Validity of a 2-D Wave Field Model in MR Elastography of the Liver

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Introduction: MR Elastography (MRE) is an MRI-based technique for assessing the mechanical properties of soft tissues by visualizing propagating shear waves and processing the data with an inversion algorithm to generate quantitative stiffness maps (1). In general, the inversion algorithm requires datasets that sample the pattern of wave propagation in 3-D space, with acquisition of the x, y, and z cyclic displacement at each point within the 3-D volume, and imaging at multiple time points in the wave cycle – essentially 7-dimensional imaging. The acquisition time required to obtain 7-D data is lengthy and particularly inconvenient for abdominal imaging, where it is best to image during suspended respiration. Fortunately, there are situations in which the characteristics of the wavefield can be optimized so that 2-D wave imaging can provide valid results in much shorter acquisition times. For instance, multiple studies have demonstrated that 2-D MRE of the liver (with acquisition times as short as 15 sec) can be used to reliably diagnose and stage hepatic fibrosis, in some cases eliminating the need for biopsy (2-4). The purpose of this study was to further validate the 2-D acquisition approach for hepatic MRE and to identify parameters where the 2-D wavefield model may consistently break down.

Materials and Methods: All experiments were implemented on a 1.5 T whole-body GE imager (Signa, GE Healthcare, Milwaukee, WI, USA). Experiments were conducted using a pressure-activated acoustic driver system that has been designed to generate shear wave fields that are well-suited for axial 2-D wave imaging (5). The driver system generates shear waves that arise mainly in the anterior and right lateral margins of the liver and propagate roughly transversely (4), as shown in Fig.1. We performed 2-D and full 7-D wave imaging in 3 normal volunteers and 12 patients with biopsy-proven hepatic fibrosis were imaged after obtaining informed consent and in compliance with the Mayo Clinic IRB. A gradient echo based MRE sequence with gradient moment nulling was used to collect axial wave images with identical parameters to those in reference (4). The location for the 2-D acquisitions was determined by selecting the widest part of the liver, as shown in the green band of Fig.1. Full 7-D wave imaging was implemented with a spin-echo echo planar imaging (EPI) technique to collect wave data throughout the entire liver with 5-mm slice thickness with identical parameters to those in reference (6). The total acquisition time for the entire MRE exam is around 5 minutes. We analyzed the single-slice MRE data with a multi-scale direct inversion algorithm (7). The EPI MRE data were analyzed using directional filters (8) and local frequency estimation (LFE) inversion algorithms (7). ROIs for the mean stiffness measurements were designed to exclude large hepatic and portal vessels; to exclude ascitic fluid, bowel gas, or areas outside the liver; to be as large as possible yet be slightly away from the edges; and to have no areas of poor shear displacement or non-planar wave propagation. Finally, a least-squares linear regression with zero intercept was performed to estimate the 2-D and 3-D MRE stiffness measurements.

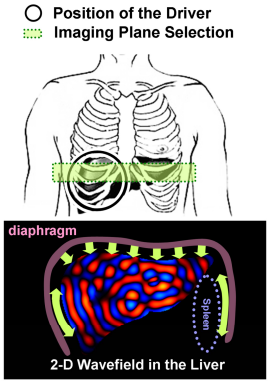


Fig.1 Optimized acoustic driver vibrates the diaphragm, which acts as a secondary intrinsic driver that is well coupled to the anterior and lateral margins of the liver.

Results: The results of the 7-D wave acquisition and inversions were used as "ground truth". Analysis showed that 2-D imaging and inversion of sections located within 1 wavelength of the superior margin of the liver consistently resulted in markedly erroneous stiffness values, due to the obliquity of wave propagation at this level (Fig 2, top row). The 2-D wavefield model also frequently broke down in the inferior part of the right lobe of the liver, where longitudinal propagation is often present along with multipath interference (Fig 2, lower row). In contrast, 2-D imaging in the "widest" cross section of the liver (green bands in Fig 2) consistently yielded inversion results that were comparable to those obtained with the much more time consuming 7-D imaging approach. Fig.3 summarizes the results obtained in all 15 subjects of this study. Within the favorable region, there was a strong correlation (R^2 = 0.98) between the 2-D and 3-D measurements in this study cohort and the agreement was within 6%.

Fig.2

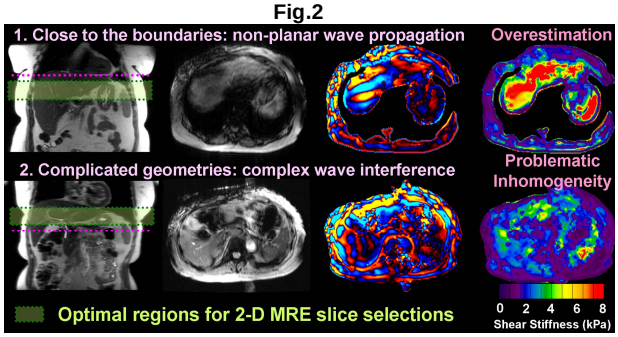
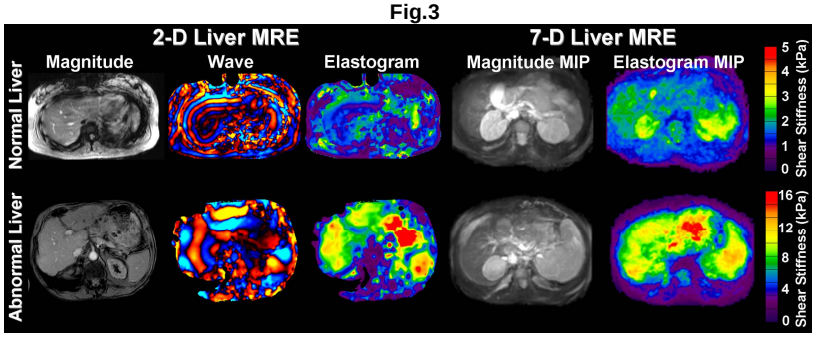
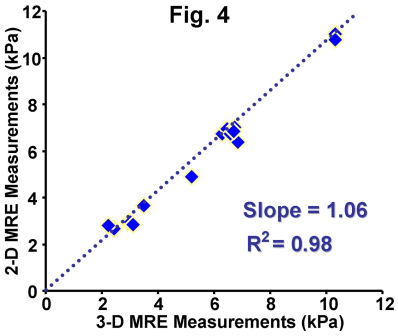


Fig.3





Discussion: One advantage of liver MRE over biopsy or ultrasound-based transient elastography is its ability to reduce sampling error by measuring liver stiffness in multiple areas of the liver. While full 7-D wave imaging offers valid measurement of stiffness throughout the liver, the 2-D approach provides valid results in a significant part of the volume, with a substantially reduced imaging time. The key element of the protocol that makes this possible is an acoustic driver system that has been optimized to provide a wave propagation geometry that is suitable for 2-D wave imaging.

Conclusions: The results show that with an optimized acoustic driver for hepatic MRE, the 2-D wave field model is generally valid in the axial imaging planes distanced at 2~10 cm away from the superior margin of the liver, assuming the liver has average vertical height of 15 cm. 2-D wave analysis should be avoided within one wavelength of the superior margin of the liver and in the inferior portion of the right lobe, where the assumptions of the model are not sufficiently met.

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