MR Elastography of Human Lung Parenchyma: Feasibility of Echo-Planar and Respiratory-Triggered Echo-Planar Imaging

Yogesh K Mariappan[1], Kevin J Glaser[1], Rolf D Hubmayr[2], Richard L Ehman[1], and Kiaran P McGee[1]

[1]*Radiology, Mayo Clinic, Rochester, MN, United States,* [2]*Pulmonary and critical care medicine, Mayo Clinic, Rochester, MN, United States*

Introduction. It is appreciated that function is dictated by the intrinsic mechanical properties of lung parenchyma and that these properties are known to undergo significant alteration in several lung diseases [1]. Despite its central role, non-invasive methods to quantify lung mechanical properties are limited. Magnetic resonance elastography (MRE) is a novel method for quantifying and spatially resolving the shear stiffness of soft tissues such as the liver and other solid organs [2-4]. However, its implementation within the lung is challenging due to low lung tissue density, ultra short T_2* as well as cardiac and respiratory motion induced artifacts. We have recently demonstrated that shear wave propagation can be visualized within in vivo human lungs and that the shear stiffness can be spatially resolved using a breath-held conventional spin echo MRE pulse sequence [5]. We hypothesize that it is possible to extend this approach to echo planar imaging (EPI) in combination with respiratory-triggered acquisition schemes. The purpose of this work was to test this hypothesis by developing and testing a respiratory triggered EPI pulmonary MRE sequence and to validate this sequence in healthy volunteers.

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

^{1}H EPI MRE: An ^{1}H EPI-based MRE sequence with a short echo time (effective TE = 13 ms for an echo train length of 8) was developed with the implementation of fractional motion encoding, split motion-encoding gradients (MEG) and crusher gradient removal [5] and is shown in figure 1a. The EPI sequence included two 2-ms MEG lobes to image the shear wave propagation. To achieve low TE values, chemical pre-saturation pulses were used instead of a spatial-spectral RF pulse for fat suppression. The developed sequence was tested on healthy volunteers with the experimental setup shown in figure 1b. 50 Hz shear vibrations were induced within the lungs using active-passive driver system with the passive drum driver placed on the anterior chest wall. MRE data were acquired with breath-held acquisitions both at residual volume and total lung capacity.

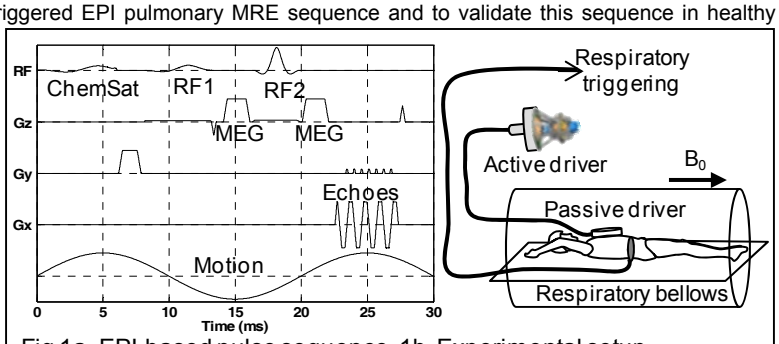

Fig 1a. EPI based pulse sequence. 1b. Experimental setup

Respiratory triggering: The EPI sequence was further modified to include the capability of respiratory triggered acquisitions and involved a respiratory bellow attached to the abdomen to enable respiratory triggering (fig 1b). MRE data were acquired with free-breathing at four different states of respiration including functional residual capacity (FRC), normal end inspiration (NEI) and two intermediate states, controlled by a delay parameter varied under pulse sequence control. With a TE of 13 ms the total acquisition time was approximately 2 minutes for a single respiratory state for a subject with a 16 breaths per minute respiration rate. A local frequency estimation algorithm with spatio-temporal directional filters was used for the calculation of shear stiffness maps (elastograms) [6]. Other imaging parameters included: imaging plane = axial/sagittal, ETL = 4 (8 for respiratory-triggered acquisitions, RTA), FOV = 35 cm, acquisition matrix = 128x64 (64x64 for RTA), frequency-encoding direction = RL/SI, motion-sensitizing direction = SI/RL, TR/TE = 320/13 ms, slice thickness = 10 mm, and 4 phase offsets.

