Sensitivity of viscosity and elasticity in preserved pig lung by Magnetic Resonance Elastography

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Introduction

The viscoelastic properties of lungs would be a very sensitive pulmonary probe of the organ condition as they depend on its biological state, structures (distensibility gradient depends on gravity and it suffers a reduction with inflation), and related pathologies. Over than physical examination, which is only qualitative and poorly sensitive, exploration of viscoelastic properties *in vivo* is not attainable. Hyperpolarised helium-3 MR-elastography on the lung has been demonstrated *in vivo* and shear wave displacements have been detected [1]. This new technique was applied *ex vivo* and the viscoelastic properties of a preserved pig lung were quantitatively evaluated and compared both with helium-3 and hydrogen MRE [2]: the fluid/structure coupling was found to be strong, validating helium-3 lung MRE as a consistent tool for lung exploration. This work focuses, in depth, the sensibility of viscoelastic properties of hydrogen MRE, applied on the preserved pig lung inflated at three different volumes: pointing out a connection with boundaries conditions and gravity effects, behaviour of shear wavelength dynamic and loss shear modulus distribution maps, is clearly visible throughout the inner area and the outer peripheries of the lungs in relation to density structured tissue changes.

Methods and materials

Experiments were performed on Bioquest® preserved pig lungs in a 1.5 T scanner (Achieva, Philips Medical Systems, The Netherlands) at CIERM, Bicêtre Hospital, France. The left lung was placed in a cylindrical support surrounded by a dual Flex-M coil for hydrogen MRE. A MR-compatible transducer (Philips Medical Systems, The Netherlands) [3], induced a mechanical excitation at 85 Hz onto the upper lobe of the left side of the preserved lung. Motion sensitizing gradients of 25.2 mT/m, synchronised with the mechanical wave, were implemented in a spin-echo sequence for hydrogen MRE, over 12 slices, to acquire eight snap-shots of the propagation wave during the oscillatory cycle along three directions x (phase), y (measurement), and z (slice). The acquisition parameters were FOV = 530×159×96 mm, matrix = 68×20×12, TE/TR = 17/23 ms, and T_{ACQ} /direction = 27 s. Sets of MRE data were taken on three different inflation volumes, 0.8L, 1L, and 1.2L, with a constant nitrogen flow. Shear wavelength (λ), dynamic and loss shear modulus distribution maps (respectively elasticity, Gd and viscosity, Gl), were estimated on each slice displaying the pixels occurrence and slices progressing from the posterior to anterior periphery of the lung.

Results

Table 1 furnished the values range of shear wavelength, dynamic and loss shear modulus at the three volumes of inflation. Figure 1-3 showed a set of three images of shear wavelength, dynamic and loss shear modulus distribution along the slices progressing from posterior (where the lungs were lying) to anterior lung peripheries at 0.8 L (Fig. 1), 1 L (Fig. 2), and 1.2 L (Fig. 3).

V = 0.8 L	V = 1 L	V = 1.2 L
5 mm<λ< 67 mm	18 mm<λ<77 mm	18 mm<λ<80 mm
5 KPa<Gd< 47 KPA	5 KPa<Gd<47 KPa	5 KPa<Gd<47 KPa
0.2 KPa<Gl< 29 KPa	0.2 KPa<Gl<30 KPa	0.2 KPa<Gl<28 KPa

Table 1: range of values for shear wavelength, dynamic and loss shear modulus at different volumes: 0.8L, 1L, and 1.2L.

