

Investigation of the Anisotropic Properties of White Matter Tracts in the Human Brain using Waveguide Constrained MR Elastography

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Background: The evaluation of the elastic properties of the human brain using MR Elastography (MRE) is a very active area of research[1-3]. This is a promising new approach in the sense that if these material parameters can be non-invasively determined with accuracy, they may provide a valuable metric for the evaluation of the pathological nature of brain structures. While efforts to date tend to homogenize the brain structures to provide “effective” stiffness and viscoelastic parameters, here we apply a method which attempts to track waves traveling along white matter pathways such as the Cortico-Spinal Tracts (CST), the Corpus Callosum, etc. These structures differ from grey matter in that they are comprised of fiber bundles, and can act as waveguides for wave propagation. The purpose of this work is to apply a previously introduced approach called Waveguide Constrained MRE [4] to investigate the anisotropic properties of these fibrous structures. Here, we apply this method to the CST of a 38 year old male volunteer.

Methods: Waveguide Constrained MRE requires a knowledge of the pathways along which elastic waves may travel, as well as a measurement of the dynamic displacements within the volume surrounding the pathways. Given a knowledge of the position vectors of the pathways, a spatial-spectral filter, in the form of a spatially dependent Radon transform, is applied to the measured displacements in an attempt to identify only those waves which are traveling parallel along the fiber at every point as if it were a zero-order waveguide mode. At this time as well, a Helmholtz decomposition is performed which separates the total field into its longitudinal and transverse components. A sliding window spatial Fourier transform is then applied to these filtered displacements for dispersion analysis, yielding local stiffness values.

For the MRE measurement, the experiment was run on a standard 1.5T clinical MRI scanner (Siemens, Erlangen, Germany). A head-cradle extended-piston driver was used for 50Hz harmonic head stimulation. A single-shot spin-echo EPI sequence was used for acquiring three Cartesian components of the wave field in 30 adjacent transversal slices and eight time steps over the vibration period. Further sequence parameters: 2x2x2 mm³ isotropic image resolution, 2 averages, motion encoding gradient: 60 Hz, 3 cycles with trapezoidal shape and first gradient moment nulling. Total acquisition time was six minutes.

For the fiber position measurement, Diffusion Tensor Imaging (DTI) data was acquired using a single-shot EPI sequence (TR/TE-8500/96 ms) with 12 non-colinear directions and one b0 volume (b-value=1000 mm/s², 6 averages). Tensor calculation and tractography along the CST was performed using the tools from the FMRIB Software Library (FSL), i.e. dtifit and probtrackx. Total acquisition time was twelve minutes.

Results: In Figure 1, we show the MRI of the head as well as the positions of the X, Y, and Z displacement components. In Figure 2, we show the results from the DTI for an evaluation of the fiber pathways comprising the CST, and we show the results of applying the spatial-spectral filter to the MRE data along the CST fibers. In Figure 3, we show the results of applying a sliding window spatial Fourier transform along two sample fibers for an evaluation of the local shear stiffness values, C₄₄ and C₅₅, within the fiber's local reference frame. While estimates for brain stiffness vary considerably in the literature, average values of around 2 kPa have been reported for the mean shear modulus within slices including both gray and white matter. Here, the shear stiffness values along the white matter tracts appear to vary from around 2.5 to 10 kPa (1.5 to 3.6 m/s) and are spatially dependent as we follow along the right and left CST from the bottom to the top of the head, while the compressional waves along the fibers have a much higher wave velocity. Future research will apply this approach to other brain structures and at different frequencies. This work supported by the Office of Naval Research.

References:

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3. Green M.A., et al, NMR Biomech 2008; 21:755-764.
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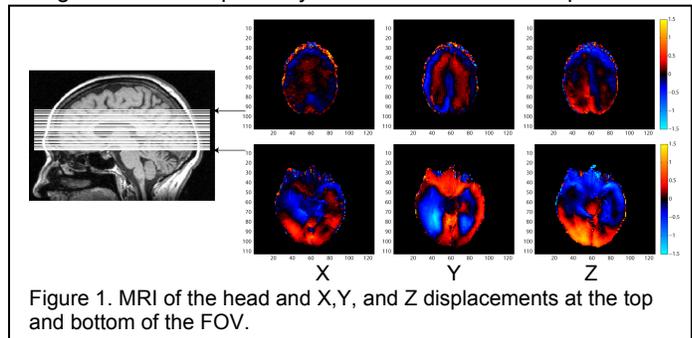


Figure 1. MRI of the head and X, Y, and Z displacements at the top and bottom of the FOV.

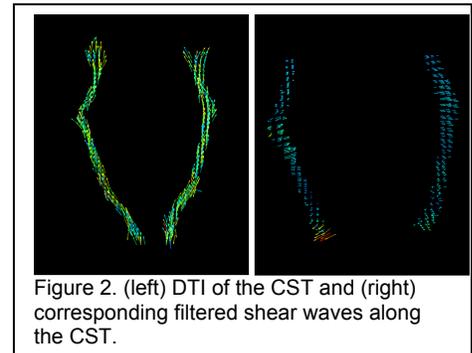


Figure 2. (left) DTI of the CST and (right) corresponding filtered shear waves along the CST.

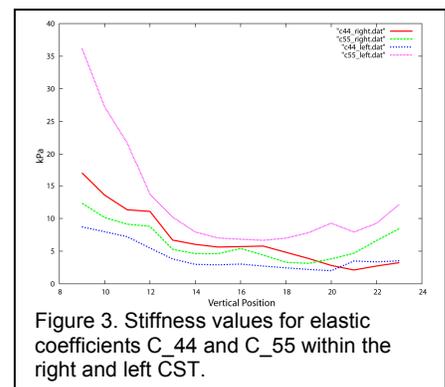


Figure 3. Stiffness values for elastic coefficients C₄₄ and C₅₅ within the right and left CST.