

MR ELASTOGRAPHY OF LIVER WITH IRON OVERLOAD: DEVELOPMENT, EVALUATION AND PRELIMINARY CLINICAL EXPERIENCE WITH IMPROVED SPIN ECHO AND SPIN ECHO EPI SEQUENCES

Yogesh K Mariappan¹, Sudhakar K Venkatesh¹, Kevin Glaser¹, Kiaran P McGee¹, and Richard L Ehman¹

¹Department of Radiology, Mayo Clinic, Rochester, MN, United States

Introduction. MR Elastography (MRE¹) is a noninvasive imaging technique that can measure the stiffness of soft tissues by introducing shear waves into the organ of interest, tracking the wave motion with a phase-contrast MR pulse sequence and calculating the relevant mechanical properties by application of mathematical inversion algorithms. MRE is being investigated for an array of applications and has obtained clinical acceptance for the assessment of hepatic fibrosis^{2,3}. While the MR signal of the liver during a standard gradient echo (GRE) MRE exam is very high, the deposition of iron in various pathological processes such as hemochromatosis can result in significant T_2/T_2^* -dependent signal reduction. It has been reported in a large study of 1377 patients that among the ~5.6% of exams that resulted in technical failure, high iron deposition accounts for nearly 75% of such cases. This is an important clinical problem since iron deposition is known to be a coexistent condition in various chronic liver diseases. We hypothesized that the liver signal and hence the success rate of MRE can be improved by developing pulse sequences that are less sensitive to T_2 . The goal of this work was to develop and evaluate short-TE spin echo and spin echo EPI pulse sequences in healthy volunteers and in patients with iron overloaded livers.

Methods. All experiments were conducted in accordance with institutional review board guidelines and were performed on a 1.5-T whole-body MR scanner (Signa EXCITE, GEHC, Waukesha, WI).

Spin Echo MRE: The standard clinical hepatic MRE protocol uses a fast GRE pulse sequence (GRE MRE) which is sensitive to the T_2 of the liver parenchyma, which can be as low as ~1.3 ms in iron overloaded livers. To address this, a spin echo MRE pulse sequence (SE MRE) was developed to make the signal less sensitive to the reduced T_2 . The sequence was optimized using modifications recently described for pulmonary MRE⁵, including fractional motion encoding, crusher gradient removal and split-unipolar motion-encoding gradients (of 2 ms duration) positioned on either side of the 180° RF pulse. With these developments, the TE of the sequence could be reduced to 10 ms, and a schematic representation of this sequence is shown in the middle row of figure 1. The conventional GRE MRE sequence (with 23.1 ms TE) is shown in the top row for comparison.

Spin Echo EPI MRE: In addition to the SE MRE sequence, a spin echo EPI pulse sequence was also developed allowing for faster imaging with modifications similar to the SE MRE pulse sequence. The advantages and disadvantages of EPI-specific parameters including the number of shots (and therefore the length of the echo train) and the effective TE were investigated. Eight shots (echo train length of 8 with 64 phase encodes) with a TE of 10.1 ms were determined to be optimal for liver MRE. To achieve the low TE value, chemical presaturation pulses were used instead of a spatial-spectral RF pulse for fat suppression. A schematic of this pulse sequence is shown in the bottom row of figure 1.

To determine if the new sequences provide similar hepatic stiffness measurements to the current standard, the sequences were evaluated on 6 subjects who had no known iron deposition in their livers; 3 of these subjects were healthy volunteers and the other 3 were undergoing clinically indicated liver MRE. Shear vibrations of 60 Hz introduced into the liver with a pressure activated driver system were imaged with the standard GRE MRE pulse sequence and the two optimized sequences developed in this work. A multimodel direct inversion algorithm was used to calculate the tissue stiffness from the displacement images and the values obtained from the 3 pulse sequences were compared. Other imaging parameters included: imaging plane = axial, FOV = 42 cm, motion-sensitizing direction = SI, and 4 phase offsets. The applicability of these sequences to imaging livers with high iron deposition was assessed by performing MRE on two patients with known hepatic iron overload.

