Estimation of global gravity-induced gradients and oxygen uptake from hyperpolarized ^{3}He p_AO_2 imaging

Hoora Shaghaghi[1], Hooman Hamedani[1], Stephen Kadlececk[1], Kiarash Emami[1], Yi Xin[1], Puttisarn Mongkolwisetwara[1], Masaru Ishii[2], Milton Rossman[3], and Rahim Rizi[1]

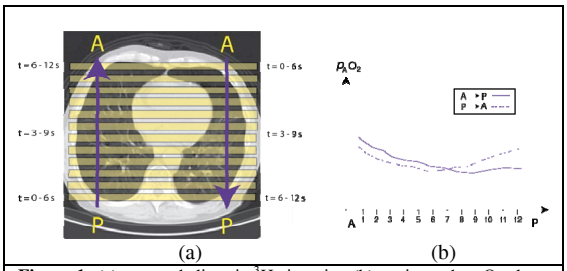
[1]*Department of Radiology, University of Pennsylvania, Philadelphia, PA, United States,* [2]*Otolarynology, Johns Hopkins Medical Center, Baltimore, Maryland, United States,* [3]*Pulmonary, allergy and Critical Care Division, University of Pennsylvania, Philadelphia, Pennsylvania, United States*

INTRODUCTION: The effect of gravity on dependent regions of the lung was studied with different modalities of lung imaging. Hyperpolarized ^{3}He imaging was proved to be sensitive to these gravitational effects; specifically, ventilation and oxygen tension imaging were able to detect these gradients in different postures. In a supine position, the imaged p_AO_2 levels were observed to drop monotonically from the anterior-to-posterior slices [1] in the same manner that was known to be present in the upright posture. The multislice scheme that was presented in p_AO_2-imaging reveals the mentioned gravitational gradients combined with the effect of relative oxygen uptake due to the different acquisition times for each slice. Presented in this abstract is a method capable of globally decoupling the effects generated by these two factors so as to statically compare them to pulmonary function tests.

METHODS: 22 Human subjects were classified into three cohorts of healthy nonsmokers (4M, 2F), of asymptomatic smokers (8M, 2F with smoking history 28±8 pack-yrs.), and of smokers with mild COPD (3M, with smoking history 36±8 pack-yrs.). Each cohort underwent ^{3}He p_AO_2-imaging with the scheme presented in [1]. Four series of images were acquired for each slice, and the rate of depolarization during ~6 seconds was used to evaluate the partial pressure of oxygen. Subjects inhaled a normoxic mixture of imaging gas diluted by nitrogen based on their total lung capacity (total volume: 12% TLC), and imaging occurred during a 12-second end-inspiratory breath-hold. A total of twelve 13-mm coronal slices were imaged using an interleaved acquisition scheme with a slice-selective gradient echo imaging pulse sequence at a spatial resolution of 8.3×8.3 mm^2 (TR/TE = 6.7/3.2ms, FOV = 30×40 cm^2, flip-angle = 5˚, Slice-Gap = 20% and Number of Phase Encodings N_{PE} = 48). For each subject, two sets of back-to-back p_AO_2-imaging were acquired with different temporal ordering; for instance, the ascending anterior-posterior acquisition direction was reversed in the second imaging set (refer to Fig. 1a). The summations of signal intensities in all of the voxels were evaluated in all four consecutive images for each slice, and were then used in the estimation of p_AO_2 based on the model presented in [1]. Assuming a linear oxygen uptake during the 12-second breath-hold, the evaluated average p_AO_2 for each slice can be thought of as the global oxygen tension in the middle of the imaging time for that slice (refer to Fig. 1). The two, otherwise identical, image sets for each slice can be averaged to correct for the effect of oxygen uptake due to timing so as to calculate the pure gravity gradient along the slices. On the other hand, the difference between the p_AO_2 of identical slices in the opposite acquisitions can be thought of as the pure effect of oxygen uptake. A line was fitted according to the difference in p_AO_2 values and the average of p_AO_2 values as a function of slice position z, weighted by $1/\sqrt{SEM_{AP}^2 + SEM_{PA}^2}$, where standard errors for each slice were estimated as $\sigma/\sqrt{n}$, where σ and n are the standard deviation of p_AO_2 values and the number of valid voxels in each given slice, respectively. The slope of $r(z)$_is related to the oxygen uptake rate, R, as:

$$R = \frac{dr}{dz}\frac{1}{4.TR.N_{PE}}$$

Prior to the p_AO_2-imaging, a pulmonary function test (PFT) was performed on all of the entering subjects. The PFT results were statistically compared to the evaluated rate of oxygen uptake and to the slope of assumed linear gravity gradient.



