

A Novel Method using Proton MRI and Image Registration to Investigate Relative Regional Pulmonary Compliance

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INTRODUCTION Chronic obstructive pulmonary disease (COPD) results in airway obstruction and altered compliance affecting lung mechanics. It is conventionally assessed with lung function tests (LFTs) and computed tomography (CT). However, CT has an undesirable associated radiation dose, and LFTs can only provide information on a whole-organ level, which is of limited utility, particularly in early disease. In order to assess regional changes in lung compliance and mechanics associated with COPD a different method is required. Magnetic resonance imaging (MRI) has the capacity to safely provide structural and functional information on a local level. Previous work using MRI has explored regional dynamics through grid-tagging [1] and produced deformation fields using image registration [2]. Regional ventilation has been investigated with inhaled contrast agents such as oxygen [3] and helium-3 [4], or through registration of MRI images [5]. However, many of these methods require special equipment or methods such as breath-holding which can be difficult for patients. Furthermore, the link between regional ventilation and local compliance changes in disease has thus far not been made. As such, a method is presented here utilising proton MRI in conjunction with image registration to gain relative regional lung compliance information without the need for exogenous contrast agents or invasive procedures.

METHODS Image Acquisition: 2D proton lung images were acquired during free-breathing using a 1.5T Philips Intera scanner (Philips Medical Systems, Best, the Netherlands). A half-Fourier acquired single-shot turbo spin echo (HASTE) sequence was optimised for the lung. Cardiac triggering was integrated to achieve maximal stable lung vasculature in images using a peripheral pulse unit trigger with a delay time of 150ms. Single-slice coronal images were acquired with scan parameters of TR=3 heartbeats, TE=2.9ms, ETL=68, FOV=450x450mm, matrix=128x128 and slice thickness=10mm. Sixty dynamics were acquired in order to capture maximum variation in breathing cycle position. Respiratory bellows were used to monitor breathing.

Image Ordering and Registration: The respiratory bellows log gave information as to whether an image was acquired in inspiration or expiration. An active shape model [6] was also used to find the diaphragm position in each image, allowing inspiratory/expiratory images to be ordered into a representative breathing cycle. Ordered images were then registered over the different stages of the respiratory cycle using a group-wise affine registration [7]. The registration uses a triangulated mesh of control points defined over the lung, as shown in Figure 1. An initial pair-wise registration of points on all images to points on the first image in the set is carried out to obtain the global pose of the warp. A model reference image is then calculated from the texture and shape in all images, and control points on each image are repositioned to fit with the model reference. Registration optimisation begins on a coarse level and becomes iteratively finer.

Local Compliance Calculations: Compliance of a lung region is defined as the regional volume change due to a unit change in pressure. Therefore, if one assumes uniform pressure across the lung, the change in volume of a lung region relative to the volume change of the whole lung will be equal to the region compliance divided by whole lung compliance. It is therefore possible to calculate relative local compliances by considering volume changes. Registration outputs were used to define mesh control point positions at each point in the breathing cycle represented by the images. For each image, the area of each mesh element was calculated and normalised to its area in the model reference image. The whole lung area was then calculated by manually defining the lung outline and summing the areas of all elements inside the lung. These were again normalised to the reference image area value. The relationship between global and local lung expansion/contraction can be plotted as shown in Figure 2. Functional residual capacity (FRC) and total lung capacity (TLC) were calculated from images and a linear function was fitted to data points between FRC and 80% TLC for each element, as per [8]. The log of the gradient of the linear fit for each element was then mapped across the lung as a relative regional compliance measurement.

RESULTS The above methods were applied in a group of healthy volunteers (n=6) and COPD patients (n=6). Representative results achieved for the group are shown in Figure 3 for a healthy volunteer and a patient with severe COPD. Both maps illustrate regions of lower compliance corresponding to major lung vessels in structural images. Vessels follow the main bronchi and so these regions are inherently stiffer than surrounding lung tissue. Aside from bronchial structures, the healthy volunteer map appears essentially homogenous. The map representing the COPD patient, however, shows additional regions of low compliance, particularly in the lung apices. It is concluded fibrotic tissue may be present in these regions, reducing the capacity for normal respiratory motion. Similarly, other patient examples showed regions of high relative compliance, and so were concluded to possibly contain emphysematous tissue.

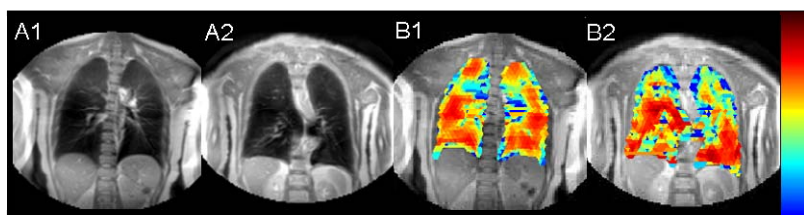


Fig. 3 - B1 and B2 show compliance maps of a healthy female volunteer (24yrs) and a male patient with severe COPD (67yrs) respectively. Heterogeneity in the healthy subject corresponds to major vessels in structural image **A1** situated along the main bronchi. This can similarly be seen in regions in **B2** and corresponding major vessels in **A2**, but there are additional regions of abnormal compliance in the COPD patient which cannot be accounted for thus. Scale shown is log of relative compliance.

CONCLUSIONS This method can illustrate variations in lung compliance on a regional level and is thus a potentially useful tool in disease diagnosis and monitoring progression and treatment effects alongside existing methods. Maps of relative regional lung compliance showed low compliance in stiff lung regions, such as around the bronchi, but could also show additional differences in COPD patients on comparison with healthy maps, indicating likely regions of disease. Cross-correlation to CT/histology may be required to make firmer conclusions. Combining the technique with measurements of pleural pressure changes during breathing using, for example, an esophageal balloon catheter may also allow measurements of absolute regional compliance to be made.

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Fig. 1 - Mesh used in the registration. Control points exist on vertices of every triangle.

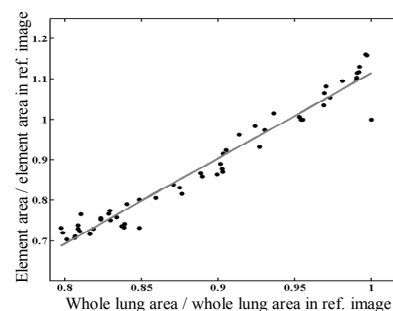
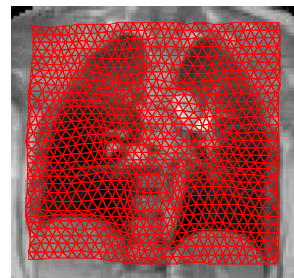


Fig. 2 - Example of fitting linear function for one element.