Discussion

During the inflations, the morphology (Fig. 1b, 2b, and 3b) in the inner slices, where the main airways are dominant, registers very little change. Meanwhile in the outer slices, the volume increases in the upper side of the lung (anterior periphery) more than in the lower side (posterior periphery) because structured tissue is subjected to the gravity and boundaries effects. Shear wavelength, dynamic and loss shear modulus distribution maps (Fig. 1a, 2a, and 3a) are in good agreement with this observation. λ and Gd distribution increase with higher inflation on the outer slices, above all, in a remarkably way, on the anterior side of the lung. The lung's inner slices maintain similar values during the three inflations because of the strong presence of airways. Meanwhile, Gl distribution decreases with the rise of the inflation on the anterior lung's periphery. It maintains the same range of values on the posterior one and in the centre. The alveolar recruitment could explain this behaviour as a lessening of density with the increase of rigidity, moving toward a higher volume, so that for λ and Gd distribution are higher on the peripheral slices and Gl one shifts towards inferior values on the anterior side.

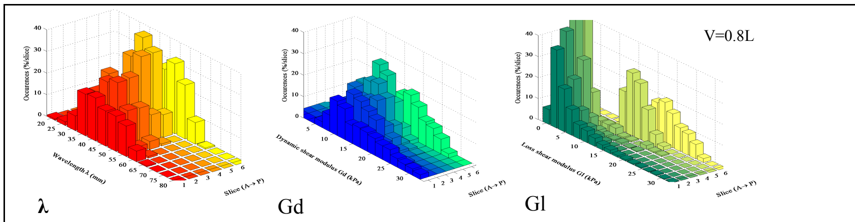

Fig. 1a

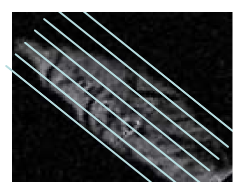

Fig.1b

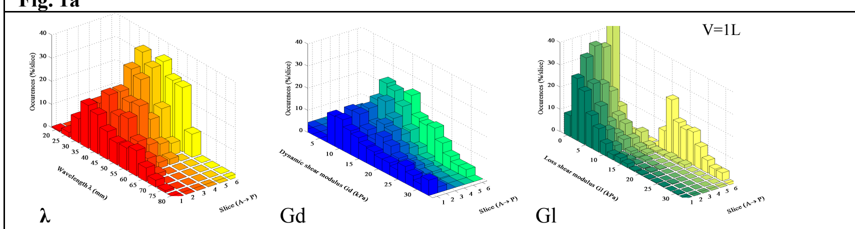

Fig.2a

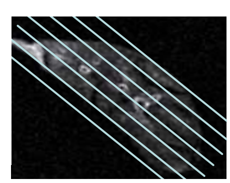

Fig.2b

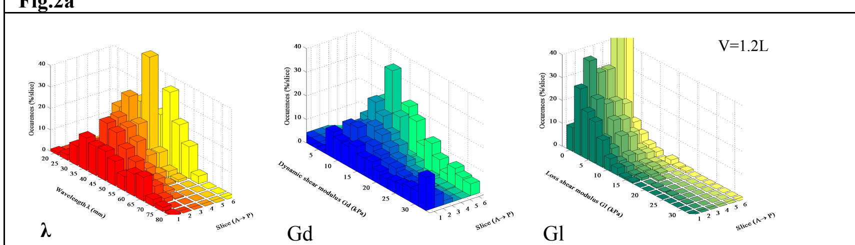

Fig.3a

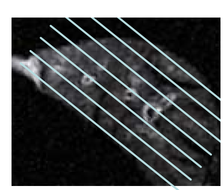

Fig.3c

In the figures on the left, λ, Gd, and Gl are evaluated at different inflation volumes, 0.8l L (Fig. 1), 1 L (Fig. 2), and, 1.2 L (Fig. 3). Increasing the volume, in the three morphology images (Fig. 1b, 2b, and 3b), a larger inflation is evident towards the anterior side of the lung compared with the posterior, while on the inner slices the changes are minimal.

On the λ, Gd, and Gl distribution maps, in the peripheral slices the alveolar recruitment is highlighted by the increasing of λ and Gd, values, more evident in the upper (anterior) side of lung; the decreasing of Gl is due to the lessening of tissue density.

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