In Vivo Waveguide Elastography of White Matter Tracts in the Full Human Brain

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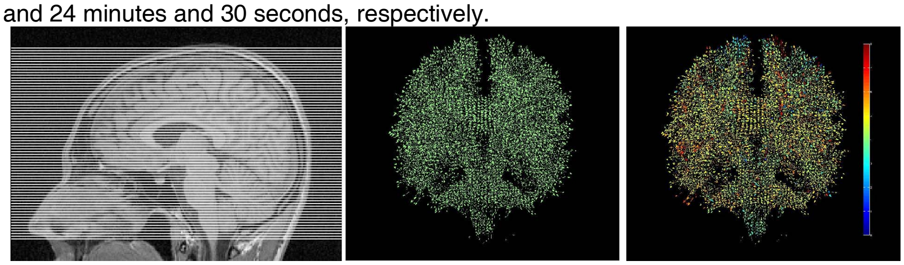
Target Audience: Neurologists, Radiologists, Biomedical Researchers, and Engineers

Purpose: This research was performed to evaluate the anisotropic properties of the 12 major white matter tracts in the human brain such that they may be used as metrics for the evaluation of brain health and pathology.

Methods: Waveguide Elastography (WGE)[1] attempts to evaluate the material parameters of fibrous structures such as white matter tracts. These structures differ from gray matter in that they are composed of myelinated axons which can act as anisotropic waveguides. This method was applied in the Cortico-spinal tract of healthy volunteers as well as in patients suffering from Amyotrophic Lateral Sclerosis and was able to successfully differentiate between the two groups ($P < 0.0001$)[2]. Here, we extend this approach in the analysis of the full brains of healthy volunteers and classify the anisotropic properties of the 12 major white matter tracts[3]. Of six measured volunteers, here we provide the preliminary results of the analysis of a 29 year old male.
WGE requires knowledge of the pathways along which elastic waves may travel (provided by Diffusion Tensor Imaging, DTI), as well as a measurement of the dynamic displacements within the volume surrounding the pathways (provided by Magnetic Resonance Elastography, MRE). An Orthotropic inversion algorithm is applied to the data to evaluate the corresponding viscoelastic, anisotropic stiffness coefficients. The MRE and DTI measurements were performed on a standard 1.5T clinical MRI scanner (Siemens, Erlangen, Germany). 60 Hz harmonic head stimulation was used for the MRE measurements and a full set of data consisted of 70 adjacent transverse image slices with a $2x2x2mm^3$ isotropic voxel resolution (128x104 pixels). Total acquisition time for MRE and DTI was 14 minutes and 47 seconds and 24 minutes and 30 seconds, respectively.



Results: In the figure above on the left, we show the 70 transverse slices, in the middle, the DTI mapping of the principal eigenvectors of the full brain of a healthy human volunteer, while on the right, we show the results for a typical anisotropic inversion for the shear stiffness coefficient, C_{44} , in kPa[4]. In this instance, the values range from 1-7 kPa with a global mean value and standard deviation of 4.95 ± 0.14 kPa.

	CGC	CGH	CST	ATR	SLF	SLFt	ILF	IFO	UNC	Fmaj	Fmin	MC
C_{11}	37.77±1.77	39.18±1.20	40.69±1.56	39.45±3.62	41.24±1.74	41.11±2.79	40.19±0.97	40.89±1.19	40.73±1.05	40.84±1.15	41.67±0.16	41.97±0.99
C_{22}	40.89±2.15	40.02±3.16	39.97±1.51	38.85±2.39	39.84±2.02	40.18±2.11	42.16±0.71	42.56±0.77	43.17±1.90	42.23±1.16	42.43±0.27	41.04±1.00
C_{33}	44.02±0.90	42.59±0.29	39.19±3.29	40.89±3.64	44.22±2.89	43.23±1.84	42.56±1.71	42.48±1.54	42.75±2.71	42.51±0.97	41.78±0.82	38.26±1.50
C_{44}	5.34±0.46	4.99±0.44	4.90±0.14	4.93±0.15	4.89±0.12	4.94±0.13	4.97±0.13	4.95±0.13	4.93±0.36	4.80±0.09	4.89±0.08	4.98±0.13
C_{55}	5.07±0.32	4.89±0.18	4.86±1.11	4.93±0.17	4.80±0.09	4.86±0.16	4.99±0.19	4.97±0.03	5.01±0.17	4.93±0.03	4.94±0.08	4.94±0.05
C_{66}	5.59±0.21	5.64±0.14	5.49±0.23	5.58±0.20	5.37±0.23	5.59±0.36	5.58±0.09	5.57±0.20	5.75±0.28	5.57±0.04	5.62±0.08	5.57±0.16
C_{12}	26.61±0.86	27.65±1.01	29.37±0.04	30.96±1.13	31.85±1.07	28.26±0.99	32.82±0.38	31.49±2.06	31.72±1.71	31.64±2.64	33.96±2.98	38.02±4.55
C_{13}	21.62±2.66	20.22±9.87	21.19±5.25	20.98±8.51	26.46±3.72	22.47±4.52	27.55±5.56	24.17±7.42	25.27±7.32	33.53±8.17	37.48±11.7	25.65±6.71
C_{23}	22.91±9.06	20.31±7.84	20.18±2.26	25.19±9.32	28.89±2.24	25.08±7.47	30.05±10.9	28.93±3.84	29.08±2.04	34.93±7.70	38.39±16.5	34.24±4.88

In the table above, we show the results of the inversions (in kPa) for the 12 major white matter tracts as outlined by Wakana[3]. Column Heads: CGC = Cingulum cingulate gyrus part, CGH = Cingulum hippocampal part, CST = Cortico-spinal tract, ATR = Anterior thalamic radiation, SLF = Superior longitudinal fasciculus, SLFt = Temporal component of the SLF, ILF = Inferior longitudinal fasciculus, IFO = Inferior fronto-occipital fasciculus, UNC = Uncinate fasciculus, Fmaj = forceps major, Fmin = forceps minor, MC = midcallosal fibers. Mean values and standard deviations were evaluated from the global inversions using separate DTI masks for each structure.

Discussion: Masks for the 12 major white matter tracts were applied to the full brain inversions to extract the anisotropic properties of each structure and it was determined that except for the Forceps Major, Forceps Minor, and the Mid-Callosal structures, virtually every other structure could be represented by Hexagonal anisotropy (transverse isotropy) comprised of five coefficients, while the other three were of higher anisotropy (Tetragonal and Orthotropic).

Conclusion: WGE is capable of providing the anisotropic properties of white matter in the human brain. This approach provides a noninvasive method for the determination of the viscoelastic anisotropic properties of white matter such that they may be used as metrics for the evaluation of brain health and pathology. This work supported by the Office of Naval Research.

References:

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