Improvements in Hepatic Stiffness Assessment with 3-D/3-axis MR Elastography

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Introduction:

MR Elastography (MRE) (1) is an MRI-based technique for quantitatively assessing the mechanical properties of soft tissues by studying the propagation of shear waves. Multiple studies (2-4) have reported on developments of MRE for assessing the viscoelastic properties of abdominal organs. In general, MRE inversion algorithms require datasets that sample the pattern of wave propagation in 3-D space, with acquisition of the x, y, and z components of motion at each point within the volume for multiple time points in the wave cycle. The acquisition time required to obtain 3-D data is lengthy and particularly inconvenient for abdominal imaging, where it is best to image during suspended respiration. Fortunately for hepatic MRE applications, there are situations in which the characteristics of the wavefield allow for optimized 2-D wave imaging capable of providing results in much shorter acquisition times (5,6). However, even in the liver, the largest abdominal organ, shear wave propagation can be complicated due to boundary and geometric effects which cause the 2-D wavefield model to break down in certain regions which limit its applicability for assessing hepatic tissue stiffness over the entire liver. Therefore, a practical 3-D MRE acquisition and inversion strategy is needed for improving the reliability of shear stiffness estimates in the abdomen. The purpose of this study was to evaluate a spin-echo multi-slice EPI MRE acquisition and 3-D local frequency estimation (LFE) approach for hepatic MRE compared to conventional 2-D MRE.

Methods and Materials:

All experiments were implemented on whole-body GE imagers (Signa, GE Healthcare, Milwaukee, WI, USA) after obtaining informed consent and in compliance with the institutional review board. 14 normal volunteers (3.0T scanner) and 2 clinical patients (1.5T scanner) with chronic liver disease were imaged in the supine position with an acoustic pressure-activated driver placed against the body wall adjacent to the liver. Shear waves were generated using 40-Hz continuous vibrations of the abdomen. A spin echo EPI MRE sequence was used to collect 3-D/3-axis axial wave images (x/y/z/t/axis: 96×96×40×3×3, isotropic voxel size = 3.5 mm^3) within three breath holds ($T_{acq} = 3\times16$ seconds). Elastograms were obtained with a 2-D multiscale direction inversion of the through-plane component of motion (as is done for routine clinical MRE exams) as well as with a 3-D local frequency estimation (LFE) inversion(5) incorporating all 3 components of motion. ROI's were determined for the central 30 slices, excluding any non-hepatic tissues (e.g., vascular structures, ascites, bowels) and areas with poor shear displacement (phase-to-noise ratio (PNR) less than 3). The homogeneity of the elastograms was determined by histogram analysis and both Bland-Altman and Intra-Class Correlation (ICC) analysis were performed on the 2-D and 3-D MRE stiffness measurements.

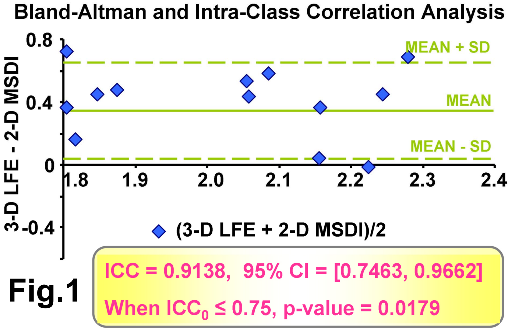
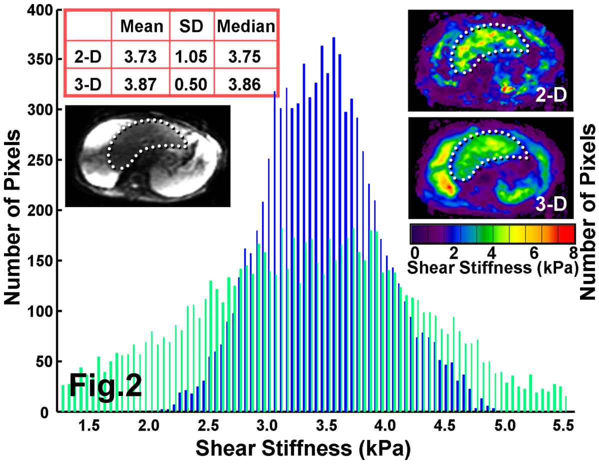


Fig.1

ICC = 0.9138, 95% CI = [0.7463, 0.9662]
When $ICC_0 \leq 0.75$, p-value = 0.0179

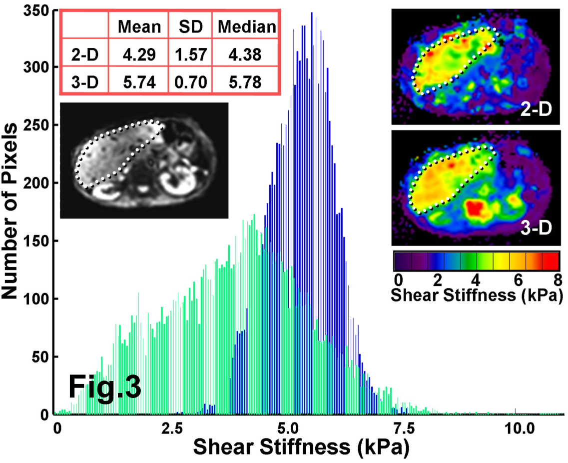
Results:

For each subject, the shear stiffness was evaluated over an average volume of $43,040 \pm 3,417\ mm^3$. Fig.1 illustrates that a good correlation ($p < 0.05$) was found in the mean hepatic stiffness between the 2-D and 3-D methods on the 14 normal volunteers. The Bland-Altman analysis shows reproducible hepatic stiffness estimates with a positive bias between the 2-D and 3-D stiffness values. Figs. 2-3 illustrate the hepatic stiffness analysis for the two patient volunteers showing histograms of the stiffness within the ROI (center: green=2-D; blue=3-D); tables summarizing the mean, SD and medium of the histograms (upper left); magnitude images (middle left); and 2-D and 3-D elastograms (upper and middle right, respectively). The 3-D results demonstrate improved homogeneity of the stiffness estimates with narrower histogram width and smaller SD compared to the 2-D analysis.



	Mean	SD	Median
2-D	3.73	1.05	3.75
3-D	3.87	0.50	3.86

Fig.2



	Mean	SD	Median
2-D	4.29	1.57	4.38
3-D	5.74	0.70	5.78

Fig.3

Discussions:

Shear wave propagation is very complicated within the liver, and the 2-D method frequently used for MRE involves processing only a portion of the full vector displacement field, which can lead to erroneous stiffness estimates when the 2-D wavefield model breaks down. Within the favorable central portion of the liver, it has been shown there is a strong correlation and good agreement (6) between 2-D and 3-D MRE measurements. In this study, ROI's were used which covered a significant portion of the liver in which the shear wave amplitude, as assessed by the PNR, was large. As a result, these ROI's included some regions that would normally be considered unfavorable for 2-D analysis due to the presence of oblique wave propagation and multipath interference, thus contributing to some of the dispersion in stiffness values reported by the 2-D technique.

Conclusions:

An advantage of liver MRE over biopsy and ultrasound-based transient elastography is its ability to reduce sampling errors by measuring liver stiffness over a large area of the liver. While the current 2-D approach provides valid results in a substantial part of the liver, using a 3-D/3-axis wave analysis can increase this coverage even more (6). In this study, we implemented an EPI- based method for 3-D wave imaging of the liver and compared 2-D and 3-D inversions of the data. The good correlation with the conventional 2-D analysis and improved homogeneity makes this fast 3-D approach practical for clinical applications.

References:

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