Comparision of MR Elastography and Compressive Loading Shear Modulus Estimates for Agar Gel Inclusions

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Introduction: Dynamic Magnetic Resonance Elastography (MRE) (1) has been demonstrated to be able to determine mechanical properties of soft tissues. While prior studies have compared mechanical testing and elastography, these studies had very large samples for elastography testing (approximately 1900 to 3000 mL) (2,3). The purpose of this study was to estimate the shear modulus in small (10 mL) agar gel inclusions in a homogenous background material using MRE at 3 Tesla and compare the modulus to that determined by a quasi-static compressive test.

Methods: All scanning was performed on a GE Signa 3 Tesla system with a standard head coil. For this study, ten agarose (Sigma) gel concentrations were made with purified water and 0.5mM GAD: 0.5, 0.625, 0.75, 0.875, 1.0, 1.125, 1.25, 1.5, 1.75 and 2.0%. For each batch, three cylinders were cast into plastic vials (internal diameter = 20.3 mm), two for mechanical testing (approximately 1.5 cm tall), and one for elastography (approximately 3 cm tall). The 3 cm tall samples were embedded in pairs in a homogeneous background of 1.0% agar gel for elastography imaging. The five phantoms for elastography imaging had inclusion pairs of 0.5% and 0.625%, 0.75% and 1.0%, 0.875% and 1.125%, 1.25% and 1.5%, and 1.75% and 2.0%. The embedded agar cylindrical inclusions were imaged with the spin echo-based elastography method with ten motion encoding gradients (3.5 G/cm amplitude) and 28 motion cycles at 500 Hz. Sixteen delay offsets were acquired at every eighth (0, .25, .5, .75, 1, 1.25, 1.5, 1.75 ms) of the motion period with a starting phase of 0 and 180 degrees. The acquisition matrix was 256x160 with a TR of 175 ms. Therefore, the scan time for each phantom was approximately eight minutes. Shear modulus estimates were determined by the Local Frequency Estimation method (4) using 8 phase difference images calculated from the two images of opposite motion polarity.

Compressive tests were performed using a servohydraulic materials testing system (MTS Bionix 858, Minneapolis, MN) with non-porous platens on the top and bottom of the sample. Sandpaper was attached to the upper and lower platens with cyanoacrylate to reduce slippage of the samples during compression. The upper, movable platen was manually lowered to the top surface of each sample and the position measurement was zeroed. The loading protocol was to compress the sample by 2 mm at a rate of 1 mm per second, hold for 3 seconds, and unload at a rate of 0.5 mm per second. Forty compression trials were performed on the randomly ordered samples, with two trials for each of twenty samples. The Young's modulus was determined by linear regression of the stress-strain curve in the strain range starting at the strain corresponding to an initial force (0.1 N) up to 10% strain. The shear modulus was calculated from the Young's modulus by assuming a Poisson's ratio of 0.495 (2).

Results and Discussion: For three samples, the compression data was not analyzed due to slippage of the sample. Across the range of agar gel concentrations tested, there was generally very good agreement between the two methods. The highest concentration of 2.0% agar is the only one where the mean or 1 SD error bars of the elastography method do not overlap with the mechanical test results. The average values for shear modulus were found for the mechanical test results, and least squares linear regression was used to find the relationship between shear modulus and agar gel concentration for the two methods. The results are shown in Figure 1, and the 95% confidence intervals for the slope were determined to be 1693 to 2697 for the mechanical testing and 1705 to 3517 for elastography. For the intercept, the 95% confidence intervals were found to be -5.2 to 7.1 for mechanical testing and -10.3 to 12.0 for elastography. Hence, the linear regression terms for the two methods were not found to be significantly different (P> 0.05). The agreement of the mean shear modulus estimates for agar gel for the two methods fall very close to the y=x line except for the measurement at 2.0%, where the elastography method overestimates the shear modulus compared to the mechanical testing method. This value greatly influences the linear regression between the two methods, which is found to have 95% confidence intervals for the slope and intercept to be 1.06 to 1.40 and -7.34 to -0.95 for the slope and intercept, respectively. Therefore, the elastography method is found to slightly overestimate the shear modulus at high agar concentrations and underestimate the shear modulus at low agar concentrations compared to mechanical testing.

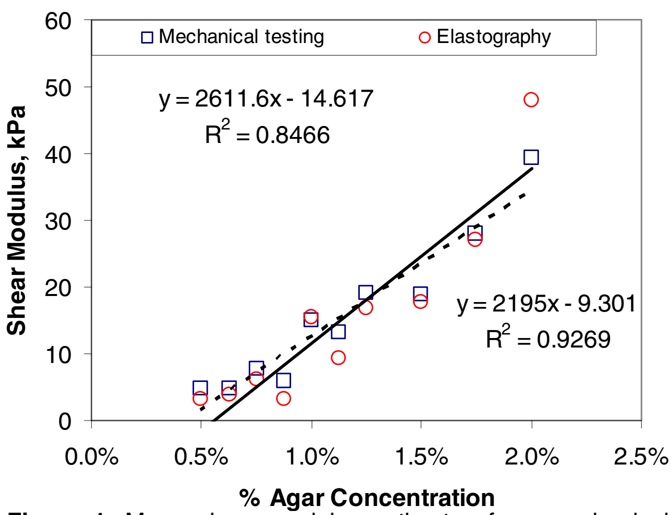

Figure 1. Mean shear modulus estimates from mechanical testing and elastography.

Fundamental causes for disagreement between the methods include loading-rate dependence on the shear modulus and indirectly calculating the shear modulus from mechanical testing based on an assumed Poisson's ratio. However, the elastography method is found to be adequately accurate for shear modulus estimation, especially in determining relative differences between materials.

Acknowledgements: This work is supported by NIH grant R01 AG17762.

References:

[1] Muthupillai R, et al., Science, 296, 1854, 1995.
[2] Hamhaber U, et al., MRM, 49:71-77, 2003.
[3] Ringleb S, et al., MRM, 53:1197-1201, 2005.
[4] Manduca A, et al., Med. Im. Analysis, 5:237-254, 2001