Evaluation of MR Elastography Reproducibility: Effect of Motion Encoding Gradient Direction, Slice Position, and Meal Ingestion

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Introduction: Magnetic Resonance Elastography (MRE) is increasingly gaining acceptance as a valuable tool for non-invasively assessing liver stiffness (LS). In MRE, low frequency mechanical waves are coupled to the liver from an external transducer placed on the patient, and resulting tissue displacement is encoded in the phase of the MRI signal using motion-encoding gradients (MEG). From these displacement maps, local shear wave speed is calculated, and is converted into a stiffness estimate. Carefully performed studies at expert centers have demonstrated that increased in LS can be used as a non-invasive imaging surrogate for liver fibrosis [1-2]. Liver MRE is particularly appealing as it can eliminate the need for invasive biopsies, and could serve as a monitoring tool for fibrotic treatment response. As MRE continues to gain broader clinical acceptance, the reproducibility of LS measurements in clinical centers will be affected by the implementation of MRE into clinical practice. In this study we sought to determine the impact of following factors in reproducibility of MRE: (a) Direction of MEG; (b) Slice position (3 axial slices centered at mid-liver); and (c) Effect of high-caloric food intake.

Methods: *Subjects and Study Design*: 8 healthy subjects (3 female; age: 43.5±12.7 yrs; BMI: 23.8±3.6 kg/m^2) participated in this prospective IRB approved study. All subjects were imaged four separate time points: twice before (experiments B1, and B2) the consumption of a 1050 calorie standardized meal after overnight fasting (MacDonalds-Big Breakfast), and twice after (experiments A1 and A2) the meal (30 and 45 minutes after). Between each experiment, the subject was removed from the scanner, and the transducer/coil set-up was repositioned to assess test-retest reproducibility.

MRI Data acquisition: All subjects were imaged at 3.0T scanner (Philips, Ingenia 3.0T). MRE images were acquired over three axial slices with the central slice positioned at the largest area of the liver as seen from the scout images. Acquisition parameters of the MRE sequence were: TR/TE/flip angle: 50 ms/21.6 ms/30^o; field of view (FOV): 420 mm x 400 mm; acquired voxel size: 1.6 mm x 4.6 mm x 10 mm; bandwidth: 110 Hz/pixel; MEG displacement sensitivity: 12 µm/rad. The MEG was flow compensated, and applied sequentially along Anterior-Posterior (AP), Foot-Head (FH), Right-Left (RL) directions. Along each direction, four displacement wave images were acquired at progressively increasing delays between the MEG and mechanical excitation lasting 13.5 s per slice.

MRE Transducer: A passive acoustic driver (Resoundant™, Rochester, MN) was tightly secured at the level of the xyphoid in the anterior, right hemi-thorax, and scout images were obtained. From the scout images, the relative position of the transducer center (from the location of the vitamin E capsule on the transducer) and the center of the liver were determined, and the transducer was moved in the FH direction so that the center of the transducer was consistently over the largest area of the liver. A TTL signal from the scanner triggered the driver system for synchronizing mechanical excitation with MEG. The driver amplitude was adjusted (30% or 60% of the peak capacity of the driver) to ensure sufficient penetration of shear waves within the liver.

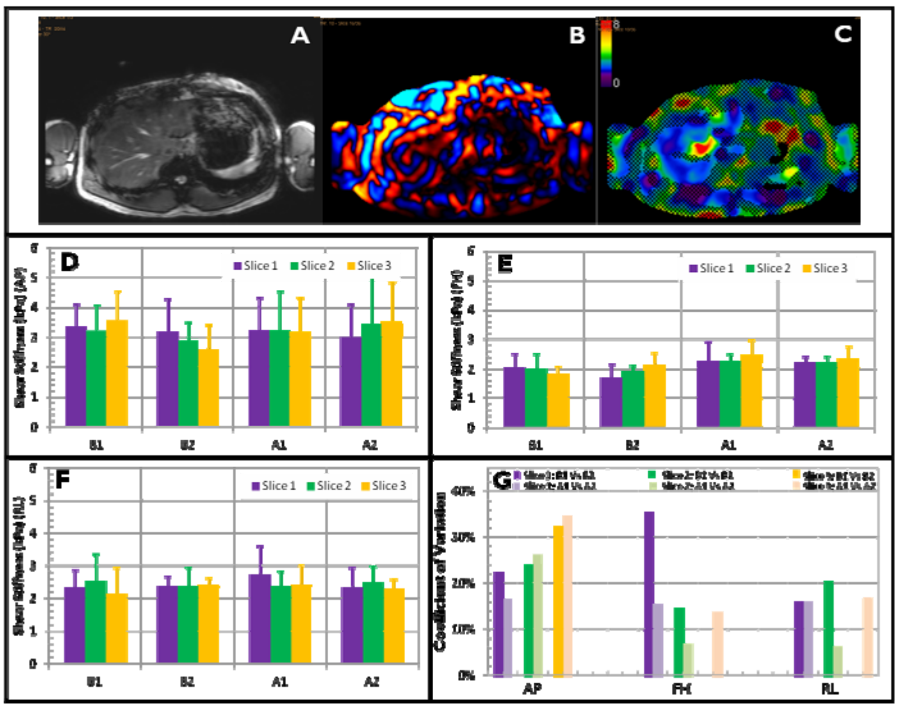

Figure 1: Magnitude, shear wave and stiffness images from mid liver location are shown in panels A-C respectively. Stiffness images are masked with CM (hashed regions). Note that the shear stiffness estimated with MEG along FH (E) was consistently lower than when MEG was along AP or RL (D&F). MEG along FH direction yielded the best reproducibility for mid-liver slice (G).

MRE Analysis: The displacement images were converted to LS maps using MRE software developed by the Mayo Clinic (used under a research agreement). The software also provided confidence maps (CM) for LS estimates. Regions of interest (ROI) were drawn on magnitude images masked by the CM (custom written software) to estimate regional LS.

Statistics: Test-retest reproducibility was calculated between the B1 Vs B2, as well as A1 Vs A2. Statistical significance of LS values before and after meal ingestion were also assessed using pair-wise, two-tailed Student's t-test. A p-value < 0.05 was assumed to be statistically significant.

Results: A total of 288 slices were analyzed (8 subjects x 3 slices/subject x 3 directions/subject x 4 measurements/subject). A representative MRE image is shown in panels A-C. Specific findings from the study are as follows: (1) LS measurements in the FH direction were consistently lower than AP/RL directions (Figure panels D-F). (2) MRE images acquired in the mid-liver location were most reproducible in the FH direction (< 15% for both pre and post meal ingestion or 0.3 kPa). (3) In normal healthy volunteers, the consumption of a 1050 calorie meal did not affect LS measurements. There was a trend toward slight elevation in LS after ingesting the meal when MEG was along the FH direction ($p<0.05$ for B2 Vs A1). This finding needs to be confirmed in a larger group of subjects. We expect to confirm these initial findings in this ongoing study.

Conclusions: MRE estimates of LS are most reproducible (less than 0.3 kPa) when MEG is applied along the FH direction. In this study, the imaging slice positioned directly over the largest area of liver yielded the best reproducibility (slice 2). In this group of normal subjects, there was little difference in LS before or after 1050 calorie meal ingestion.

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References:

1) Yin, M. *Clin Gastroenterol & Hepatol*. 2007 Oct; 5(10): 1207-121 2) Yin, M. 2011, *AJR Am J Roentgenol.* 197(1):64-70;