Magnetic Resonance Elastography of the Lung: Initial Feasibility

B. C. Goss[1], K. P. McGee[1], S. A. Kruse[1], A. Manduca[1], R. L. Ehman[1]
[1]Mayo Clinic and Foundation, Rochester, MN, United States

Synopsis:
Many diseases affect pulmonary function by altering both dynamic and static lung compliance. Conventional pulmonary testing provides an averaged estimate of overall lung compliance, but no regionally-specific information. We evaluated the feasibility of measuring the elastic properties of lung tissue through MR-based phase-contrast imaging of propagating shear waves. Initial results in porcine lung specimens inflated with air indicate that the shear modulus in lung is within the range of values previously reported in the literature.

Introduction

Changes in lung compliance (stiffness) may be caused by a variety of disease processes including interstitial fibrosis and emphysema. Conventional pulmonary testing provides an averaged estimate of overall lung compliance, however, lung pathology affecting compliance is often anatomically heterogeneous. The availability of a technique for quantitatively imaging the elastic properties of lung tissue would offer new opportunities for investigating lung diseases that affect compliance. The goal of this research was to assess the feasibility of assessing the mechanical properties of lung tissue by phase-contrast MR-based imaging of propagating shear waves. This technique, which has been called Magnetic Resonance Elastography (MRE), has not previously been applied for lung imaging. The low spin density of lung tissue, presence of susceptibility effects, and the very low shear modulus of lung tissue offer special challenges for implementing this technique.

Materials & Methods:

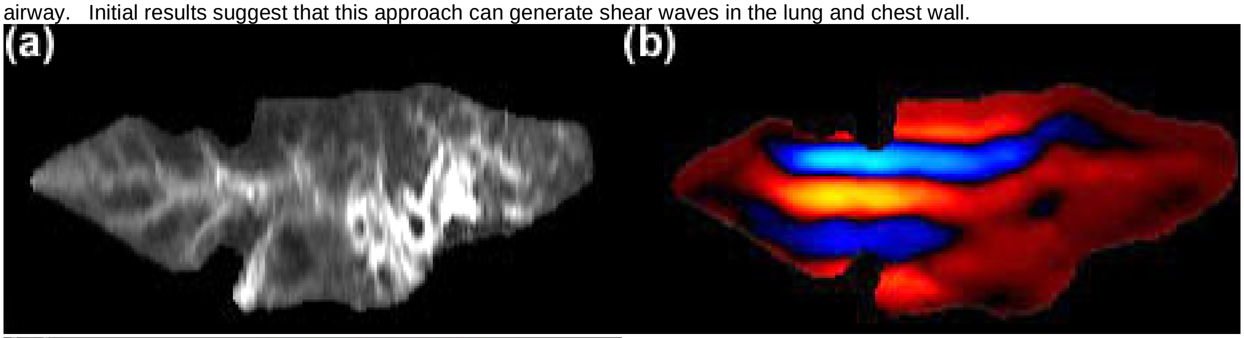
Lung MRE was tested with excised porcine lung specimens with a fast spin echo train version of a previously described MRE sequence [1,5]. A custom-made acoustic driver, used to induce shear waves at 200 Hz, was mechanically coupled to the anterior surface of the lung. Axial phase-contrast images, which provide local estimates of the wavelength of the mechanical shear wave, were acquired using a 5-inch surface coil and the following parameters: TR/TE/ETL/NEX = 1000msec/17msec/1/2. The resulting wave images were processed with a local frequency estimation algorithm to determine the shear wavelength at each point in the tissue. From this local wavelength data, a shear modulus image was generated using the relation $\beta=\rho f^2\lambda^2$, where β is the shear modulus of the tissue with density ρ, and λ is the wavelength of the propagating shear wave of frequency, f. When calculating the shear modulus, lung tissue was assumed to have a uniform density of $0.2 g/cm^3$ [6].

Results:

Figure 1(a) shows a fast spin echo image of the lung slice in which MRE was performed. Figure 1(b) shows a directionally-filtered phase difference image of the shear waves propagating in the lung tissue while Figure 1(c) shows the MR elastogram generated from that wave data. In Figure 1(c), the masked portions of the elastogram indicate areas of insufficient SNR for wavelength calculation via phase data inversion and checkerboard overlay indicates areas of SNR less than 5. In the shear modulus image, conduction zone structures such as the respiratory bronchi can be visualized. More importantly, tissue that comprise the respiratory zone, which determine regional and global compliance, can also be seen. Based on the shear modulus image, the measured shear modulus of alveolar tissue was 0.76±0.05 kPa. This value is consistent with published values for human lung tissue of 1kPa [7].

Discussion:

The preliminary results suggest that MRE should be further evaluated as a method for non-invasively assessing regional lung compliance. In order to implement this method in vivo, we are developing a technique for introducing mechanical shear waves using low frequency sound waves through the airway. Initial results suggest that this approach can generate shear waves in the lung and chest wall.



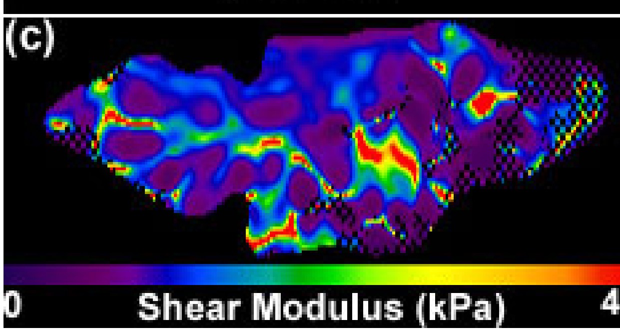


Figure 1. (a) Fast spin echo image of lung tissue. (b) Directionally filtered phase difference image showing propagating shear waves. (c) Shear modulus map.

References:
1. R Muthupillai et al., Science **269**, 1854,1995.
2. JA Smith et al., ISMRM *Fifth Annual Meeting,* **3**, 1905,1997
3. MA Dresner et al., ISMRM *Sixth Annual Meeting,* **1**, 463, 1998
4. AJ Lawrence et al. , ISMRM *Sixth Annual Meeting,**1**, 233, 1997*
5. R Muthupillai et al., Magn. Reson. Med., **36**,266,1997
6. S Ganesan et al., Respir Physiol Oct;**110**(1):19-32**,** 1997
7. Lai-Fook and Hyatt, J Appl Physiol Jul;**89**(1):163-8, 2000