MRI "Spirometry" for Regional Pulmonary Function Analysis

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Introduction: Clinical assessment of pulmonary function is solely performed on the entire pulmonary system and thus is incapable of delivering localized information. MRI methods have been developed to test pulmonary function on a regional basis. MRI spirometry, the first of its kind, was performed using ultrafast MR grid-tagging of the parenchyma to dynamically analyze lung mechanics. The technique's potential is demonstrated with a regional flow-volume loop obtained during quiet breathing.

Methods: MR tagging velocimetry was developed for quantification of regional lung parenchyma motion. Studies were performed on a 1.5T Siemens Avanto scanner. The sequence, similar to that described in Chen *et al.*[1], used the following parameters: TR = 1.5ms, TE = 0.61ms, FA = 5º, matrix size = 160x192. Coronal measurements in a 20mm slice were made over multiple respiratory cycles during quiet breathing. A multiple-tag technique was used for continuous imaging over extended time periods, i.e. multiple breath cycles. A data acquisition cycle consisted of a spin-tagged grid and acquisition of two images, an image pair. Image pairs were post-processed using an automated algorithm to provide regional parenchymal displacement. The algorithm, based on cross-correlation methods[2], was used to interrogate sub-regions between succeeding images to measure displacement of the grid. Knowing the time delay between paired images and the measured displacement, velocity vector maps were generated, from which quantities such as strain[3] and dilatation[4] can be extracted. To demonstrate the capability to track changes in localized regions during ventilation, local volume change was calculated from the velocity measurements and plotted as a function of both time and flow rate. The volume calculations are performed under the assumption that volume change in material region is solely due to ventilation.

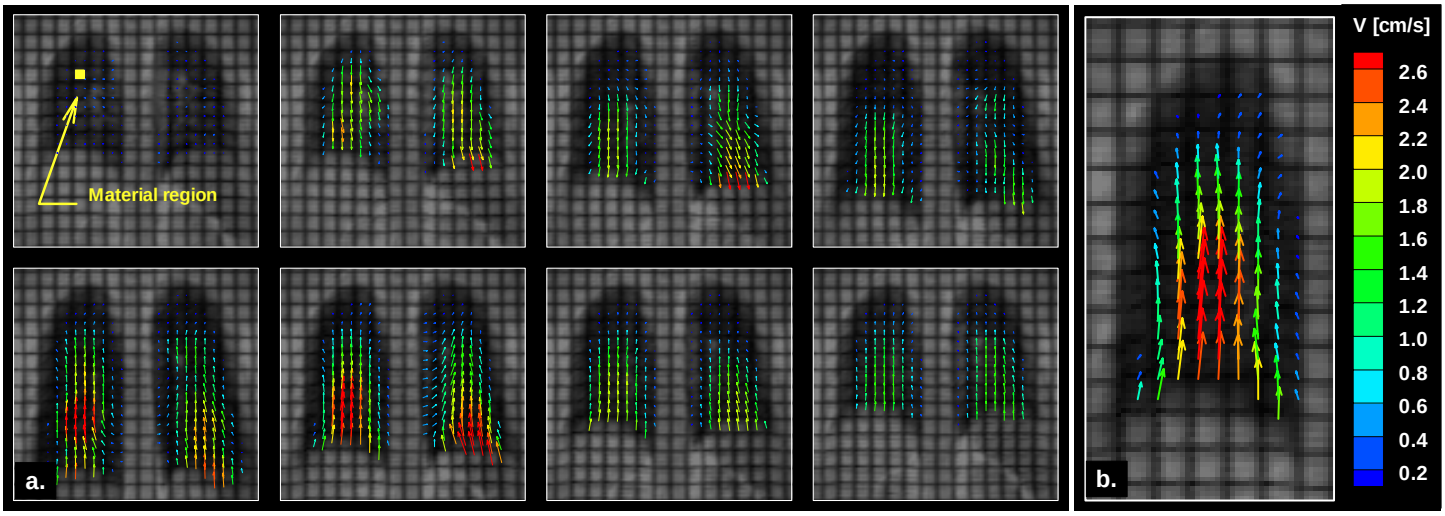

Figure 1a. Eight velocity vector fields show lung motion during an entire respiratory cycle of quiet breathing; top/bottom rows depict inspiration/expiration.
1b. Exemplary vector field enlarged to show detailed motion; colored vectors indicate velocity magnitude, and blue-to-red scale implies increased displacement.

Results: Movies of velocity vectors superimposed on tagged images were generated over a multiple breath cycles. One complete cycle – inspiration to expiration – is shown in Fig 1a. The enlarged vector plot of the right lung during expiration (Fig 1b) is an excellent example of the resolution of tagging velocimetry. Displacement measurements are accurate to 0.5mm; spatial resolution of the measurements is 41.7mm and over-sampling, to satisfy the Nyquist condition, yielded 10.4mm vector spacing. Temporal resolution, determined by the time delay between paired images, is 160ms. Volume change due to ventilation was calculated for both global and local regions. Total lung volume change (per unit depth) was calculated using registered images and is plotted versus time (Fig 2). Note the breath cycle corresponding to Fig 1 is denoted by the boxed region. Local volume change (i.e., dilatation) calculations are demonstrated for a 2.4cm^3 material region (as noted in Fig 1), assuming 2D motion; the results are also shown in Figure 2. Tidal flow-volume curves for the material region are displayed for three respiratory cycles in Figure 3.

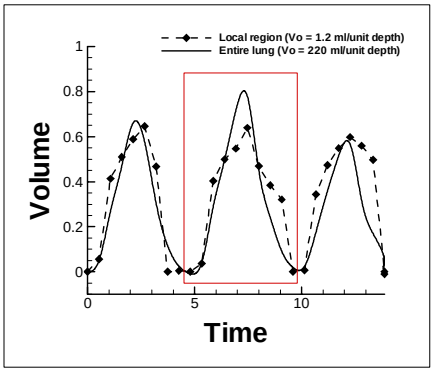

Figure 2. Global and local tidal volume plotted vs. time over three respiratory cycles; Volume is normalized by resting lung volume, V_o.

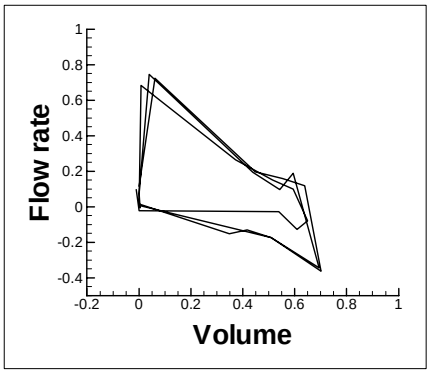

Figure 3. Flow-volume loop; flow rate units are *ml/sec/unit depth*, volume units are *ml/unit depth*.

Discussion: Velocity measurements of lung displacement using grid-tagged MR provide a powerful tool for examining regional mechanics. Qualitatively, displacement measurements agree well strain calculations from previous studies[3]. In Fig 2, local and global volume change is compared; volume is normalized by the resting volume, V_o. Both the phase and magnitude of the local and global volume change are similar. For the first time, sub regions of the lung are examined with flow-volume curves (Fig 3), providing a useful metric for regional assessment of pulmonary function. The overlay of the flow/volume relationship for three cycles exhibits the repeatability of the associated measurements. This technique will be implemented for clinical studies on regional differences in diseased lungs.

References

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