Quantitative Evaluation of Hyperpolarized Gas Retention in the Lungs During Time Resolved 3D MRI

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Introduction: Noble gas MRI is a promising technique with which to explore lung disease. One of the methods to interpret helium MRI data is that the gas detected to have prolonged residence within a localized lung area is considered retained due to pathologies of lung diseases. This work represents a method to quantify expiratory gas retention using histogram analysis of dynamic hyperpolarized helium-3 (HP ^{3}He) MR images acquired using a 3D Multi-Echo-PR (ME-VIPR) acquisition [1]. This histogram is then characterized by its skewness and compared to spirometry values.

Method: *Imaging*: Imaging was performed on 12 volunteers including controls and subjects with severe and non-severe asthma using a 1.5 T clinical scanner equipped with broadband capability (GE HealthCare, Milwaukee, WI, USA). Images were acquired using a rigid birdcage coil (Rapid Biomedical, Würtzburg-Rimpar, Germany) tuned to ~48 MHz, the resonance frequency of ^{3}He at 1.5 T. A ME-VIPR acquisition was performed using a cubic 42 cm FOV, ±125 kHz receive bandwidth, ~1^o flip angle, TR of 4.4 ms, first echo time of 0.22 ms, with 3 full echoes and 2 half echoes acquired per TR, and ramp sampling with maximum radial distance from the center in k-space corresponded to 64 evenly spaced points on a Cartesian grid. During imaging, subjects performed a 4 s inspiration maneuver followed by breath-hold of 14% of TLC (~1 L) of HP ^{3}He for approximately 10 s concluded with a forced exhalation and normal breathing for the remaining scan duration.

Reconstruction: Iterative HYPR (I-HYPR) [2] was used to reconstruct images every 0.5 s throughout the ~60 s long acquisition. A sliding window composite consisting of ~8 s of acquired data was used with 6 iterations of the I-HYPR algorithm. Each reconstructed volume used 1 s of acquired data resulting in a minimum temporal fidelity of 1 s.

Gas retention quantification: A gas retention map was calculated by dividing a post forced exhalation volume by the volume at the end of the breath hold on a voxel by voxel basis. The volume at the end of the first inspiration after forced exhalation was used as the post-expiration volume. This volume was assumed to contain gas retention information and to be closely registered with the end breath hold volume. The threshold used to define the lung area was set as the mean background signal plus 6 times the standard deviation of the background. The signal decay due to the time interval between the two volumes was corrected by an exponential curve which was fit to the decay curve during the breath-hold period, which represents a combined decay for both T_1 and RF effects. Whole lung skewness values were then calculated and compared with forced expiratory volume in 1 s percent predicted (FEV1%pred), which is a frequently used index for assessing airway obstruction, bronchoconstriction or bronchodilatation.

Results: Figure 1 shows the typical results for 2 subjects, one with significant basal lung trapping, and one with diffuse obstruction. Subject A has a high skewness value while subject B has a low skewness value. The two subjects show significant difference in the post forced exhalation volumes compared to end of breath hold volume respectively. Figure 2 shows a plot of FEV1%pred versus the skewness of signals in the lung, which demonstrates a correlation between these measures.

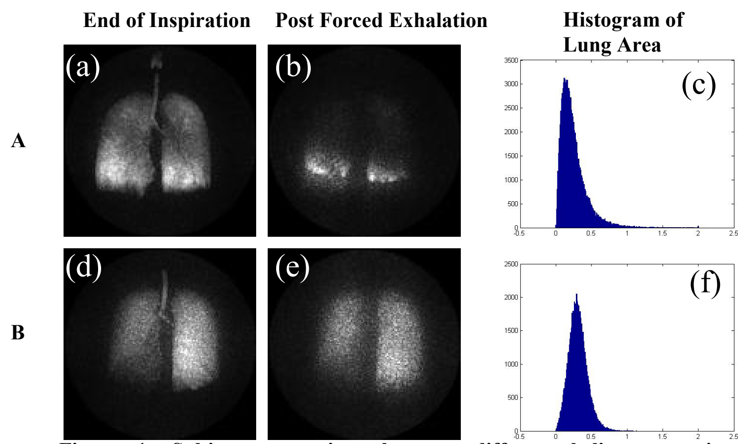

Figure 1: Subject comparison between different helium retention phenotypes. Images a and d are coronal maximum intensity projections (MIP) for end breath hold volumes and b and e are post forced exhalation volumes. Subject A shows significant gas retention in the basal lung, which results in a high skewness value (c). Gas retention in subject B is distributed relatively uniformly, which results in a low skewness (f).

Discussion and Conclusion: Skewness of the gas retention map is a measure of the asymmetry of the histogram. A higher skewness is hypothesized to indicate gas retention which is likely localized as in Fig. 1b, due to the spatial localization of gas retained in lung. Figure 1 presents the potential ability of skewness to characterize localized gas retention. However, the skewness measure needs to be mapped to a localized parameter in order to add value beyond FEV1%pred, which is inherently a global measure. One approach that will be explored is to apply a localized skewness parameter map using a convolution algorithm. An analogy of the skewness concept to CT densitometry will be explored by combining thresholding with this measure and comparing to lung function measures of air trapping. In addition, to generalize this approach deformable registration between different volumes will be implemented to support longitudinal tracking the variation in the skewness values.

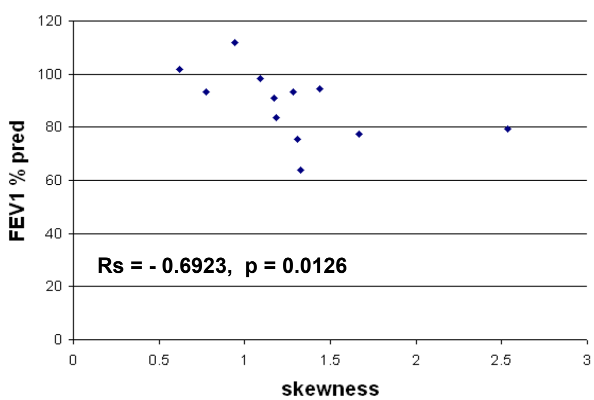

Figure 2 Plot of FEV1%pred vs. whole lung skewness. Spearman correlation coefficient is shown.

References: [1] Holmes, et al. Magn Reson Med 2008 [2] O'Halloran, et al. Magn Reson Med 2008

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