Mapping Regional Pulmonary Expansion in Patients with Sarcoidosis Using Tagging MRI

Vitaly NAPADOW¹, Phillip BOISELLE², Vu MÀI³, Richard GILBERT¹, Robert EDELMAN³, Qun CHEN³

¹Massachusetts Institute of Technology, Cambridge, Massachusetts United States; ²Beth Israel Deaconess Medical Center, Boston, MA United States; ³Northwestern University, Evanston, Illinois United States;

Introduction
Sarcoidosis is a multi-systemic granulomatous disease of unknown etiology. Although sarcoidosis may affect any organ or system in the body, the lungs are the target of the disease in approximately 88% of patients. The pathophysiology of respiratory insufficiency in sarcoidosis is mainly restrictive, most commonly presenting with decreased lung volumes, which may progress to interstitial pulmonary fibrosis.

Tagging MRI has been used to investigate pulmonary parenchymal deformation in normal subjects [1,2]. In this study we have extended this methodology to map the effects of sarcoidosis on regional parenchymal expansion.

Methods
MRI experiments were conducted on three patients with documented sarcoidosis using a 1.5 T MRI system (Magnetom VISION, Siemens AG). Imaging was performed with a TurboFLASH sequence (TR = 1.6msec, TE = 0.4msec, flip angle = 4° , FOV = 480mm, Matrix = 96 x 128, Slice Thickness = 12mm). Image acquisition time was 154 msec.

Tagging was performed once the patient had fully exhaled to their residual volume (RV, or V∞ in the equation below), following which, the patient forcefully inhaled to Total Lung Capacity (TLC). During inhalation, parenchymal deformation was tracked until tag fade (5-6 images), which showed the tagging mesh in various states of deformation. Un-deformed tag spacing was 25mm.

The deformed tagging mesh was resolved by defining triangular elements with nodes at tag line intersections. Strain in each element of the 2D imaging plane was assumed to be non-linear and element dilatation (e, normalized volume change) was computed by

\[ e = \frac{\Delta V}{V_0} = \left[ \epsilon_{xx} + 1 \right] \left[ \epsilon_{yy} + 1 \right] - 4 \epsilon_{xy}^2 - 1 \]

Where \( \epsilon_{xx} \) is the normal strain in the medial-lateral direction, \( \epsilon_{yy} \) is the normal strain in the superior-inferior direction, and \( \epsilon_{xy} \) is the in-plane shear strain. Because our analysis is strictly in-plane, this dilatation measure in effect describes an in-plane, normalized area change.

Volume change was referenced to the Residual Volume condition, thus regions presenting with positive dilatation were expanding, while those presenting with negative dilatation were contracting. The results were displayed by color coding individual elements overlaying the tagged images. The images were then compiled into a dynamic dilatation map which tracked regional deformation during inhalation.

Results
Coronal view dilatation maps showed progressively and regionally variant expansion as the lungs were inflated with air. The data for a single representative sarcoidosis patient shows that although most regions throughout the lung expand with increasing total lung volume, regions in the lower lobe of both lungs expanded to a greater extent, while regions in the upper lobe and upper portions of the lower lobe (approximate middle of the visible lung) did not expand as much. The right middle lobe was not prominent with such a posterior slice selection. These results were in contrast to the preliminary results seen in normal subjects, wherein regional parenchymal expansion increased more as a function of distance from the bronchovascular insertion at the hilum of the lung [2].

Discussion
Sarcoid granulomas can occur throughout both lungs but typically involve the upper 2/3 of the lung and are central, due to the fact that the disease predominates along bronchovascular segments [3]. In our results, regional expansion was curtailed in the upper portion of the lower lobe and lower portion of the upper lobe in both lungs. This was most likely due to the presence of granuloma formation or fibrosis along the bronchovascular bundles, thus limiting the extent to which these parenchyma regions deform with increasing air filling.

The severity of sarcoidosis visualized by chest radiography correlates poorly with actual clinical or functional impairment [4]. Similarly, in our MRI images, areas of the lung with increased signal intensity did not always correlate directly with decreased regional expansion. Hence, fibrosis may not always adversely affect regional lung expansion, and an imaging modality which determines pulmonary function directly could provide great clinical utility. Tagging MRI may in fact provide this functional imaging paradigm for accurate assessment of sarcoidosis, as well as for other restrictive interstitial diseases.

References