Non-linear image registration of ³He lung diffusion MRI acquired at different inflation states, exemplified by alveolar ventilation maps

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Introduction: Hyperpolarized ^{3}He MRI allows for assessment of the alveolar size by measuring the apparent diffusion coefficient (ADC). Besides age and disease related changes, ADC also depends on inspiration volume and subject position [1,2]. Hence, image registration can allow precise regional comparison of data acquired in different inflation states. This makes it possible to use the difference in ADC (delta ADC), i.e. difference in alveolar size at expiration and inspiration, to create a ventilation map. Since the respiratory movement under inspiration is a non-linear transition, we use a non-linear, low-dimensional warping approach for image registration prior to ADC analysis [3].

Materials and Methods: A non-linear, low-dimensional warping algorithm implemented in SPM 5 (Statistical Parameter Mapping, UCL London, UK) was used for non-linear registration of non-diffusion weighted expiratory ^{3}He-images to inspiratory ^{3}He-images with a transformation matrix (TM) as an outcome. The inverse of the forward TM was calculated to enable a backward transformation from the inspiratory to the expiratory coordinate system. The ^{3}He-images were acquired with a 1.5T Siemens Vision scanner using a 3D diffusion weighted SPGE-sequence (b=1.6s/cm^2, TR/TE = 8.6/5.7ms, FA = 1.1 deg, FOV = 470x353x240 mm^3, matrix = 128x51x20, scan time =16.6 s) on 5 healthy subjects. To test the quality of the non-linear transformation processes, the generated TM for one subject was applied to a synthetic image, consisting of 8x8-squares with large differences in intensities. The backward TM was applied to the resulting inspiratory frame square image. Differences, detected visually, between the original square image and the forward and backward transformed square image was assessed. The forward TM for the non-linear registration of expiratory to inspiratory ^{3}He-images was calculated and applied to diffusion- and non-diffusion-weighted images for all subjects. ADC-maps were calculated for the original expiratory, the registered expiratory and the original inspiratory ^{3}He-images. To quantify the effect of the registration on the actual ADC-values, 4 ROIs were defined in a selected slice in the inspiratory frame by dividing the image in 4 quadrants at the carina and combine with a lung mask. The backward transformation was applied to the ROIs and mean ADC in corresponding ROIs in the expiratory and inspiratory frames were calculated. The displacement length of each pixel position from the registration process was further determined. Delta ADC alveolar ventilation maps were constructed.

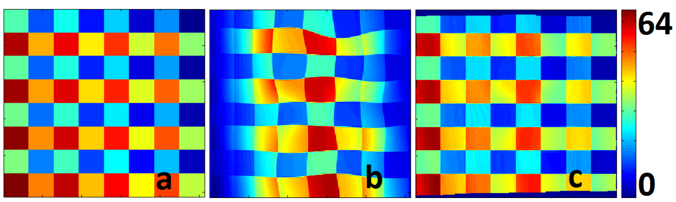

Fig. 1. Synthetic expiratory checkerboard pattern containing 8x8 regions a) before registration b) after forward transformation c) after forward and backward transformation

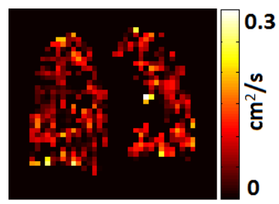

Fig. 3. Low resolution alveolar ventilation map of a central slice

Registered expiratory ADC
Expiratory ADC with transformed ROI

	ROI 1	ROI 2	ROI 3	ROI 4
S1	0.186	0.189	0.189	0.152
	0.188	0.187	0.189	0.153
S2	0.206	0.185	0.193	0.179
	0.206	0.184	0.194	0.176
S3	0.209	0.228	0.214	0.205
	0.212	0.232	0.216	0.203
S4	0.155	0.174	0.216	0.204
	0.156	0.174	0.214	0.202
S5	0.222	0.212	0.273	0.244
	0.222	0.214	0.273	0.245

Table 1. Mean ADC [cm^2/s] per ROI given for all subjects (S1-S5) in the inspiratory (blue) and expiratory frame (red) in a posterior slice.

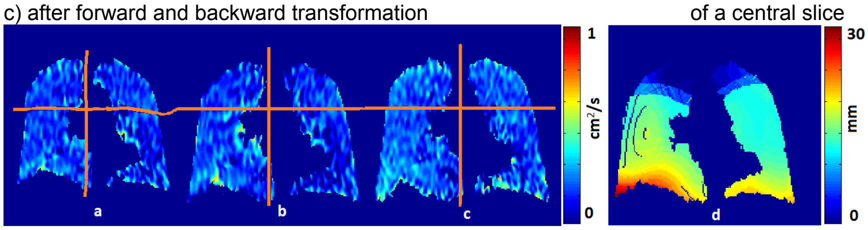

Fig. 2. ADC and displacement maps at the middle slice: a) original expiratory ADC map with four transformed ROIs, b) registered expiratory and c) original inspiratory ADC map including ROI position, d) absolute displacement map

Results and Discussion: The forward and backward transformations of the synthetic expiratory image (Fig. 1a) are displayed in Figs. 1b and 1c. The checkerboard character is preserved after forward and backward transformations, with signal cutoff only at the outer peripheries which are of no importance for the lung images. In the case of the registered expiratory lung images, the shape and structure were in coherence with the inspiratory data. The backward transformation of the ROIs that were defined in the inspiratory frame (Fig. 2b-c) is displayed in Fig. 2a. Deformations of the ROI borders are visible. The displacement map (Fig. 2d) showed that displacement occurred mostly in posterior-anterior (up to 12 mm) and superior-inferior direction (gradually increasing from 0 mm to 25 mm). The maximum displacement of 30 mm was located at the diaphragm and pointed in anterior-inferior direction. These findings are well in accordance with known physiology results [4]. Results from the ROI analysis (Table 1) showed only a small difference in mean ADC between corresponding ROIs (less than 2%) and alveolar ventilation maps could be constructed (Fig. 3).

Conclusion: It is feasible to use non-linear image registration on hyperpolarized ^{3}He MRI diffusion data acquired in different inflation states. Results from the forward and backward transformation of the synthetic pattern demonstrated the robustness of the registration algorithm. The transformation did not change the ADC values considerably, and ventilation maps can be derived. This method's main advantage is that it allows regional analysis, which makes it useful for multiple applications.

References:

[1] Diaz S, et al., JMRI, 2008;27:763-770, [2] Dorniok T, et al., ESMRMB, 2009;26:229, [3] Friston K, et al., Statistical Parameter Mapping, 2003;2:63-80, [4] Zhao T, et al., Med.Phys, 2009;36:5183-5189

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