Validation and Testing of 7T MR Elastography Sequence and Stiffness Reconstruction

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Introduction: Magnetic resonance elastography (MRE) is a technique for determining the mechanical response of tissue using applied harmonic deformation of the tissue and motion sensitive magnetic resonance imaging (MRE) [1]. Currently, studies investigating the mechanical properties of the human brain using MRE are performed at conventional clinical MRI scanner with magnetic field strengths of 3 Tesla (T) and 1.5T, but more recently, there have been a few attempts at the ultra-high field strength, 7T [2,3]. However, in the most recent studies comparing 1.5T, 3T, and 7T MRE of the human brain, MRE at 7T and 1mm resolution resulted in significantly lower stiffness values than MRE at 1.5T and 3T at 2mm resolution [2,3]. However, one study indicated that when down sampled to 2mm, the 7T MRE results matched the traditional MRE field strength results, but in a second study, the difference remained [2,3]. Therefore, the purpose of this study is to determine whether higher resolution and/or change in field strength inherently changes the results of MRE for a homogeneous linear elastic material, or if any changes in stiffness when imaging at the brain 7T are a physical phenomenon due to fine viscoelastic features [2].

Materials and Methods: MRE was first performed at 3T with 2.5mm isotropic resolution on a custom silicone MRE phantom (CIRS 049) with a background Young's modulus of 5±1 kPa. This MRE data was acquired for 48 slices with 3D motion encoding gradients using an echo planar spin echo 2D pulse sequence [4] with vibration frequency 50Hz in a 3T Siemens Skyra scanner with a 16-channel head coil (Siemens Healthineers). MRE was then performed at 7T using a custom multi-slice 2D-EPI pulse sequence with 3D motion encoding gradients, a vibration frequency of 50Hz and 8 phase offsets in a 7T Siemens Terra scanner with a 32-channel head coil (Siemens Healthineers) at 2.5mm, 1.7mm, 1.3mm, and 1.0mm isotropic resolutions. In both cases, external vibration was applied to the surface of the phantom using a custom pneumatic actuator described in [5], this time with a 3000W power amplifier (Behringer) and high-pressure plastic tubing (3/4" ID). Shear stiffness maps of the phantom's cross section were obtained using the algebraic inversion as described in [5]. The mean of each stiffness map of five homogeneous slices per scan (2.5mm at 3T, 2.5mm, 1.7mm, 1.3mm, and 1.0mm at 7T) were compared both visually and using a one-way ANOVA with a post-hoc Tukey test to compare between groups.

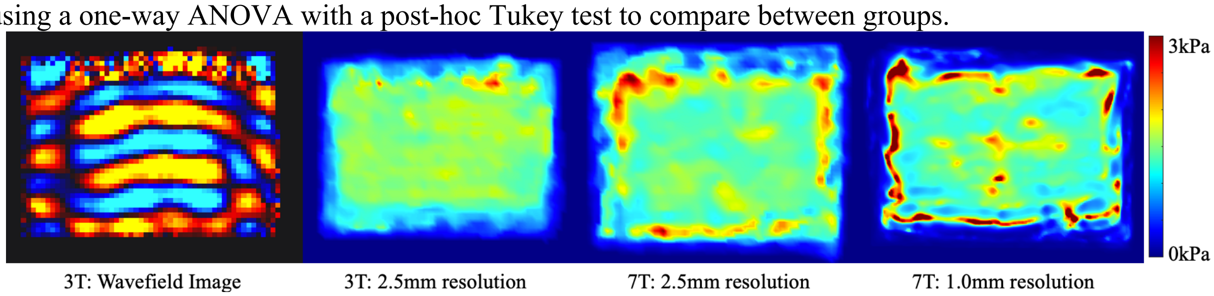

Figure 1. Wavefield image at 3T and shear stiffness maps of the center slice calculated using 3T MRE at 2.5mm and 7T MRE at, 2.5mm, and 1.0mm resolutions (from left to right) with the color bar scale from 0 to 3kPa.

Results and Discussion: Shear stiffness maps were successfully calculated for MRE scans at both 3T and 7T using a custom pneumatic actuator and custom 7T MRE sequence, as well as for each resolution at 7T. The average shear stiffness for a homogeneous slice at 3T and 2.5mm resolution was 1.430±0.025kPa, and the average shear stiffnesses at 7T were 1.440±0.018kPa, 1.445±0.038kPa, 1.460±0.025kPa, and 1.456±0.016kPa at 2.5mm, 1.7mm, 1.3mm, and 1.0mm resolutions respectively. All of these are within the specification range of the custom phantom, which, assuming a Poisson's ratio of 0.5, would be a shear stiffness between 1.333-2.000kPa. Comparing the five data sets each with n=5 samples, there was no significant difference found between any of the pairs of data sets ($p>0.50$). This would indicate that in a homogeneous material, changing neither field strength nor resolution inherently changes the calculated stiffness of the material being imaged. This procedure can now be used to image the human brain at 7T with the knowledge that the resulting elastograms will have good accuracy.

Conclusion: In this study, we successfully validated the performance of MRE at 7T at multiple resolutions, indicating that this procedure results in accurate wavelength-based stiffness estimates.

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