Imaging V/Q by Mapping the T_1 of Inert Fluorinated Gases

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Introduction: We present a method for mapping ventilation-perfusion ratios (V/Q) by imaging the ^{19}F longitudinal relaxation time (T_1) of an inert fluorinated gas, in this case SF_6. We take advantage of the fact that, in these gases, the T_1 is dominated by the spin-rotation interaction, mediated by molecular collisions. In the lung, the T_1 is roughly linear in the SF_6 concentration because collisions of SF_6 with less massive molecules (O_2, CO_2, H_2O) contribute differently to relaxation than SF_6-SF_6 collisions. Further, in a subject breathing 30%SF_6:70%O_2, the concentration of SF_6 is increased wherever V/Q is low, due to the removal of O_2 by perfusion. Using these known relationships, T_1 images are readily converted to V/Q images. Note that for this method, the subject breathes a 30%SF_6:70%O_2 mixture during the entire procedure, which should be well-tolerated by patients with obstructive lung disease. This is an advantage over our previous method of mapping V/Q using SF_6 spin density images [1], which required a reference image made while the subject breathes a normoxic gas mixture.

Methods: We have developed a modified Look-Locker [2] T_1 sequence, optimized for measuring the T_1s of SF_6 in lungs, which cover the range 0.8-1.3 ms. The pulse sequence consists of a π pulse, followed by a series of eight ~$\pi/4$ inspection pulses at 0.04, 1.00, 1.93, 2.89, 3.81, 5.00, 6.74, and 9.54 ms after inversion (TR=11.7 ms). We are also testing a modified fully-relaxed inversion recovery (FRIR) sequence: π–τ_1–$\pi/2$–T–π–τ_2–$\pi/2$–T–π–τ_3–$\pi/2$–T–$\pi/2$–T, with τ_1, τ_2, τ_3, T = 0.05, 0.41, 1.21, 6.12 ms (TR=26.1 ms). (Note that a time savings is achieved over standard FRIR by eliminating π–τ_4, since the signal from the last $\pi/2$ pulse is the same as one would obtain using π–τ_4–$\pi/2$, with τ_4=5T_1.) Either T_1 sequence is combined with 3D FID projection imaging [3] at 1.9 T to spatially resolve T_1. The T_1 sequence is repeated for 1750 different imaging gradient directions (G=6.9 mT/m), with an FID (880pts, 1MHz) acquired immediately after each inspection pulse. An image (2 mm isotropic resolution) corresponding to each inspection pulse in the T_1 sequence is constructed, and T_1 is determined from a 3-parameter fit of the time dependence of the signal in each image voxel.

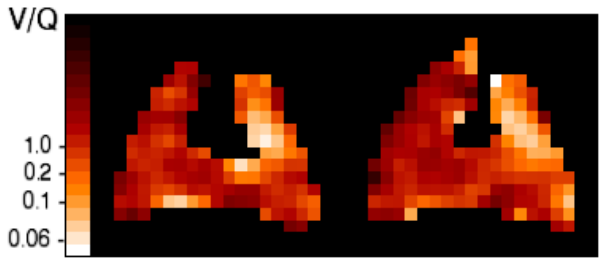

Fig. 1 Two consecutive planes from a 3D SF_6 T_1 image of a rat with a partially obstructed left bronchus. The left lung is displayed on the right side of the image.

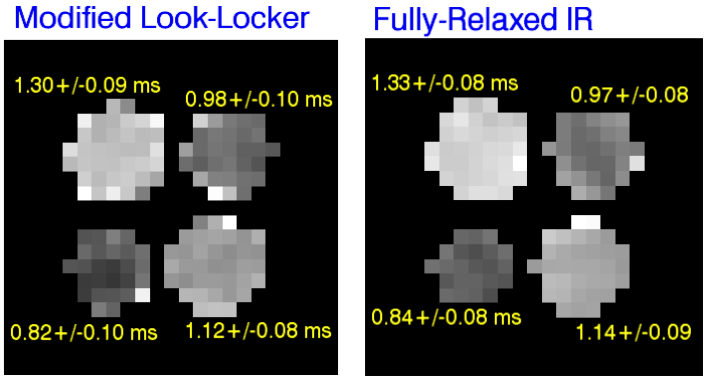

Fig. 2 Comparison of T_1 imaging pulse sequences. The average T_1 and standard deviation for each SF_6 mixture are indicated by the labels on the image.

Results: Fig. 1 shows two planes from a 3D T_1 image (Nex=108, total image time=88 min.) of a mechanically ventilated rat with a partially obstructed left bronchus. Here, the expected T_1 for healthy lung tissue is 0.89 ms (V/Q=0.85). The average T_1 value of the 1023 voxels in the right (unobstructed) lung is 0.88 ms (standard deviation = 0.08 ms), in very good agreement with the expected value. In the left lung, the obstruction due to the bead is evident. In the lower left lung (434 voxels), T_1ave=0.97 ms (V/Q=0.19). The upper left lung (225 voxels) shows a greater degree of obstruction, with T_1ave=1.05 ms (V/Q = 0.10). Recently, we have compared the Look-Locker sequence with the FRIR sequence using a phantom of SF_6-air mixtures (with T_1s of 0.82, 0.97, 1.15, 1.35 ms). Comparison T_1 images (one plane from each is depicted in Fig. 2) demonstrate that the modified FRIR sequence improves the T_1 precision for the same imaging time.

Conclusions: Combining a modified Look-Locker T_1 sequence with FID projection imaging, we obtained a T_1 map of SF_6 gas in the lungs of a live rat that quantifies V/Q at a meaningful resolution. Although the resolution is not as high as that of our prior V/Q mapping technique based on SF_6 spin density imaging, the advantage of breathing a high-O_2 gas mixture during the entire procedure motivates us to further refine this new technique.

References: [1] D.O. Kuethe et al, 'Imaging obstructed ventilation with NMR using inert fluorinated gases,' J. Appl. Physiol. 88:2279-86(2000), [2] D.C. Look and D. R. Locker, 'Time saving in measurement of NMR and EPR relaxation times,' Rev. Sci. Instrum. 41:250-1(1970). [3] D.O. Kuethe et al, 'Imaging lungs using inert fluorinated gases,' Magn. Reson. Med. 39:85-8(1998).