A Protocol for Assessing Hepatic Fibrosis in Iron-Overloaded Liver Tissue with MR Elastography

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Introduction: MR Elastography (MRE) [1] is increasingly being used to measure tissue stiffness in different areas of the body. It has recently shown great success in the liver for the evaluation of hepatic fibrosis in patients with chronic liver diseases [2]. Patients that have had high iron concentration in their liver tissue, which leads to severely, shortened T2/T2*, can be problematic at 3.0T because it produces poor MR signal in the liver and MRE liver stiffness measurements may not be valid due to the extremely low SNR. Motivated by this particular difficulty, we explored the relationship between the SNR and the motion sensitivity of MRE by varying the time duration of the motion-encoding gradients (MEG) in the MRE pulse sequence. A modified MRE protocol with broader receive bandwidth and fractional period MEG was developed for use in patients with iron-overloaded liver tissue. The hypothesis of this work was that the modified protocol would improve the SNR in liver MRE exams while maintaining or improving the stiffness estimates.

Theory: The current MRE protocol for clinical hepatic imaging uses 60 Hz mechanical motion to generate shear waves within the liver tissue. One set of flow-compensated trapezoidal MEG [3] with time duration of 16.7 ms (i.e., 1/(60 Hz)) is used in the gradient-echo-based MRE sequence to obtain wave images. This protocol works well for most human subjects with normal T2* values of the liver above 30 msec. For an iron-overloaded patient, the T2* value of the liver could be as small as a few milliseconds. We expect that shortening the echo time will improve the SNR in these patients, but this requires that the MEG time duration to be reduced substantially [4]. We analyzed the phase sensitivity of various flow-compensated trapezoidal MEG of duration $T_{meg} = 1/F_{meg}$ for various frequencies of vibration F_v, as demonstrated in Fig. 1. The motion sensitivity decreases rapidly when the duration of the MEG is less than that of the motion. For the proposed modified protocol, the MEG duration was shortened by 45% to 9.2 ms. In this case, the sensitivity will decrease by about 75%, but the echo time will also decrease by about 7.5 ms.

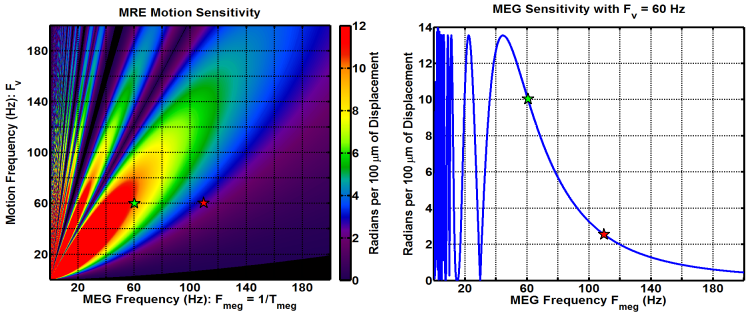

Fig.1: MRE motion sensitivity for different motion and MEG frequencies. Stars indic

Methods: All experiments were performed on a 1.5T and 3.0T MR scanner (Signa, GE Healthcare, Milwaukee, WI, USA), using an 8-channel torso coil. 10 normal volunteers with no known liver disease and one patient with hemochromatosis were imaged in the supine position with a 19-cm cylindrical passive pneumatic driver placed against their anterior body wall. Continuous vibrations at 60 Hz were applied, producing shear waves throughout the abdomen. A gradient-echo-based MRE sequence with flow compensation was used to collect axial wave images with the standard protocol (16.7 ms MEG) and the modified protocol (9.2 ms MEG). The standard protocol is identical to that in reference #2. For 1.5T, the modified imaging parameters were: TR/TE =33.3/16.6 ms, receiver bandwidth = 32 kHz, flip angle = 23^0, 4 phase offsets. The 3.0T modified protocol was the same except the flip angle was changed to 16^0, and TR/TE = 33.3/15.8 ms. We analyzed the MRE data with a multiscale direction inversion algorithm with multiple directional filters to generate stiffness maps (elastograms). Identical ROIs were selected in each individual liver under all four situations (1.5T and 3.0T, standard and MODIFIED protocols). The mean liver stiffness and magnitude SNR were then analyzed to determine if there is a significant difference in the liver stiffness measurements and the MR signal between the two protocols.

