Hyperpolarized 3He Diffusion MRI of Acinar Airways in Canines with Induced Emphysema: Comparison with Computed Tomography.

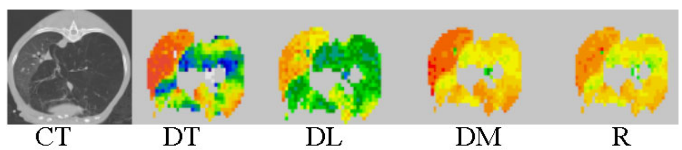
T. S. Tanoli[1], J. C. Woods[1,2], K. Ty Bae[1], M. S. Conradi[1,2], J. C. Hogg[3], J. D. Cooper[4], D. A. Yablonskiy[1,2]

[1]Mallinckrodt Institute Of Radiology, Washington University, St Louis, Missouri, United States, [2]Physics, Washington University, St Louis, Missouri, United States, [3]The UBC McDonald Research Laboratory, St Pauls Hospital, Vancouver, British Columbia, Canada, [4]Surgery, Washington University, St Louis, Missouri, United States

Introduction: Computed tomography (CT) has established itself as a quantitative measure of emphysema in humans [1], but the presence of ionizing radiation limits its utility. Measurement of Apparent Diffusion Coefficient (ADC) of hyperpolarized ^{3}He gas in lung shows great promise for quantifying emphysema [2-6]. It is non-invasive, free of ionizing radiation and may be a preferable tool for diagnosis and follow-up of this disease. One means of validating ADC is to compare it with an established method i.e. CT. Such attempts have been made previously for standard, Stejskal-Tanner-type ADC measurements [3, 5]. This presentation is devoted to a detailed analysis of the relationship between ^{3}He gas diffusivity in acinar airways [4] and CT measurements in healthy dogs and dogs with induced emphysema.

Method: Six mongrel dogs were studied after approval by the local animal study committee. Emphysema was induced in the right lung of 5 dogs by lavage with porcine pancreatic elastase [7]. Contiguous 3-mm CT sections were obtained from apex to base on a spiral scanner (Siemens Medical Systems, Iselin, NJ). The mean CT linear attenuation coefficient was evaluated in each lung, using a threshold of –500 Hounsfield units (HU). Hyperpolarized ^{3}He diffusion MRI with 9 b-values (Δb=0.95 sec/cm^2) was performed according to the method proposed in [4], (5 slices, 20 mm thick, TE=7.2 ms, FoV= 160×320, Matrix= 32×64, flip angle= 3.5º) using a 1.5 T MR scanner Vision (Siemens, Erlanger, Germany). MR data analysis was based on a model of gas diffusion [4] where lung geometry at the acinar level was described in terms of cylindrical airways covered by alveolar sleeves [8]. Diffusion in each airway was considered anisotropic and characterized by a longitudinal diffusion coefficient along the airway axis D_L, and diffusion coefficient D_T transverse to the airway axis. Since many acinar airways with different directions reside in the imaging voxel, a total MR signal was presented as a sum of signals from isotropically distributed airways [4]. Anisotropic gas diffusion coefficients were extracted in lung acinar airways despite airways being too small to be resolved by direct imaging. Also, the method allows evaluation of acinar airway radii, R, and mean ADC, D_M.

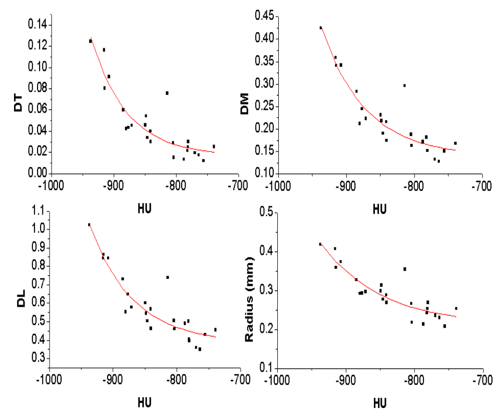
Results: Images on the right represent example of CT image and corresponding diffusion maps from healthy (left) and emphysematous (right) lung. Dependences of D_T, D_L, D_M, and R on HU in corresponding CT images are shown as scatter plots. All diffusion coefficients are measured in cm^2/sec and airway radii in mm. Each point represents mean value for one lung. Data were fit to exponential curves and the following equations were obtained:



$$D_T = 0.017 + 0.34 * \exp(-0.018(HU + 1000))\,;\; D_M = 0.14 + 0.76 * \exp(-0.015(HU + 1000))$$

$$D_L = 0.38 + 1.62 * \exp(-0.015(HU + 1000))\,;\; R = 0.21 + 0.43 * \exp(-0.011(HU + 1000))$$

Scatter plots demonstrate good correlation with proposed equations (r^2 = 0.82, 0.84, 0.85 & 0.78 for D_T, D_L, D_M & R respectively).



Discussion: D_T in healthy dog lungs is 3-4 times smaller than in healthy human lungs, while the more traditionally measured D_M is only slightly reduced. This indicates a greater sensitivity of D_T to lung microstructure evaluation than conventional D_M. For healthy dogs our analysis yields mean acinar airway radius of about 0.25 mm as compared to 0.36 mm in healthy human lung. We note that the theoretical model [4] that we have used for data analysis is only valid for healthy lungs and lungs with mild emphysema. With the progression of emphysema, acinar airways become enlarged and alveolar walls undergo destruction, hence description of acinar airways in terms of cylinders becomes less relevant. The parameters D_T, D_L, & R in severe emphysema can be considered only as apparent. At the same time, mean diffusivity D_M preserves its meaning as it turns out to be model independent. In particular, for tissue free space (-1000 H.U), the equation for D_M gives 0.9 cm^2/sec in good agreement with the unrestricted diffusion of ^{3}He in the trachea. All graphs and equations show dramatic increases in parameter values with emphysema progression, demonstrating the sensitivity of the proposed approach to evaluation of emphysema level. As shown previously [3] in patients with severe emphysema, there is a strong correlation between diffusivity measures and HU. Our data on dogs further confirm this conclusion.

Conclusion: A strong correlation between CT values and acinar anisotropic ADC measurements ranging from healthy dogs to dogs with severe emphysema found in this work suggests that a classification of emphysema based on ^{3}He gas diffusivity measurements in acinar airways can be created, employing the existing CT classification.

Acknowledgement: Supported by NIH grants RO1 HL 70037, RO1 HL 62194.

References: (1) Gevenois, P.A. and J.C. Yernault, Eur Respir J, 1995. **8**(5): p. 843-8. (2) Saam, B.T., et al., Magn Reson Med, 2000. **44**(2): p. 174-9. (3) Yablonskiy, D.A., et al., Supplement To Radiology, 2001. **221(P)**: p. 631. (4) Yablonskiy, D.A., et al., Proc Natl Acad Sci U S A, 2002. **99**(5): p. 3111-6. (5) Salerno, M., et al., Radiology, 2002. **222**(1): p. 252-60. (6) Woods, J.C., et al., Magn Reson Med, 2004. **51**(5): p. 1002-8. (7) Chino, K., et al., Exp Lung Res, 2004. **30**(4): p. 319-32.
(8) Haefeli-bleuer, B. and E.R. Weibel, The Anatomical Record, 1988. **220**: p. 401-414.