MODELING OF THE SPATIO-TEMPORAL DISTRIBUTION OF PULMONARY VENTILATION VIA PERFLUOROPROPANE GAS ENHANCED MRI

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Purpose: MRI of pulmonary ventilation using perfluoropropane as a gas contrast agent enables a dynamic, multi-breath assessment of the spatio-temporal distribution of gas within the airspaces. The dynamic nature of the acquisitions can be modelled to generate various intensity and parametric based biomarkers of pulmonary ventilation encompassing ventilation distribution, efficiency and the severity, size and persistence of gas trapping and ventilation defects. In this work we demonstrate the extraction of these parameters from various pulmonary conditions including COPD, asthma and lung transplant. For brevity, only COPD results are shown in this abstract.

Methods and Analysis: Imaging was performed on a Siemens Trio 3T MRI scanner (Siemens, Erlangen, Germany) and consisted of three-plane 2D FLASH localizers (^{1}H @ 123.25 MHz) to approximate the lung field of view and repeated 3D GRE VIBE functional scans using a normoxic perfluoropropane gas (C_3F_8) mixture (^{19}F @115.96 MHz). All acquisitions were performed in the supine position at total lung capacity. A total of at least 8 sequential breath holds were performed, interleaved with 4-5 breaths of the O_2/PFP mixture (during wash-in), or room air (during wash-out). All data was acquired under IRB approved protocols[1].

^{19}F MRI DICOM files were transferred offline for automated analysis in a program developed in-house called Washout written in Python that has both a command line and GUI based interface (shown Fig.1) to facilitate data inspection and interpretation. DICOM data is loaded as a 4D slice-time ordered stack. A "lung mask" is calculated to determine voxels within the pulmonary space based on intensity thresholds, background noise and morphological filtering. Each spatial location within the pulmonary space is fitted to the following model $s(t) = P * \left\{\left[1 - R_1^{(t-D_1)}\right] - \left[1 - R_2^{(t-D_2)}\right]\right\} + B$ based on an extension of the work by Horn[2] to characterize both the dynamic wash-in and wash-out of ^{19}F contrast agent. P is peak voxel intensity, R_1 and R_2 are wash-in/wash-out intensity rate changes, D_1 and D_2 are the delay times after switch to ^{19}F and room air respectively, and B is a baseline constant to account for Rician background noise. A constrained Levinburg-Marquardt optimization minimized a least-squares fit of voxel data to the model.

Results and Discussion: Subjects for COPD, asthma and lung transplant all successfully completed imaging protocols and automated data analysis. 3D stacks of parameter maps were collated for each model parameter. Sufficient time points were acquired to visualize both wash-in and wash-out dynamics for the whole lung. Localized variability was seen in parameter values for all maps Results for one COPD subject are shown here in Fig.2 for all fitted parameters. To minimize subject breath holds, no images were acquired until PFP has been inhaled. This resulted in negative function shifts for Delay 1, which the model was able to handle as shown in Fig.1 plot (time axis in min^{-1}). Voxels in the COPD patient with discernable image intensity in late time points showed lower Rate 2 values, as would be expected for slowly clearing or possible regions of gas trapping. Voxels at the extremes of the head/foot orientation showed parameter variations liekly due to the subject having different full inhalation volumes for the time points. Results from the Washout application were archived to XML files that stored full processing provenance. Results can also be exported in a variety of image and text based formats.

Conclusion: Automated calculation of a parametric model provides direct quantitative measures of ventilatory heterogeneity and specific information about localized changes in the lung that can help detect pathological changes or response to treatment.

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