^{3}He Diffusion MRI of the Lung[1]

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Rationale and Objectives. MR imaging of the restricted diffusion of laser-polarized ^{3}He gas provides unique insights into the changes in lung microstructure in emphysema.

Results. We discuss measurements of ventilation (spin density), mean diffusivity, and the anisotropy of diffusion, which yields the mean acinar airway radius. In addition, the use of spatially modulated longitudinal magnetization allows diffusion to be measured over longer distances and times, with sensitivity to collateral ventilation paths. Early results are also presented for spin density and diffusivity maps made with a perfluorinated inert gas, C_3F_8.

Methods. Techniques for purging and imaging excised lungs are discussed.

Key Words. Lung; Diffusion MRI; Helium-3; anisotropic diffusion; gas MRI

The development of laser-polarized helium-3 (^{3}He) technology (1,2) now allows for imaging of the gas spaces of human and animal lungs (3,4). Typical absolute polarizations of 30%–50% are approximately 100,000 times that available at thermal equilibrium in typical imaging fields of 1.5 T, with a corresponding increase in signal to noise (S/N) for a given quantity of gas. Many of the early applications of hyperpolarized ^{3}He magnetic resonance (MR) imaging used ventilation images (or spin-density images) (3,4), which show the spatial distribution of the ^{3}He after inhalation of a bolus followed by breathhold. In small animals with continuous breathing of ^{3}He, exquisitely resolved microimages have been reported (5).

In recent years, the effort of our group at Washington University has focused on MR determinations of the changes in airways at the acinar level (airways lined with alveoli) using ^{3}He diffusion MR. The following describes the approaches we have taken and presents some of the results at our institution and is not intended as a review of the field (for more comprehensive reviews, see references 3 and 4).

METHODS

All the images reported here were obtained on a 1.5 T Siemens Vision scanner. Three home-built polarizers and a General Electric (Durham, NC, formerly Amersham Health) polarizer were used, producing 0.5–1.0 L ^{3}He gas at 30%–50% polarization (4). The studies involving human subjects were performed with the approval of the Washington University Human Studies Committee, under an Investigational New Drug Exemption of the US Food and Drug Administration

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In vivo images were acquired using a homemade Helmholtz pair tuned to the ^{3}He resonance frequency at 48.47 MHz. The coil is tunable to proton frequency without moving the patient, which allows coregistration of proton and ^{3}He images for later comparison. Ex vivo images were acquired using a single-turn solenoid-like coil, built to take advantage of the lack of saline-induced loss and to achieve high Q and sensitivity. Because experimental details for each of the classes of experiments described here differ greatly, additional methods are discussed within each subsection that follows.

RESULTS AND DISCUSSION

Ventilation Imaging

Spin-density images provide visualization of gas during inspiration and after a breathhold to allow for some equilibration. Compared with diffusion maps, as discussed in the following section, their interpretation is straightforward. Spin-density images are useful in visually identifying the regional abnormalities in the distribution of ventilation, which are frequently marked in patients with severe emphysema. In our investigations, these patients are often imaged several days before lung volume reduction surgery (LVRS) (6,7).

Axial slice images of a female patient, pre-LVRS and on 6-month postsurgical follow-up, are presented in Fig 1a. These are gradient-echo images with small-angle radiofrequency (RF) pulses (typically 5–10°) with in-plane resolution of 7 mm × 7 mm; the slice thickness is 10 mm. The intensity of signal and hence the concentration of ^{3}He after a single breath of polarized gas show improved uniformity after surgery. Some regions that received essentially no gas presurgery are ventilated after surgery. As expected, lung size decreases postoperatively as air trapping and hyperinflation decrease. This is a major mechanism for the relief of dyspnea noted in almost all patients undergoing LVRS at our institution. We note that the total ^{3}He signal integrated across the lung only reflects the volume and polarization of the inhaled gas. Thus the important issue is the uniformity of such images.

Images pre- and post-LVRS for a male patient with a large bullous region in the left lung (right side of figure) are presented in Fig 1c. Successful matching of the slices is evident from the similar appearance of the two major bronchi (appear as two foci of high signal intensity between the lungs) in both axial images. Before surgery, essentially no gas is evident in the left lung; after surgery, ventilation is returned to the anterior regions of the left lung. In this patient, this pattern persists more than half the length (superior to inferior) of the lung (not shown).

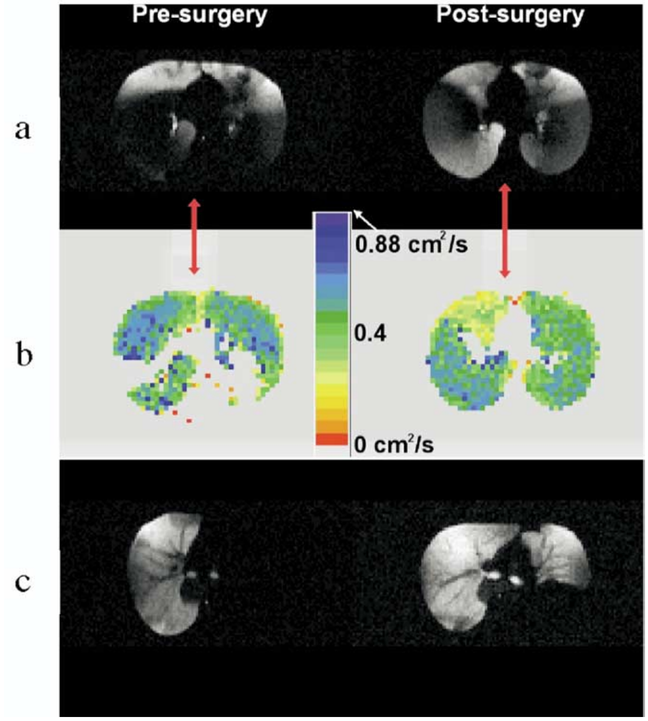

Figure 1. Transverse slice ^{3}He images of two patients with severe emphysema, pre–lung volume reduction surgery (left) and 6 months after surgery (right). The images **(a)** and **(c)** are spin-density images to reveal the distribution of gas upon inhalation and breathhold; the central, color images **(b)** are ADC maps of the same patient and slices as **(a)**. After surgery, the ventilation distribution is more uniform. The patient in **(c)** had a large bullous region presurgery in the left lung that is only partially rectified by the surgery.

Diffusion Imaging

Emphysema is defined as a disease of dilation of the acinar airways associated with destruction of the acinar airway and alveolar walls in the absence of significant fibrosis (8). The changes in the tissue microstructure are easily observed in an adequately inflated lung sampled and viewed under a microscope. The much larger alveolated airway "compartments" present in emphysema imply that the apparent diffusion coefficient of a gas will be larger (less restricted) than in healthy lung tissue (9,10). In particular, ^{3}He has a small atomic mass, so a high thermal velocity, and has a small diameter, so a small collision cross-section; both result in a large free diffusivity, D_0 (11). At 300 K and 1 atmosphere, D_0 of the ^{3}He is 2.2