Gas content dependence in Magnetic Resonance Elastography of the lungs

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Introduction

MR-elastography (MRE) 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[2], we circumvent the SNR limitations of MRE in the airways. However, the gas contained in the lung is a source of elasticity and therefore its effect must be considered in MRE measurements. Previous experiments of wave propagation in dog lungs[3] suggested that the elastic moduli of lungs are essentially a function of pressure and that gas inertia does not affect the viscoelastic properties of the lung parenchyma, however that method was able to measure only longitudinal waves and global elastic constants. MRE is able to record both shear and longitudinal waves regionally throughout the lung. Here we perform MRE measurements in excised pig lungs inflated with three different gases of widely varying density, air, helium-4 (4He), and sulphur hexafluoride (SF6), in a phantom designed to make pixel by pixel comparison possible.

Method

In order to compare MRE measurements in the same lung for different inflations with the three gases, air, 4He, and SF6, a lung phantom was constructed to ensure inflation to a reproducible volume and shape. A Bioquest® preserved pig lung was inflated with air flowing at 2 L·min^{-1} while immersed in liquid silicon, then the silicon was allowed to harden overnight. This resulted in a firm mould containing the lung when deflated, and closing around the lung when inflated.

MRE measurements were obtained with a 1.5 T scanner (Achieva, Philips Medical Systems, The Netherlands). The lung phantom was placed in a Sense head coil and inflated while an MR-compatible vibrator (Philips Medical Systems, The Netherlands) induced a mechanical excitation at 85 Hz onto the upper left lobe of the preserved lung. Further 21 mT/m motion sensitizing gradients, synchronised with the mechanical wave, were implemented in a spin-echo sequence, over 11 slices, with FOV=244×194×44 mm, matrix=64×64×11, TE/TR=41/59 ms, and $T_{ACQ/direction}$ =4 min 42 s, along three directions x (phase), y (measurement), and z (slice), to acquire eight snap-shots of the propagation wave during the oscillatory cycle. Sets of MRE data were taken while the lung was inflated to fill the mould, with air, 4He, air, and SF6. Shear wavelength (λ), dynamic and loss shear moduli distribution maps (elasticity, G_d and viscosity, G_l), were computed for each slice progressing from the posterior to anterior periphery of the lung. Proton MRI morphology and computed λ, G_d and G_l maps were compared on a voxel-by-voxel basis by computing the mean differences between corresponding voxels in each image slice. Mean values of λ, G_d and G_l over the acquired lung volume could also be compared.

Results and Discussion

Morphology data between air/4He, Air/Air and Air/SF6 measurements agree to 12%, 13% and 21% respectively. Calculated λ values between air/4He, Air/Air and Air/SF6 agree to 16%, 15% and 15% respectively. The corresponding Gd values agree to 26%, 25% and 26%, and the Gl values to 54%, 52% and 53%. These pixel by pixel variations are large and Gl, being very structured, appears the most sensitive parameter to tissue displacements from one inflation to another. However, these differences can be attributed to misregistration since global values of λ, Gd, and Gl for the lung phantom inflated with air, 4He, and SF6 agree very well within 14.03±0.08 mm, 1.84±0.02 kPa, 0.58±0.02 kPa, respectively. These figures clearly corroborate Butler *et al.*[(2)] earlier findings. For a given inflation volume, namely a given transpulmonary pressure, the viscoelastic properties of the lung parenchyma do not depend on the gas content.

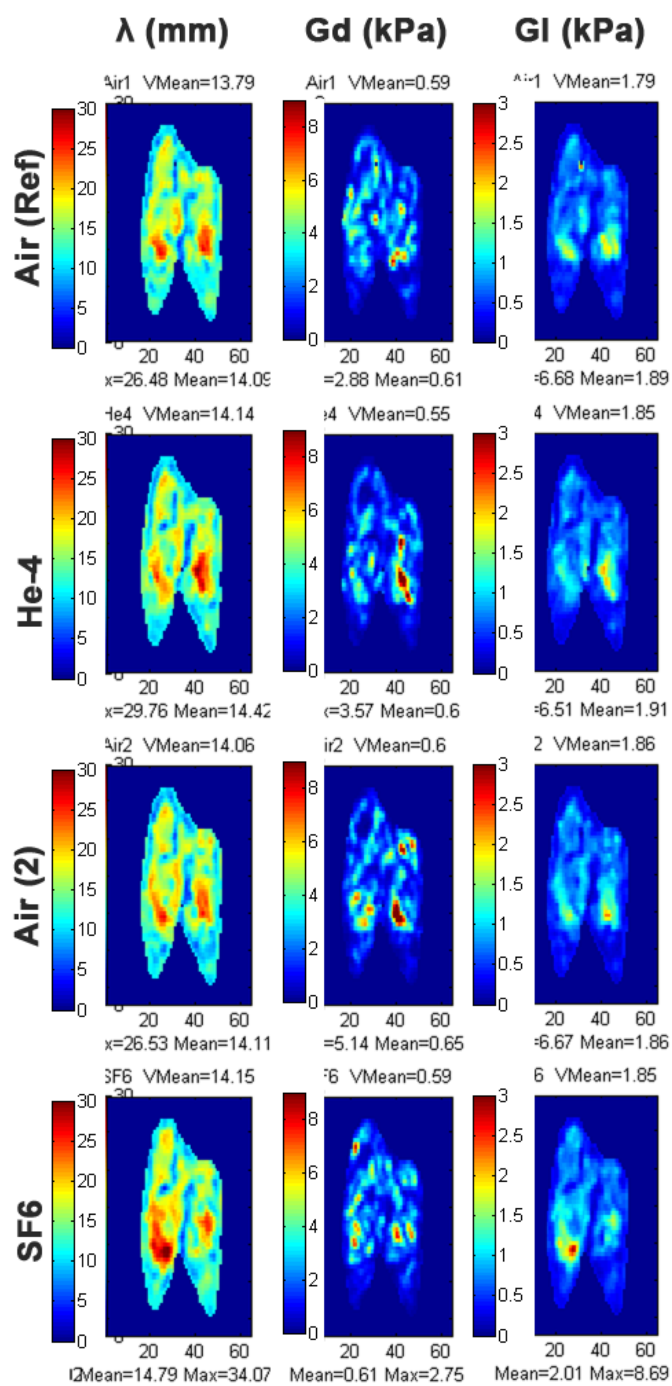

Figure 1: Wavelength (λ), dynamic shear modulus (G_d), and loss shear modulus (G_l) maps (left to right) in the preserved pig lungs for the central slice for air, 4He, air, and SF6 inflation (top to bottom).

References

[1] Muthupillai R et al *Science* , **26**1854 (1995), [2] Santarelli R. in *ESMRMB* 2008. Valencia, Spain, [3] Butler et al, *J. Appl. Physiol.* **62,** 1349-55 (1987)