

In-vivo brain viscoelastic anisotropic properties using DTI and MR-Elastography

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Introduction: Pathological changes as a result of brain disease or injury can lead to changes in the anisotropic nature of the brain tissue. Diffusion tensor imaging (DTI) is used to probe the diffusive properties of brain tissue and it has been shown that loss of tissue structure in diseases such as white matter atrophy [1] and Alzheimer's [2] leads to a reduction of fractional diffusion anisotropy. Changes in anisotropy of brain tissue viscoelasticity may also be occurring at early onset or during these diseases. The purpose of this study was to investigate the feasibility of measuring the anisotropy of the viscoelastic parameters of the human brain using a combination of DTI and Magnetic Resonance Elastography (MRE).

Methods: A 1.5T full-body MRI scanner acquires high resolution T2, MRE and DTI (16 gradient directions) images in a co-registered manner. A transducer consisting of two coaxial coils is driven by a signal generator, mounted onto a standard head-coil and triggered by the MR spectrometer (Philips Medical Systems). The vibrations are transmitted to the brain using a bite-bar and mouthguard for coupling. An excitation of 80Hz was used to optimise wave penetration while maintaining attenuation at a reasonable level. An optimised motion-sensitized, spin-echo sequence, including double motion encoding gradients is phase-locked to the mechanical excitation to image 3D steady-state displacement fields. A full 3D reconstruction of the viscoelastic parameters (complex-valued shear modulus) was applied with optimised filtering and application of the curl operator [3] to remove longitudinal wave contributions. Using the eigenvector associated with the largest eigenvalue (measured via DTI) as the local fibre axis, we solve the complex-valued, transversely isotropic, inverse elasticity wave equation. With the fibre direction given via DTI, the inverse problem becomes linear and more stable since 2 (the Euler angles) of the 6 unknown parameters are predetermined. Shear moduli describing the propagation of the wave perpendicular ($\mu \perp$) and parallel ($\mu \parallel$) to the fibre direction are thus calculated [4]. These two values are used to give a measure of the shear modulus fractional anisotropy (FA). In a similar manner, fractional anisotropy for shear viscosity is also calculated and a total fractional anisotropy quantity is given as an average of both of these quantities.

Results: Coronal plane images were acquired beginning with a high resolution T2-weighted slice image as shown in Fig 1a. The cerebrum and cerebellum are clearly visible and the associated DTI image showing regions of high fractional anisotropy in yellow and red is displayed in Fig 1b. Eigenvectors from this image are used to measure shear modulus perpendicular ($\mu \perp$) and parallel ($\mu \parallel$) (Fig 1c, d) and then used to get a measure of shear modulus fractional anisotropy (Fig 1e). Similar to the fractional anisotropy measured via DTI we observe that white matter is mechanically more anisotropic than grey matter. Also the region of the corpus callosum appears anisotropic. Thus, there are many similarities between mechanical and diffusive FA in terms of structure and also differences in terms of strength. Grey and white matter in the cerebrum have total fractional anisotropy values (Fig 1f) of 0.40 and 0.48 respectively and were statistically significant ($P = 0.0002$). Average values across all test subjects for grey and white matter in the cerebellum were 0.41 and 0.44 respectively.

Discussion: This study presents the first set of viscoelastic anisotropy measurements using DTI information for the cerebrum and cerebellum for healthy subjects. The measurements indicate a significantly higher level of fractional anisotropy in white matter than grey matter in the cerebrum. Grey and white matter values in the cerebellum are of similar value with no significant differences. The results show the incorporation of DTI measurements with MR-Elastography calculations is feasible and could be used to investigate viscoelastic atrophy in brain disease and aging processes.

References

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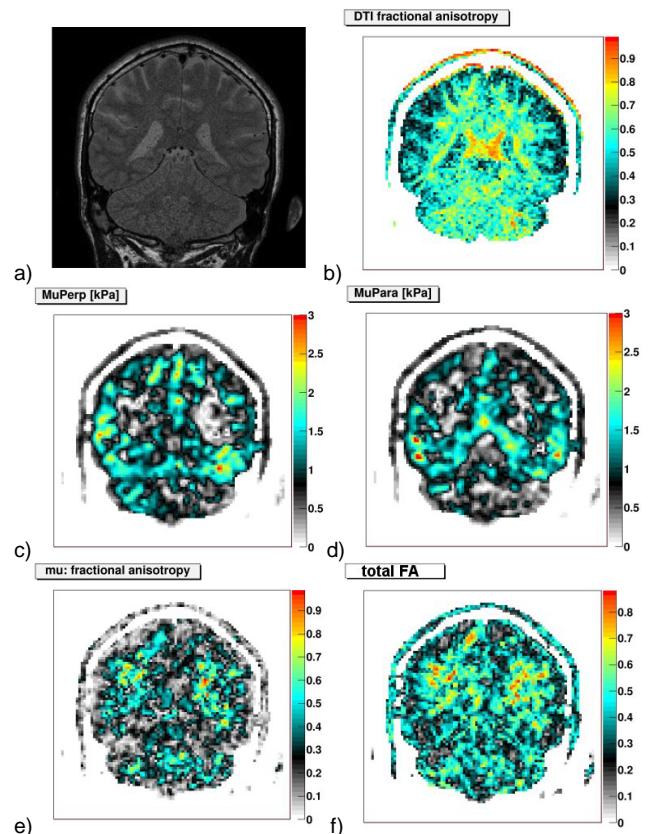


Fig.1: a) High resolution T2 image of the brain in coronal plane. b) DTI fractional anisotropy image. c) Reconstructed image of $\mu \perp$ and d) $\mu \parallel$ in units of kPa. e) Reconstructed image of shear modulus fractional anisotropy and f) total fractional anisotropy (average of shear modulus and shear viscosity FA).