Alveolar-duct Geometry during Expiration via ^{3}He Diffusion MRI

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Introduction

Acinar geometry has been the subject of several morphological and imaging studies in the past; however, little is known about how acinar microstructure changes when the lung inflates or deflates. Lung morphometry with hyperpolarized ^{3}He diffusion MRI [1,2] allows evaluation of lung microstructural geometrical parameters. The diffusion-weighted ^{3}He MR signal decays non-mono-exponentially as a function of diffusion-sensitizing gradient strength due to anisotropic diffusion within the acinar ducts. Anisotropic diffusion coefficients along and perpendicular to the duct axis (D_T and D_L) can be extracted from the diffusion weighted images and used to determine acinar duct dimensions [1,2]. The purpose of the present study is to investigate how these dimensions change as a function of total lung inflation volume.

Materials and Methods

Five normal canine lungs were excised after sacrifice for unrelated cardiac experiments, for which Animal Studies approval was obtained. The main bronchus of each lung was cannulated and all minor leaks were repaired. For each experiment a mixture of hyperpolarized ^{3}He and N_2 was injected into the lung via syringe to a maximum transpleural pressure of 23 cm H_2O to ensure that gas was uniformly distributed throughout the lung. The gas mixture was then partially evacuated to obtain one of three desired pressures (approximately 18, 7.5, and 2.5 cm H_2O corresponding to approximately 100%, 78%, and 66% of total lung capacity). 2-D FLASH images at 9 b-values (0 to 14 s/cm^2) were obtained on a 1.5-T Siemens Magnetom Sonata scanner. Imaging data were fit to a cylindrical airway model [2], where periodically spaced and segmented annuli represent the alveoli that line the walls of the acinar ducts [3]. From this model, diffusion coefficients D_T and D_L transverse and longitudinal to the cylinders (respectively) are extracted; the coefficients relate mostly to outer and inner airway radii R and r (Figure 1). Lung volume was determined by counting the total number of voxels with ^{3}He signal from the complete set of ^{3}He images.

Results

All images demonstrated high signal-to-noise, sometimes in excess of 100, allowing evaluation of geometrical parameters R and r with high confidence. Each lung showed independent yet consistent changes in both R and r (Fig. 2, Table 1) with r decreasing (in absolute terms) approximately the same amount as R. On average a 30-40% decrease in volume led to a 40% decrease in r and a 15% decrease in R. The average change in R-r, which represents the length of the alveolar walls protruding into the acinus, was less than 1%. Regional variation (about 18% for r and 12% for R) was seen in each case, but the spatial variation in r and R was consistent at each volume.

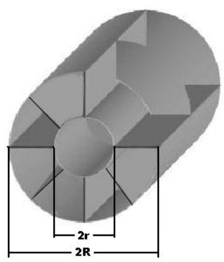

Figure 1: Model of an acinar airway. Two sections of the periodic structure are shown. The outer walls of two adjacent alveoli in each section have been removed [2].

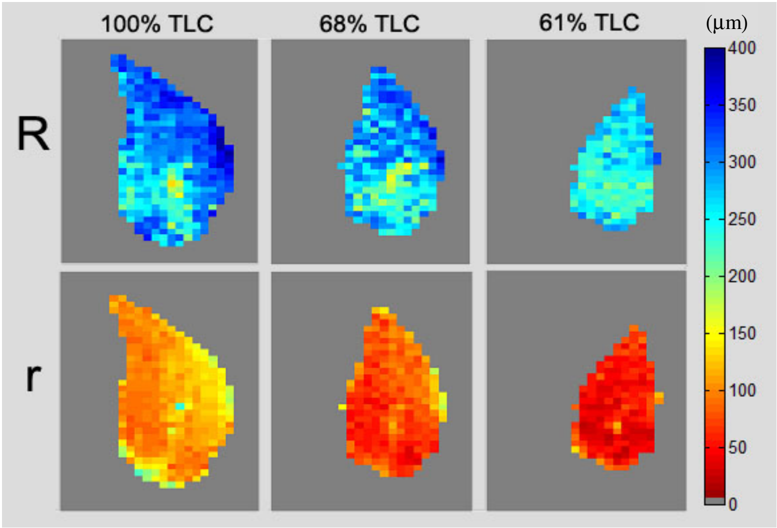

Figure 2: Transverse images of R and r in dog lung 4 at multiple volumes. Top row: R-maps in microns at 100%, 68%, and 61% TLC (L to R). Bottom Row: r-maps at identical volumes

	% Max Vol.	R (μm)	r (μm)	R-r (μm)
Lung 1	100	312	117	195
	77	283	115	168
	57	249	68	180
Lung 2	100	244	79	164
	83	217	64	154
	64	210	50	160
Lung 3	100	314	120	195
	84	292	94	198
	72	273	68	205
Lung 4	100	286	108	178
	68	270	74	196
	61	243	48	196
Lung 5	100	306	86	220
	78	284	78	205
	76	253	45	208

Table 1: Data for r and R for each canine lung, averaged over all voxels

Conclusions

We have determined for the first time geometric changes in lung microstructure during the inflation cycle at physiologically relevant volumes by ^{3}He diffusion. Our data imply that during a change in lung volume from TLC to 60% of TLC during deflation, both R and r decrease by approximately 46 microns, implying the alveolar wall length (R-r) undergoes no significant change. While there is regional variation in the measured values, the consistency of the average alveolar wall length between volumes implies that these variations are physiologic.

References

[1] Yablonskiy et al., *PNAS* 2002; 99: 3111. [2]Sukstanskii, Yablonskiy, *J Mag. Reson*. 2008; 190: 200. [3]Haefeli-Bleuer, B. & Weibel, E. R., *Anat. Rec*. 1988; 220: 401.