Imaging of dual ^{19}F tracer gases for measurement of lung ventilation properties

Peter E Thelwall[1,2], Christopher R Fox[2], Hannah Walden[3], and Andrew Fisher[2]

[1]Newcastle Magnetic Resonance Centre, Newcastle University, Newcastle upon Tyne, United Kingdom, [2]Institute of Cellular Medicine, Newcastle University, Newcastle upon Tyne, United Kingdom, [3]Biomedical and Biomolecular Research Centre, Northumbria University, Newcastle upon Tyne, United Kingdom

Target Audience: Research scientists and clinicians with an interest in pulmonary MRI and hyperpolarized/^{19}F gas imaging.

Purpose: MRI of tracer gases is used to make measurements of lung structure and function, capable of demonstrating progression of pulmonary diseases or effects of therapeutic strategies. The majority of pulmonary gas MRI studies have employed hyperpolarized noble gases (^{3}He, ^{129}Xe, ^{83}Kr). Studies have shown that gas imaging is possible with thermally polarised ^{19}F-containing inert gases, such as SF_6 and fluorocarbons (1,2). Such an approach has the disadvantage of lower SNR that hyperpolarised gas imaging. However, the ^{19}F approach does not suffer from loss of polarisation during the experiment, and the short ^{19}F T_1 (1-30 ms) allows a high degree of signal averaging. The presence of multiple equivalent ^{19}F nuclear per molecule further aids SNR, as does use of a high B_0 field. In combination, these factors provide a viable gas imaging method, and both preclinical and human application of ^{19}F gas imaging has been demonstrated (1,2).

We performed gas tracer wash-out / wash-in studies in lung phantoms and ex vivo rat lungs. We hypothesised that the displacement of one ^{19}F-containing gas by another could be monitored by MR spectroscopy to measure ventilation properties. In addition we hypothesised that for imaging applications the large ^{19}F chemical shift between SF_6 and C_2F_6 would result in a chemical shift artefact of sufficient size to completely spatially separate the components of a gas mixture in ^{19}F images (controlled by careful choice of image field of view and receiver bandwidth), facilitating imaging of regional ventilation efficacy and measurement of differences in regional compliance.

Methods: Ventilation and gas-displacement experiments were performed on excised rat lungs and on a lung phantom. The phantom was constructed from a ~3.5 mL balloon that was filled with foam sponge. Ventilation gases were SF_6 and C_2F_6. A ventilation chamber was constructed from a 50 mL centrifuge tube, with chamber pressure pneumatically controlled via a syringe. MR data were acquired using a Varian 7T magnet and spectrometer. A 25 mm diameter Helmholtz RF coil was constructed around the ventilation chamber and tuned to the ^{19}F resonant frequency (282 MHz). ^{19}F spectra employed a pulse-acquire sequence (tip = 90°, TR = 15 ms, SW = 50 kHz, NEX = 10 averages) with a time resolution of 150 ms in dynamic studies. Images were acquired using a gradient echo sequence (TR = 5ms, TE = 1.6ms, NEX = 20) with an acquisition bandwidth of 78 kHz, close to double the chemical shift difference between the SF_6 and C_2F_6 resonances. The scan duration was 6.4sec.

Results: Figure 1 shows an excised lung in the ventilation chamber / ^{19}F coil. A ^{19}F spectrum from a mixture of SF_6 and C_2F_6 is shown in Figure 2. Fig 3 shows the change in peak intensity during a SF_6 wash-out / C_2F_6 wash-in experiment. SF_6 signal (green) decreases as C_2F_6 signal increases (blue). The variation in total lung gas content (red) is calculated from the sum of SF_6 and C_2F_6 components. Thus simultaneous measurement of lung volume, ventilation dead volume and ratio of wash-in : wash-out gas can performed dynamically during respiration. Figure 4 shows a ^{19}F images from a C_2F_6 wash-out / SF_6 wash-in experiment, showing chemical shift separation of SF_6 and C_2F_6 components in the image.

Discussion and Conclusions: We have demonstrated that ^{19}F-containing tracer gases detected by ^{19}F MR spectroscopy can be used to determine change in tracer mixture ratio and content over time. In addition, the chemical shift difference between gas resonances can be exploited to spatially separate gas mixture components in ^{19}F images. This approach is technically similar to hyperpolarised xenon studies that exploit the chemical shift difference between gaseous and dissolved ^{129}Xe for simultaneous yet independent imaging of these two components (3), though our approach provides different information on pulmonary properties. Our methods provide tools to monitor ventilation efficacy, and thus report on lung functional properties that change in disease, with potential for non-invasive preclinical investigation of pulmonary function.

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References: (1) Kuethe et al, Magn Reson Med 39, 85-88 (1998). (2) Soher et al, Proceedings of the 18th ISMRM meeting, Stockholm, pg 3389 (2010). (3) Mulger et al. PNAS 107, 21707-21712 (2010).

Figure 1

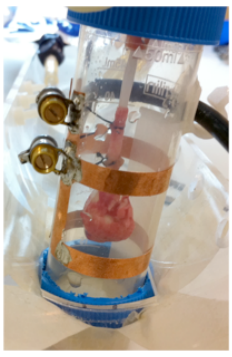

Figure 2

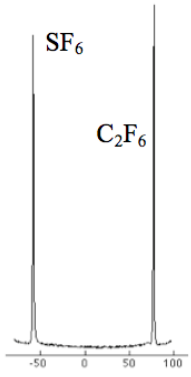

Figure 3

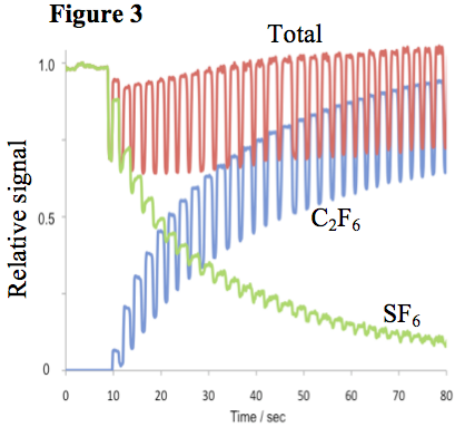

Figure 4