Nonlinear fitting method for high resolution mapping of Apparent Diffusion Coefficient (ADC) by hyperpolarized 3He

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Introduction: In hyperpolarized ^{3}He MRI ADC measurements, a bipolar gradient is introduced in the pulse sequence for diffusion sensitization. During imaging, however, the signal decay of a series of images is caused by both diffusion through these gradients and the applied RF pulse. Double acquisition or single acquisition techniques and a linear fitting algorithm is typically applied in order to separate these two effects [2,3]. However, these techniques are particularly sensitive to low signal-noise ratio(SNR) when high image resolution is desired.

Method: In the nonlinear fitting method, the gradient factor b is a nonlinear function of image number n, $S_n = S_0 \cdot \exp(Nn\ln(\cos(\alpha)) \cdot \exp(-b(n)\cdot D)$. In our study we choose $b(n) = b_0 * (\sqrt{M} - \sqrt{n})$, as the optimal relationship based on numerical simulation. M is the total number of images ,and b0 can be appropriately chosen so as to not exceed the scanner gradient hardware limit. Here high gradient factors are applied in the first several images of the series in order to utilize the initially higher 3He polarization. It should be noted that this $b(n)$ function is not unique, but the chosen function gives a smoother gradient development than other functions we have tried.

As shown in table 1, numerical simulations are implemented to compare the noise effects of these three techniques. Respectively, the b values for single, double, nonlinear techniques are [0.0 0.0 0.3 0.6 0.9 1.2 1.5], [0 0.3 0.6 0.9 1.2 1.5], [0.0 1.7305 1.1506 0.7056 0.3305 0](s/cm^2). It can be seen the nonlinear fitting technique shows better noise performance.

	Single linear	Double linear	Nonlinear
D (cm^2/s)	0.21+-0.10	0.20+-0.06	0.20+-0.02
α	2.47+-0.28	2.51+-0.11	2.50+-0.07

Table 1. numerical simulations of the noise effects on three ADC measurement techniques. Nominal values : D = 0.2cm^2/s; alpha = 2.5

Results and Discussion: To validate the nonlinear technique, we carried out a phantom experiment with a plastic bag filled with 100ml ^{3}He and 500ml N_2. A 2D gradient echo(GRE) sequence with a bipolar diffusion-sensitization gradient was used to acquire images with the following parameters: FOV 300 mm; slice thickness 100mm; TR/TE:10ms/6.46ms; resolution 128×128; 6 images were acquired in the series with b values[0 0.4944 0.3287 0.2016 0.0944 0]. Nonlinear fitting calculation is implemented via the Matlab optimization toolbox, which applies the Nelder-Mead Simplex Method. As shown in figure1 , the average ADC value agrees closely with the theoretical value when ^{3}He is heavily diluted in N_2 [1].

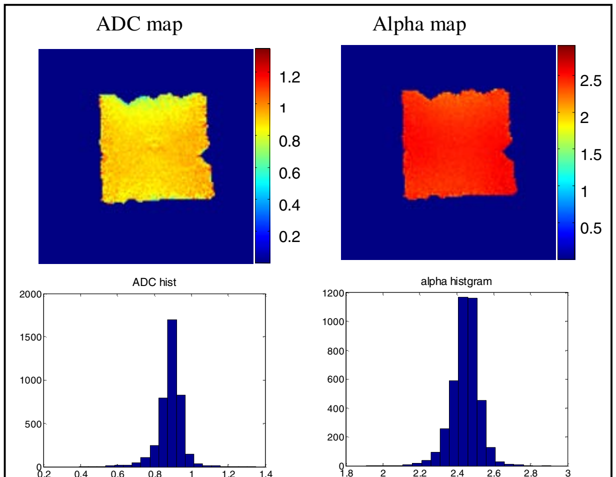

Fig.1. Phantom ADC experiment results: alpha=2.45+-0.07; D = 0.89 +- 0.06 cm^2/s

Animal experiments were conducted using an IACUC approved protocol. A Yokshire pig was sedated with ketamine and kept under anesthesia and then placed supine in a birdcage coil inside a 1.5 T scanner (Siemens Sonata). HP ^{3}He gas was prepared in a prototype polarizer (General Electric Health System, Durham, NC) and tidal volume of 500 ml consisting of 200 ml O_2 and 300 ml HP ^{3}He gas was administered to the pig. The key parameters of diffusion-sensitization GRE sequence are: FOV 240 mm; slice thickness 20mm; TR/TE:10ms/6.46ms; resolution 128×128; 6 images were acquired in the series with b values [0.0 1.7305 1.1506 0.7056 0.3305 0.0] (s/cm^2). The average SNR of the first image in the series is approximately 30. The experiment results are shown in fig. 2. It should be noted that the ADC value of the main branch in slice 2 (the red region) is consistent with the phantom experiment result.

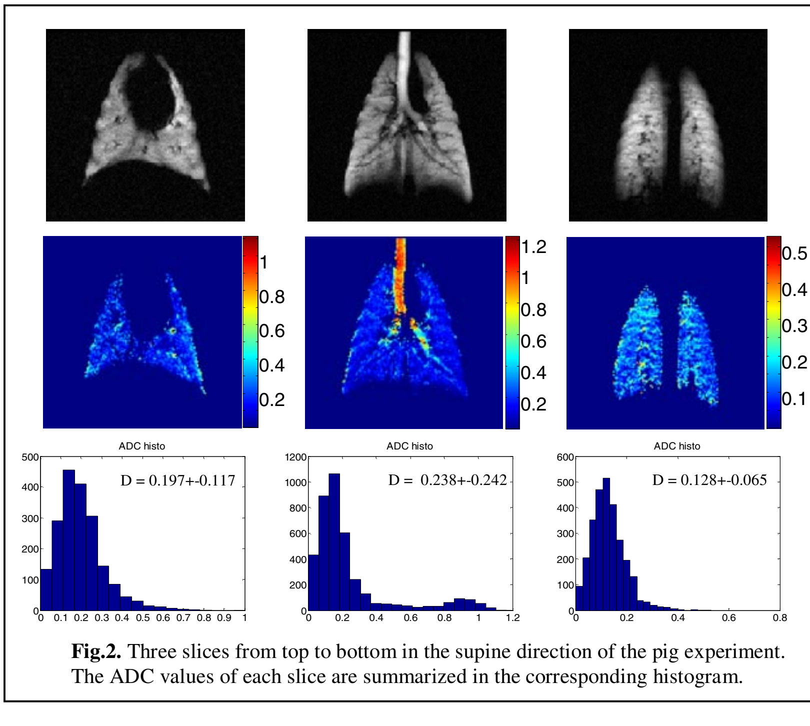

Fig.2. Three slices from top to bottom in the supine direction of the pig experiment. The ADC values of each slice are summarized in the corresponding histogram.

Conclusion: In this study, we present a new nonlinear fitting technique for high resolution ADC mapping, which is more robust with respect to noise than the conventional linear fitting method.

References: 1.) Yablonskiy D. A.. *et al.*, *PNAS* **99**, 3111(2002). 2.)Mayo J.R. *et al., Radiology* **222**, 8(2002). 3.) Salerno M. *et al. Radiology* **222**, 252(2002).