mixing time (τ_m)=35ms, *G* varied between 0 and 241 mT·m⁻¹) and using five gradient direction combinations on the porcine spine ($\delta=3$ ms, $\Delta=15$ ms, $\tau_m=75$ ms, *G*=0, 340 mT·m⁻¹). Three ROIs were taken from the “gray matter” phantom (fig. 1a), to examine its heterogeneity, one covering most of the image and the other two taken from within the image. Six ROIs were taken from the spine (fig. 2a).

Results and Discussion: ROI-1 (fig. 1b) covering most of the “gray matter” phantom, exhibits the echo attenuations as d-PGSE spectroscopy, indicating that the addition of an imaging block has a minimal effect on the resulting signal. All collinear echo attenuations coalesce in ROI-2 (fig. 2c), which indicates a completely random distribution of tubes. There is additional restriction along the *z*-direction in ROI-3 (fig. 2d), which suggests non-uniform tube orientations with preferential alignment within the *x-y* plane. Nevertheless, the difference in the resulting collinear and orthogonal echo attenuation curves in all ROIs in the “gray matter” phantom indicates local anisotropy of the water inside the tubes. Macroscopic anisotropy is observed for both white and gray matter in the spine (fig. 2b), however, anisotropy is greater for the white matter. Additional microscopic anisotropy can be observed from the difference in the echo attenuation profiles between the collinear and orthogonal gradient combinations in the *x-y* plane. This microscopic anisotropy is generally not apparent using conventional DWI techniques, such as DTI. In order to gain a sufficient spatial resolution while keeping the experiment time short, only one *b*-values greater than zero could be used in this study.

Conclusion: Joining the d-PGSE filter with a fast MRI method produces a way to image of a novel contrast mechanism. The observation of microscopic anisotropy in spinal cord in a range of *b*-values achievable in clinical scanners suggests the suitability of this method for biological and clinical applications.

Reference: 1. P. T. Callaghan, *et al. Magn. Reson. Chem.* **40**, S15 (2002) 2. Y. Cheng, *et al. J. am. Chem. Soc.* **121**, 7935 (1999) 3. M. E. Komlosh, *et al. J. Magn. Res.* **189**, 38 (2007) 4. P. T. Callaghan, *et al. J. Chem. Phys.* **120**, 4032 (2004)

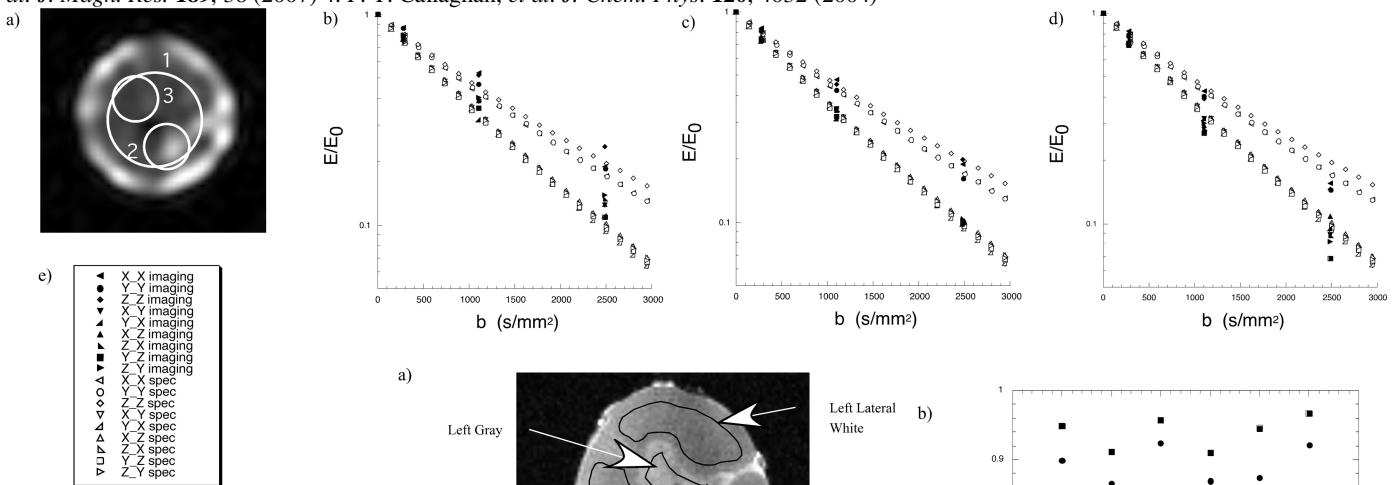


Figure 1: a) d-PGSE image with the corresponding ROIs. b-d) d-PGSE filtered MRI echo attenuations vs. *b*-value in the “gray matter” phantom using MRI (filled symbols) and NMR spectroscopy (open symbols) b) ROI-1 c) ROI-2 d) ROI-3 e) Legend.

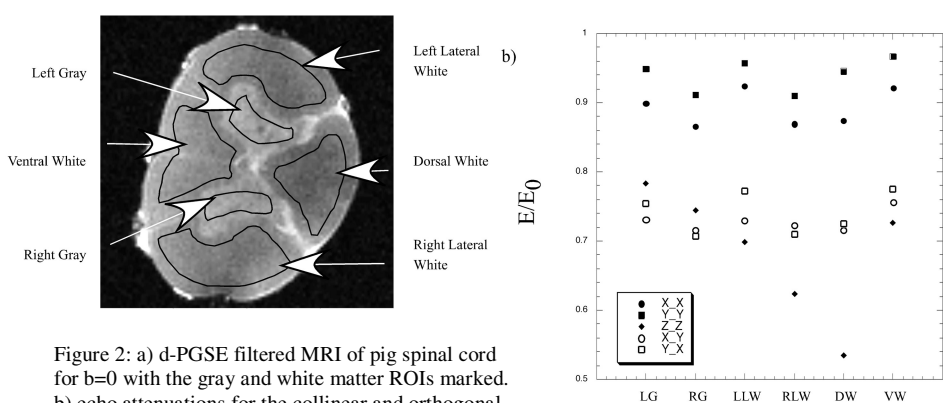


Figure 2: a) d-PGSE filtered MRI of pig spinal cord for $b=0$ with the gray and white matter ROIs marked. b) echo attenuations for the collinear and orthogonal direction using pixels from the marked ROIs.