MR Elastography of the Eye: Initial Feasibility

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Introduction: The eye and its accessory structures form a complex organ that is relatively small and heterogeneous, and is comprised of neural, connective and muscular tissues, as well as liquid and solid structures. A number of functional pathologies of the eye are known to manifest themselves as changes in the mechanical properties of these constituent components. A notable example is age-related macular degeneration (AMD), whereby the macula begins to deteriorate for reasons that are not well understood, leading to irreversible loss of visual acuity in the central field of vision[1]. Ocular rigidity is believed to be an important factor in the progression of AMD, and has also been shown to change with age and other conditions, such as glaucoma and Graves' disease[2]. Currently, tonometry is the only non-invasive method that exists for measuring ocular rigidity. Other methods are generally invasive, indirect and/or of questionable accuracy[3]. As such, the purpose of this work was to establish the feasibility of using MR Elastography (MRE) to measure the mechanical properties of the eye, such as ocular, intraocular and orbital rigidity. MRE is a highly-sensitive phase-contrast based imaging technique that has been used to image the stiffness of various tissues and organs, such as the liver and breast. It encodes the propagation of mechanical shear waves induced in a material with the application of bipolar gradients phase-locked to the applied motion[4].

Materials & Methods: All imaging was performed with a 1.5 T MRI scanner (GE Health Care, Waukesha, WI). An *ex vivo* bovine globe was suspended in air and imaged with an adjacent 1.75" receive-only surface coil using a gradient-echo MRE sequence with the following parameters: TR/TE 250/17 ms, 30 degree flip angle, 8 cm FOV, 3 mm slice, 256x128, 1NEX. Using a short nylon rod fixed to a 1.25" piezoelectric disc, 300 Hz mechanical excitation was applied orthogonally to the fluid-backed portion of the sclera posterior to the cornea. The resultant wave images were low-pass filtered, and a curved line profile was used to extract displacement information along the direction of the propagating wave. In addition, axial images of a human orbit were acquired *in vivo* using a head coil and gradient-echo MRE sequence with the following parameters: TR/TE 150/13 ms, 60 degree flip angle, 24 cm FOV, 5 mm slice, 256x64, 1 NEX. Motion at 80 Hz was introduced into the head with a pair of pneumatic drivers placed at the back of the skull. The resultant x-sensitized wave images were directionally-filtered along the direction of the right lateral rectus, an extrinsic muscle of the eye.

Results & Discussion: Figure 1a is a magnitude image of the suspended bovine globe that clearly depicts the cornea, lens, vitreous chamber, sclera and residual accessory structures. The y-sensitized wave image is shown In Figure 1b, where the white arrow indicates the location and direction of the applied 300 Hz motion. Waves can be seen propagating away from the mechanical driver in the azimuthal direction. The wavelength of this propagating wave is dictated by the fluid-membrane interaction in the vitreous chamber, specifically the combined elastic properties of the sclera, choroid, and retina and the chamber pressure. Incidentally, inducing shear waves in the globe *in vivo* is challenging because the eyelid naturally resists the transfer of shear waves to the sclera. Results of the *in vivo* human experiment are shown in Figure 2. The magnitude and wave images are shown in Figures 2a and 2b, respectively, where the line profile indicates the location of the right lateral rectus, and the dashed circle denotes the location of the globe. Waves are clearly evident in the accessory structures of the orbit and surrounding tissues, and there is also some indication of low-amplitude intraocular displacement. Figure 2c is a line profile of the wave data from 2b.

Conclusions: These preliminary results demonstrate the feasibility of using MR Elastography to image propagating shear waves in the globe and accessory structures of the orbit. The eye is not a homogeneous tissue, and therefore future studies will require the development of more sophisticated inversion methods than currently exist to determine the mechanical properties of the unique structures of the eye. Nevertheless, these results are promising and warrant further study.

References:

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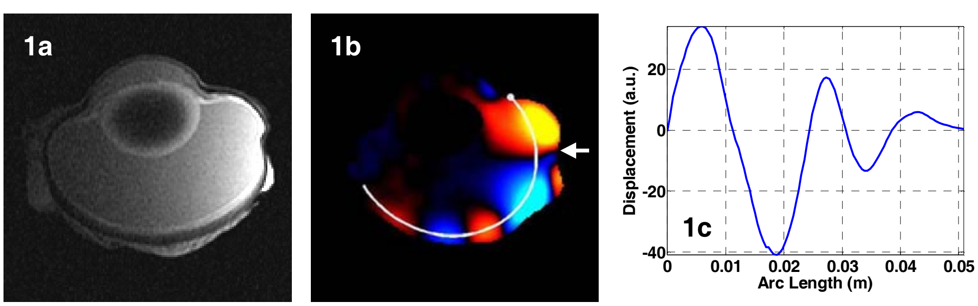

Figure 1 – **a)** The cropped magnitude image of an *ex vivo* bovine globe, **b)** the y-sensitized wave image of the globe with 300 Hz applied motion, where the arrow indicates the location and direction of applied motion, and **c)** the displacement data from the curved line profile drawn in 1b.

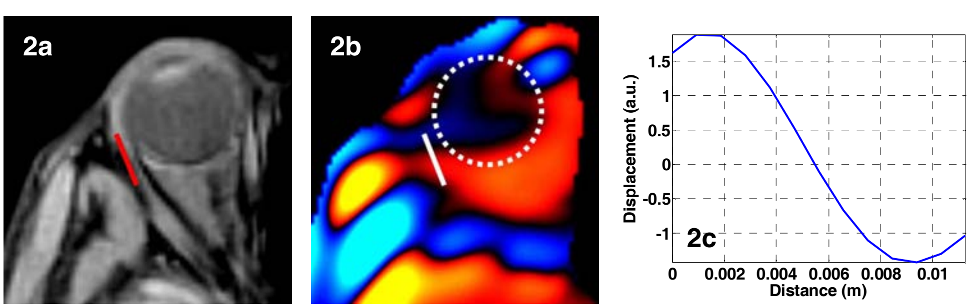

Figure 2 – **a)** The cropped axial image of a human orbit *in vivo* with a line profile indicating the location of the right lateral rectus, **b)** a directionally-filtered wave image of 80 Hz x-sensitized motion, where the dashed line indicates the location of the globe, and **c)** displacement data from the line profile drawn in 2b.