In-vivo measurements of gas flow in the upper airways with hyperpolarized helium-3 and xenon-129

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Target audience: Lung MRI, hyperpolarized gas, flow imaging

Purpose: This work uses phase contrast velocimetry methods to measure gas flow in the upper airways of healthy volunteers with hyperpolarized (HP) ^{3}He and ^{129}Xe gases. Velocity maps inside the trachea and the first lung bifurcations are successfully demonstrated for both gases.

Introduction: Both HP ^{3}He and ^{129}Xe can be used as tracer gases for lung imaging with multiple aspects of functional sensitivity available with different MR pulse sequences. This work aims to combine HP ^{3}He and ^{129}Xe MRI with phase contrast velocimetry (PCV) to measure velocity maps of airflow in the main upper airways during a breathing cycle. The combination of HP ^{3}He with radial PCV was demonstrated previously vitro in a lung model to validate CFD simulation of gas flow[1] with preliminary in vivo[2] demonstrations of a single axial image of ^{3}He flow in the upper trachea. ^{129}Xe gas has different fluid dynamic properties to ^{3}He, being a much heavier atom, hence comparison of gas flow regimes with the two gases in-vivo may be of interest in understanding airflow patterns in the airways for airways disease and inhaled therapy research.

Materials and Methods: The PCV sequence is a multiple interleaved 2D Cartesian spoiled gradient echo using 4 point balanced velocity encoding scheme. It was implemented on a GE HDx 1.5T scanner (max gradient strength of 33 mT/m, slew rate 120 T/m/s). Imaging experiments were performed with HP gas inhalation on one healthy volunteer (F 26Y). Both gases were polarized on-site with spin exchange polarizers providing polarization values of approximately 25 % and 15 % for ^{3}He and ^{129}Xe respectively. The volunteer was trained before each experiment to breathe in a constant way at the target flow through a pneumotachograph. During experiments, the HP gas (300 mL for ^{3}He and 500 mL for ^{129}Xe) was mixed in a 1L Tedlar bag with N_2 at atmospheric pressure and inhaled by the volunteer who reproduced the training breathing conditions. Flows of approximately 150-200 mL/s (Reynolds number 920 < Re < 1230) were achieved for ^{3}He corresponding to relatively slow breathing conditions. Because of higher mass density of xenon and a corresponding higher Re, lower flows (between 50 and 90 mL/s, 1035 < Re < 1865) were desired to stay in the laminar regime. The bipolar velocity encoding gradients were designed to obtain a field of speed in each direction of ± 151 cm/s for ^{3}He and ± 57 cm/s for ^{129}Xe leading to a pulse sequence T_E/T_R of 4.9/9 ms and 6.3/10.5 ms respectively. All data were reconstructed offline using the phase difference reconstruction to extract the 3 velocity components of each pixel. After phase reconstruction, manual phase unwrapping was implemented when necessary and a binary mask based on signal intensity threshold was multiplied with the obtained velocity maps.

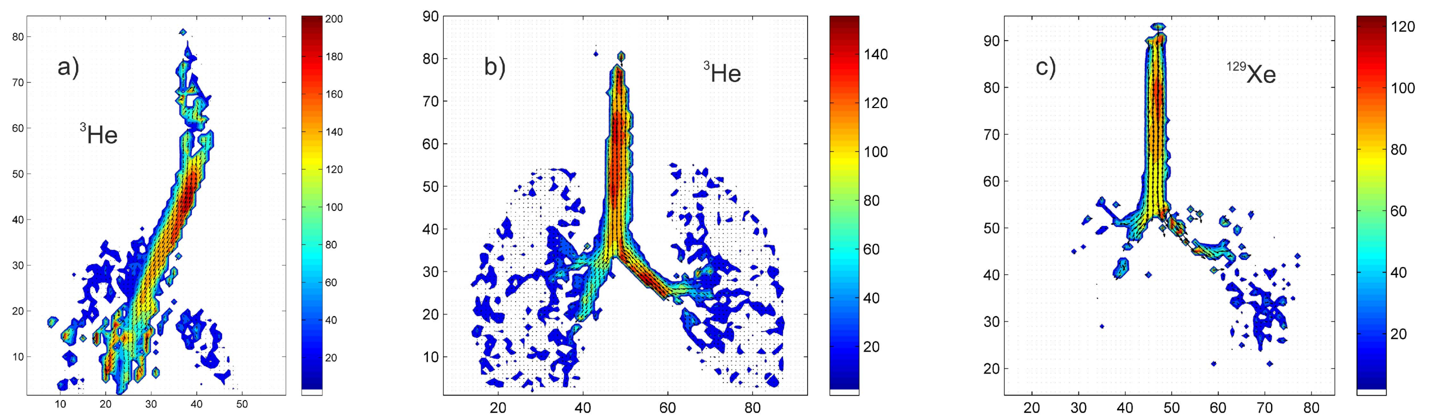

*Figure 1: Sagittal (a) and coronal (b and c) images of the flow of HP ^{3}He (a and b) and ^{129}Xe (c) in the upper airways of a healthy volunteer. The colored contours represent the absolute velocity (sum of square of the three components) in cm/s while the transverse motion is shown with black vectors. a) 5 cm slice thickness, 25*18.75 cm FOV, 96*72 matrix, 6.5° flip angle and SNR of 48 b) 10 cm slice thickness, 25*25 cm FOV, 96*96 matrix, 6.5° flip angle and SNR of 53 c) 10 cm slice thickness, 30*30 cm FOV, 96*96 matrix, 6.5° flip angle and SNR of 21*

Results and discussion: Sagittal and coronal velocity maps in the trachea and down to the second bifurcation are shown in Fig. 1. As expected due to the higher polarization and γ, the SNR for ^{3}He was > 2 times that for ^{129}Xe experiments although the concentration of the latter was 67 % higher and the field of view was increased from 25 to 30 cm. Nevertheless an adequate SNR of 21 was obtained with ^{129}Xe leaving the possibility of better resolution velocity maps by increased polarization or gas ratio in inhaled mixtures. In the HP ^{3}He images, the motional averaging effect over the pixel size can be seen in the lungs outside the main airways as a white-blue background corresponding to low absolute velocities. These primary results also suggest higher velocities in the left main bronchus than in the right bronchus probably because of its second bifurcation being more distal due to the location of the heart. The high SNR obtained with ^{3}He should allow us to achieve the best possible resolution set by the free diffusion (~ 1 mm). Further work will focus on reducing the acquisition time to enable rapid dynamic acquisition during a breathing cycle by using sparse encoding strategies (parallel imaging / compressed sensing / non-Cartesian sampling). In addition, the application of the gas is being developed in an automated way so that the exact flow conditions will be recorded and controlled to get reproducible flows. In this way, the investigation of velocity maps in different groups of population and comparisons with CFD simulation based on the same parameters should be possible.

References: 1 L. De Rochefort et al. Journal of Applied Physiology, vol. 102: 2012-2023, 2007.
2 L. De Rochefort et al. Magnetic Resonance in Medicine, vol. 55: 1318-1325, 2006.

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