Nonlinear fitting method for the measurements of Regional Alveolar Oxygen Pressure and Oxygen Depletion Rate by Hyperpolarized 3He MRI

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Introduction: Hyperpolarized (HP) ^3He gas can be used to measure the alveolar oxygen partial pressure (P_AO_2) and oxygen depletion rate (ODR) in lungs. The measurement relies on the observation that ^3He depolarizes in the presence of oxygen with a rate that depends linearly on the partial pressure of oxygen. To separate the oxygen induced depolarization from the depolarization effect of the applied RF fields during the measurement, several acquisition techniques can be employed. The double-acquisition method [1,2], which requires two series of images with different inter-scan times to eliminate the RF effect, requires two breath holds. The single-acquisition methods [3], utilizing only one series of images, requires a special pulse sequence loop for multi-slice measurement.

Method : During the hyperpolarized ^3He MRI P_AO_2 measurements, the signal decay in a series of images can be expressed as $S(n) = S_0 \cdot \exp[Nn\ln(\cos\alpha) - \xi(PO_2 \cdot t - 0.5 \cdot ODR \cdot t^2)]$. After normalization, the RF effect is linear with image number n. If one chooses a timing scheme that is not evenly spaced, i.e., the sampling time t is not linear with n, in principle the RF and PO2 effects can be separated since they develop in a different pattern. Thus the nonlinear fitting method can be applied for this timing scheme, avoiding the fitting convergence problem. Also it should be noted that the timing scheme is not unique, thus providing great flexibility for the measurement.

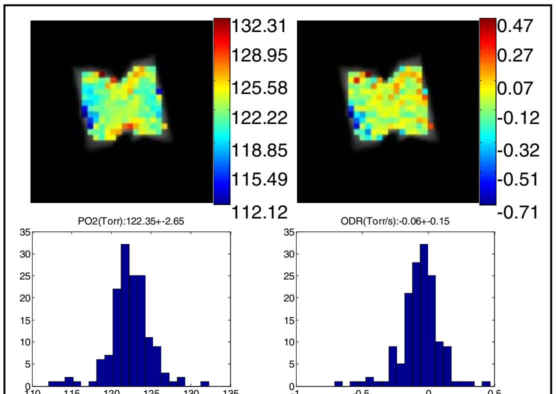

Fig.1. Phantom experiment results:
PO2=122.35+-2.65 Torr; ODR = -0.06+-0.15 Torr/s;

Result and Discussion: A phantom experiment, using a plastic bag filled with 300ml ^3He, 250 ml N_2, 100 ml O_2, was prepared to validate this technique. 6 images were acquired with the timing scheme [0 0.4100 10.4200 20.4300 25.4400 28.4500] (seconds), which is directly extracted from the DICOM image files. Since relaxation due to oxygen dominates the signal decay this timing provides an accurate measure of PO2, as verified in our numerical simulations. Nonlinear fitting calculation is implemented via Matlab optimization toolbox, which applies the Nelder-Mead Simplex Method. As shown in fig. 1, the average PO2 is in good agreement with the nominal value 117 Torr and ODR is averages very near the expected 0.0 Torr/s.

Animal experiments were conducted under an IACUC approved protocol. Yorkshire pigs were induced, intubated, paralyzed and placed supine in a birdcage coil and positioned in a 1.5 T whole-body imager (Sonata, Siemens). The hyperpolarized ^3He used for imaging was generated using a commercial polarizer (Amersham Health, Durham, NC). MRI imaging began immediately after administration of a gas mixture consisting of 100 ml O_2, 200 ml N_2 and 200 ml of ^3He that was polarized to a level of about 30%. We used a 2D fast gradient-echo(GRE) pulse sequence with the following imaging parameters: flip angle 2.2°; TR/TE 6.4/2.9 ms; FOV 260mm; base resolution 64×64; slice thickness 30 mm; The timing scheme for the 6 measurements in the series was [0 1.2275 12.0575 22.8850 28.7150 32.5450] (seconds). Figure 2 shows the static images and a map of P_AO_2 and ODR values for three slices of the pig lung. Also shown in this figure are histograms of the measured parameters. The mean and standard deviations of the parameters is consistent with the previous publications [1,2,3].

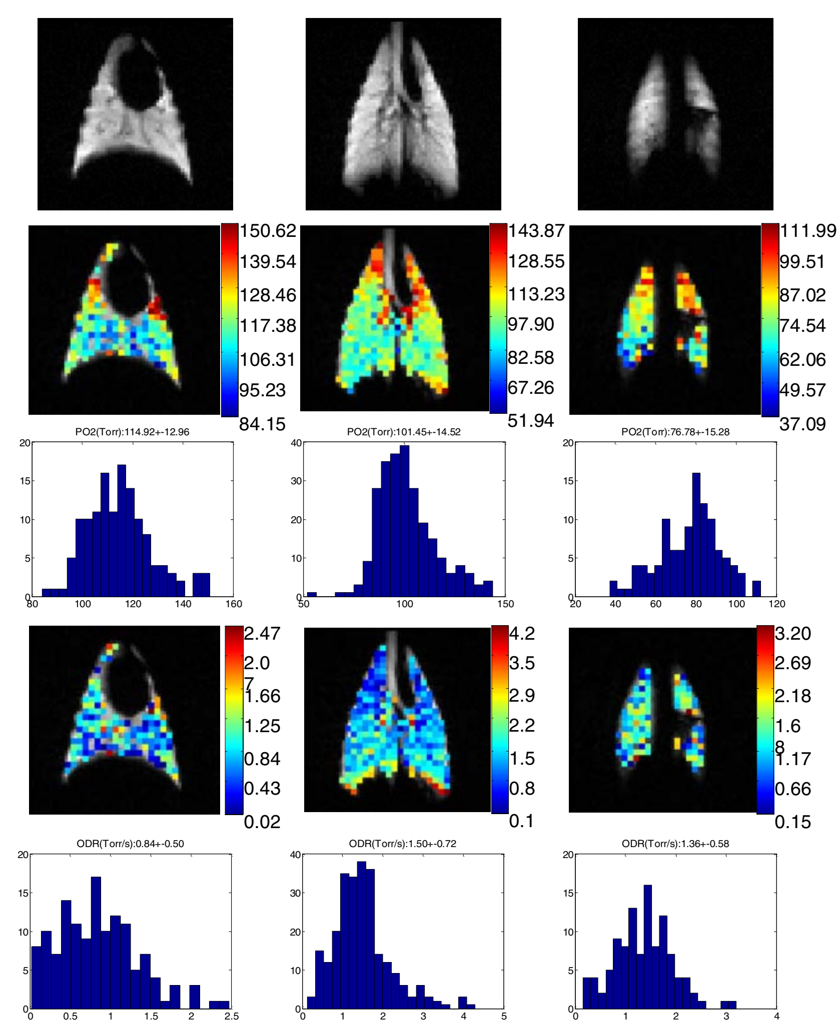

Fig.2. Three slices in the supine direction of the pig experiment. From the top to bottom: raw images, PO2 maps, PO2 histograms, ODR maps, ODR histograms. The PO2&ODR statistical values of each slice are shown in the histogram.

Conclusion: In this study we demonstrate a nonlinear fitting method with a new timing scheme for multiple slices P_AO_2 and ODR measurements. The phantom and animal experiments confirm the validity of this technique.

References: 1.) Deninger, A. J. *et al.*, *J Mag Res* **141**, 207 (1999). 2.) Deninger, A. J. *et al.*, *Mag Res Med* **47**, 105 (2002). 3.) Fischer, M.C. *et al.*, *Mag Res Med* **52**, 766 (2004).