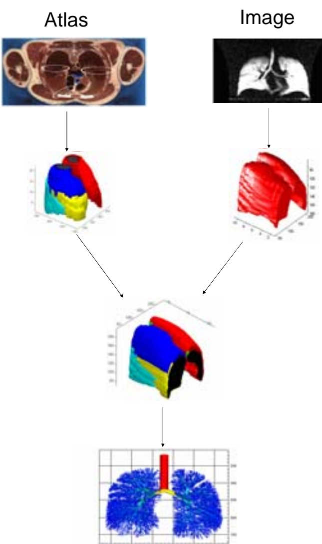
Personalized Airway Trees from a Generative Model, Lung Atlas, and Hyperpolarized Helium MRI

William Mullally[1], Aladin Milutinovic[2], Mitchell Albert[3], Margrit Betke[1], Kenneth Lutchen[2]
[1] Computer Science Department, Boston University, USA
[2] Department of Biomedical Engineering, Boston University, USA
[3] Hyperpolarized Noble Gas MRI Laboratory, Brigham and Women's Hospital, USA

Abstract

Biomedical researchers are actively interested in building anatomically explicit computational models of the lung to further their understanding of pathologies, for example asthma, which affect the human body. Current methods have relied on a generic lung airway model which may not accurately reflect the physiology of a given subject. Patient specific models are needed to overcome this limitation. We propose a method for creating personalized models of the lung from Hyperpolarized Helium MRI images (Hyp. ^{3}He MRI). As Hyp. ^{3}He MRI images are of insufficient resolution to identify lung lobes, an estimate of lung lobe locations is obtained by registering a lung atlas to the MRI images. We then use an generative technique to create a lung airway model within the estimate lung lobe volumes. Initial testing indicates significant differences in predictions of lung function between the personalized model our approach generates and a generic airway model.

Method



Segment Lung Surfaces

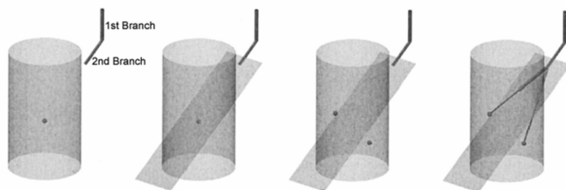
The lung atlas is hand segmented. Lung surfaces are obtained from the Hyp. 3He MRI scans using a threshold and morphological operators. The trachea and bronchi are removed by hand.

Register Lung Surfaces

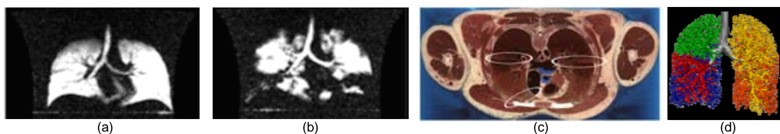
The lung atlas is aligned with the MRI scan by computing an affine transformation using an iterative closest point algorithm on the lung surfaces.

Generate Airway Tree Model

A recursive algorithm generates airways towards the center of mass of a lobe volume. With subsequent divisions of the lung volume, more airways are generated until terminal airways are reached.



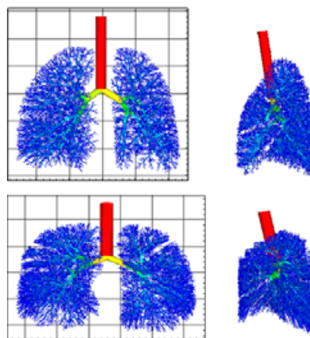
Data



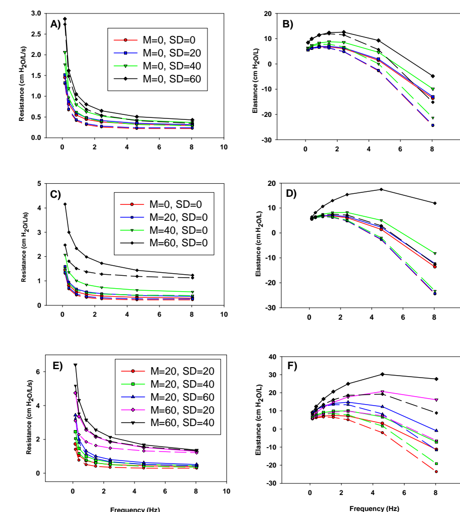
(a) (b) (c) (d)

Hyp. ^{3}He MRI of the lung a healthy individual (a) and a constricted asthmatic (b). Brightness relates to degree of ventilation. In the healthy lung, all regions of the lung are ventilating normally. In the asthmatic lung, large regions of the lung are receiving little or no ventilation. Cryosection image (c) from Visual Human Data Set [3] with fissures marked. Tawhai airway tree model (d).

Results



The generic airway tree of Tawhai (top) vs. personalized airway tree (bottom). Both a frontal and sagital view are shown. The overall shape of the two models is significantly different and the personalized model is less symmetric.



Mechanics simulation of the resistance and elastance of the lung over a range of oscillatory frequencies for patterns of various mean and standard deviation of constriction of the airways below the 12th generation. Dashed lines represent the Tawhai model and solid lines represent our personalized model.

Conclusion and Future Work

Using IFM, Tgavalekos et al [2]. have shown that constriction of small airways (less than 2 mm in diameter) cause lung function impairment that is present in asthmatics. The 3D model used by Tgavalekos et al. has been a generic airway model by Tawhai et al [1]. Our method has made it possible to generate airway models that are patient specific. The personalized model provides a better characterization of airways for that particular individual since it is generated into the space from which ventilation is mapped. Our tests show that there are meaningful differences between our personalized model and the original Tawhai model in the number of airways, their distribution across generations, and the simulated mechanics. These changes may significantly impact researcher's ability to understand lung mechanics using this model.

Future studies should more closely investigate how changes in the airway distributions and diameters affect the IFM simulations. Other sensitivities with regard to the number of terminal airways should also be investigated. Future work may also improve the mapping of the lung lobes from the atlas to the MRI scan, perhaps by using a non-rigid approach or by using a statistical atlas.

References

[1] M. Tawhai, A. Pullan, and P. J. Hunter. Generation of an anatomically based three-dimensional model of the conducting airways. *Ann Biomed Eng*, 28(7):793–802, 2000.
[2] N. T. Tgavalekos, M. Tawhai, R. S. Harris, G. Musch, M. Vidal-Melo, J. G. Venegas, and K. R. Lutchen. Identifying airways responsible for heterogeneous ventilation and mechanical dysfunction in asthma: An image-function modeling approach. *J App Physiol*, 31(4):363–373, 2005.
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