Feasibility Study of in situ Lung MRE in a Porcine Model: Correlation of Shear Stiffness and Transpulmonary Pressures

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Introduction: Quantification of the mechanical properties of the lung parenchyma is an active area of research due to the association of this metric with disease stage and progression in a variety of interstitial lung diseases [1] An MRI-based elasticity imaging technique known as magnetic resonance elastography (MRE) is being investigated for clinical applications in solid organs such as the liver and brain [2]. However, due to the inherently poor ^{1}H MR signal properties of lung parenchyma, the implementation of lung MRE has been slow and challenging. MRE experiments using hyperpolarized helium to improve the MR signal of the lungs have provided promising results [3, 4]. However a ^{1}H MRI implementation of lung MRE would likely be more beneficial and widely accepted. Animal experiments performed to date [5] have indicated that it is feasible to quantitate lung shear modulus with ^{1}H MRI, when the driver is in direct contact with the lungs The purpose of this work is to apply this technique to an in situ porcine model with a noninvasive mechanical driver placed on the chest wall of the pig and to test the feasibility of this technique to measure the change in stiffness of the lung parenchyma as a function of transpulmonary pressure (P_{tp}) .

Methods: All experiments were performed with a 1.5-T whole-body scanner (Signa EXCITE, GE Healthcare, Milwaukee, WI). Two animals were studied and all experiments were performed according to IACUC guidelines. The animals were put to sleep using a fatal dose of anesthesia to remove cardiac and respiratory artifacts. A pressure tractable air line was introduced into the trachea to enable controlled inflation (and deflation) of both the lungs to any desired pressure. For this study, the lungs were inflated to four different transpulmonary pressures (5,10,15 and 20 cm H_2O) and MRE was performed at each pressure. The animal was positioned supine and a pressure-activated passive drum driver (similar to the one used in [6]) was placed on the anterior body wall of the pig as shown in Figure 1. Continuous vibrations at 100 Hz were applied and coronal images that included both lungs within the same imaging slice were acquired. A spin echo pulse sequence was used for imaging the displacement of the lung tissue to reduce the susceptibility effects due to the air within the lungs. This pulse sequence included two 5-ms motion-encoding gradient lobes, placed one on each side of the 180˚ refocusing pulse, separated by a time interval of 15 ms. Other imaging parameters included FOV = 30 cm, acquisition matrix = 128x64, frequency-encoding direction = SI, motion-sensitizing direction = SI, TR/TE = 210/26 ms, slice thickness = 10 mm, and 4 phase offsets. The local frequency estimation algorithm with spatio-temporal directional filters was used for the calculation of shear stiffness maps (elastograms) of the lungs from the wave images [7, 8].

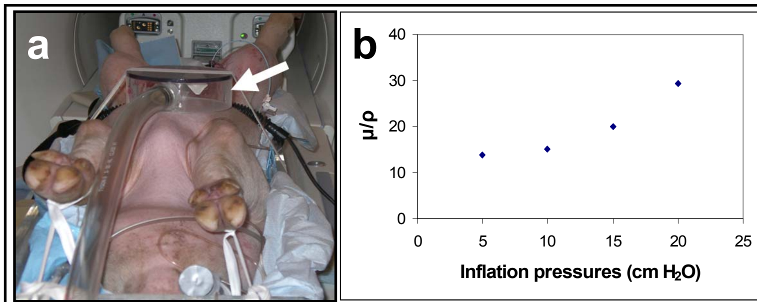

Figure 1: (a) Experimental setup: the passive driver is indicated by the arrow. (b) Density-weighted shear modulus measurements for the four different inflation pressures. The gradual increase in the stiffness of the parenchyma with increasing pressures is visible.

Results: Figure 2 shows the results obtained from one of the experiments. Figures 2a and 2b show the magnitude images of the coronal slices obtained at P_{tp} of 5 cm H_2O and 20 cm H_20, respectively, and the increase in the lung volume at the higher P_{tp} can be easily seen. One of the phase offset images of the segmented lungs of the corresponding slices are shown in Figures 2c and 2d. Even though the magnitude signal within the lungs is low, coherent phase information with quantifiable shear wave amplitude was observable in all cases. The presence of shear waves and the difference in the wavelength between the two datasets is evident (arrows). It can also be seen that the shear wave amplitude within the lungs is higher at the higher pressure which can be attributed to better coupling between the driver and the lungs at the higher pressure. The corresponding elastograms are shown in Figures 2e and 2f, and as expected from the wave images, in the regions with good shear wave amplitude the lung parenchyma shows increased stiffness at the higher pressure. This trend was true for all the pressure values in this experiment and can be seen in Figure 1b, where the mean, density-weighted shear stiffness values of a ROI with good wave amplitude are plotted against the corresponding P_{tp}.

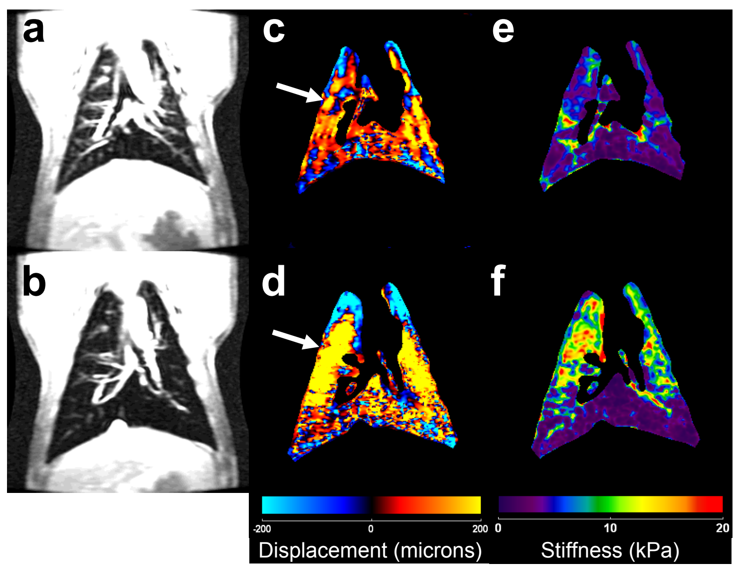

Figure 2: Coronal magnitude images of lungs with (a) 5 cm H2O and (b) 20 cm H2O. (c,d) Single wave images of the corresponding slices showing the shear waves. The shear wavelength in (d) is longer than in (c) (arrows). (e,f) Density-weighted elastograms showing an increased shear stiffness at increased pressure.

Conclusion: These data suggest that MRE of in situ lungs is feasible with an externally placed mechanical driver in a porcine model and that MRE is capable of differentiating the shear modulus of the lung parenchyma at different inflation pressures. The data provide motivation for further experiments to develop and test the ability of MRE for the assessment of lung diseases in animal models and eventually in clinical applications.

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