Relating Heterogeneous Constriction and Ventilation Distribution in Healthy versus Asthmatic Lungs through Visualization with Hyperpolarized ^{3}He MRI

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Introduction

Two primary characteristics of asthma have long been predicted by lung mechanics models: 1. the heterogeneous constriction of airways, and 2. the inability of an asthmatic to recover from a Methacholine-stimulated airway constriction after deep inspirations. These predictions, however, have never been confirmed through the simultaneous acquisition of airway mechanics measurements and lung images.

Approach

Both hyperpolarized (HP) ^{3}He MR static ventilation images and dynamic lung mechanical measurements were acquired before Methacholine (Mch) challenge (preMch), after Mch challenge (postMch), and after deep inspirations (postDI) from healthy and mild-to-moderate asthmatic subjects:. The HP ^{3}He MR images were acquired during breathhold of a 1 L ^{3}He-N_2 mixture, using a Fast GRE pulse sequence, 17°-18° flip angle, with coronal slice thickness 13 mm, 256×128 matrix, and 46 cm FOV. The dynamic lung mechanics were measured using Optimal Ventilator Waveforms (OVW), a forced oscillatory technique containing energy at seven mutually prime frequencies [1]. Experimental protocols were approved by the Institutional Review Board and informed consent was obtained from all volunteer subjects.

Results and Discussion

Figure 1 depicts representative resistance and elastance values as a function of frequency for an asthmatic measured using OVW. The postMch case (red), is elevated compared to the preMch case (black), especially at the lowest frequencies. Furthermore, there is a static offset in elastance likely due to closure of many airways. Both of these changes are indicative of a heterogeneous constriction pattern. The postDI case (blue) shows some level of recovery, but not a complete return to baseline. In contrast, the postDI data for a healthy subject returns to baseline (not shown). In Figure 2, a homogenous ventilation distribution can be seen for the preMch image of the healthy subject's mid-coronal slice. The distribution becomes heterogeneous postMch, but largely recovers postDI. The representative asthmatic ventilation has heterogeneity present even at baseline, which further aggravates postMch. Unlike the healthy subject, much of the additional heterogeneity from the Mch challenge remains postDI. All these phenomena visualized using HP ^{3}He MRI corroborate the OVW predictions.

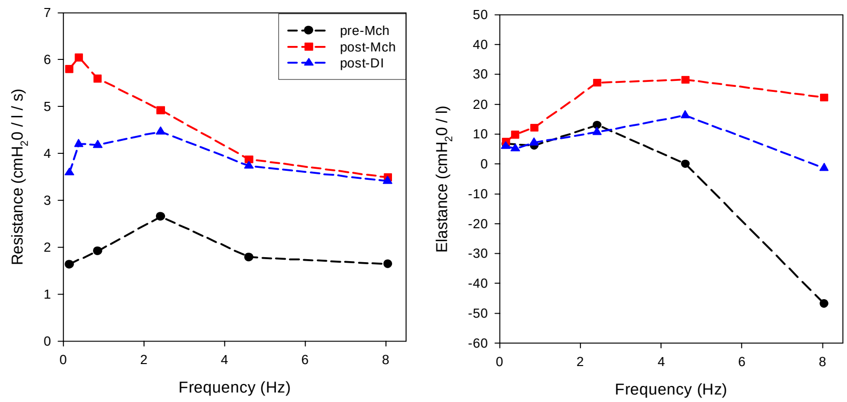

Figure 1. Representative Lung Mechanics Measurements for an Asthmatic.

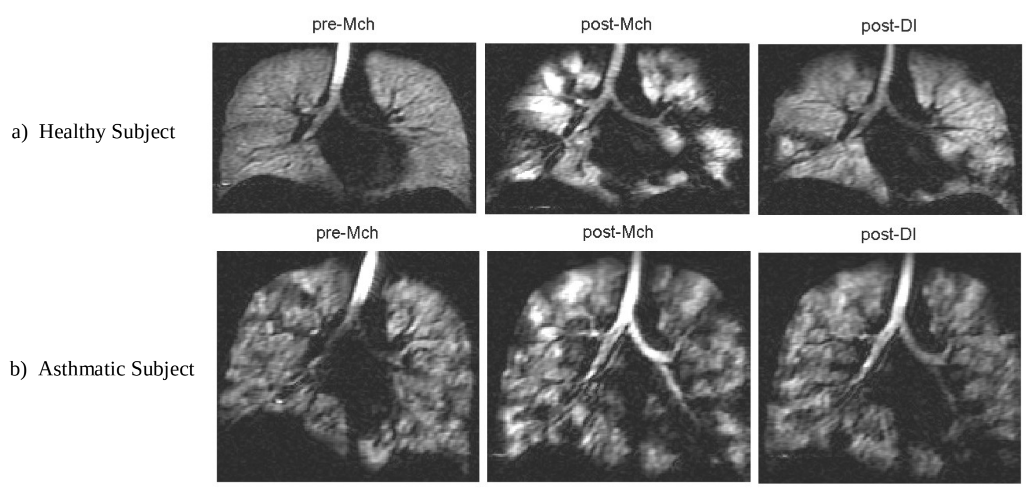

Figure 2. Representative HP ^{3}He MR Images of a Mid-Coronal Slice during Static Breathhold.

Conclusion

Using both HP ^{3}He MRI and OVW, heterogeneity is clearly observed to be elevated in asthmatics. Unlike in healthy subjects, their postMch heterogeneity does not approach preMch levels even after deep inspirations. The two approaches to lung diagnostics corroborate and complement each other, suggesting fundamental structure-function differences in healthy versus asthmatic lungs.

References

1. KR Lutchen, et al., JAP 75(1):478-88, 1993.
2. TA Altes, et al., JMRI 13:378-384, 2001.

Sponsor: NIH grant EB-001689-02