Results. The validation study of 6 volunteers comparing the stiffness values from the 3 pulse sequences is shown in figure 2. It can be seen that the spin echo pulse sequences provided shear stiffness values that were comparable to the standard GRE MRE pulse sequence. This indicates that these sequences could be used clinically for the assessment of hepatic fibrosis with the current diagnostic stiffness thresholds. The results obtained from one of the patients with iron overload in the liver are shown in figure 1. The top row shows the magnitude image and the shear stiffness map obtained from the standard sequence. The middle and the bottom rows show the corresponding data from the SE and SE-EPI MRE sequences, the significant increase of the liver parenchyma signal can be appreciated from the magnitude images. Due to the low liver signal in the GRE data (comparable to the background noise), the inversion algorithm masked away the liver region completely and hence no shear stiffness information could be calculated for the liver. However, due to the improved SNR in the spin echo approaches, the stiffness could be calculated with high confidence (3.2 kPa and 3.3 kPa for the SE and SE-EPI MRE sequence, respectively). Similar results were obtained from the second patient.

Conclusions. Our preliminary results suggest that these SE and SE-EPI liver MRE sequences can quantify hepatic fibrosis in iron overload patients and provide shear stiffness measurements comparable to standard GRE MRE. Currently we are evaluating these sequences in a larger group of patients.

Acknowledgements. This work was supported by NIH EB07593, NIH EB001981

References. (1) Muthupillai et al., *Science* 269: 1854-1857, 1995. (2) Huwart et al., *Radiology* 245 :458-466, 2007. (3) Asbach et al., *MRM* 60 :373-379, 2008. (4) Yin et al., ISMRM 19th Annual meeting, 390, 2011. (5) Mariappan et al., *JMRI* 33 :1351-1361, 2011.

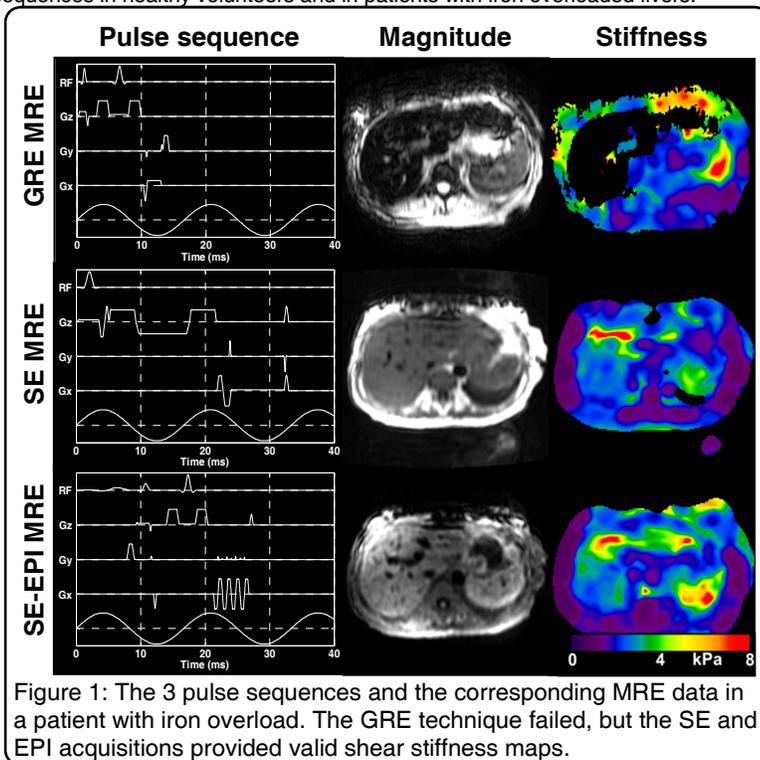


Figure 1: The 3 pulse sequences and the corresponding MRE data in a patient with iron overload. The GRE technique failed, but the SE and EPI acquisitions provided valid shear stiffness maps.

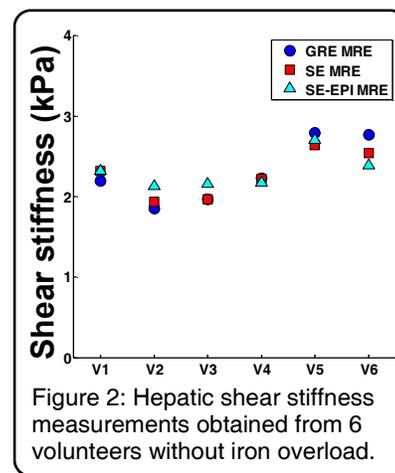


Figure 2: Hepatic shear stiffness measurements obtained from 6 volunteers without iron overload.