3D Strain Mapping in the Lung

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TARGET AUDIENCE This abstract would be of interest to respiratory physicians and lung imaging physicists.

PURPOSE Mechanical properties of the lung, such as compliance, become altered in disease. These are difficult to assess on a regional level using lung function tests or CT (computed tomography). Magnetic resonance imaging (MRI) methods have previously been shown to allow calculation of regional lung mechanical properties in 2D utilising image registration of serially acquired structural images[1]. The purpose of this study was to extend this work to 3D, calculating regional lung tissue motion and strain in healthy volunteers.

METHODS ***Theory:*** Compliance, *C*, of the lung is defined as the change in volume (*V*) that occurs due to a unit change in pressure (*P*). As pressure cannot be measured on a local level, regional tissue compliance is difficult to calculate. However, the bulk modulus of a material, *K*, is inversely proportional to compliance through the equation $K = -V\Delta P/\Delta V = \sigma/\varepsilon \propto 1/C$, where σ is stress and ε is strain. As such, calculation of tissue strain can provide information about local lung compliance. ***Imaging:*** Six young healthy males (mean age 27 years, range 26-32) were scanned using a 1.5 T Philips Achieva MRI scanner (Philips Medical Systems, Best, the Netherlands). A multi-slice 2D HASTE (half-Fourier acquired single-shot turbo spin-echo) sequence was used to acquire breath-hold images at end-inspiration and end-expiration. Breath-hold duration was approximately 11-13s, with the sequence cardiac triggered to acquire at mid-diastole. Data was acquired in the sagittal orientation, with separate acquisition for left and right lungs. Sequence parameters were as follows; *TR* = 1 heartbeat, *TE* = 3.44 ms, FOV = 450x275x104 mm, matrix = 144x88 pix, *ETL* (echo train length) = 47, 13 slices per lung, slice thickness = 8 mm. ***Image Processing & Analysis:*** The lung was manually segmented from each image slice. Images were then compiled into four 3D volumes – 1 per lung per respiratory stage. Data was then registered using a finite-element mesh-based group-wise affine image registration[2]. The registration is based on tetrahedral groups of correspondence points between images, whose positions are optimised using shape and texture models. The final position of control points was then used to calculate expiratory motion fields for each lung. These allowed calculation of local deformation fields (Fig.1). The deformation gradient, *F,* was then computed allowing derivation of the strain tensor according to $\varepsilon = 0.5(I - (F^{-1})^T F^{-1})$, where *I* is the identity matrix (Fig.2). Eigenvalues E_1, E_2 and E_3 could then be calculated from the strain matrix, as well as the trace of these producing dilation/volumetric strain, *D*.

RESULTS & DISCUSSION Application of methods in healthy volunteers allowed calculation of strain eigenvalues as well as dilation (Fig.3&4). Maps appeared fairly homogenous overall, as expected in healthy volunteers. Low strain was seen in the region of large vessels. This might be expected as the bronchi follow the major vasculature. Low strain was also seen around the heart and at lobe fissures.

CONCLUSIONS A novel method to calculate local tissue strain in 3D using proton MRI and image registration techniques has been demonstrated in healthy volunteers. Further development and studies in diseased lung are warranted. The technique could in future provide information about the effects of pathology on local lung mechanics, and be used in the assessment and diagnosis of lung disease, such as pulmonary fibrosis or emphysema.

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REFERENCES 1. Morgan, A.R. et al. *Assessment of Relative Regional Lung Compliance in Patients with Chronic Obstructive Pulmonary Disease* Proc Intl Soc Mag Reson Med 19 2011; 543. 2. Cootes, T.F. et al. *Computing Accurate Correspondences across Groups of Images* IEEE PAMI Vol.32 2010; 11: 1994-2005

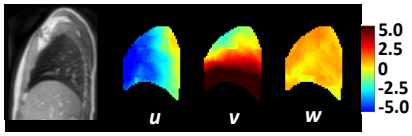

Figure 1: Displacement map for right lung motion in a healthy volunteer. Tissue displacement in inspiration in *x*- (*u*), *y*- (*v*) and *z*-direction (*w*) in voxels.

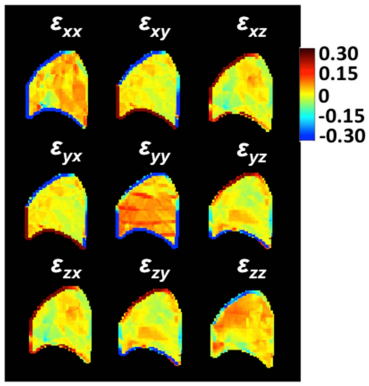

Figure 2: Directional strain for a central slice in the right lung of a healthy young male. (Image slice as in Fig.1. Units arbitrary.)

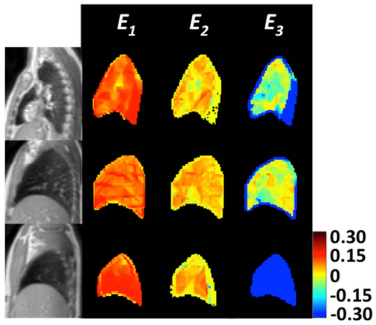

Figure 3: Eigenvalues E_1, E_2 and E_3 for three slices in the right lung.

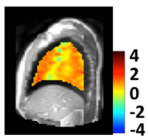

Figure 4: Example dilation map (with *D* normalised to the dilation of the whole lung). (Image slice as in Fig.1)