MR Elastography of the Ocular Vitreous Body

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Introduction: The posterior chamber of the eye is filled with a gel-like substance known as the vitreous body, which undergoes a gradual process of liquefaction with age [1]. Ultimately, this process can lead to posterior vitreal detachment (PVD), causing increased traction on the retina during saccadic eye movements, and ultimately resulting in retinal detachment and loss of sight [2]. Although retinal detachment is a relatively straight forward condition to diagnose, historically, means to evaluate the mechanical properties of the vitreous body have been invasive and technically challenging [3-7]. The development of a reliable technique to noninvasively measure the mechanical properties of the vitreous body would improve our understanding of the underlying physiology of this condition, and aid in evaluating patients and potential treatments. Recently, motion-encoded MRI (CSPAMM) has been used to measure physical deformations in the vitreous in an effort to make inferences about its mechanical state [8]. Another imaging-based technique that may prove suitable for this task is magnetic resonance elastography (MRE), a highly-sensitive phase contrast-based technique capable of mapping the mechanical properties of tissues [9]. The purpose of this work was to investigate the utility of MRE as a simple, noninvasive means to quantify the viscoelastic properties of the ocular vitreous body.

Methods: Imaging was conducted on a 1.5 T scanner (GE Health Systems, Waukesha, WI). Two fresh, enucleated porcine globe was cleaned of extraneous tissue and immersed in a container of 10% bovine-gelatin (Figure 1). The container was placed at the center of a pressure-activated driver system [10] and vibrated with continuous motion at 10 Hz. The eyes were imaged with a spin echo-based MRE sequence with the following parameters: 300/50-ms TR/TE, 12-cm FOV, one 3-mm slice, 128x64 matrix, 1 NEX, 0.75 A/P phase FOV. A single bipolar gradient with a period of 20 ms was used to encode the shear waves propagating within the vitreous body. The resulting wave images were then phase unwrapped, bandpass filtered (8-40 waves per FOV), directionally filtered (8 directions) [11], and processed using a local frequency estimation (LFE) inversion algorithm [12] to provide maps of shear stiffness. The average shear stiffness of the vitreous body was measured with an elliptical ROI placed in the posterior chamber of the eye.

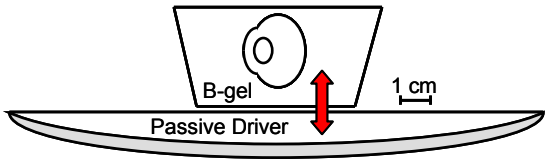

Figure 1: Experimental Setup. A pressure-activated driver was used to apply 10 Hz longitudinal (up-down) motion to an enucleated porcine globe suspended in bovine-gelatin.

Results & Discussion: The spin-echo based magnitude image of the eye is shown in Figure 2a. A corresponding wave image of the segmented globe is shown in Figure 2b, depicting shear waves in the intraocular space and vitreous body due to mode-conversion [13] of the 10 Hz longitudinal waves. Results of the LFE inversion are shown in Figure 2c, demonstrating an average shear stiffness of 10 ± 4 Pa in the vitreous body. This shear stiffness value is several orders of magnitude lower than that of other soft tissues of the body, such as the liver (~ 2 kPa), but remains in general agreement with a number of other shear modulus values reported for bovine, porcine and human vitreous, acquired using a variety of *ex vivo*, *in vivo*, static and dynamic rheological techniques [3-7].

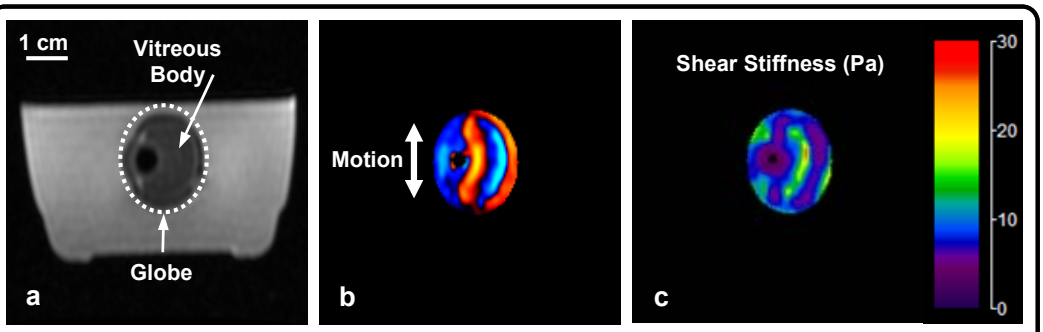

Figure 2. MRE Results. a) Magnitude image of the porcine globe imbedded in a bovine-gelatin substrate. **b)** Up-down sensitized wave image, showing the mode-conversion of 10-Hz longitudinal waves at the corneoscleral surface and propagation of the resulting shear waves inside the vitreous body. **c)** Shear stiffness map generated with a local frequency estimation algorithm, yielding an average stiffness of 10 Pa for the vitreous body.

Conclusion: In conclusion, these *ex vivo* results represent the first application of MRE to the vitreous body of the eye, and suggest that MRE may provide a convenient, noninvasive means to quantify the mechanical properties of the vitreous body. The ability to perform this measurement *in vivo* could provide a useful tool to study PVD and retinal detachment, including the underlying physiology, and the clinical evaluation of patients and potential therapies. Further work is needed to determine the clinical viability of this application, however, including *in vivo* application, and technical developments to improve the acquisition of low-frequency MRE data.

References: **1.** Sebag J, Balazs EA. Invest Ophthalmol Vis Sci 1989;30(8):1867-1871. **2.** Coangeli E, et al. Proc COMSOL Users Conf, Grenoble, 2007. **3.** Lee B, et al. Biorheology 1992;29(5-6):521-533. **4.** Lee B, et al. Biorheology, 1994;31(4):327-338. **5.** Tokita M, et al. Biorheology, 1984;21(6):751-756. **6.** Zimmerman RL. Biophys J 1980; 29(3):539-544. **7.** Bettelheim FA, Wang TJ. Exp Eye Res 1976;23(4):435-441. **8.** Piccirelli M, et al. Proc ISMRM, 2009, Honolulu, HI, #710. **9.** Muthupillai R, et al. Science 1995;269(5232):1854-1857. **10.** Yin M, et al. Clin Gastroenterol Hepatol 2007;5(10):1207-1213. **11.** Manduca A, et al. Med Image Anal 2003;7(4):465-473. **12.** Manduca A, et al. Med Image Anal 2001;5(4):237-254. **13.** Mariappan YK, et al. Magn Reson Med 2009, ahead of print.