Development of a Three-Dimensional Visualization and Atlasing Tool for Pulmonary Gas Distribution from Hyperpolarized ^{3}He Magnetic Resonance Imaging

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Purpose: Hyperpolarized helium-3 magnetic resonance imaging (^{3}He MRI) image acquisition tools have been developed and refined over the last decade to provide a new and unique functional window into the three-dimensional (3D) structure/function relationships of the lung in a variety of respiratory conditions. We are focused on developing new image processing, registration and segmentation methods for pulmonary functional imaging using noble gas MRI. As part of our suite of image processing tools, we generated a new visualization tool that allows for 3D views of gas distribution incorporating cluster segmentation of the different pixel intensities in the image into a three-dimensional (3D) object that can be easily rotated and manipulated. Such maps for 55 COPD subjects (GOLD Stage I-IV) have been registered using deformable methods to create a 3D COPD lung functional atlas that can show the transitions between GOLD stages of COPD.

Materials and Methods

Subjects: Fifty five subjects with COPD (GOLD Stage I-IV) provided written informed consent and underwent spirometry, plethysmography and hyperpolarized ^{3}He MRI. COPD patients were enrolled between the ages of 47 and 79 years (mean age = 68).

Image Acquisition: MRI was performed immediately after pulmonary function tests, on a whole body 3.0 Tesla Excite 12.0 MRI system (GEHC, Milwaukee, WI USA) with broadband imaging capability. ^{1}H images were acquired prior to ^{3}He imaging with subjects scanned during a 1L breath-hold of ^{4}He/N_2 using the whole body RF coil and proton fast spoiled gradient-echo (16s total data acquisition, relaxation time (TR)/echo time (TE)/flip angle = 4.7 ms/1.2 ms/30°, field-of-view (FOV) = 40 x 40 cm, matrix 256 x 256, 14 slices, 15 mm slice thickness, 0 cm gap). Prior to ^{3}He MRI, a polarizer system (HeliSpin™, GEHC, Durham, NC), with spin-exchange optical pumping, was used to polarize ^{3}He gas to 30-40 %. Doses (5 mL/kg body weight) were administered in 1 L Tedlar® bags diluted with ultrahigh purity, medical grade nitrogen (Spectra Gases, Alpha, NJ). Polarization of the diluted dose was quantified by a polarimetry station immediately prior to subject administration in a room adjacent to the MR suite (GEHC, Durham, NC). Hyperpolarized ^{3}He MRI coronal static ventilation images were acquired using a ^{3}He coil (14s data acquisition, TR/TE/flip angle = 4.3 ms / 1.4 ms / 7°, bandwidth = 31.25, FOV = 40 x 40 cm, matrix 128 x 128, 14 slices, 15 mm slice thickness, 0 cm gap) with multi-slice 2-D simultaneous acquisition of a ventilation image (no T_1-weighted sensitization) and a T_1-weighted image. Only ventilation images with no T_1-weighted sensitization were used in the analysis.

Image Analysis: ^{3}He MRI ventilation segmentation was performed using two-dimensional landmark-based registration of ^{3}He and ^{1}H pulmonary images, and subsequent application of a modified K-means clustering algorithm[1] to the ^{3}He image pixel intensity values within the thoracic cavity. The resultant ^{3}He/^{1}H segmented images provided five clusters representing unventilated, hypo ventilated, ventilated and hyperventilated voxels. The boundaries of each cluster on each slice were automatically contoured and the set of contours for each cluster was converted into a surface. Each contour was interpolated so that all contours for a given cluster had an equal number of vertices. The vertices of each contour were ordered in a clockwise manner and the vertex with the largest y-value was labeled as the reference vertex. Beginning with the reference vertex, a set of triangular patches was constructed between adjacent contours by connecting vertex i of contour c with vertex i and i+1 of adjacent contour c+1 and vertex i of contour c with vertex i+1 of contour c and c+1.

Results: As shown in Figure 1 for a single subject with COPD, a fully rotational 3D surface of each region was generated. Figure 1a shows 5 of the 14 images in the hyperpolarized helium-3 stack. Figure 1b shows the 5 images after they have been processed by the clustering software. The ventilated and hyper-ventilated lung are bounded by the blue contour, the hypo-ventilated lung by the green and blue contours and the ventilation defects by the yellow and green contours. Figure 1c displays the ventilation surfaces constructed from the contours bounding the ventilated regions: the blue opaque surface bounds the ventilated and hyper-ventilated lung, the semi-transparent green surface bounds and blue opaque surface bounds the hypo-ventilated lung and the semi-transparent yellow mesh and green surface bounds the ventilation defect region.

Conclusions: 3D surface segmentation of differing regions of intensity in helium-3 MR images may aid in the visualization of the distribution of gas in the human lung especially in progressive chronic diseases such as COPD.

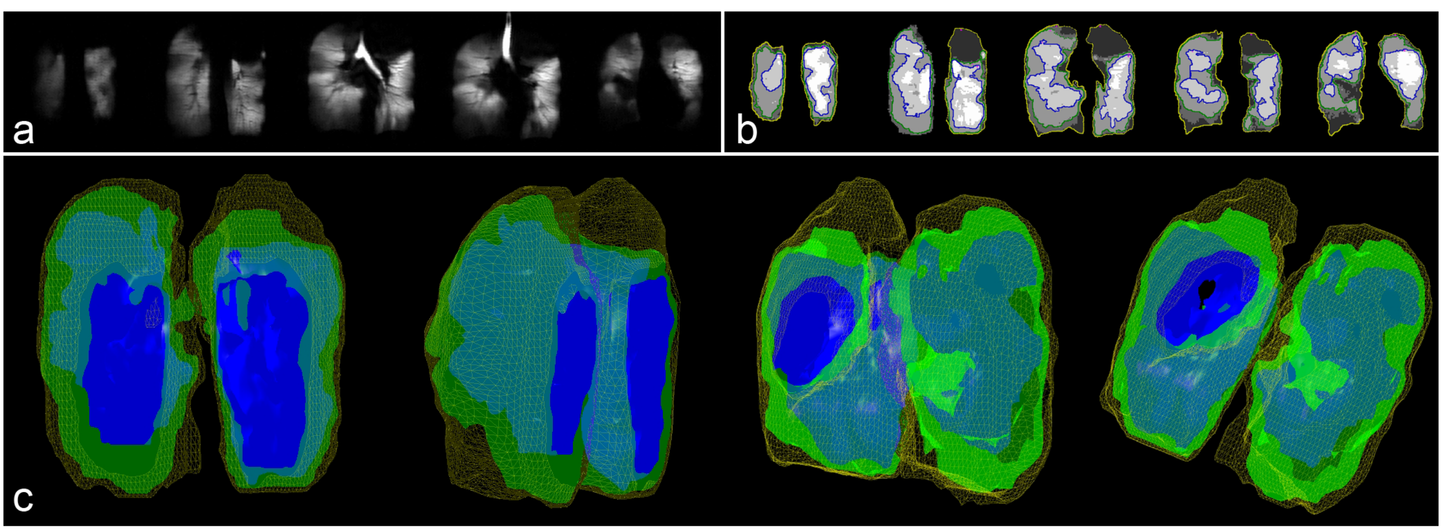

Figure 1. Fully rotational 3d surface of segmented regions of gas distribution in the helium lung. a) Hyperpolarized helium-3 MRI lung images. b) Contours of k-means clustering of helium-3 images. c) 3d surface rendering of contoured clusters. Blue contour and surface bounds the ventilated and hyper-ventilated regions, green bounds the hypo-ventilated regions and yellow bounds the ventilation defect regions.

References

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