Image Functional Modeling of the Lung Using Hyperpolarized ^{3}He MRI

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INTRODUCTION

•Asthma is a chronic respiratory disease characterized by inflammation of the bronchial lining and constriction of airway smooth muscle (ASM).

•Identifying the regions of airway closure is critical for determining target sites for anti-inflammatory drugs.

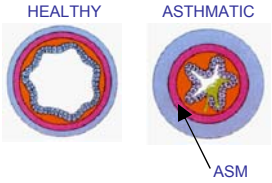


Figure 1. Healthy and asthmatic airway lumen are depicted. In an asthmatic, constriction of ASM and inflammation of bronchial lining results in airway diameter reduction and decreased alveoli ventilation.

•One way to assess asthmatic lung structure is through a new imaging modality, Hyperpolarized (HP) ^{3}He MRI.

•Traditional MRI utilizes the protons in water to capture various body tissue, but cannot image lungs well due to lack of water content.

•HP ^{3}He MRI is able to image airspace through the inhalation of polarized noble gas.

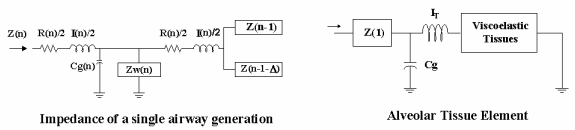
ANATOMICALLY-BASED MODELING

Figure 2. The image on the left represents a 3D Human Model of the Lung developed by Tawhai et al. in 2000.

•This model is able to predict whole lung mechanics based on a generic airway tree with asymmetric bifurcations.

•Each airway is modeled as a function of diameter and thickness with an alveolar tissue element attached to each terminal airway.

•The properties of each airway are combined in serial and parallel fashion (see below) to get a total lung resistance and lung elastance as a function of frequency.



PROJECT GOAL

•Use HP ^{3}He MRI to determine ventilation distribution for baseline and post-Methacholine (Mch) challenge conditions.

•Synthesize image with 3D model to identify non-ventilated regions in model.

•Compare measured lung mechanics and model-based simulations to assess the size and location of airways that can or cannot be constricted in an asthmatic lung.

•Establish how airways in asthmatics are distinct from healthy subjects via an analysis of deep inspirations.

PATIENT SPECIFIC DATA

LUNG MECHANICS

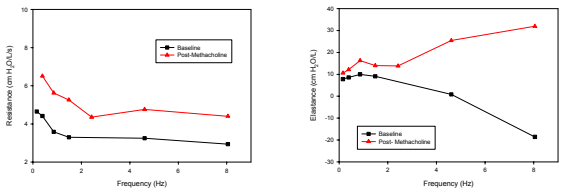


Figure 3. Plotted above are measured dynamic lung resistance and elastance versus frequency pre- and post-bronchial challenge in a healthy subject. In the post-Mch challenge, elevated resistance and elastance values are evident.

PATIENT SPECIFIC DATA (cont'd)

HP ^{3}He MRI IMAGES

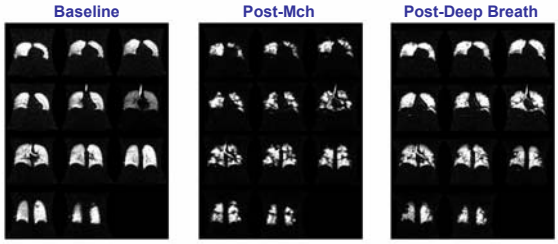


Figure 4. Coronal slices (13 mm thick) are taken in a healthy subject prior to and after Mch challenge. On the left, full ventilation of the lungs is indicated by the higher intensity pixels (white). In the post-Mch challenge (center), distinct dropout regions, or areas of no ventilation are evident. Following a deep inspiration (right) ventilation is restored.

EXTRACTION OF VENTILATION FOR IFM ANALYSIS

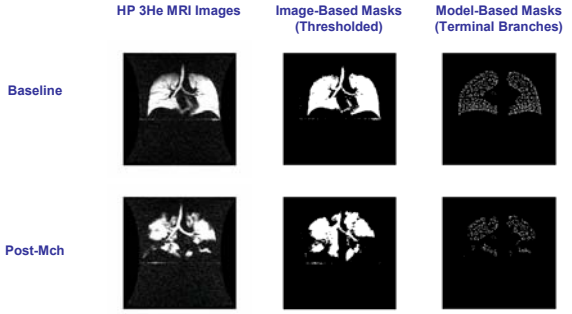


Figure 5. Zoomed in on the left is one slice from the baseline and post-Mch images. Note that the size, shape, and areas of ventilation in the terminal branch masks correspond to the image-based masks.

•The first step in MRI image analysis requires thresholding the baseline MRI image to isolate the healthy lung boundary. This results in an image-based mask for each slice.

•Each terminal branch slice is then morphed to the size and shape of its corresponding HP ^{3}He MRI baseline image mask.

•Ventilated terminal branches for each slice are then identified and used to find the post-Mch condition ventilation.

IFM IMAGING RESULTS

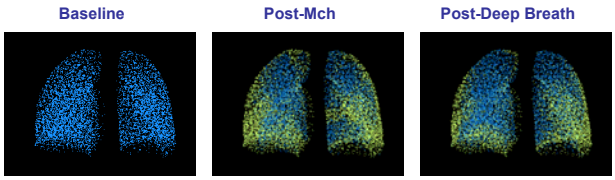


Figure 6. Shown above are projection images of 3D ventilation distribution for the baseline, post-Mch, and post-deep breath conditions. Blue represents ventilated terminal branches.

SUMMARY / FUTURE WORK

•IFM identifies ventilation defects in terminal lung units occurring with broncho provocation.

•IFM identifies impact and re-opening of airway with deep inspiration.

•Future work will identify airway constriction necessary to match both IFM to the MRI images of Figure 4 and the mechanical data of Figure 3.

ACKNOWLDEGEMENTS

•Research Experience for Undergraduates Program (NSF-REU)