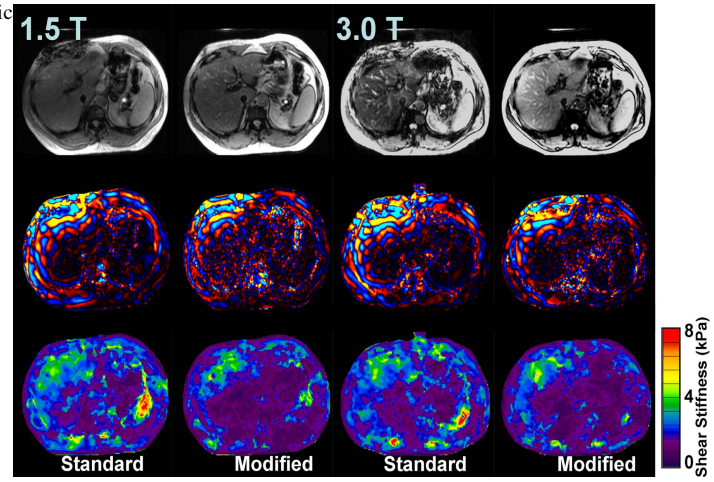

Fig.2. Example data from one patient with mild hemochromatosis. 1.5T results are on the left, and 3.0T results are on the right. The left column in each case shows data from the standard protocol (Full MEG), whereas the right column shows the data from the modified (55% MEG) protocol.

Results: Fig.2 shows anatomical (MR magnitude) images, wave images, and elastograms for one volunteer comparing the standard and modified protocols at 1.5T and 3.0T. The result of the modified protocol at 1.5T from the patient with hemochromatosis is illustrated in the far right of Fig.2 as well. The average mean values of the 10 volunteers for liver stiffness and SNR measurements are listed in the table below (Table 1). The average liver stiffness (kPa) and the SNR measurements were compared by protocol using the paired T-test (1.5T standard protocol (1.5S) to the 1.5T modified protocol (1.5M), the 3.0T standard protocol (3.0S) to the 3.0T modified protocol (3.0M), and the 1.5T standard protocol (1.5S) to the 3.0T modified protocol (3.0M)) (Table 2). There were no significant differences ($p < 0.05$) between the different protocols in regard to liver stiffness. There was a significant difference in SNR between the 1.5S/1.5M and 3.0S/3.0M protocols, but there was not a significant difference in the SNR between the 1.5S/3.0M protocols. SNR increased by 85% from the 3.0S protocol to the 3.0M.

Table 1	Liver Stiffness (kPa)	SNR
1.5 S	2.287 ± 0.38 kPa	8.489 ± 2.02
1.5 M	2.237 ± 0.34 kPa	9.901 ± 2.33
3.0 S	2.363 ± 0.38 kPa	5.248 ± 1.89
3.0 M	2.305 ± 0.37 kPa	9.729 ± 2.96

Table 1. Mean averages for liver stiffness and SNR from 10 volunteers using the standard protocol and the modified protocol at 1.5T and 3.0T.

Table 2	Liver Stiffness (kPa)	SNR	SNR Change
1.5S/1.5M	**p = 0.363**	*p < 0.013*	**17%**
3.0S/3.0M	**p = 0.105**	*p < 0.010*	**85%**
1.5S/3.0M	**p = 0.820**	**p = 0.226**	**15%**

Table 2. P-values and percent SNR changes between the standard protocol and the modified protocol at 1.5T and 3.0T.

Conclusion: The hypothesis of this work was that the new modified liver MRE protocol would improve SNR without affecting tissue stiffness measurements for iron-overloaded patients. On all the ten normal volunteers, it was demonstrated that there was no significant difference in liver stiffness at 1.5T or 3.0T between the standard and modified protocols. However, there was a significant increase in SNR with the modified technique at both 1.5T and 3.0T. It was also noted that there was not a significant difference in SNR between the standard 1.5T protocol and the 3.0T modified protocol. The SNR increase is due primarily to the change in TE when changing from the standard protocol to the modified protocol. By decreasing the TE, the T2* effects decreases which contributes to the increase in SNR. This modification to the liver MRE pulse sequence will allow patients with an iron-overloaded liver to be imaged at 3.0T.

Reference: [1]. Muthupillai R, Lomas DJ, Rossman PJ, Greenleaf JF, Manduca A, Ehman RL. Science 1995;269(5232): 1854-1857.

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