On The Development of Wave-Guide Constrained Magnetic Resonance Elastography

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Introduction: The determination of the elastic properties of biological materials such as muscle tissue is of great interest. Such materials, however, are generally comprised of a complicated structure of fibers, intricately intertwined, which often vary in both their orientation as well as their thickness. Because of these inherent structural complications, typical methods for the determination of the elastic moduli from displacement data often yield inconsistent results due primarily to the rotations of the fibers and their degree of elastic anisotropy.[1,2] In this paper, we present a novel extension of standard Magnetic Resonance Elastography (MRE)[3] measurement methods which is applicable in cases where the biological material under investigation is characterized by fiber bundles (i.e. muscle, neuronal pathways, etc) leading to wave-guide constrained propagation of elastic displacements. As an initial demonstration, we implement the method on a fibrous stalk of celery.

Figure (1) Clinical MRI scan of celery

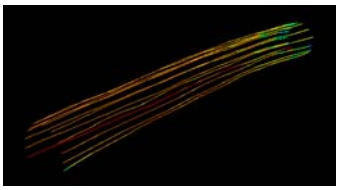

Figure (2) Paths of 13 dominant fibers.

Theoretical and Experimental Development: A stalk of celery was soaked in gadalinium doped water, then embedded in a background matrix of bovine gelatin. Clinical MRI was utilized to identity the pathways of the individual fibers of the celery, and standard 3-D MRE was performed throughout the volume containing the fibers for a measurement of the elastic displacements at 300 Hz. Dot product projections between the elastic displacements measured in the global coordinate system and three vectors representing the tangent and two corresponding orthogonal vectors (representing a rotating Frenet reference frame) along each particular fiber path yield the displacement contributions to wave propagation along the fiber as if it were a waveguide. Spatial Fourier transforms were then performed over the length of the fiber to obtain dispersion images which portray velocity and attenuation information along the fiber.

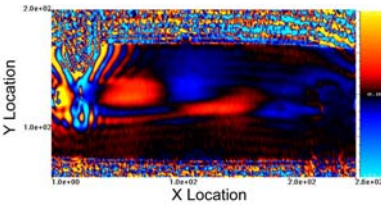

Figure (3) Y-component of elastic displacement within celery at 300 Hz.

Analysis of Results: In Fig. (1), we show the results for a clinical MRI scan of the celery, with a FOV of 20 cm. From the 36 axial slices (of thickness 0.5 cm), the locations of the individual fibers comprising the stalk (13 fibers in all) were determined, and cubic splines were fit to these locations, and are shown in Fig. (2). Next, the celery was subject to acoustic excitation at 300 Hz, and MRE was utilized to measure the three displacement components throughout the volume containing the celery with a spatial discretization of 0.08 cm. In Fig. (3), we show a slice along the celery within a plane containing the driver, with a FOV of 20 cm. With a knowledge of the paths as shown in Fig. (2), the tangent, the unit principal normal, and binormal vectors defining a rotating Frenet frame of reference were determined, and a dot product projection between this orthogonal triplet of vectors and the displacements yield the projection of the displacements along the "waveguides" as shown in Fig. (4). A sliding window spatial Fourier transform was implemented, and the resulting wave velocities were determined along the fiber paths. As shown in Fig. (5), the velocities along the y and z directions (perpendicular to the fiber orientation) can be seen to vary between 20 and 50 m/s and are spatially dependent. Additionally, the velocity associated with the displacement component along the fiber axes is around 100 m/s or higher, becoming primarily a compressional wave at the end of the celery furthest from the driver. Clearly, this structure is anisotropic, with shear waves changing polarization and velocity as functions of position.

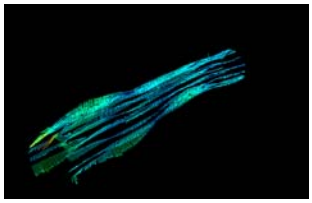

Figure (4) Projection of elastic displacements along dominant fiber paths.

Conclusions: It has been demonstrated that the combination of clinical MRI with MRE enables the tracking of waves along arbitrarily oriented fibers, establishing a method for waveguide constrained MRE. Future work will investigate the use of Diffusion Tensor Imaging (DTI)[4] and Structural Intensity (SI) in the determination of the fiber pathways in human tissue.

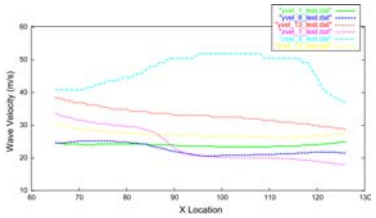

Figure (5) Wave velocity along fibers 1,8, and 13 (clockwise reference to Fig. (4))

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References:

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