In vivo helium-3 MR-elastography: Assessment in small animal and human lungs

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Introduction

The mechanical properties of lung tissue play a key role in the basic function of the organ. They could be very sensitive pulmonary biomarkers as they are dramatically altered by most lung diseases. Currently available imaging modalities fail to regionally probe them in vivo. Initiated in 1995 [1], MR-elastography was recently implemented on a tracer gas, hyperpolarized helium-3, to explore the viscoelastic properties of the lung. The underlying assumption on gas confinement was asserted on phantoms [2] and the technique was proven to be sensitive to lung inflation [3] and insensitive to pulmonary gas content [4]. This work demonstrates the feasibility in vivo of helium-3 MR-elastography in small animal and human lungs.

Materials and methods

Experiments were carried out in a 1.5 T scanner (Achieva, Philips Medical Systems, The Netherlands) at CIERM, Bicêtre Hospital. The rats were lying in a helium-3 double-bracelet Helmholz coil, in supine position, while shear waves were induced at 290 Hz in the animal lungs by pressure waves, remotely generated by a loudspeaker and guided to the top of the chest. A 30-slice gradient echo sequence was implemented with FOV=(80×80×37.5) mm³, voxel=(1.25×1.25×1.25) mm³, TE/TR=5.2/10 ms. The human volunteers were lying, supine, in a prototype helium-3 bird-cage coil (RapidBiomedical, Würzburg, Germany) while shear waves were induced at 100 Hz throughout the lung volume by a home-built MR-compatible transducer fixed on the chest. A 5-slice gradient echo sequence was implemented with FOV=(350×350×60) mm³, voxel=(12×11×12) mm³, TE/TR=15/100 ms. Hyperpolarized helium-3 doses of 10 mL for the rats, and 600 mL for the volunteers, were respectively administered and inhaled before 17 s and 12 s apnoeas, as required for the acquisition of each motion-encoding direction. Motion sensitizing gradients along the three spatial directions were synchronized with the mechanical waves at different time offsets with respect to the excitation. As a result, for each spatial direction, eight and four snapshots of the propagating waves were recorded for the rat and human experiments, respectively. In data processing [5], resulting maps were averaged over three consecutive slices and the viscoelastic shear moduli were corrected to account for the lung parenchyma density with a factor was inferred from X-ray computed tomodensitometry [6].

Results

Figure 1 shows the helium-3 ventilation images and the wavelength, dynamic and loss shear modulus maps for the averaged three central slices for rat and human lungs. As summarized in Table 1, mean shear wavelengths (Figure 1b) are (4±0.04) mm and (44±0.5) mm in the rat and human volunteer's lungs, respectively. Corresponding dynamic shear moduli (Figure 1c) are (0.72±0.002) kPa and (1.83±0.02) kPa, respectively. Corresponding loss shear moduli (Figure 1d) are (0.16±0.003) kPa and (0.25±0.008) kPa, respectively.

Discussion and Conclusion

These results represent the first in vivo measurements of shear wave propagation within both rat and human lungs with hyperpolarized helium-3 MR-Elastography. The inferred mean shear dynamic moduli agree fairly well with both stiffness values found ex vivo by previous indentation tests [6,7] and density corrected stiffness mean values obtained in vivo with dedicated lung parenchyma hydrogen MR-Elastography [8]. Here the structures revealed in the coronal maps of the lung mechanical properties in Figure 1 (b, c, and d) roughly match the expected rat and human organ morphology with a stiffer and more viscous central bronchial tree. The loss shear modulus (Figure 1d) is associated with tissue viscosity and it was recently correlated to the inflammation of tissue cells [9,10]. This opens up promising insights into diseased lungs in patients suffering from emphysema, fibrosis, or cancer.

Table 1: Mean viscoelastic moduli for rat and human lungs before and after tissue density correction. The correction factor was inferred from X-ray computed tomodensitometry after conversion of Hounsfield Units (HU) in g mL⁻¹: ρ=(HU+1000)/1000 with HUl=600 and HUhuman=−880.

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