Quantitative analysis of asynchronous motions in human pulmonary parenchyma via non-rigid registration

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Introduction: It is known that the paradoxical motions in thoracoabnominal motions and/or right and left hemidiaphragmatic motions are observed in patients with pulmonary disorders such as emphysema [1]. The quantification of these asynchronous respiratory motions could be a diagnostic method to evaluate the progression of emphysema. We previously demonstrated that a non-rigid image registration algorithm could be used to compute voxel-by-voxel deformation between successive MR images of the human lung [2]. The method could quantify the changes in the regional pulmonary parenchymal motion in magnitude and direction [3]. In this study, we applied the method to quantify the asynchrony in the right and left parenchymal and hemidiaphragmatic motions. Given the heterogeneity of disease and the slow progression of emphysema, a pilot clinical study would be difficult to design and costly to carry out. As an alternative, we tested our hypothesis in healthy volunteers that our MR-based method could quantify the asynchronous parenchymal motion between left and right in the lateral decubitus postures.

Materials and Methods: Eight healthy men (mean, 32.3 years; range, 23-42 years) were enrolled in this study. MR imaging was conducted with a 1.5T body MR scanner (Signa^{TM}, GE) with a torso coil. A dynamic study was performed in coronal single plane at the level of immediate posterior to the heart using multi-slice fast imaging with steady-state acquisition (FIESTA) on a selected sagittal slice of the right lung. Imaging parameters were: TR = 3.2 msec, TE = 1.5 msec, flip angle = 45°, field of view = 35 cm, matrix size = 224x224, slice thickness = 15 mm, NEX = 2. The subjects were instructed to breath slowly and deeply to complete half of respiration (between maximum inspiration and maximum expiration) during the acquisition of 10 images (14 sec), covering approximately two and a half respiratory cycles. These imaging sessions were repeated at three different postures (supine and left and right decubitus positions). Among the series of MR images, four different phase images over a respiratory cycle (end- and mid-inspiratory, and end- and mid-expiratory phases) were selected. Between the end-inspiratory and end-expiratory phases, the maximum diaphragmatic displacement was measured as a diaphragmatic excursion (mm) in individual hemidiaphragms. A non-rigid registration algorithm was applied to generate the displacement vector field maps between successive images in the sequence. A quantitative analysis was performed to localize motion differences between the left and right lungs. In each upper and lower region in the right and left lung, the mean pulmonary displacement magnitude was calculated. To assess the orientation distribution of the voxel-wise displacements in each region, the motion vectors were binned into 6 groups according to the subdivision shown in Fig. **1?**. Subsequently, the percentages of the number of vectors in each span of 60 degrees, from I to VI, relative to the total number of vectors in each region, were computed. Then, we compared these measurements among the different postures in four different respiratory phases (early/late inspiratory and expiratory phases) and the diaphragmatic motion.

Results and Discussion: Supine posture: The total excursions of the right diaphragm was greater (74.5±10.9, p<.046) than that of the left (88.9±10.1). The mean magnitude of the lower parenchymal motion (Fig.1A) in the right and left lung were almost identical in the early inspiratory and the late expiratory phase while the left motion was greater in the late inspiratory and the early expiratory phase.
Decubitus postures: The right and left diaphragm moved together in the inspiratory phase but the hemidiaphragm in the dependent side showed an obvious asynchrony, moving faster and completing the process earlier in the expiration phase (Fig.1B). The mean magnitude of the parenchymal motion in the dependent side demonstrated grater movement in the early inspiratory phase but smaller in the late phase (Fig.1A, Table 1), however, the difference between the sides were smaller that that observed in the diaphragmatic motion. The orientation of the parenchymal motion on the transverse direction to the body axis was in the non-dependent side.

These results suggested that the decubitus position led the diaphragmatic motion in the dependent side and chest wall movement in the non-dependent side to enhance the parenchymal movement. Our method could quantified the asynchronous parenchymal motion between left and right in the lateral decubitus postures, implying that the method could be used to detect asynchronous movement relating to pathologic-changes. The technique is also useful for better understanding of the respiratory function in patients with pulmonary diseases.

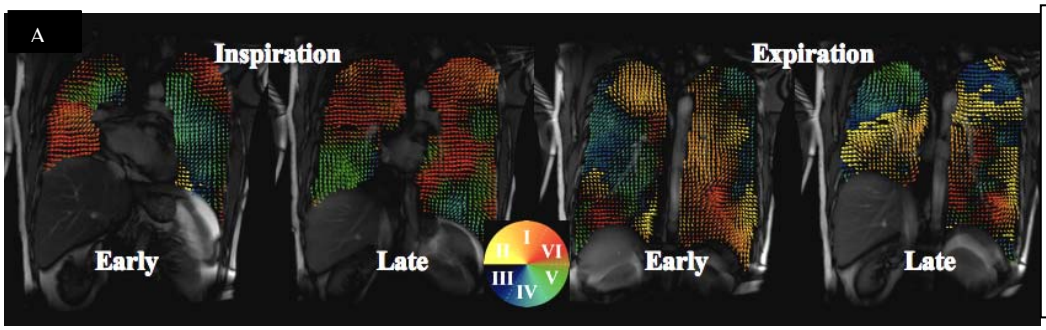

Fig. 1A. Representative coronal MR images superimposed with displacement field vectors in the right decubitus posture at four respiratory phases. Note each vector shows the magnitude of the displacement (length) and is colored depending on its displacement angle as described in the color scal.

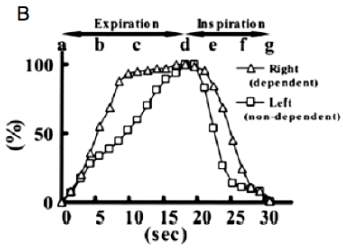

Fig.1B. The diaphragmatic displacement –time curves in the right decubitus posture. The vertical axis indicates the percent completion of each expiratory and inspiratory phase.

Table 1. The magnitude of displacement (mm) in the lower lung.

	Inspiratory phase		Expiratory phase	
Left Dec.	early	late	early	late
Left	5.3 ± 1.6*	4.7 ± 1.9	3.9 ± 1.0	4.9 ± 1.9
Right	4.4 ± 1.4	5.4 ± 1.5#	6.7 ± 1.0#	4.8 ± 0.9
Right Dec.				
Left	3.9 ± 0.8	5.0 ± 1.5	4.4 ± 1.1	3.9 ± 1.0
Right	4.4 ± 1.9	4.5 ± 1.2	3.2 ± 0.8	4.9 ± 0.8

Reference
1. T. Iwasawa et al. Eur Respir J 19:225 (2002), 2. J. Gee et al. Acad Radiol 10:1147 (2003), 3. Kubo S et al., 14th ISMRM Annual Meeting, Seattle, USA (2006).