Value of Shear Wave Attenuation as a Tissue Characterization Parameter in MR Elastography of the Liver

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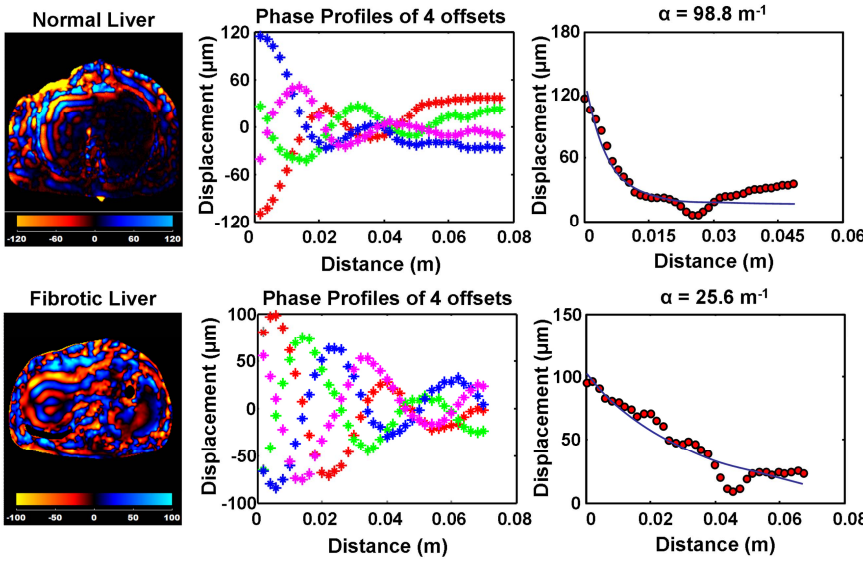
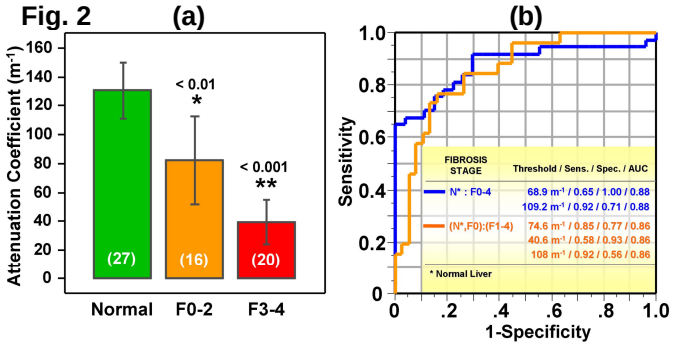
Introduction: Chronic liver disease is a world-wide problem, with many underlying causes. The major pathobiologic process is hepatic fibrosis, a nonspecific response to chronic liver injury that, if unchecked, can progress to irreversible cirrhosis and high mortality. The current gold standard for diagnosing liver fibrosis is biopsy, which is invasive and associated with sampling error. Conventional imaging modalities are not capable of demonstrating liver fibrosis prior to the onset of cirrhosis. Recently, assessing the dynamic mechanical properties of biological tissue has been an emerging field in medical imaging research. There are two main methods to induce and measure shear waves in soft tissues. One is ultrasound-based transient elastography. The other is Magnetic Resonance Elastography (MRE) (1), which has many advantages in depth capability and volumetric measuring. Shear stiffness measured with MRE (equal to squared shear velocity) has been shown to be an accurate method for diagnosing hepatic fibrosis (2-4). Shear wave attenuation, which causes a decrease in the amplitude of shear waves with distance, may be a potential independent indicator of pathological changes in the liver, accessible from the same data as used for MRE. The goal of this work was 1) to calculate shear attenuation from MRE wave images of the liver; 2) to determine whether shear attenuation can be used in detecting and characterizing hepatic fibrosis; 3) to test whether the combination of shear stiffness and shear attenuation improves diagnostic ability. If confirmed, this could have a further substantial impact on the management of patients with chronic liver disease, where it is crucial to diagnose and treat fibrosis before it progresses to irreversible cirrhosis.

