Investigating Regional Lung Motion in 3D using Proton MRI and Image Registration Methods

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INTRODUCTION Lung disease, such as emphysema and fibrosis, can result in regions of altered pulmonary mechanical properties. For example, a fibrotic part of the lung would have a decreased compliance resulting in decreased local tissue motion in this region. Conventional diagnosis methods, such as pulmonary function tests (PFTs), are not able to fully assess altered lung mechanics in disease on a regional level, and X-ray CT has an undesirable associated radiation dose. Previous methods using MRI to investigate lung motion in 2D include grid-tagging [1] and image registration [2]. More recently, a proton MRI method, utilising non-linear image registration techniques to investigate local lung motion and compliance in 2D has been developed [3], and also illustrated in both health and disease [4]. However, limitations of a 2D method include effects of through-plane motion of lung tissue and limited utility for diagnosis. The methods presented here aim to extend this initial work into 3D, providing regional motion information with full lung coverage.

METHODS *Image Acquisition:* Multi-slice 2D structural lung images were acquired in 2 healthy volunteers (1 male, 1 female; aged 32 and 30 years respectively) using a 1.5 T Philips Achieva scanner (Philips Medical Systems, Best, The Netherlands). A centrically reordered half-Fourier acquired single-shot turbo spin echo (HASTE) sequence was used, with images acquired in the sagittal orientation thus minimising potential through-plane tissue motion. PPU (peripheral pulse unit) triggering to mid-diastole was employed to prevent cardiac cycle effects, such as in-flow and motion blurring. Scan parameters used were; TE = 3.125 ms, TR = 1 heartbeat, slice thickness = 8 mm (13 slices per lung), FOV = 530 x 530 x 104 mm^3, phase encoding steps = 112 and echo train length = 30, with a SENSE acceleration factor of 2. Subjects were instructed to breath-hold a total of four times – twice at full inspiration and twice at full expiration, providing images with full lung coverage at both extremes of respiration for the left and right lung separately. With each breath-hold lasting 13-15 s, depending on individual heart rate, acquisition time for each subject was less than 2 minutes in total.

Image Registration and Analysis: The lungs were first segmented from the multi-slice 2D images using a manual mark-up of the outline in each slice. Segmented data were compiled into four 3D volumes representing the left and right lung at both extremes of respiration. Left and right lung data were analysed separately. The full-inspiration and full-expiration volumes were registered using a 3D group-wise affine image registration method [5], utilising a tetrahedral mesh made up of control points defined over the lung region. Initial registration took place on a coarse level, establishing the global pose of control points. Optimisation was then carried out on an iteratively finer scale, using texture and shape models, until eventually control point positions were individually modified to reflect correspondence between images obtained at the two respiratory stages. An 8 x 5 x 8 tetrahedral mesh was initially used, with an increase to 16 x 10 x 16 at later stages of registration, resulting in 62720 tetrahedra made up of 12337 control points in total. Final optimised control point positions could then be used to define a warp representing the vector field of local lung motion between full-inspiration and full-expiration.
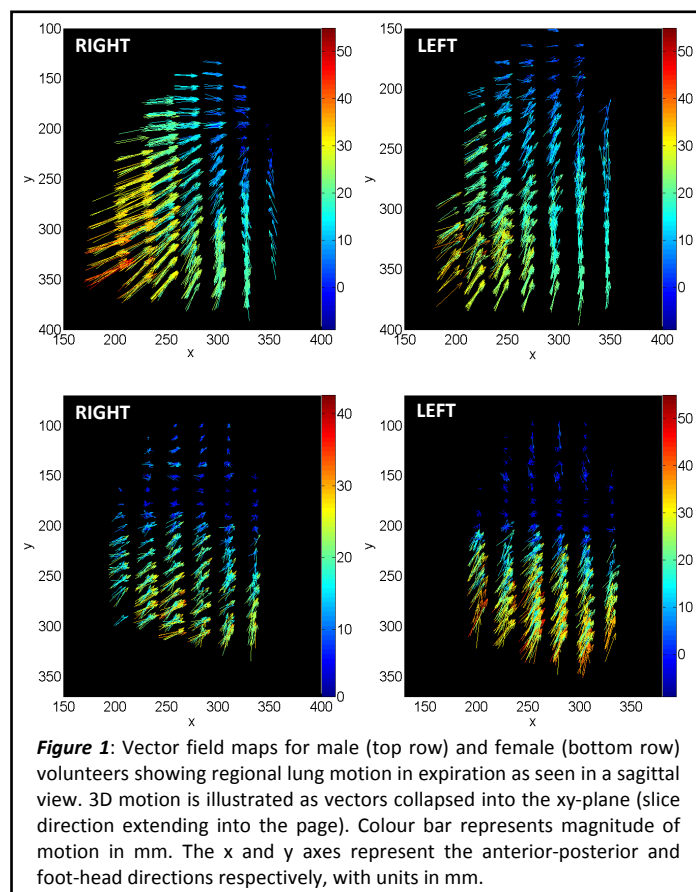

Figure 1: Vector field maps for male (top row) and female (bottom row) volunteers showing regional lung motion in expiration as seen in a sagittal view. 3D motion is illustrated as vectors collapsed into the xy-plane (slice direction extending into the page). Colour bar represents magnitude of motion in mm. The x and y axes represent the anterior-posterior and foot-head directions respectively, with units in mm.

RESULTS Vector field maps produced from the two volunteers showed an increasing magnitude of motion from lung apex to diaphragm, as expected in healthy lungs, with the majority of motion at the anterior of the lung moving not only in a head-foot direction but also anterior-posteriorly. Vector field maps for both volunteers are shown for both lungs in Figure 1.

CONCLUSIONS A 3D method has been developed allowing individual lung tissue motion to be calculated on a regional level over the entire organ. These methods could easily be incorporated into diagnostic MRI protocols due to the rapid nature of the acquisition. This could provide complimentary information on local lung function, with the potential to identify regions of the lung with altered motion, and as such, likely regions of diseased tissue. Additionally, local deformation information could be used to inform calculations of regional lung compliance.

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