MR Imaging and Quantification of Distal Airway Lung Dysfunction

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Introduction: Symptomatic patients with distal airway lung dysfunction often exhibit normal spirometry during standard pulmonary function testing. While impulse oscillometry (IOS) can indicate heterogeneity of distal airway time constants, it cannot define the distribution, localization, or extent of the distal process. In the current work we present the preliminary results of the application of an MR tissue tracking technique for quantitative measurement of spatial distribution and severity of distal airway dysfunction. The goal of this work is to develop a means for early detection of airways disease before any gross changes are observed in standard spirometric variables.

Methods: Twelve subjects were studied representing three groups: healthy control subjects, subjects with clinical diagnosis of asthma, and subjects with suspected isolated distal airway disease. MRI data were acquired on a 3T Siemens TIM Trio whole-body MR scanner using a tissue-tracking MRI technique that has been previously described [1]. Measurements were made in sagittal imaging planes and were acquired in real-time at rates up to 10 frames per second (fps). The subjects were instructed to take a series of normal tidal breaths followed by maximal inspiration and maximal forced expiration. This procedure was specifically chosen because airway collapse and distal airway dysfunction are most likely to be elicited during maximal effort when intrathoracic pressure is markedly positive. Lung motion was analyzed by estimating pixel displacements using an optical flow method [2]. From the calculated deformation fields local volume vs. time curves were produced that were then used to compute regional FEV_1/FVC values for each pixel [1]. These values were then used to generate a map of FEV_1/FVC as well as a histogram representing the distribution of FEV_1/FVC. The mean value of the regional FEV_1/FVC histogram was used as an MRI derived metric of distal airway function. These MRI data were compared to IOS derived frequency dependence of resistance (R_{5-20}) data that were acquired on the same day.

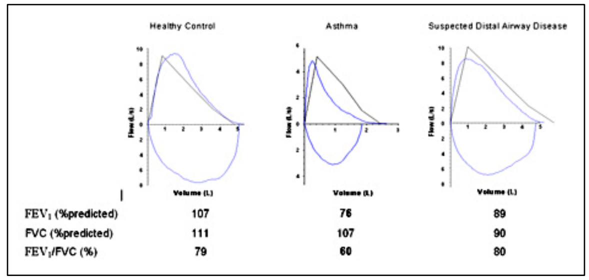

Fig 1. Spirometry data of three representative subjects.

Results: Figure 1 shows standard spirometry data in three representative subjects obtained on the same day as the MRI evaluation. Note that in the subject with suspected isolated distal airway disease the flow volume contour, FEV_1, and FEV_1/FVC were within the limits of a healthy control, indicating normal large airway function despite new onset of lower respiratory symptoms. In contrast, the IOS data (Table 1) shows that for the subject with suspected isolated distal airway disease total airway resistance determined at an oscillating frequency of 5Hz (R5) was elevated despite normal spirometry, suggesting the presence of disease in airways more distal than those evaluated by spirometry. In particular, the value for R5 is similar to the value seen in the subject with asthma where spirometry was abnormal. Figure 2 shows histograms for the distribution of MRI-derived regional FEV_1/FVC. The healthy control subject exhibited a narrow peak of regional FEV_1/FVC with a mean value of 0.81 ± 0.11. In the subject with asthma the peak was shifted to the left at a mean value of 0.67 ± 0.11. This finding is in accord with reduced FEV_1/FVC seen on spirometry and presumably reflects large airway disease due to asthma. In the subject with suspected isolated distal airway disease the mean value for regional FEV_1/FVC was also left shifted at 0.73 ± 0.12. This reduction in regional FEV_1/FVC occurred despite normal whole lung FEV_1/FVC as assessed by spirometry. These data confirm the presence of distal airway disease and is in accord with the interpretation of the IOS data. Figure 3 illustrates the spatial distribution of regions with abnormal FEV_1/FVC (defined as ratio <0.70, red line in Fig 2), demonstrating the spatial distribution and severity of distal airway lung dysfunction.

Table 1: ISO Data (abnormal values are indicated in bold)

	Healthy Control	Asthma	Suspected Distal Airway Disease
R5 (cmH2O/L/s)	3.60	**6.73**	**6.28**
R5-20 (cmH2O/L/s)	0.57	**0.67**	**2.84**
Reactance area (cmH2O/L)	1.55	**5.48**	**25.94**

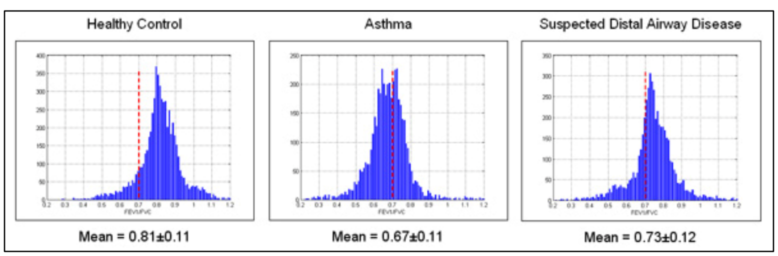

Figure 2. Histograms generated from the MRI data for distribution of regional FEV_1/FVC obtained from three representative subjects.

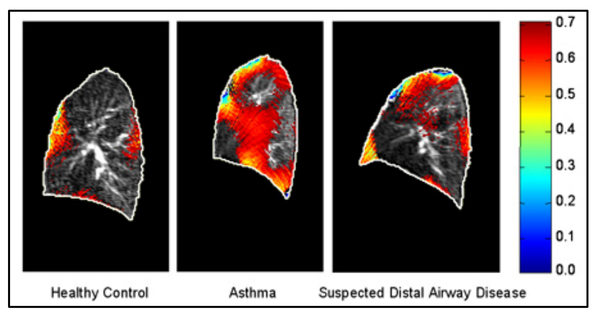

Figure 3. Illustration of the distribution of regions with abnormal FEV_1/FVC (defined as ratio <0.70). The color map shown on the right indicates the degree of dysfunction.

Conclusions: We have demonstrated the feasibility of using tissue tracking MRI for the imaging and quantification of distal airway lung dysfunction. In the case of symptomatic patients with distal airway lung dysfunction, topographic mapping of regions with low FEV_1/FVC revealed that dysfunctional segments were predominately located in the periphery. Distal airway dysfunction as determined by MRI and IOS were tightly linked, confirming presence of distal airway disease that is not apparent on standard testing.

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References:

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2. Xu C, et al. Utility of the optical flow method for motion tracking in the lung. Proc ISMRM 16, 2008:2638.