

Composite inversion recovery DTI model can separate sub voxel components

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Introduction:

Diffusion tensor imaging (DTI) is the most common diffusion based method used to investigate brain white matter and structural connectivity and. Nevertheless, the ability of DTI¹ to provide an adequate description and characterization of tissue micro-structure is limited due to the inability of this model to cope with partial volume effects. Those may occur at the boundaries of white matter with surrounding tissue or even within the white matter where several fiber-bundles pass through the same voxel. While tissue components within a voxel may not differ enough in their diffusion properties to allow DTI, or other advanced methods to differentiate between them, they may differ in other physical parameters. Particularly in white matter, the amount of myelin might be the basis for separating different axonal populations. For example, it is known that small and large diameter axons have different amount of myelin lamellas. As a consequence, different fibers that pass through the same voxel might have different myelin contents. The most sensitive MRI parameter to myelination is T₁. Thus, in this work we set to explore whether a composite inversion recovery diffusion tensor imaging acquisition and analysis will allow more robust separation of sub-voxel fiber populations.

Methods:

This work was done on a phantom consisting of a fixated porcine optic and sciatic nerves. These two nerves are different in their axonal properties including axon diameter distribution and myelin content. The two nerves were placed perpendicularly one above the other immersed in a proton free fluid (Fluorinert FC-77). The experiments were performed on a 7T Bruker Biospec. The imaging experiments were based on inversion-recovery spin-echo diffusion weighted echo planar imaging (IRSE-DW-EPI) scan. An adiabatic 180° inversion pulse was applied prior to the standard DTI scan protocol at different inversion time (TI) resulting in multiple DTI acquisitions. The DTI scans were acquired with similar experimental properties: TR/TE= 4000 / 23 ms, 4 shot EPI, Δ of 20 ms, δ of 3.2 ms, at 6 b-values (linearly increment of gradient strength from 5G/cm to 30G/cm) in 16 non-collinear directions at 2 different TIs of 175 and 900ms. All scans were acquired with similar geometric properties: matrix of 96x128 with isotropic in plane resolution of 0.200mm² and slice thickness of 10mm that includes both porcine nerves. Each scan lasted about 1.5 hours for 4 averages. MRI experiments were acquired with relatively long TR of 4s (< 5 times of the nerves T₁), as the nerves relaxation property is shorten (~200-400ms) due to the fixation procedure with 4% formalin.

Analysis:

DTI model¹ was extended to analyze simultaneously multiple DTI data sets at different TI. The signal of each image voxel is attenuated according to its diffusion and T₁ properties and modeled by incorporating the exponential decay function of the recovery of the longitudinal magnetization by spin-lattice relaxation to the diffusion tensor equation. Since the phantom includes a crossing fiber region, each voxel was characterize by two diffusion tensors.

Results & Discussion:

Multiple IR-DTI dataset was acquired with varied TIs to examine the extent of signal attenuations according to the tissue diffusivity and T₁ properties. However, the analysis was demonstrated of 2 TIs, 175 and 900 ms due their higher SNR. Figure 1 shows diffusion weighted images (at b of 310s/mm²) of representative direction at different TIs between 175-900ms, to emphasis the distinct T₁ properties of each of the examined nerves. Note that at TI of 300ms, the optic nerve is almost entirely eliminated, while the sciatic preserved, where the opposite occurs at TI of 400ms. The multiple IR-DTI analysis was done on the crossing region of the two nerves. Figure 2A demonstrates the bi tensor analysis diffusion at the crossing region. However, when analyzing both diffusion and T₁ data the two nerves fibers were separated based on their different T₁ (Figure 2B). The T₁ of the optic nerve was 292ms while the sciatic nerve was 200ms. By incorporating the two properties, longitudinal relaxation and diffusivity, more accurate definition of tissue classifications could be achieved. IR-DTI framework presented in this work shows that integrating different tissue characteristics allow more accurate definition of tissue compartments. IR-DTI framework is applicable, and requires only two DTI scans with different TIs which will provide means to differentiate between different sub-voxel diffusion components.

References: (1) Basser PJ *et.al.* MR diffusion tensor spectroscopy and imaging. *Biophys J* 1994. (2) Barbier EL, *et.al.* Imaging cortical anatomy by high-resolution MR at 3.0T: detection of the stripe of Gennari in visual area 17. *Magn Reson Med.* 2002. (3) Clark VP, *et.al.* In vivo myeloarchitectonic analysis of human striate and extrastriate cortex using magnetic resonance imaging. *Cereb. Cortex* 1992. (4) Barazany et al., Visualization of Cortical Lamination Patterns with Magnetic Resonance Imaging, *cereb. cortex.* 2011.

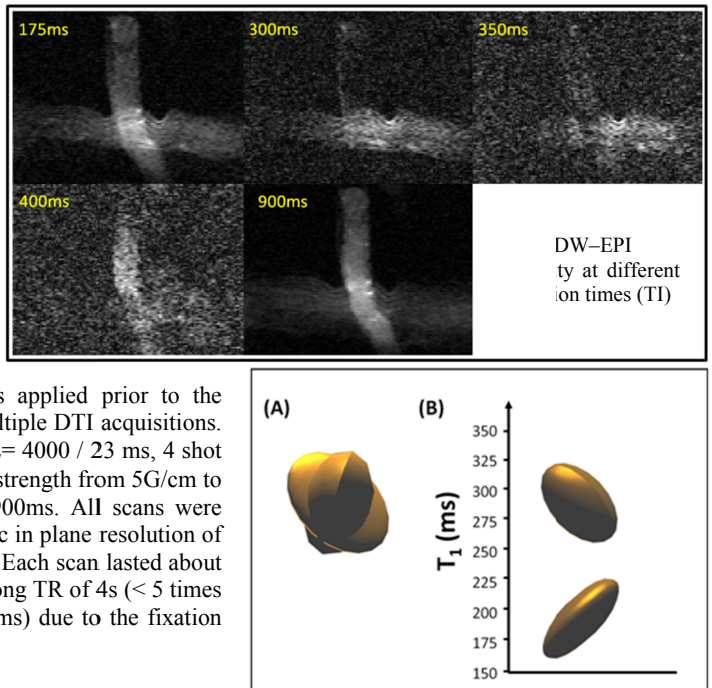


Fig 2: Multiple IR-DTI analysis can distinguish between the two nerves at their crossing region by combining their longitudinal and diffusion properties. (A) demonstrates the bi-tensor fit (B) results of the composite T₁-DTI analysis separating the two tensor based on their T₁ properties.