Airflow modulation due to the cardiac cycle in healthy subjects

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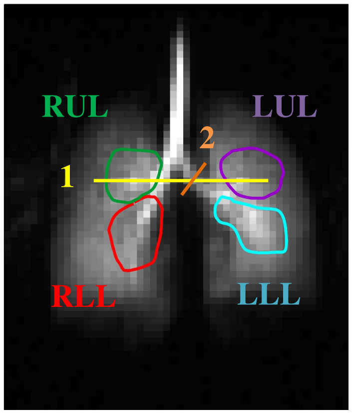

Figure 1: Sum of the 140 dynamic coronal ^{3}He images acquired in one inhalation of a healthy subject and the 4 ROIs RUL, RLL, LUL and LLL. The slice locations 1 and 2 for the PCV sequence are shown.

Target audience: Lung MRI, hyperpolarized gas, flow imaging

Purpose: Investigation of cardiac modulation of regional ventilation and airflow in the airways of human lungs during inspiration.

Introduction: Hyperpolarized (HP) ^{3}He can be used as a tracer gas for lung imaging. Rates of gas flow in the major airways and the periphery can be assessed with dynamic acquisition[1]. Yanping *et al.*[2] found recently a left-right alternation of inspiratory airflow between the two lungs of healthy subjects, whose period seemed to match the heartbeat. This work aims to further assess and explain this phenomenon. Standard Cartesian dynamic ventilation sequences and phase contrast velocimetry (PCV) techniques were used with HP ^{3}He to elucidate dynamic gas uptake in the main lobes. The results are of interest in understanding airflow patterns in the airways and for inhaled therapy research.

Methods: Imaging experiments were performed on a GE HDx 1.5T scanner.
Dynamic coronal images of 5 healthy subjects were obtained with a spoiled gradient echo sequence with the following parameters: 40*32.5 cm FOV, 64*52 matrix, 25 cm slice thickness, T_E/T_R of 0.8/2.7 ms and 140 frames with a time resolution of 140 ms. **2D and 1D Cartesian PCV** sequences were used to measure the time variation of the velocity profiles across the Left and Right Main Bronchi (LMB/RMB). An axial 1D projection below the carina was measured in 1 subject (see slice 1 on Fig. 1, 20 cm FOV, 128 points, 1 cm slice thickness, 120 cm/s field of speed and 10 ms time resolution), and a 2D oblique slice through the LMB was imaged in 3 subjects (see slice 2 on Fig. 1, 5*3.75 cm FOV, 32*24 matrix, 1.5 cm slice thickness, 175 cm/s field of speed and 232.2 ms time resolution).
The subjects breathed from a 1L bag containing 200 mL (or 300 mL for PCV sequence) of HP ^{3}He mixed with N_2 in a 7-14 s constant inspiration. ^{3}He was polarized to ~ 25% with a spin exchange polarizer. Heartbeat was monitored during the experiments with a finger probe. **Data analysis:** for the dynamic ventilation images, 4 ROIs corresponding to the Right/Left Upper/Lower Lobes (RUL/LUL/RLL/LLL) were chosen (see Fig. 1) and the average signal was calculated for each time frame. For the PCV data, phase difference reconstruction was performed with the two interleaves of each frame to extract the average velocity in the direction perpendicular to the slice for each pixel. The velocities were integrated over the area of the LMB and/or RMB to obtain the time evolution of the flow inside the main bronchi.

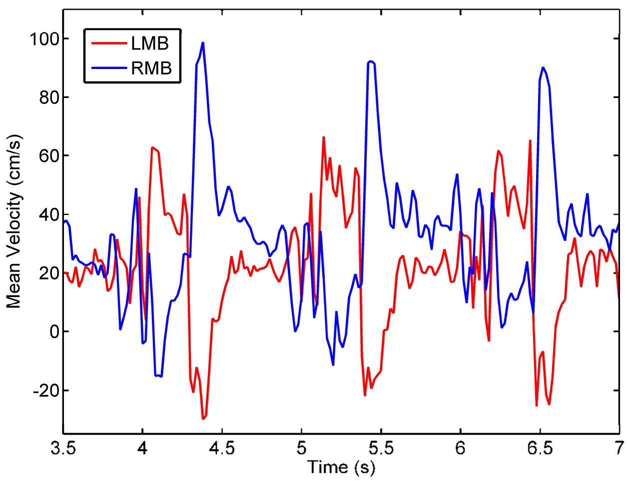

Figure 2: Time evolution of the average velocity in the LMB/RMB during inhalation from the 1D PCV projection (yellow line profile of Fig. 1).

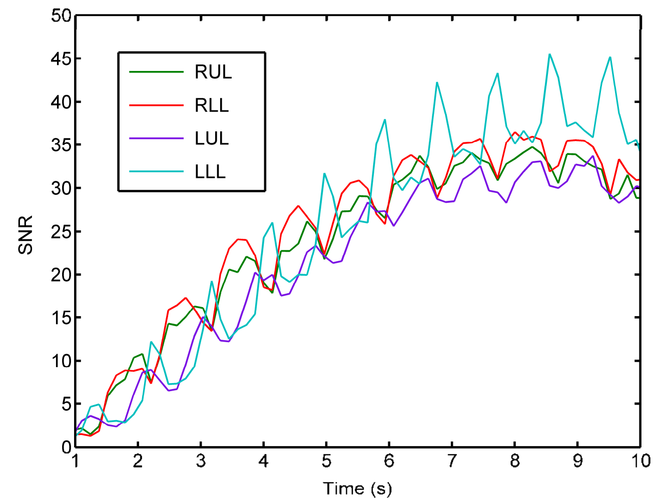

Figure 3: Time evolution of the SNR in the 4 ROIs for the subject shown in Fig. 1.

Results: PCV: the flow values in the LMB of 3 subjects showed periodic oscillations at the frequency of the cardiac cycle. In one of the subjects, the instantaneous flow was even negative for a short period of the cycle. This subject underwent the 1D PCV measurement and the flows in the LMB and RMB were found to oscillate asynchronously (see Fig. 2), which confirms previously published results from images with dynamic ventilation imaging[2]. **Dynamic ventilation:** the SNR or gas inflow in the LLL lobe was found to oscillate clearly at the heartbeat rate in all subjects (e.g. Fig.3 blue). The signal in the RUL (green) and RLL (red) was of opposite phase to that in the LLL and smaller in magnitude. Interestingly, the signal intensity in the LUL was mostly in phase with the right lung and not with the LLL in 4 of the subjects (as in Fig. 3). For the last subject, no variation of LUL SNR was found.

Conclusion: The results confirm the existence of a cardiac modulation resulting in a 'ventilatory alternans' between the left and the right lungs during inspiration in healthy subjects. However, our data suggest that this alternans is the result of greater flow oscillation in the LLL due to the proximity to the heart, while the oscillations are weaker and have an opposite phase in the other lobes of the lung. We believe that the heartbeat is temporary blocking the air inflow inside the left lower lobe, which results in higher inflow in the other lobes. The mechanism of this phenomenon remains to be fully understood but the fact that the LLL is the closest to the heart suggests that it could be simply explained by physical movement and compression. These results could have a great impact in the field of lung airflow simulation as the influence of the heart is usually not taken into account.

References: 1 P. Koumellis *et al.* Journal of Magnetic Resonance Imaging, vol. 22: 420-426, 2005; 2 S. Yanping *et al.* Respiratory Physiology & Neurobiology, vol. 185: 468-471, 2013. *Acknowledgements to the European AirPROM project for funding.*