F-19 MR Imaging of Ventilation and Diffusion in Lungs

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INTRODUCTION

Hyperpolarized noble gases have been used as the signal source in pulmonary imaging with the goal of assisting in the diagnosis and selection of treatment options for emphysematous patients [1]. However, the difficulty and high cost of producing and handling hyperpolarized gases have hindered its widespread or clinical use. Perfluorinated gases, such as C_2F_6 and C_3F_8, may be viable alternatives to hyperpolarized gases for lung airspace imaging [2]. These gases are inert, have low solubility in lipids, can be mixed with oxygen for multiple breath-hold imaging, have multiple equivalent ^{19}F atoms per molecule, and have T_1s short enough for rapid signal averaging (10 – 20 ms). Additionally, ^{19}F has a relatively high magnetic moments (94% of proton) and no background signal in the human body. The diffusion of these gases is expected to be sensitive to restrictions imposed by the lung microstructure; thus, maps of the apparent diffusion coefficient (ADC) will give information about local tissue destruction. The low free diffusivity of these large and heavy perfluorinated gases makes calculation of the local surface-to-volume ratio feasible by measurement of the ADC at typical diffusion times [3].

MATERIALS AND METHODS

Excised emphysematous human lungs removed at transplant and healthy human donor lungs rejected for implantation were used. The lungs were sealed of leaks and thoroughly purged of air and filled with C_2F_6 or C_3F_8 gas in a bell jar. Images were obtained with a 1.5 T Siemens Vision full-body scanner and a home-built, high-Q (>100) solenoidal RF coil. A 3D FLASH pulse sequence was used to acquire one 320 mm thick slab, typically with 10 partitions and an in-plane resolution of 5.5 mm x 5.5 mm. Maps of the ADC were made by acquiring two interleaved images, one with b = 0 s/cm^2 and one with b = 17.87 s/cm^2. The ADC was then calculated by comparing the images on a pixel-by-pixel basis.

RESULTS

Ventilation images and ADC maps show that good-quality ^{19}F images can be acquired in human lungs. The information content of the ADC maps is comparable to that of similar maps made with ^3He, in spite of lower signal-to-noise. There is a significant difference between the restriction to diffusion imposed by healthy lung tissue and emphysematous lung, demonstrating that the ADC of perfluorinated gases is sufficiently sensitive to discern changes in lung microstructure caused by emphysema (Figure 1). However, it is critical that the lung be filled uniformly with a known concentration of gas, as mixtures with lighter and smaller nitrogen or oxygen increase the free diffusivity of the perfluorocarbons, complicating interpretation of the ADC map. Higher-resolution ventilation images with good signal-to-noise can also be made in reasonable imaging times (Figure 2).

CONCLUSIONS

Good-quality ventilation images and ADC maps can be made with perfluorinated gases, avoiding complications and costs associated with hyperpolarized gases. Healthy and diseased excised human lungs are readily distinguished by ^{19}F ADC measurements. The results demonstrate the feasibility of extending this work to *in vivo* pulmonary imaging, with the goal of developing a simple technique for disease diagnosis and selection of treatment options.

REFERENCES

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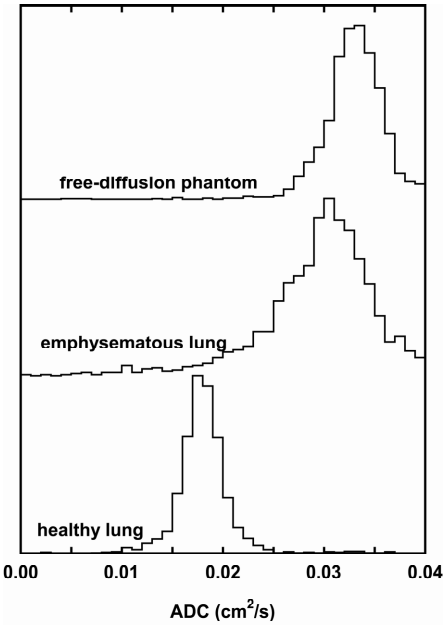

Figure 1: Histograms showing the ADC of C_2F_6 gas in a free-diffusion phantom (top) where D_0 = 0.033 cm^2/s; an excised emphysematous human lung (middle, the mean ADC = 0.031 cm^2/s); and an excised healthy human lung (bottom, the mean ADC = 0.018 cm^2/s). Both lungs were purged and filled with C_2F_6 in a bell jar. The dramatic difference in ADC between the emphysematous lung and the healthy lung demonstrates that C_2F_6 gas ADC measurements readily distinguish healthy from emphysematous lung tissue.

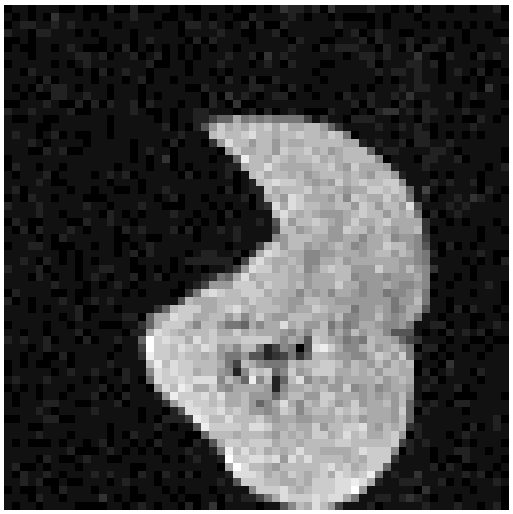

Figure 2: A higher resolution (3.1 mm x 3.1 mm) 10 mm thick partition (of 32 total) of an excised healthy human lung using C_2F_6. This image was made with a spin echo pulse sequence with an echo time of 4 ms. The ten signal averages required 287 s and resulted in a signal-to-noise ratio of 12.5.