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How magnetic resonance elastography (MRE) could provide biomechanical property to complete computed tomography (CT) scan lung diagnostic?

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1. Introduction

Currently, the detection of pulmonary fibrosis is performed with computed tomography (CT) scan that uses radiation. From this test, subjective morphological data, with inter and intra operator variability, is obtained (Chassagnon et al. 2018). There is an important need to objectively and non-invasively quantify pulmonary fibrosis to better observe the effect of treatment and undertake the follow-up of disease. Thus, one alternative is Magnetic Resonance Elastography (MRE) that is a non-invasive technique, based on the application of motion encoding gradients (MEG) to estimate the shear modulus parameter, allowing the quantification of the biomechanical properties of different soft tissues. Other MRE parameters such as the damping ratio, the attenuation, etc. have been correlated to the physiological and structural properties of the tissue, demonstrating that additional MRE markers could provide complementary information. While the liver is the first organ approved for clinical MRE test (Pouletaut et al. 2023), additional MRE research protocols are extensively developed for the brain, kidney, prostate, muscle (Debernard et al. 2011; Chakouch et al. 2022). The COVID-19 pandemic has spurred research in the characterization of the lung tissue (Chakouch et al. 2022). Thus, the purpose of the study is to combine different imaging techniques to demonstrate the relevant biomechanical property that can be provided by MRE test.

2. Methods

2.1 Computed Tomography (CT) scan

Patients (N=10) had a CT scan to monitor a cough, the impacts of tobacco, asbestos, etc. Lung CT

images have been acquired with multi-detector row on General Electric (GE) machine (Figures 1A-1B).

Patients were examined during a single breath-hold and the following parameters were applied for the thoracic CT acquisition: FOV: 43 x 43 cm²; matrix: 512 x 512; voxel size: 0.84 x 0.84 x 0.625 mm³; slice thickness: 0.625 mm; 100 - 140 kV according to the patient's weight. A radiologist read all CT acquisitions.

2.2 Magnetic Resonance Elastography (MRE)

MRE tests were performed, at the same slice level as the CT scan, by using spin-echo echo-planar imaging (SE-EPI) sequence on a 1.5 T MRI GE machine to obtain 4 axial slices of the lungs.

The scan time was 22 s at breath-hold. A round pneumatic driver, used for MRE liver (Leclerc et al. 2013), was placed on the right lung. It is connected to a plastic tube where an air pressure is induced at a frequency of 50 Hz using an acoustic speaker system.

The MRE pulse sequence including a motion-encoding gradient, which oscillated in the Z direction, was used to image the displacement of the shear waves. The phase images were recorded with the following parameters: FOV: 48 x 48 cm²; TR: 250 ms; slice thickness: 15 mm; number of axial slices: 4; voxel size: 3.75 x 3.75 x 15 mm³; matrix: 128 x 128; 4 phase offsets.

To measure the lung biomechanical properties different steps are followed: 1) a region of interest is drawn to select only the right lung to avoid the heart motion, 2) the apparent lung shear modulus is calculated from the phase images using multi-model direct inversion (MMDI) and a specific post-processing (Silva et al. 2015), and then 3) corrected with the cartography of the density hereafter described.

2.3 Lung density

The shear modulus being proportional to the density, a cartography of lung density for each patient is necessary to obtain a true cartography of the shear modulus (Figures 1C-1D).

MRI was performed at breath-hold, at the same slice level as the CT scan, with a fast gradient recalled echo (GRE) sequence (Holoverda et al. 2011) and a TR: 15 ms, from which the initial signal of the lung was estimated. Then, the lung density was obtained in reference to a Gadolinium-doped water phantom (Figures 1C-1D) placed on the chest. The MRI acquisition is realized with: FOV: 48 x 48 cm²; voxel size: 7.5 x 7.5 x 15 mm³; matrix: 64 x 64; slice thickness: 15 mm; and flip angle: 10°.

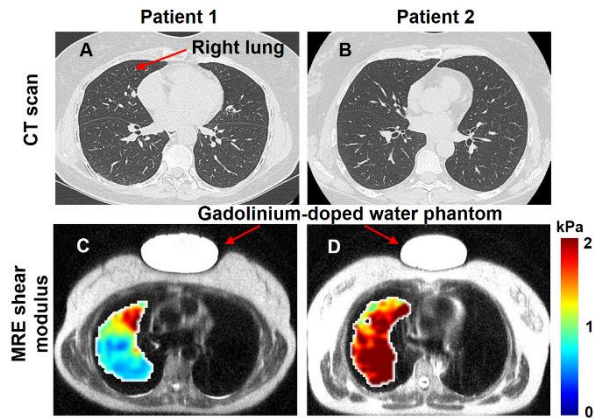


Figure 1: Example of two patients among the cohort with lung axial CT scans (A-B) and MRE shear modulus cartographies (C-D) of the right lungs. Red arrows show the localization of the gadolinium-doped water phantom.

3. Results and discussion

Figures 1A and 1B show an example of CT scan results obtained for two patients with unknown lung disease. No detectable solid mass or any other lung disease was identified on both CT scans, leading to the conclusion that the two patients have healthy lungs.

The figures 1C and 1D show the results of the true MRE cartographies of the shear modulus tests obtained for the two patients. The mean shear modulus for patient 1 and patient 2 are 1.15 ± 0.58 kPa and 2.40 ± 0.82 kPa, respectively. The value obtained for patient 1 is in agreement with the literature for healthy lung (Fakhouri et al. 2022). However, patient 2 revealed a higher shear modulus indicating a pathological biomechanical property of the tissue.

To summarize, the CT scans for both patients had healthy structural properties but the MRE tests have highlighted different biomechanical behaviors. This result shows possible benefits of the MRE tests which can provide complementary information to better diagnose the lung tissue.

4. Conclusions

This study has showed that MRE test could become a non-invasive lung diagnostic tool, allowing the quantification of the lung shear modulus, a potential biomechanical marker of lung disease. In perspective, the CT scan parameters could be correlated to the MRE parameters to predict the evolution of the lung disease. In addition, MRE protocol must be further enhance for the biomechanical characterization of the both right and left lungs. The present study shows the potential interest of MR elastography in the regular care of lung disease and paves the way for other lung applications.

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