# Liver Stiffness Assessment by Tagged MRI of Cardiac-induced Liver Motion

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**INTRODUCTION:** Liver disease is an important and growing public health problem, with its frequently being clinically silent progression to the later serious complications of cirrhosis. A pathological hallmark of the progression to cirrhosis is the development of liver fibrosis, so that monitoring the appearance and progression of liver fibrosis can be used to guide therapy. Fibrosis of the liver is known to result in increased mechanical stiffness [1], as can be felt on direct palpation at surgery or postmortem examination; this is the basis of current noninvasive approaches to the assessment of liver stiffness with ultrasound or MRI [2, 3], using these modalities to detect the motion of the liver induced by external sources. In this study, we used the pulsations of the heart as an intrinsic motion source to transiently deform the liver and magnetization-tagged MRI [4] to measure the cardiac-induced motion and deformation in the liver for the assessment of liver stiffness; the initial feasibility study was presented at [5]. In this work, we described a practical implementation and quantitative analysis of this liver tagged MRI method.

**METHODS:** An electrocardiogram-gated tagged MR sequence was performed on 8 healthy volunteers (32 ± 4 years old) and 7 patients (61 ± 13 years old) with MRI evidence of cirrhosis. Subjects were scanned using 3T (Tim Trio; Siemens) or 1.5T (Avanto; Siemens) MRI systems, with standard phased-array coils, breath-holding by the subjects and the following imaging parameters: field of view = 300x300 mm$^2$, acquisition matrix = 256x256, slice thickness = 6 mm, TE = 4 ms, flip angle = 10°, TR =48 ms, tag spacing = 7 mm, 15-20 images/heartbeat, total acquisition time ~ 20s. Since heart induces a complex 3D motion in the liver, tagged MR images were acquired in 3 coronal and 3 sagittal planes encompassing both the liver and the heart, as shown in Fig. 1; the acquisition of 6 imaging planes added about 5 min to clinical exams. For image analysis, a Gabor filter bank [6] was used to adaptively detect the tag position information and then the displacement and strains were calculated within the liver. For data analysis, regions of interest (~18x18 mm$^2$, 240 pixels) were chosen in liver regions below the diaphragm where the greatest average value occurred for the displacement and P1, P2 strains. The local maximum P1 and minimum P2 strains (as well as the maximum displacement) were found over the cardiac cycle among the 6 imaging planes and were then normalized by the maximum displacement for the quantitative comparison between subjects.

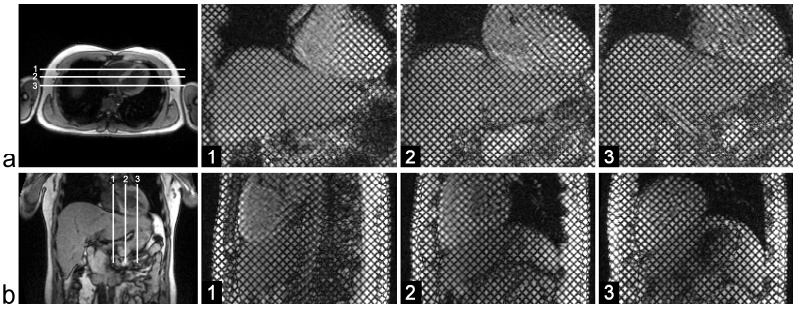


FIG. 1 **a:** Axial localizer image with the three coronal imaging planes (white lines), and corresponding grid-tagged images. **b:** Coronal localizer image with the three saggital imaging planes (white lines), and corresponding grid-tagged images.

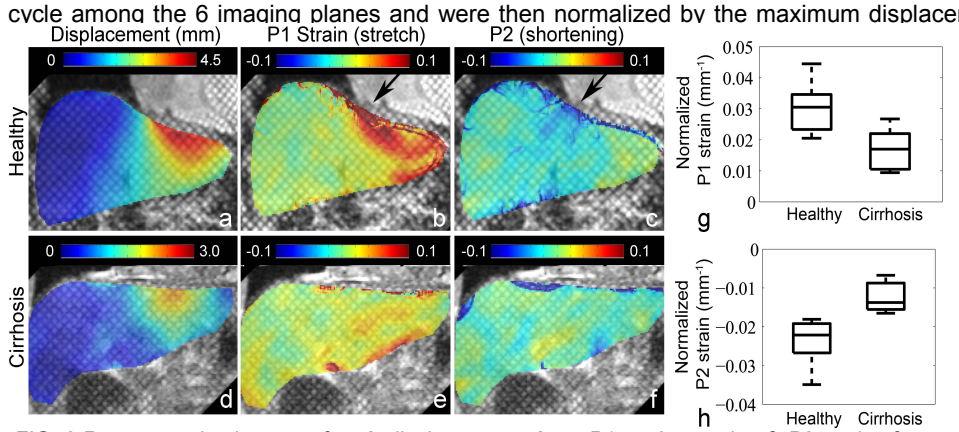





FIG. 2 Representative images of **a, d:** displacements, **b, e:** P1 strains, and **c, f:** P2 strains for a healthy subject and a cirrhotic patient. **g:** Normalized P1 strain and **h:** normalized P2 strain for all healthy subjects and cirrhotic patients (p<0.005 for all).

**RESULTS:** Fig. 2a-2f show images of displacement, P1 and P2 strains of a representative healthy subject and a cirrhotic patient, in representative coronal planes, superimposed over the liver. In the healthy subject, relatively high concentrations of the motion and deformation are seen to be localized beneath the heart, but this is appreciably less so in the cirrhotic patient, reflecting the greater stiffness of the cirrhotic liver and its resistance to stretching and shearing deformations. The boxplots in Fig. 2g and 2h show statistically significant differences in the normalized P1 and P2 strains between healthy subjects and cirrhotic patients (0.030 ± 0.008, 0.017 ± 0.007; -0.024 ± 0.006, -0.013 ± 0.004; healthy, cirrhosis; respectively; p < 0.005 for all).

**DISCUSSION:** This study described a quantitative approach for the new noninvasive method using tagged MRI to measure cardiac-induced motion and deformation in the liver to assess liver stiffness, which is expected to provide an early marker for the development of liver fibrosis. This method could be complementary to other methods (e.g., ultrasound or MRE) since it is mainly sensitive to the properties of the left lobe of the liver, while others primarily approach the right lobe of the liver. This method may have some potential problems if applied to patients with ascites, pericardial effusions, cardiac arrhythmias, systolic heart failure, or short left lobe of the liver. In conclusion, this noninvasive method performed with conventional MRI equipment provides a set of image-derived measures that are very directly and intuitively related to the underlying mechanical stiffness of the liver, without the need for extended indirect analyses. Therefore, there is a significant potential for this method to have a beneficial impact on patient care.

**References:** [1] Yeh WC, et al., Ultrasound Med Biol, 28(4):467-474, 2002. [2] Tristan M, et al. Ultrasound Med Biol. 12:927-937, 1986. [3] Mariappan YK, et al. MRM 62, 2009. [4] Axel L and Dougherty L. Radiology 171:841-845, 1989. [5] Chung S, et al. Proc. ISMRM, #254, 2010. [6] Chung S, et al. Proc. ISMRM, 2007.