Measurement of Regional and Global Lung Ventilation Using Non-Rigid Image Registration

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Introduction: Ventilation is often reported qualitatively in ventilation/perfusion scintigraphy using inhaled radioisotopes. Total lung ventilation can also be measured using spirometry, but without crucial spatial information. Traditional magnetic resonance techniques have been used to investigate regional ventilation using hyperpolarized gases[1], molecular oxygen[2], grid tagging[3], and landmarked registration[4], but have provided either qualitative measurements or require exogenous agents and specialized hardware. Recently, ventilation has also been measured at 0.2T using changes in signal intensity[5]. We present an MRI technique using image morphing for measuring both regional and total ventilation in a single short scan with conventional pulse sequences. Simultaneous pneumotachometer (spirometry) measurement of total ventilation provides validation for this approach.

Methods: *Image Acquisition*: 5 healthy volunteers (26±3 yrs, 4 male) were imaged on a Siemens Sonata 1.5T MRI scanner with informed consent and IRB approval. Subjects varied their respiration between normal, fast, and slow to produce a wide range of physiologic ventilation rates (2.7 – 28.6L/min). Images were acquired using both HASTE and FLASH sequences with typical acquisition parameters: no cardiac gating, 12-15 sagittal slices (25% spacing) for full lung coverage, 1.0×1.0×15.0mm^3 resolution, 45 repetitions, 1 min (FLASH) and 1.5 min (HASTE) total imaging time. Tidal volumes, respiratory rates, and total ventilation were measured with a pneumotachometer (Parevo Medics True Max 2400 Metabolic Measurement System, Salt Lake City, UT) simultaneous with imaging studies.

Ventilation Analysis: Normalized position of the diaphragm along a perpendicular one-dimensional profile was used to identify the respiratory phase of each image and respiratory rate. For each slice, repetitions were sorted by respiratory phase and the 10th and 90th percentile images were selected as representative end-inspiration and end-expiration images. A lung contour was manually traced once per slice at end-expiration to identify a reference image region. User interaction during analysis is required only in identifying a diaphragm profile and lung tracing. An open-source image registration toolkit "elastix"[6] aligned each end-expiration image to end-inspiration using b-spline deformations and a mutual information metric. Total computation time per slice was 30 seconds on a Pentium 4 3.2GHz computer. The resulting deformation field describes translational motion at every voxel, from which volume change maps for a single breath can be computed. For the sagittal slice orientation, through-plane deformations are assumed to be relatively small. The total volume change per breath is the summation of the volume change map over the traced lung region and over all slices, and total lung ventilation is computed by multiplication with the respiratory rate.

Results: MRI measurements of total ventilation correlated well with spirometry (R^2=0.88, Fig. 1), as did respiratory rate (R^2=0.997). Both FLASH and HASTE sequences provide sufficient vascular contrast for accurate morphing. Image correlation coefficients between end-inspiration and end-expiration images in the traced lung region before morphing (0.77±0.12) and after morphing (0.89±0.06) were significantly different ($p<0.001$). Posterior regions were found to have greater average ventilation (30±16% volume increase) compared to anterior regions (19±15%, $p<0.001$), as illustrated in representative local ventilation maps for the right lung (Fig. 2) and previously reported for supine orientation[7].

Conclusions: Deformation maps calculated by non-rigid registration of end-inspiration and end-expiration images acquired with conventional MRI sequences can be translated into local volume change maps. These maps directly visualize regional ventilation, and can also be summed to derive total lung ventilation, which correlates well with gold-standard spirometery.

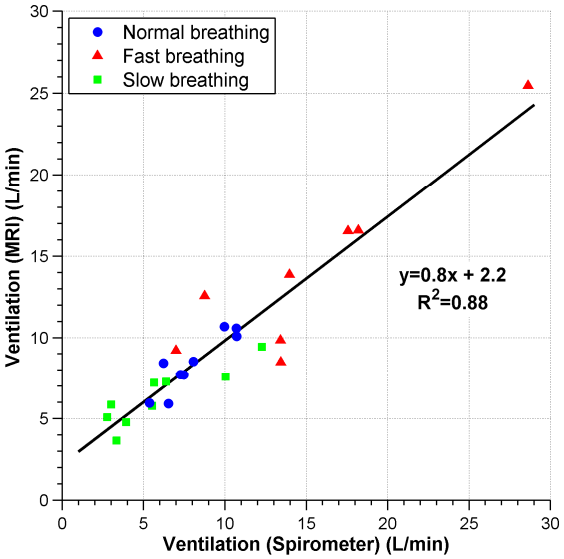

Fig. 1 (left) Total lung ventilation comparison between MRI and spirometry for 5 subjects in three respiratory regimes.

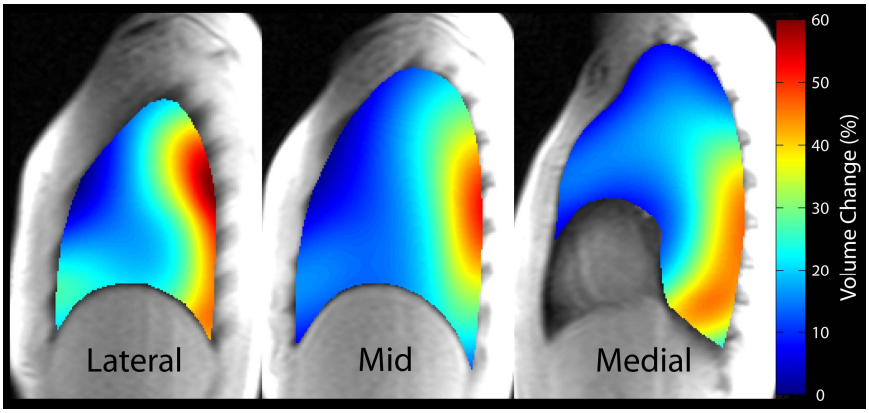

Fig. 2 (right) Representative local volume change maps for three slices of the right lung, showing increased local ventilation posteriorly.

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