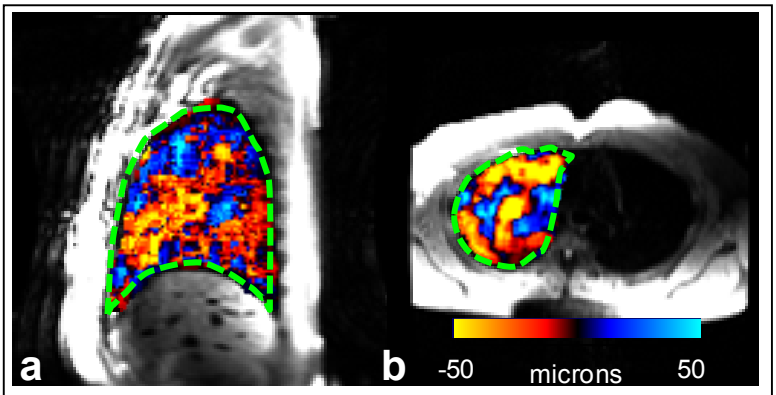

Fig 2: 2a. Sagittal and 2b. axial shear wave field obtained with EPI based MRE superimposed onto the magnitude images

Results. Figure 2 shows shear wave fields superimposed onto the magnitude images obtained from the EPI MRE experiments in both the sagittal (2a) and the axial imaging planes (2b). Shear wave propagation is more easily visible when observing the 4 phase offsets instead of a single static image, however these data demonstrate feasibility of EPI-based MRE for visualization of shear wave propagation within the lungs. Figure 3 shows MRE data obtained from the respiratory-triggered acquisition at the FRC (3a) and NEI (3b) in the sagittal imaging plane. The dashed region of interest shows the boundary of the lung and the larger area and the longer shear wavelengths in fig 3b in comparison to fig 3a are visible. Inversion results at the four respiratory states indicated that the non-density corrected stiffness values increased from FRC to NEI and were found to be 4.8, 5.4, 4.8 and 6.4 kPa respectively.

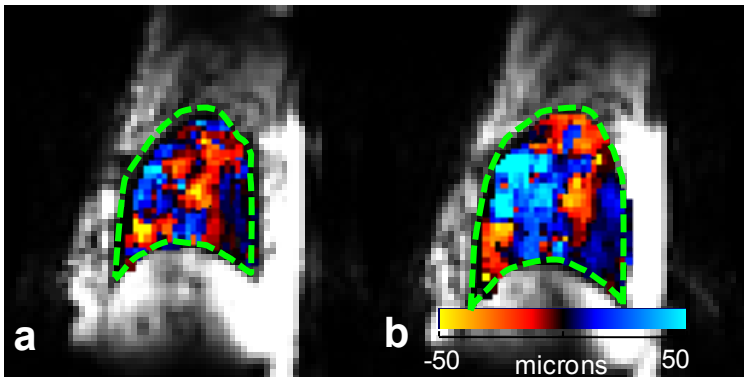

Fig 3. Sagittal wave images superimposed on the magnitude image at FRC (3a) and NEI (3b). The difference in the lung area and the shear wave lengths is evident.

Conclusions. We have presented the first pulmonary MRE data obtained with a respiratory triggered ^{1}H EPI-based pulse sequence, demonstrating the feasibility of free breathing EPI-based ^{1}H lung MRE. On going work involves the evaluation of this technique in non compliant populations including patients with compromised respiratory function.

Acknowledgements. This work was supported by NIH EB07593, NIH EB 001981

References. (1) Suki et al., Respir Physiol Neurobiol 163 : 33-43, 2008. (2) Muthupillai et al., *Science* 269: 1854-1857, 1995. (3) Huwart et al.,NMR in Biomed 19: 173-179, 2006. (4) Asbach et al., MRM 60 :373-379, 2008. (5) Mariappan et al., JMRI 33 :1351-1361, 2011. (6) Manduca A et al., *Med Imag Anal*. 5: 237-254, 2001.