(a) (b)

Figure 1- (a) coronal slices in ^{3}He imaging (b) estimated p_AO_2 along to the slice positions in anterior-posterior and reverse direction

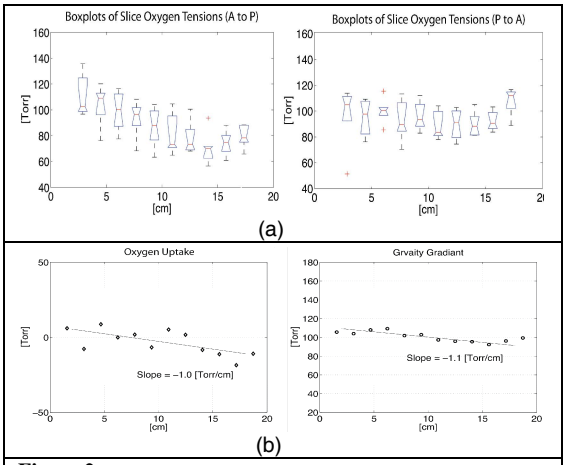


Figure 2- (a) Boxplots of oxygen tensions along the slices for all the subjects inn both anterior-posterior and posterior-anterior acquisitions. (b) linear-fit along the slices for oxygen uptake and gravity

RESULTS: Fig. 2a summarizes the boxplots of oxygen tensions along the slices for every subject in both, anterior-posterior and posterior-anterior acquisitions (A to P and P to A). Fig. 2b shows a representative linear-fit along the slices according to the difference and the average of p_AO_2 values that were used to calculate the oxygen uptake and gravity gradients, respectively. Table 1 presents the results of all 22 subjects included in the study as well as the average and standard deviation for each group. The oxygen-uptake average was lower in the smokers and in the COPD subjects, but not significantly. The gravity gradients were also less evident in the smokers. In the case of subjects with COPD, the gradients change direction toward higher values in the dependent regions (notice the positive values). Table 2 lists the average and standard deviations of the PFT parameters for each group. Table 2 also lists the results of *Pearson* correlation coefficients between each PFT property as well as the estimated gravity gradients and oxygen uptakes.

	#	Gravity Gradient [Torr/cm]	Oxyegn Uptake [Torr/s]
Healthy Nonsmoker	1	-1.6	-2.4
	2	0.1	-1.5
	3	-1.1	-1.0
	4	-0.7	-2.3
	5	-2.2	-2.1
	6	-1.0	-2.5
ave ± std		-1.08 ± 0.78	-1.97 ± 0.59
Asyptomatic Smoker	1	0.5	-1.9
	2	-1.0	-1.2
	3	-1.7	-2.1
	4	-2.2	-1.0
	5	1.2	-2.8
	6	0.3	-1.5
	8	-0.4	-1.7
	9	-1.2	-2.2
	10	-0.8	-2.5
ave ± std		-0.59 ± 1.10	-1.88 ± 0.59
COPD	1	1.1	-1.5
	2	1.9	-1.8
	3	0.7	-1.2
ave ± std		1.23 ± 0.61	-1.50 ± 0.30

Table 1- List of gravity gradient and oxygen uptake computed for all the subjects.

CONCLUSIONS: A method was presented to identify and segregate the effects of gravity gradients from the effects of oxygen uptake upon the observed oxygen-tension drops on anterior-to-posterior slices. The resulting oxygen uptakes were in the range of 1-2.5 Torr/s, and smokers were characterized by lower values. The gravity gradients were less evident in the smokers; in fact, the gravity gradients completely changed direction in COPD subjects. All of the measured PFT results presented a strong, significant correlation with the gravity gradients for all the subjects with the exception of DLCO, which showed significant correlation with the estimated oxygen uptake values.

REFRENCES: [1] Hamedani H. et al. Magn. Reson. Med. 2012; 67:1332–1345.

	FEV1/FVC (%)	FEF 25-75% (L/sec)	RV (L)	RV/TLC (%)	Raw (airway resistance)	DLCO/RV (%)
Nonsmokers	81.67 ± 2.34	3.57 ± 0.95	1.69 ± 0.28	28.83 ± 5.91	1.17 ± 0.65	4.82 ± 0.76
Smokers	76.56 ± 5.39	2.95 ± 0.48	2.00 ± 0.43	31.67 ± 6.87	2.01 ± 1.84	4.00 ± 0.75
COPD	61.00 ± 3.00	0.74 ± 0.28	2.92 ± 0.38	47.00 ± 6.24	3.48 ± 2.31	4.67 ± 1.57

Gravity Grad.	-0.741	-0.649	0.805	0.738	0.718	< 0.5
Oxyeg uptake	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	0.602
	Pearson Correlation Coefficients					

Table 2- Pearson Correlation Coefficients between PFT properties and the estimated gravity gradients and oxygen uptakes