Fig. 1



Materials and Methods: All experiments were implemented on a 1.5 T whole-body GE imager (Signa, GE Medical System, Milwaukee, WI, USA), using the body coil. Volunteers and patients were imaged in a supine position, with a 19-cm cylindrical passive pneumatic driver placed against their anterior body wall. Continuous vibrations at 60 Hz generated shear waves throughout the tissues in the abdomen. A gradient echo based MRE sequence with flow compensation was used to collect axial wave images with the following parameters: FOV = 32~42 cm, Flip angle = 30°, Slice thickness = 10 mm, TR/TE = 50/32 ms, Matrix = 256×64, 1 pair of trapezoidal motion encoding gradients; 4 phase offsets. The acquisition time was 40 seconds, split into 4 periods of suspended respiration. Figure 1 demonstrates the method we used to calculate the shear attenuation of the liver. The attenuation coefficient was calculated from manual measurements of 10 phase profiles perpendicular to the wave front on the MRE wave images as shown in the far left column. In the middle column, shear displacements along the selected phase profiles were illustrated for all four phase offsets in different colors. Shear displacement amplitude at 60 Hz was then calculated by extracting the amplitude value of the first temporal harmonic of each pixel along the phase profiles. Next, linear least squares curve fitting was used to calculate the attenuation coefficient α by fitting an exponential function as shown in the far right column. Considering the manually selected profiles may slightly vary from the wave propagation direction, the maximal value was assumed to be the most reliable measurement after exempting outliers. A total of 27 normal volunteers and 36 patients with biopsy proven fibrosis have been evaluated.

Fig. 2



Results: Figure 1 illustrates two examples: a normal volunteer and a patient with hepatic fibrosis. Good shear wave illuminations covered the entire liver. Shear waves in the normal liver were more attenuated than that of the fibrotic liver. Fig. 2(a) shows the mean and standard deviation of the calculated attenuation values from three groups: 27 normal healthy volunteers, 16 patients with mild fibrosis (stage 0 to 2) and 20 patients with severe fibrosis (stage 3 to 4). Liver attenuation decreased systematically with the degree of fibrosis. Significant differences (overall p-value < 0.01) were found between every two groups. ROC analysis, shown in blue curve of Fig. 2(b), demonstrated that with a cutoff value of 68.9 m^{-1}, the shear attenuation measurement has a specificity approaching 100% for identifying normal livers; while with a cutoff value of 109.2 m^{-1}, it has a sensitivity of 92% with an ROC area of 0.88. Results of another grouping are illustrated in Fig. 2(b) as well.

Discussion and Conclusion: In the clinical application of MRE for hepatic fibrosis, we observed that the penetration depth of propagating shear waves significantly increases in the liver with fibrosis. This study confirmed our visual observations that the shear attenuation decreases systematically in the liver with increased fibrosis content. Current 1-D profile based measurements provide strong motivation for further development of a reliable image-based high resolution inversion algorithm to calculate shear attenuation. To account for the viscoelastic nature of soft tissue and take advantage of the attenuation behavior of the shear wave propagation, there is a need to explore whether it can further improve the diagnostic ability of MRE with combination of both shear stiffness and shear attenuation measurements. We are expecting to provide a wider evaluation with both shear stiffness and shear attenuation of hepatic MRE in patients with suspected hepatic fibrosis, sparing them the discomfort and risk of complications associated with liver biopsy, and potentially increasing the reliability of diagnosis by reducing sampling errors.

References: [1] R. Muthupillai, Science 1995, 269: 1854-7. [2] O. Rouviere, M. Yin, et al. 2006, Radiology 240(2): 440-8. [3] L. Huwart, 2006, NMR Biomed 19(2): 173-9. [4] M. Yin, et al. 2007, Clincal Gastroenterology and Hepat 2007;5:1207-1213.