In vivo lung elastography with hyperpolarized helium-3 MRI

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Introduction

The viscoelastic properties of human tissue depend on its structures, biological conditions, and related pathologies. In the lung parenchyma, these properties participate in the basic function of the organ. They are dramatically altered by diseases like cancer, emphysema, asthma, or interstitial fibrosis. Besides tactual exploration, which is only qualitative and poorly sensitive, there is no other non-invasive technique to assess such changes. This work aims to produce a novel measurement tool based on non-invasive magnetic resonance imaging of hyperpolarised helium-3 to monitor the mechanical properties of the lung, which allow mapping of its compliance and relating it to pathology.

MR-elastography was devised in 1995 through magnetic resonance of the proton to detect the motion of tissues and to follow their response to an acoustic stress generally applied by a mechanical vibrator at the surface of the body [1]. By implementing this technique on a tracer gas, hyperpolarized helium-3, we circumvent the limitations it faces in the airways. In 2006, it was applied to a phantom that simulated lung behaviour and to excised pig lungs where helium-3 is confined [2]. In this work, we demonstrate its feasibility *in vivo*.

Methods and materials

Experiments were carried out on a healthy volunteer in a 1.5 T scanner (Achieva, Philips Medical Systems, The Netherlands) at CIERM, Bicêtre Hospital. The subject was lying in a prototype helium-3 thorax coil (Rapid Biomedical, Würzburg, Germany). A home-built MR-compatible transducer [3], positioned onto the left side of the chest, induced a mechanical excitation at 100 Hz into the lungs. 600 mL doses of helium-3 gas, polarized up to 68% (Institut für Physik, Mainz, Germany), were transferred into a Tedlar® bag (SKC, Eighty Four, PA, USA) before being inhaled and supplemented by air so the subject reached the total lung capacity and remained in apnea during the 12 second MRI acquisition. A gradient echo sequence, Figure 1, was applied over 5 slices, 12 mm thick, with FOV=350×350 mm, matrix=29×32, TE/TR=15/100 ms. Additional 10 mT·m^{-1} motion sensitizing gradients, synchronized with the mechanical wave through a trigger pulse, were set along the three directions, x (phase), y (reading) and z (slice) at different time offsets with respect to the excitation. As a result, four snapshots of the propagating wave during one oscillatory cycle could be acquired. Eventually a fourth acquisition was performed to include a reference data set without motion sensitizing gradients.

The images of the three middle slices were averaged and manually masked. The resulting phase data were then unwrapped so displacement maps could be inferred over the lungs[3].

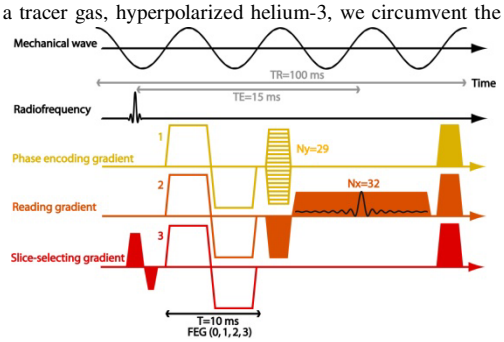
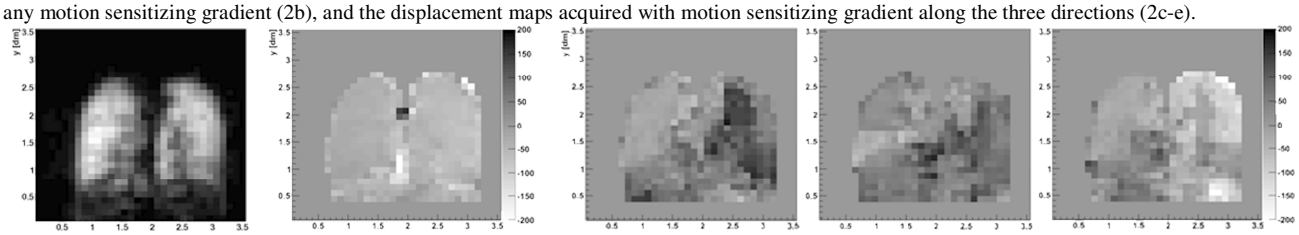


Figure 1: Gradient echo sequence with synchronized motion sensitizing gradients (FEG, 10 mT·m^{-1}) applied over different acquisitions along the three dimensions. FEG are synchronous with the mechanical wave above but delayed for the four dynamic scans. Five slices, 12 mm thick, were acquired with FOV=350×350 mm, matrix=29×32, TE/TR=15/100 ms.

Results

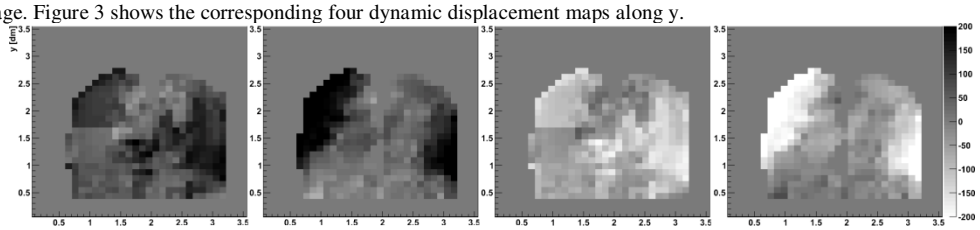
Figure 2 shows the 3-slice averaged magnitude image (2a), the reference displacement maps acquired without any motion sensitizing gradient (2b), and the displacement maps acquired with motion sensitizing gradient along the three directions (2c-e).



a. Magnitude image b. Reference image c. Displacements along x d. Displacements along y e. Displacements along z

Figure 2: (a) Magnitude image over the three middle slices and corresponding displacement maps (µm) (b) without motion sensitizing gradients and with motion sensitizing gradient (c) along the phase encoding direction, x, (d) along the reading direction, y, and (e) along the slice selection, z.

Shear displacements reached amplitudes of 118, 153, and 117 µm when motion sensitizing gradients were respectively applied along x, y, and z. They are limited to 48 µm in the reference image. Figure 3 shows the corresponding four dynamic displacement maps along y.



a. φ_0 b. $\varphi_0+\pi/4$ c. $\varphi_0+\pi/2$ d. $\varphi_0+3\pi/4$

Figure 3: Displacement maps (µm) obtained at different time offsets (a-d) with motion sensitizing gradient along the reading direction (y here)

Discussion

On the three motion-encoded image sets, shear displacements were clearly detected with amplitudes significantly elevated compared to the case without motion encoding and shear wave propagation could be monitored along the three dimensions and four dynamic images. These represent the first *in vivo* detection of shear wave propagation within the human lungs. On the reference maps, the recorded residual global displacement remains to be understood. It likely originates from the residual magnetic stray field of the mechanical driver. The rather poor signal to noise ratio have not yet allowed for tridimensional reconstruction of the viscoelastic moduli. Their extraction in the lung parenchyma is inherently challenging since the strength of the motion sensitizing gradients required to encode the mechanically-induced displacements must be limited to account for the resulting signal attenuation of highly diffusive helium-3 atoms. The future of such a technique relies now on the optimisation of the acquisition protocol, from mechanical excitation to sequence implementation.

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