Single-Acquisition Sequence for the Measurement of Regional Alveolar Oxygen Pressure and Oxygen Depletion Rate by 3He MRI

M. C. Fischer[1], J. Yu[1], M. Ishii[2], Z. Z. Spector[1], K. Emami[1], M. Itkin[1], A. Jalali[1], R. R. Rizi[1]

[1]Radiology, University of Pennsylvania, Philadelphia, PA, United States, [2]Otolaryngology, Johns Hopkins University, Baltimore, MD, United States

Introduction: Regional alveolar oxygen partial pressure (pO_2) and regional oxygen depletion rate (ODR) are of great importance in the detection and evaluation of lung disorders. These parameters can be utilized to extract the regional pulmonary perfusion and the ventilation to perfusion ratio. Hyperpolarized (HP) ^{3}He MRI has been successfully used to extract these parameters in normal and diseased lungs [1, 2].

In the presence of oxygen, the magnetization of initially polarized ^{3}He will gradually decrease due to the interaction between the two gas species [3]. The depolarization rate is strongly dependent on the partial pressure of oxygen in the gas mixture. By measuring this depolarization rate the partial pressure of oxygen can be calculated. The time evolution of pO_2, and therefore the ODR, can be obtained by extracting the evolution of the oxygen induced depolarization rate from a time series of images. In previous work, two series of pictures with different inter-scan times were analyzed, which allowed the separation of oxygen induced depolarization effects from the depolarization due to the applied imaging RF fields [1]. The method described here requires only one image series yielding similar accuracy for both pO_2 and ODR. This approach not only uses half the amount of polarized ^{3}He but also eliminates the necessity of preparing identical initial conditions two times. A previous attempt to use a single modified sequence had been undertaken but it did not yield the desired accuracy [4].

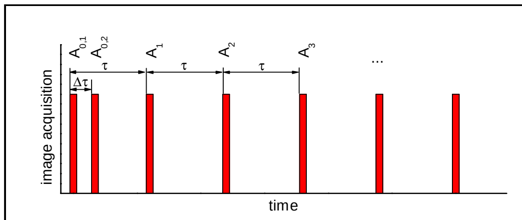
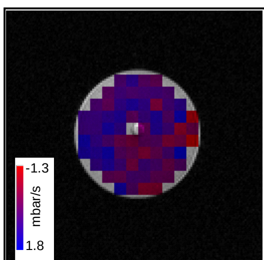


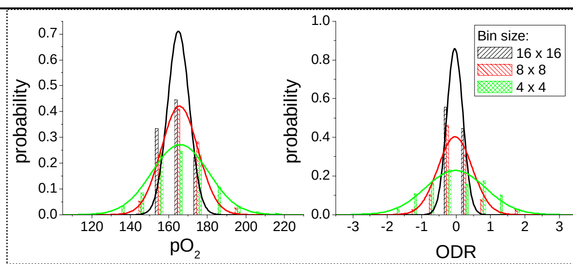
Fig. 1: Schematic of the imaging acquisition sequence.

Theory: The key idea of this sequence is to initially acquire two images at a short time interval ($A_{0,1}$ and $A_{0,2}$ in Fig. 1) in order to obtain the regional flip angle. The angle thus obtained is then used to extract the oxygen-induced decay rate from the rest of the series (images A_1, A_2, A_3, etc.). To account for the oxygen-induced depolarization during the initial flip angle determination, an iterative procedure is employed.

Method: In the first step, we tested the novel as well as the established measurement procedure on a homogeneous phantom. The phantom was a cylindrical syringe in which we adjust the oxygen concentration to about 15% by volume. By performing a regional analysis of the resulting map for pO_2 and ODR, we can estimate the accuracy of the methods. In the second step, we compared the results of both methods obtained in a Yorkshire pig. The animal was sedated with ketamine and kept under isofluorane anesthesia. It was ventilated and transferred supine to a 1.5 T imaging system (Siemens, Erlangen, Germany). For the imaging, a tidal volume of 600 ml consisting of 20% O_2 and equal amounts of polarized ^{3}He and N_2 were administered. Images with a matrix dimension of 128 x 128 were acquired using a FLASH sequence with T_R/T_E of 6.4/2.9 ms. The parameters $\Delta\tau$ and τ as indicated in Fig. 1 were 0.8 s and 6.8 s respectively.

