Validation of Regional Compliance Measurement Using Hyperpolarized 3He MRI in a Syringe Lung Phantom

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Introduction: Static compliance is a measure of lung elasticity, defined as the change in lung volume per unit change of transoral pressure, It is known to increase in emphysema patients, to decrease in the presence of pulmonary fibrosis, and may be useful predictor of response to lung volume reduction surgery. A recently proposed method for measuring static compliance in rodents has the potential to become very useful as rodents become increasingly important in molecular and genetic studies of pulmonary disease [1]. In order to ascertain the validity of the proposed measurement technique, a phantom experiment was performed. The results of the phantom experiment were then compared to theoretical calculations.

Methods: The experiment was conducted on a 10 ml glass syringe secured on a plastic bed. The syringe plunger was loaded by two linear springs in series to mimic *in vivo* regional lung elasticity, Figure 1(a). This device which models a single voxel in the lung was connected to an MR-compatible animal ventilator to produce breathing sequences and to control imaging timing. Using a stopper and the ventilator, residual volume and tidal volume were set to 3 and 1 ml, respectively. The measured dead space from the middle of the respiratory valve to the syringe was approximately 0.75 ml. Other breathing parameters were as follows: Breathing rate: 60 breath/min, Inhale time: 333 ms, Exhale time: 667 ms, and Inspiration percentage: 33%. Imaging was performed on a small-bore 4.7 T animal magnet (Varian Inc.) using a birdcage coil. The hyperpolarized ^{3}He was generated via the spin-exchange optical pumping method with the use of a commercial polarizer (Amersham Health, Durham, NC). Fractional ventilation was determined using dynamic ventilation method, Figure 1(b), introduced by K. Emami [1]. The Helium projection images were obtained using the following imaging parameters: T_E: 1 ms, TR: 1.9 ms, FOV: 4x4 cm, Flip angle: 5°, and Matrix size: 16x16. Different pre-acquisition delays, Figure 1(c), were applied to monitor the effect of the ^{3}He diffusion on the fractional ventilation value, r. To mix the fresh ^{3}He gas with the residual gas more efficiently during the initial breathing cycles, the syringe was ventilated by ^{4}He instead of air at normal breaths. Theoretically, fractional ventilation, r, and compliance, C, of the syringe could be simply calculated as follows: r=TV/(RV+DS+TV), C= dV/dP = TV/PIP, where PIP is the breathhold pressure of 26 cmH_2O, TV is tidal volume, DS is dead space and RV is the residual volume, Figure 1(a). To demonstrate the measurement technique of the regional compliance in the rat models, the following calculations were performed on ventilation data of a healthy rat and an emphysematous rat: V= TV+FRC, S= $\Sigma M_i/V$, $V_i=M_i/S$, $dv_i=r_i \cdot V_i$, $C=dv_i/PIP$, where V is the lung volume captured in the image, M_i is the magnetization matrix, S is a constant , dv_i is a lung voxel volume, r_i is the regional fractional ventilation and C is the regional compliance.

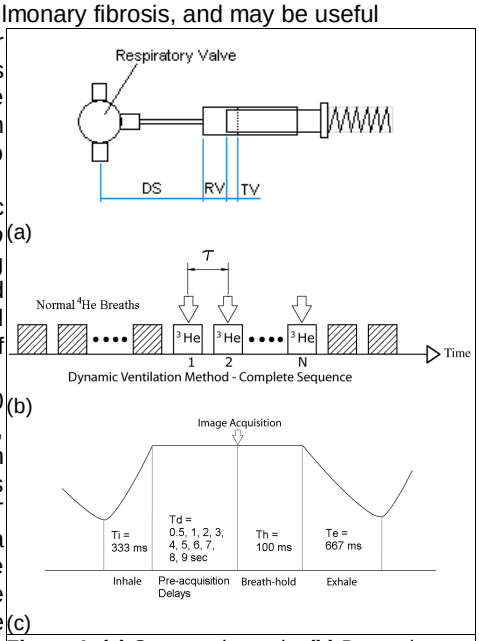

Figure 1. (a) Set up schematic; **(b)** Dynamic Ventilation sequence; **(c)** Details of the breathing cycle.

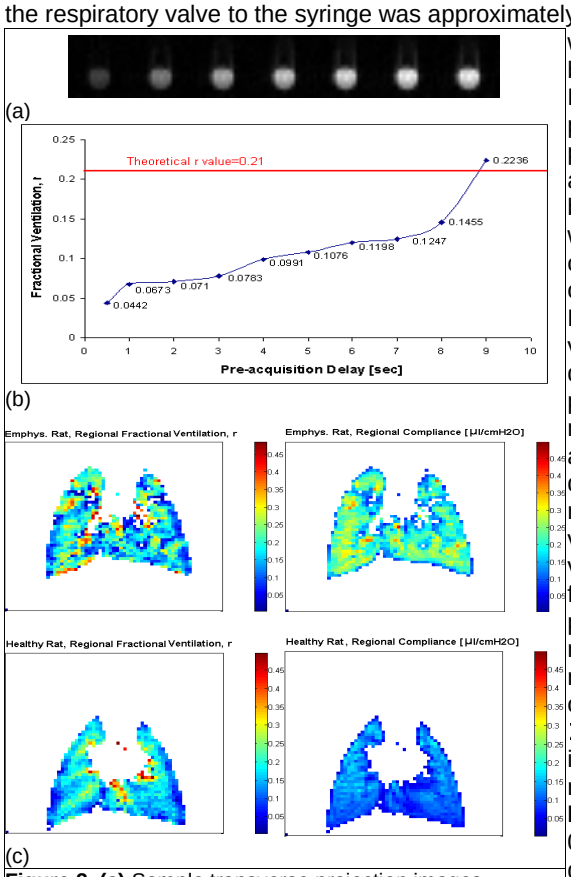

Figure 2. (a) Sample transverse projection images resembling the signal built up; **(b)** Fractional Ventilation values vs. Pre-acquisition delays in the syringe; **(c)** Regional Fractional ventilation and Regional Compliance in a healthy and an emphysematous rat.

Results and Discussion: The theoretical values of r and C of the syringe were 0.21 and 0.038 [ml/cmH_2O], respectively. The calculated r values corresponding to different pre-acquisition delays using dynamic ventilation method are shown in Figure 2(b). The longer the fresh gas mixed with the residual gas before acquisition, the closer the results approached the theoretical value. Although the r value corresponding to 9 seconds delay was very close to the theoretical value, it may be biased by the effect of the polarization decay caused by interactions with the glass syringe wall. The regional fractional ventilation and the regional compliance map of a healthy and an emphysematous rat are shown in Figure 2(c). The maximum compliance value in the emphysematous rat is about 0.4 [µl/cmH_2O] which is higher than the normal rat with the maximum of 0.18.

References: [1] Emami K *et al.*, A Novel Approach to Measure Regional Lung Ventilation Using Hyperpolarized 3He MRI – Potential in Clinical Studies; ISMRM Sixteenth Scientific Meeting, Berlin, Germany: 2007.