MR Elastography with Improved Coverage Using 3D Gradient-Echo Based EPI

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Introduction

Magnetic resonance elastography (MRE) is an MR imaging technique which can be used to visualize acoustic strain wave propagation in tissues and quantify their stiffness when tissues are subjected to external mechanical excitation [1]. Previous studies have showed that MRE is useful in the diagnosis of various diseases such as liver cirrhosis [2]. Two dimensional (2D) gradient-echo MRE techniques are commonly used for MRE of the liver. Multiple breath holds are needed to cover the liver and the acquisition time is long (e.g., [3]). Three dimensional (3D) spin-echo based echo-planar imaging (EPI) shortens the acquisition to less than one minute, but the images suffer from low spatial resolution and low SNR [4]. 2D gradient-echo based EPI pulse sequence has also been proposed but its SNR decreases with high echo train length [5]. We propose here the use of 3D gradient-echo based EPI for liver MRE that improves spatial coverage without compromising image SNR. The technique will help reduce the examination time of the liver using MRE by at least 6 folds.

Materials and Methods

The Sequence: It is a 2D EPI similar to [5] with partition encoding except that motion encoding gradient from [2] was used. The sequence supports linear reordering.

Imaging: To mimic pathological changes in the experiment, a phantom was made from three inhomogeneous agars of different stiffness. Shear wave was generated by a pneumatic driver whose direction of vibration is parallel to the main magnetic field. A driving frequency of 60Hz was used in the experiment, performed on a 3.0T MR system (Magnetom TIM Trio, Siemens, Erlangen). The head coil was used for signal reception. Coronal images were acquired.

The 3D GE-EPI sequence was first used to image the shear waves. The 2D gradient echo sequence was then used on two consecutive image positions selected from the 3D EPI for comparison. Imaging parameters for the 3D EPI sequence were: bandwidth = 1132Hz/pixel, echo train length (ETL) = 9; 1-1 water excitation pulse, 10 slices per slab, 20% slice oversampling, 6/8 slice partial Fourier. The 2D gradient echo sequence used a bandwidth of 170Hz/pixel (minimum allowed for a given TE). Other imaging parameters common to both sequences were: TR/TE = 33.33ms/23.3ms; flip angle = 10º; FOV = 20cmx20cm; matrix: 192 x 96 (50% phase resolution); slice thickness = 5 mm; motion-encoding gradient applied along the slice direction; 4 phase offsets. Parameters for the 2 sequences were set up so that the scan times for both sequences were kept the same at about 27seconds. Images from the new 3D EPI sequence was compared with the 2D gradient echo sequence in terms of SNR, spatial coverage, and stiffness images.

Image analysis: The SNR of the slices acquired by EPI were measured. The SNR of the central 2 slices from the 3D image slab were compared to the 2D slices obtained by the standard MRE sequence at the corresponding positions. Here, the SNR was defined as the mean of the magnitude images from the 4 phase offsets. The shear stiffness of the phantom of the 2 slices from the center of the 3D datasets were obtained using the "MRE wave" software downloaded from Mayo Clinic. They were visually compared to those obtained using the 2D slices at the corresponding positions..

Results

Figure 1 shows the magnitude and phase images of one slice from the 3D data set. Table 1 shows the SNR of the two slices from the two different imaging methods. Note that the SNR of the slices from the 3D technique are slightly higher than that of the 2D slices. The SNR of the 10 slices in the 3D image slab was shown in Figure 2. The SNR variation among the slices suggested that the slice profile is suboptimal. Figure 3 shows the shear stiffness maps of the 2 slices using images acquired by both methods. There was no obvious difference between the stiffness maps from the two methods.

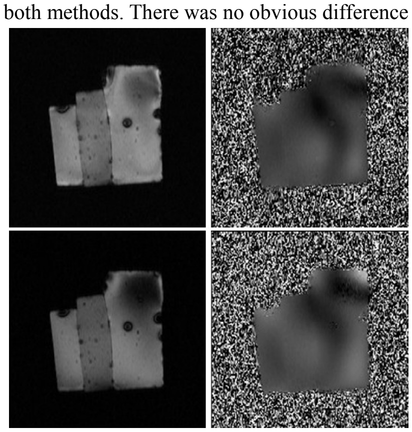

Figure 1. Magnitude and phase image from slice 5 of 3D EPI sequence (top row) and the corresponding 2D gradient echo sequence (bottom row).

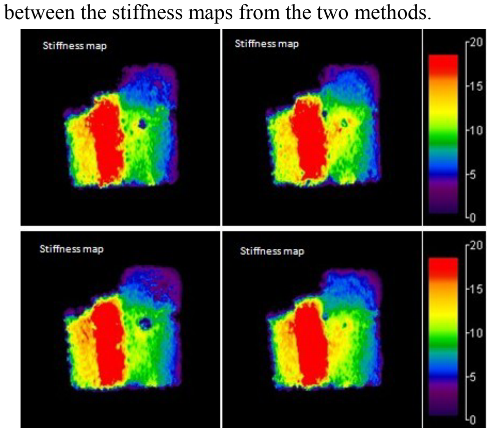

Figure 3. Stiffness map of two slices (slice 5 on left and slice 6 on right) from 3D EPI sequence (top row) and the corresponding 2D gradient echo sequence (bottom row).

Table 1 SNR comparison of two slices from the two sequences

	Slice 5	Slice 6
3D EPI	98.62	97.29
2D GRE	90.72	94.72

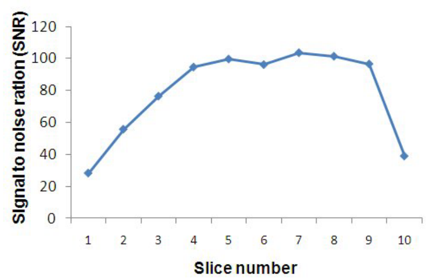

Figure 2. SNR of 10 slices from 3D EPI

Discussion

Our results demonstrated that 3D EPI sequence can be used to speed up MRE acquisitions by 6 folds without compromising image SNR. Unlike spin echo EPI based 3D MRE which has reduced SNR (by 6dB, [4]), the 3D gradient echo based EPI method maintains SNR though improved spatial coverage. In MRE, TR is dictated by the vibration frequency. For a given a specific TR, SNR in a gradient echo sequence can be maximized by reducing the readout bandwidth. In the case of the 3D EPI sequence used here, multiecho readout was used to speed up the acquisition while SNR loss was recovered by increasing spatial coverage. This approach can be exploited by using parallel imaging to further improve the spatial coverage within a shorter scan time.

In this study, only half of the slices acquired are usable. This is mainly caused by the suboptimal slice profile of the 1-1 water excitation pulse. At 3T, the time interval between the selective 1-1 pulses is very short, limiting the choice of RF pulses for improved slice profile. The use of a spatially and spectrally selective RF pulse will help improve this sampling efficiency. Despite the low sampling efficiency due to the RF pulse, the 3D EPI method still provides a 6 fold improvement in image acquisition time. The scan time reduction will drastically reduce patient examination time. The resulting 3D data set may also provide additional information about the shear wave propagation in the imaging slab.

References

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