QUANTITATIVE SHEAR WAVE MAGNETIC RESONANCE ELASTOGRAPHY: COMPARISON TO A DYNAMIC SHEAR MATERIAL TEST

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INTRODUCTION

In clinical applications, such as tumor detection, changes in the mechanical properties of soft tissues are assessed with palpation, which is subjective and has low sensitivity. In muscle, there is no clinically routine method used to measure the mechanical properties of muscle in vivo. Such a tool would greatly improve understanding of changes that occur in muscle with pathologies and treatment.

Magnetic Resonance Elastography (MRE), a non-invasive phase contrast MRI technique, can visualize small displacements from applied shear waves and quantify the stiffness of soft tissues in vivo (Muthupillai, 1995). This method has been applied to in vivo soft tissues including kidney, liver, and muscle (Kruse, 2000). However, attempts to validate the technique by comparing its stiffness estimate with a mechanical test have used only compression tests (Hamhaber, 2003).

Dynamic mechanical analysis (DMA) is a non-destructive dynamic material test that can measure the shear modulus over a given frequency range. The purpose of this study was to compare the MRE stiffness estimate to the shear modulus measured with the DMA in soft tissue mimicking agarose gel.

METHODS

Prismatic agarose gel samples (7x13.4x20.5 cm) with concentrations ranging from 1.5-3.5% in 0.5% increments were prepared. The samples were placed in a head coil and an electromechanical driver was placed on top of the sample that generated shear waves at 100, 150 and 200 Hz. The MRE tests were conducted in a 1.5 T General Electric Signa scanner. A 2D slice of the sample was imaged with a gradient-echo, cyclic motion sensitizing sequence (TR/TE of 100ms/min full, 60° flip angle, 256x64 acquisition matrix, 24cm FOV). Each sample was tested three times. The stiffness (μ) was calculated manually (equation 1), where ρ is the density (assumed to be 1), f is the frequency of the shear wave and λ is the wavelength manually measured from the displacement image (Figure 1).

\[ \mu = \rho f^2 \lambda^2 \]  

Stiffness was also estimated with two inversion algorithms, local frequency estimation (LFE) and matched filter (Manduca, 2001). The dynamic shear moduli of the gels were tested three times with a DMA 2980 (TA Instruments, New Castle, DE) in the shear sandwich mode.

![Figure 1: a) Displacement image in 3% agar gel b) wave propagating through phantom along profile (green line) in (a).](image-url)
RESULTS AND DISCUSSION

The shear modulus measured from the DMA was plotted against the MRE stiffness estimates determined from manual calculation and the LFE and matched filter inversion algorithms (Figure 2). The slope, y-intercept, and correlation coefficient ($R^2$) were recorded (Table 1).

![Figure 2: DMA vs. MRE stiffness estimates](image)

In a previous study, MRE measurements were compared with a compression test with concentrations ranging from 0.5-2.5% of agar-agar gel (Hamhaber, 2003). While generally good agreement was obtained, the differences between their manually calculated shear moduli and their compression test results showed somewhat greater deviation than our comparison of the shear modulus measured with a DMA. This suggests that a shear test may be a more appropriate material test for validating the stiffness estimate of MRE.

Our results also demonstrated that the manual stiffness calculation gave the best correspondence to the shear modulus measured with DMA. The inversion algorithms, while showing fairly good agreement as well, had systematically lower slopes and larger discrepancies than the manual calculation. This may be because inversion algorithms are sensitive to noise and edge effects from the container holding the gel (Manduca, 2001).

SUMMARY

MRE was successfully validated using a shear test in a DMA. The manual calculation of stiffness yields the closest comparison to the measured shear stiffness.

REFERENCES

Hamhaber, U et al. (2003). Magnetic Resonance in Medicine, 49, 71-77.

ACKNOWLEDGEMENT

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Table 1: Slope, y-intercept and correlation coefficient of MRE vs. DMA stiffness estimate plots.

<table>
<thead>
<tr>
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<th>Manual Calculation</th>
<th>LFE</th>
<th>Matched Filter</th>
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<tr>
<td>Slope (KPa/KPa)</td>
<td>0.9419</td>
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<td>y-intercept</td>
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<td>Correlation Coefficient ($R^2$)</td>
<td>0.9977</td>
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