Thermally Polarized ^{3}He Magnetic Resonance Elastography: Initial Feasibility

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Introduction

Lung disease is the third leading cause of death in the United States [1]. Many of the most important causes of lung-related deaths are due to diseases such as COPD and interstitial fibrosis that primarily act by changing the mechanical properties of lung tissue. Although change in lung compliance can be used to predict disease type - it increases with emphysema while decreases with interstitial fibrosis – it is a measure that lacks regional specificity (i.e. ignores anatomical heterogeneity) which limits its use as a method for early detection of lung disease.

We have previously reported that a technique known as magnetic resonance elastography (MRE) which incorporates propagating shear waves and a phase contrast imaging sequence can be used to quantitate regional stiffness differences in inflated ex-vivo porcine lung, as shown in Figure 1[2]. However, ^{1}H MRE of lung is specially challenging due to the low spin density, susceptibility differences, and overall low shear modulus of lung tissue.

To address many of these issues, hyperpolarized ^{3}He has been proposed as a method for imaging the airspace of the lung. In this work we have assessed the feasibility of ^{3}He MR imaging in the specific context of phase contrast imaging of the lung and have tested this concept using thermally polarized ^{3}He.

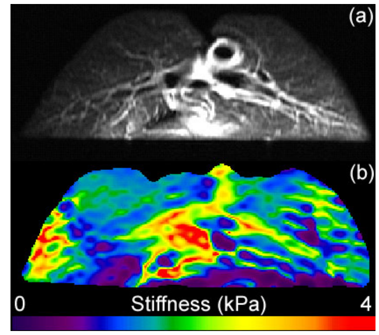

Figure 1: (a) H^{1} Magnitude and (b) shear stiffness map of excised porcine lung.

Materials and Methods

A phantom was constructed from of a flexible silicone tube filled with foam. This tube was inserted into a 500-mL polyethylene bottle that was inflated to a pressure of 345 kPa with an equal mixture of O_2 and ^{3}He gas. A custom-built acoustic driver was mechanically coupled to the opening of the bottle and induced shear waves at 150 Hz. A previously described gradient echo MRE pulse sequence [3] was used to image shear wave propagation in the tube. MRE was performed on a 1.5T whole body MR scanner equipped with multinuclear imaging capabilities (GE Healthcare, Waukesha, WI). The following imaging parameters were used: TR/TE = 2200/20 msec, excitations = 30, k_x/k_y = 64/32, 2 kHz receiver bandwidth, 0.44 Gauss / cm motion encoding gradient amplitude. Phase difference images were generated and were used to image the shear wave propagation as well as an estimate of its wavelength. The compliance of the silicone tube was then calculated using the relation $\mu=\rho(f\lambda)^2$, where μ, ρ, f, λ , are the shear stiffness, density, frequency of the applied motion, and wavelength of the propagating shear wave respectively.

Results

Figure 2(a) shows a phase difference image of the ^{3}He phantom while 2(b) is a profile through the center of the silicone tube of (a). In (a) the shear wave can be seen propagating along the tube length. In (b), the red waveform shows the original shear wave propagating along the tube axis while the black is a spatially filtered version of the shear wave. The peak amplitude of the wave motion was 90 µm. The wavelength of the propagating shear wave was determined by manual inspection to be 12.81 cm. Using the above relation, with tube density of 1.13 g/cm^{3}, we obtained a stiffness estimate of 417 kPa.

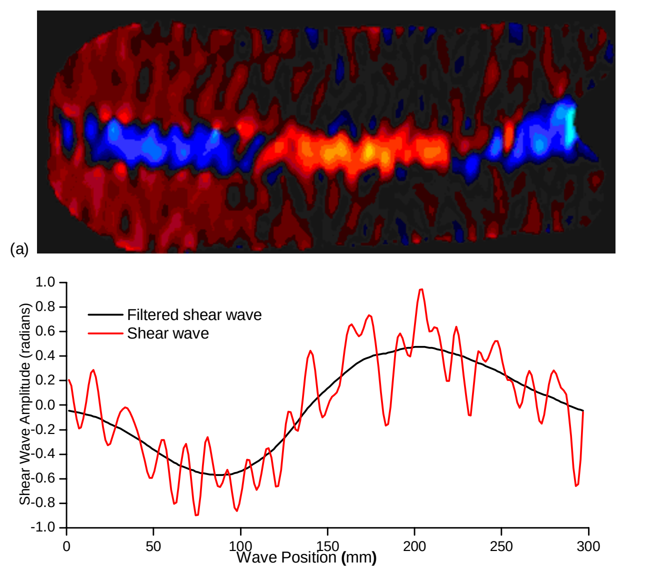

Figure 2: (a) Phase difference image of ^{3}He phantom showing wave propagation along the silicone tube. The phase difference image has been enhanced to accentuate the amplitude of the shear wave along the tube axis as compared to the background phase of the bottle. (b) Displacement as a function of spatial position along the tube. The red line shows the amplitude of the shear wave (in radians) along the tube axis while the black line is a low-pass filtered version of the original waveform. The filtered waveform was used to calculate the wavelength of the propagating shear wave.

Discussion

These initial results indicate that MR phase contrast imaging of gas can be performed using ^{3}He as an exogenous contrast agent. Further, this technique can be used to image shear wave propagation, providing an estimate of the shear stiffness of the gas' local environment. The tube/foam combination provides a restricted diffusion environment that simulates the alveolus of lung indicating that this type of structure effectively couples shear waves. This data also suggest the use hyperpolarized ^{3}He as the next step in adapting MRE to in-vivo lung imaging. Since the increase in signal-to-noise for an equivalent volume of hyperpolarized compared to thermally polarized ^{3}He is approximately 10^{5} fold greater [4], it is expected that this increase can be used to drastically decrease imaging time. The use of hyperpolarized ^{3}He in MRE could allow for in-vivo MRE imaging of lung to be a clinically feasible imaging tool for the detection and diagnosis of lung disease through regional lung compliance mapping.

References

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