Rapid Tracheal Flow Measurements during Forced Inhalation and Exhalation

Kai Ruppert[1,2], Bora Sul[3], Kun Qing[2], Vineet Rakesh[3], Craig H Meyer[2], John P Mugler III[2], Anders Wallqvist[3], Michael J Morris[4], Talissa A Altes[2], and Jaques Reifman[3]

[1]*Cincinnati Children's Hospital, Cincinnati, OH, United States,* [2]*University of Virginia, Charlottesville, VA, United States,* [3]*Department of Defense Biotechnology High Performance Computing Software Applications Institute, United States Army Medical Research and Materiel Command, Fort Detrick, MD, United States,* [4]*Department of Medicine, San Antonio Military Medical Center, Fort Sam Houston, TX, United States*

Target Audience: MR scientists and physicians interested in hyperpolarized-gas MRI and the assessment of pulmonary function.

Purpose: Attempts are underway to study airflow in the lungs using computational fluid dynamics in order to characterize disease-specific airflow patterns[1,2]. Flow-sensitive hyperpolarized-gas MRI offers a unique opportunity for experimental validation of such models in vivo. So far, such studies have only been performed in the slow-flow regime[3-5], which is believed to be less sensitive to pathological changes in flow patterns. In this work we developed a spiral-based, hyperpolarized helium-3 (HHe) MRI technique that rapidly acquires flow maps of a single slice through the trachea with a true temporal resolution of about 150 ms and an in-plane resolution of less than 0.8 mm. The purpose of our studies was to perform an initial evaluation of the feasibility of measuring gas flow through the trachea during forced inspiration and expiration in healthy subjects.

Methods: Following RF excitation, bipolar flow-sensitization gradients (VENC 6 m/s) were applied perpendicular to the imaging slice before the acquisition of each spiral k-space interleaf. The polarity of the flow-encoding gradients was inverted after each k-space line, yielding an interleaved flow-encoding pattern. Each spiral-image acquisition consisted of 7 interleaves (2 for field-inhomogeneity correction and 5 for collection of imaging data). Other imaging parameters included: TR/TE, 10.8/2.9 ms; flip angle, 60°; slice thickness, 20 mm; FOV, 50 mm; reconstructed matrix size, 64×64. The axial slice was positioned below the larynx but above the lung apices. The interleaved acquisition was run continuously for 50 repetitions. All MR studies were performed at 1.5T (Avanto; Siemens), using a 32-channel 3He chest RF coil (Rapid Biomedical), under a physician's IND for HHe MRI. Informed consent was obtained in all cases and a physician supervised each study. Helium-3 gas was polarized by collisional spin exchange with an optically-pumped rubidium/potassium vapor using a custom-built system, yielding polarizations between 40 and 60%. At the beginning of the inhalation study, the image acquisition was started. Then the subject would rapidly inhale approximately 1 L of HHe through a straw from a Tedlar bag. For the exhalation study the subject would inhale 1 L of HHe first and hold their breath. Once the image acquisition had been started the subject would exhale as rapidly as possible. Subsequently, velocity maps were calculated from the unwrapped phase difference of each interleaved image pair. The trachea was isolated by thresholding the image intensity maps. The mean flow velocity for a given frame was computed as the average flow value for each pixel weighted by its signal amplitude.

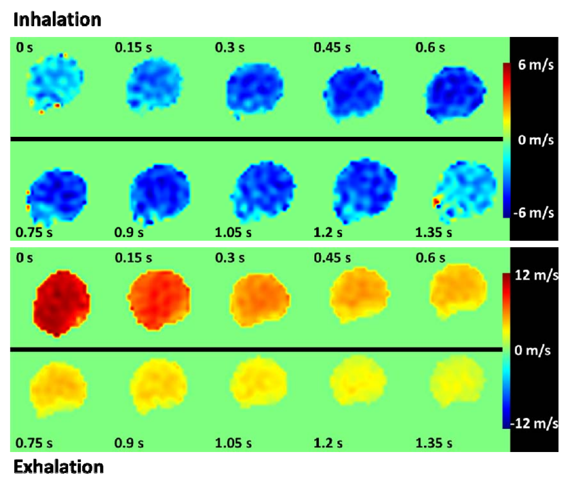

Figure 1. 10 consecutive frames of cross-sectional flow velocity maps in the trachea acquired every 150 ms during rapid inhalation (top) and exhalation (bottom).

Results and Discussion: Figure 1 depicts cross-sectional flow maps from a healthy subject (female, 20 yo) in the trachea, during rapid inhalation and exhalation, acquired with a temporal resolution of 150 ms. In addition to the flow values, the maps also illustrate the posterior-to-anterior spatial shift of the trachea during inhalation (anterior-to-posterior during exhalation) as well as the increase and decrease in tracheal diameter during inspiration and expiration, respectively. These secondary gross motion effects illustrate the importance of a high acquisition speed to minimize their impact on the flow measurement. Figure 2 shows the mean flow velocity in the trachea as a function of time for rapid inhalation and exhalation. While the exhalation phase exhibits a sharp flow peak followed by a gradual levelling off over the course of about one second, the inspiratory curve is much shallower with a peak flow of approximately 40% of that during expiration and more drawn out. This is most likely due to the circumstance that the subject had to inhale the HHe through a narrow straw, which limited the maximum achievable flow volume.

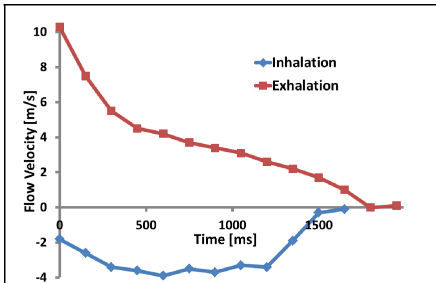

Figure 2. Average flow velocities trachea during rapid inhalation and exhalation as a function of time.

Conclusion: We demonstrated the feasibility of measuring cross-sectional flow in the trachea with high spatial and temporal resolution, which will enable us to characterize possible pathological changes in flow patterns during forced respiratory breathing maneuvers in subjects with lung disease.

References: **[1]** Yang et al. J Biomech 2006;39:2743-2751. **[2]** Sul et al. Comput Biol Med 2014;52:130-143. **[3]** Rochefort et al. MRM 2006;55:1318-1325. **[4]** Collier et al. Proc. ISMRM 2013, 1458. **[5]** Collier et al. Proc. ISMRM 2013, 1459.

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