

A novel approach for hepatic viscoelastic characterization using magnetization-tagged MRI and single-degree-of-freedom (SDOF) viscoelastic model

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Introduction: Liver fibrosis is an important prognostic factor in patients with liver disease, and it may serve as a marker of the presence of progressive liver disease while it is still in a subclinical and more treatable state. It is known to result in increased mechanical stiffness, so that the assessment of liver stiffness is a key feature of current noninvasive approaches. In our previous study [1], we described a new noninvasive approach for the assessment of liver stiffness by using tagged MRI (tMRI) to measure the cardiac-induced motion and deformation in the liver. In this study, we extended the previously used simple elastography estimation of liver stiffness, which have primarily considered the elasticity alone, to include viscoelastic properties, by looking at the time behavior of the cardiac-induced motion. A single degree-of-freedom (SDOF) viscoelastic model was applied in healthy subjects and patients with cirrhosis in order to estimate the stiffness of the liver.

Method: Tagged MRI was performed on 5 healthy volunteers (29 ± 3 years old) and 10 patients (54 ± 7 years old) with cirrhosis. Subjects were scanned using a 3T MRI system (Tim Trio; Siemens) with breath-holding by the subjects. A Gabor filter bank was used to calculate the displacement within the liver (Fig.1a). Local maximum displacement (mm) was found over the cardiac cycle within the regions of interest where the greatest average value occurred, and then was normalized by both the peak displacement and the times of end systole (Fig.1b). A SDOF viscoelastic model was applied with a harmonic excitation force ($c\dot{u}(t) + ku(t) = F \sin(\Omega t)$; u , displacement (mm); c , the damping (Ns/mm); k , the stiffness (N/mm); F , the force (N)), and the nonlinear least square fitting method was used to estimate c , k , and F for each subject. Group comparisons were made using Mann-Whitney U tests.

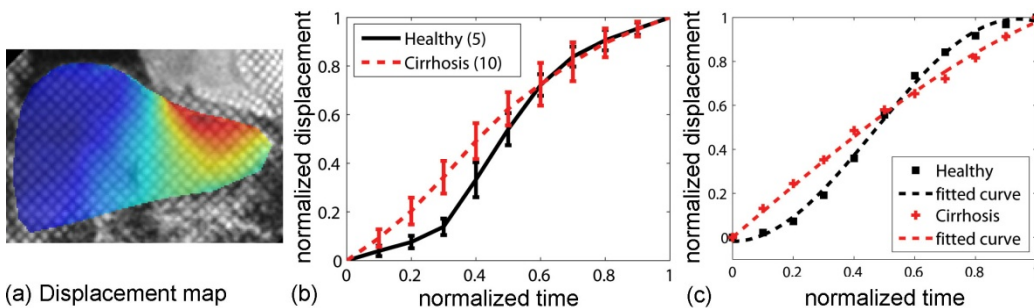


Figure 1. (a) Displacement map for a representative healthy subject, (b) normalized displacement plots for all healthy and cirrhosis patients, and (c) representative plots with fitting.

Results: Figure 1b shows the normalized displacement plots for all healthy subjects and patients through end-systole. We have observed that they respond differently when loaded. Figure 1c shows normalized displacement plots of representative healthy and patient and the corresponding fitting using the SDOF model.

In Fig.2, the boxplots show statistically significant differences between healthy and patients in the stiffness, k (0.41 ± 0.38 , 2.6 ± 0.48 ; $p < 0.001$) and in the damping, c (1.66 ± 0.2 , 0.28 ± 0.4 ; $p < 0.001$), but less significant in the force, F (2.95 ± 0.02 , 2.97 ± 0.02 ; $p = 0.012$), respectively.

Discussion: This study used a noninvasive tMRI to measure cardiac-induced motion in the liver, to assess liver stiffness. A simple SDOF viscoelastic model was used to estimate the stiffness of the liver. The results showed strong differences in the "stiffness" and the "damping" between healthy and cirrhosis livers, and it may provide an additional novel means for tissue characterization.

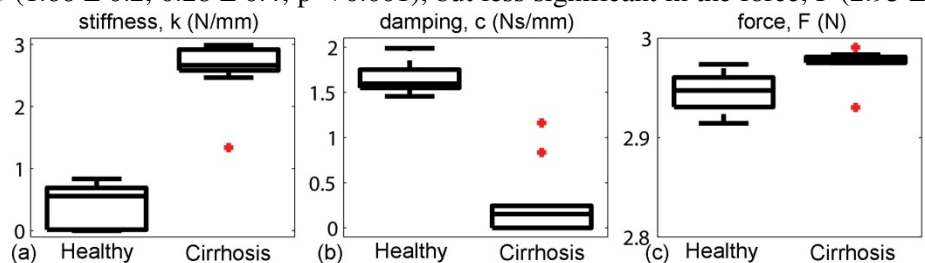


Figure 2. Boxplots of (a) the stiffness, k , (b) the damping, c , and (c) the force, F .

Future work should include more validation studies for the model with phantoms. **References:** [1] S. Chung, et al., MRM. 2011.