Results and Discussion: Figure 2 shows an example of regional data for the ODR acquired with the novel single acquisition method in the phantom. The original image was color coded corresponding to the value of the ODR. The bins were masked for SNR and homogeneity. Figure 3 shows a histogram of single acquisition pO_2 and ODR measurements in the phantom for various bin sizes. Changing the bin size effectively changes the signal to noise in the data to be analyzed. The signal standard deviation scaled roughly with the square root of the number of pixels in the bin. An increase in accuracy for decreasing bin size is clearly visible. In Fig. 4 we plot the standard deviation of the resulting pO_2 and ODR measurements versus the relative noise in the signal intensity. The standard deviations scale approximately linearly with the relative noise and both sequences produce results with comparable accuracy.





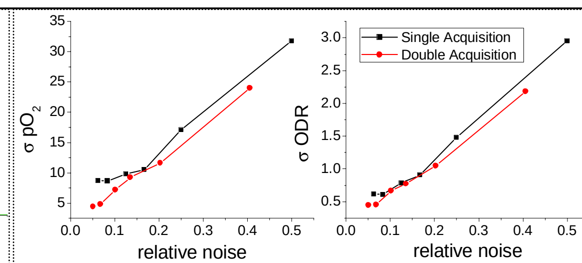


Fig. 2 (left): Sample result of the ODR in the phantom. The intensity of each pixel represents the image intensity and the color indicates the ODR. Imaging parameters were: flip angle 2°, FOV 18 cm. The slice thickness was chosen to contain the entire sample. Binning size is 6 x 6 pixels.

Fig. 3 (center): Distribution of pO_2 and ODR in the phantom. The bars show a histogram, and the solid lines show a normal distribution with similar mean and standard deviation. Results for three different bin sizes are shown.

Fig. 4 (right): Plot of the standard deviation of pO_2 and ODR in the phantom. The relative noise is inversely proportional to the initial SNR and the bin size.

In Fig. 5 we show the results of the pO_2 and ODR measurements in a Yorkshire pig. Results for both methods are displayed using the same color scale. We observe comparable trends and scatter for both methods.

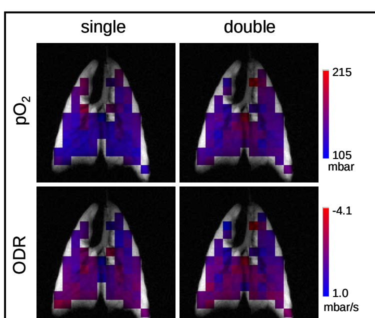


Fig. 5: pO_2 and ODR results in a Yorkshire pig. Both the novel single acquisition, as well as the established double acquisition data are displayed. Imaging parameters were: flip angle 2.5°, FOV 24 cm, slice thickness 3 cm. Binning size is 6 x 6 pixels.

Conclusions: We demonstrate a single acquisition technique to obtain regional pO_2 and oxygen depletion rate from HP ^{3}He MRI lung images. The accuracy of the results is comparable to the established double-acquisition technique but offers the advantages of smaller operating cost and greater ease of use.

Acknowledgements: This work was supported by NIH grant RO1-HL64741 and Philip Morris.

References: 1.) Deninger, A. J. *et al.*, *J Mag Res* **141**, 207 (1999). 2.) Jalali A *et al.*, to appear in *Mag Res Med*. 3.) Saam, B. *et al.*, *Phys Rev A* **52**, 862 (1995). 4.) Deninger A. J. *et al.*, *Mag Res Med* **47**, 105 (2002).