In Vivo Waveguide Elastography of the Corona Radiata

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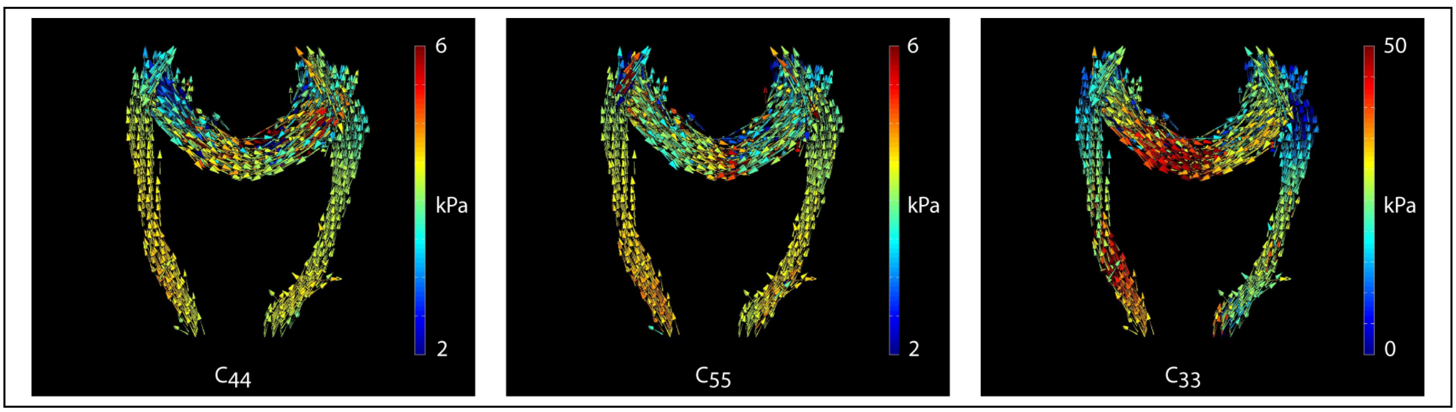
Background: The evaluation of the elastic properties of the human brain using MR Elastography (MRE) is a very active area of research[1-3]. While many efforts to date tend to homogenize the brain structures to provide "effective" stiffness and viscoelastic parameters, here we apply a method called Waveguide Elastography [4] which attempts to evaluate the material parameters of white matter pathways alone. These structures differ from gray matter in that they are comprised of myelinated axons which can act as anisotropic waveguides. Previously, we applied this method to the Corticospinal tracts of five healthy human volunteers. Here, we extend this approach to investigate the anisotropic properties of the Corona Radiata.

Methods: Waveguide Elastography 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 is applied to the measured displacements in an attempt to identify only those waves which are traveling at particular angles to and along the fibers at every point. At this time as well, a Helmholtz decomposition is implemented which separates the total field into its longitudinal and transverse components. An Orthotropic inversion is then performed along the fibers to evaluate the stiffness values. By filtering along six specific directions within the local reference frame of the fibers, the equations of motion decouple allowing for each of the nine elastic coefficients to be solved for independently of one another. This approach allows for lower order anisotropic models (such as Hexagonal or Cubic, for example) to be exposed as valid by exposing redundancies in the Orthotropic coefficients.

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 mm^3 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 B_0 volume (b-value=1000 mm/s^2, 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 the figure above we show the results of performing our inversion on the CSTs and the Corona Radiata. The first image provides the shear coefficient C_{44}, the second, the shear coefficient C_{55}, and the third, the longitudinal coefficient C_{33}. As can be observed, the CSTs have virtually the same stiffness values for the shear coefficients C_{44} and C_{55} (varying from around 4.2 kPa near the bottom to around 3 kPa near the top), while the Corona Radiata has shear stiffness varying from 2-6 kPa. As demonstrated in [4], redundancies in the Orthotropic coefficients indicated Hexagonal anisotropy (Transverse isotropy, which applies to the CST). Interestingly, in the Corona Radiata, we see that since C_{44} and C_{55} are quite different, it is concluded that this structure is, at a minimum, Orthotropic. For the longitudinal stiffness, C_{33}, both of the structures vary as a function of position ranging in values from 5-50 kPa. Future research will apply this approach to other brain structures and at different frequencies. Waveguide elastography has revealed for the first time the full anisotropic elasticity tensor of white matter tracts in the healthy human brain. While both the CST and the CR have distinct principal axes of elasticity, the Hexagonal CST presents with higher symmetry than the Orthotropic elastic CR structure. This work supported by the Office of Naval Research.

References:

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