Dynamic MR Elastography at 3T of Strain Waves of 625 to 1000 Hz

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Introduction: Dynamic Magnetic Resonance Elastography (MRE) has been demonstrated to be able to determine mechanical properties of soft tissues using a Spin Echo (SE) technique (1). The purpose of this study was to develop MR Elastography techniques at 3T for the imaging of small, stiff objects, similar to human intervertebral disc. Typically, MRE experiments are performed at frequencies of 500 Hz or less, however higher frequencies may allow elastographic evaluation of small, stiff objects. Therefore, motion frequencies of 625 Hz to 1000 Hz were developed and evaluated.

Methods: All scanning was performed on a GE Signa 3 Tesla system with a standard head coil. A bi-layer, 0.5% and 1.0% agar phantom of 8 cm height and 16 cm^2 square cross-sectional area was used. The layers were aligned vertically, side-by-side, both in contact with the external actuator contact plate. SE sequences modified with balanced, bipolar Motion Encoding Gradients (MEG's) were created that had 10 MEG's before the refocusing pulse and 10 MEG's of the opposite polarity after the refocusing pulse. Six sequences were tested, with MEG frequencies of 625, 672, 731, 800, 865, and 1000 Hz. These frequencies (except 800 Hz) minimize digitization errors when translated to the scanner time base of 4 us. All MEG's reached peak amplitudes of 3.5 G/cm. A trigger signal was sent from the scanner to a digital waveform generator (Model 33250A, Agilent) at the beginning of each TR (175 ms). The wave generator output the "motion signal" of a burst of 30 to 35 cycles of sinusoidal voltage at the same frequency as the MEG's. This signal was sent to an amplifier (A-303, A.A. Lab Systems, Wilmington, DE), connected to a piezoelectric bending element (EPA-104, Piezo Systems, Cambridge, MA) energized with ±140 V, similar to a previous technique (2). The bending element created shear waves in and out of the slice selection plane. The sequences encode phase relative to velocity in the phase image, and the "wave image" is produced by subtracting the phase image with no motion applied (Figure 1). The TE's were 0.02 + 20*(1/f) s, where f is the frequency of mechanical motion and MEG's, and NEX was 4. Eight offsets between the phase of mechanical motion and MEG's were acquired. Each offset had a scan time of 1m 50s.

The relative performance of each technique was determined by phase-to-noise ratio (PNR) maps. To calculate PNR, an absolute maximum intensity projection was performed across the eight wave images. This was divided by the arctangent of the inverse of the magnitude signal to noise, found by dividing the magnitude images by the standard deviation of the signal in a region of air and averaging across the magnitude images for the eight offsets. Finally, a single region of interest (ROI) was chosen in the 1.0% agar region to compare the techniques. The mean PNR in the ROI for the 6 experimental conditions were analyzed by a one-way ANOVA and Student's t-tests for posttests.

Results and Discussion: Waves were detectable in the 1.0% Agar region of the phantom for all frequencies tested, (Figure 1), though at low amplitude at higher frequencies. The ANOVA found significant reduction in PNR as the frequency was increased. The lowest frequency tested, 625 Hz, had by far the highest PNR, and was significantly higher at the 95% confidence level. These results show the feasibility of testing small objects at frequencies > 500 Hz. The piezoelectric bending element has sufficient response at these frequencies, does not suffer from heating, and creates detectable shear waves.

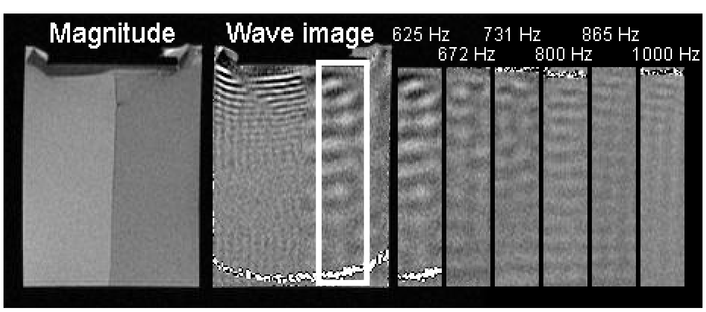

Figure 1. Magnitude and Wave Image of f=625 Hz, with "strip" images of increasing motion and MEG frequencies.

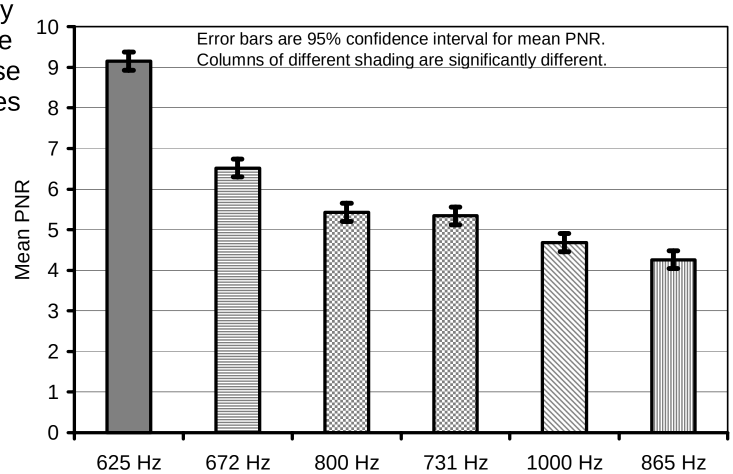

Figure 2. Mean PNR in ROI for the motion/MEG frequencies tested.

References:
[1] Hamhaber U, et al., MRM, 49:71-77, 2003. Acknowledgements: This work is supported by NIH grant R01 AR46905.
[2] Rossman P, et al., Proc. ISMRM, 1075, 2003.