Quantitative Comparison of Registration-Based Lung Motion Estimates from Whole-Lung MR Images and Corresponding Two-Dimensional Slices

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Introduction: Quantification of pulmonary deformation is useful in characterizing normal lung motion as well as the changes that occur as a result of pathological processes [4]. Magnetic resonance (MR) imaging of the lung can be used to noninvasively visualize and assess pulmonary anatomy and dynamics [2,3]. Ideally, motion quantification would be performed using whole-lung images to eliminate the confounding effect of through-plane motion. Currently, real-time imaging of deforming lungs is more easily performed at a single slice position. Here, we seek to quantify how much information about pulmonary kinematics is lost when estimating whole-lung motion at single two-dimensional (2-D) slice positions. We compare lung motion estimated via image registration from whole-lung datasets with the motion within a selected set of slices extracted from the whole-lung images. Our hypothesis is that the accuracy of lung motion measured from a single slice is affected by both the choice of imaging plane and the degree of deformation within the lung (estimated by the percent of instantaneous lung volume expired) during the specified interval of respiration.

Methods: We perform slice-by-slice whole-lung image acquisition in two healthy female volunteers during 18-second breath-holds (Siemens TrueFISP with GRAPPA, acceleration=2, matrix=128x128x60, slice thickness=2.4-3.0 mm, FOV~400 mm, # slices=60-64, TR=3.61 ms, TE=1.81 ms, FA=51°). Five images at varying instantaneous lung volumes are acquired: maximal, near-maximal, and approximately half-maximal inspiration, and near-maximal and maximal expiration. Breath-holds are self-regulated by each subject, therefore each image sequence varies in its sampling of the respiratory cycle. Before analysis, images are zero-padded and resampled to be of dimensions 256x256x128 with isotropic 1.5-mm voxels. From the resulting whole-lung images, we generate five new 2-D image datasets by extracting slices at specific positions. Three coronal locations (posterior, mid-chest and anterior) and two sagittal locations (mid-right and mid-left, excluding the heart) are selected. We employ the ISIR algorithm, which computes the forward and inverse non-rigid transformations between two images I and J, to estimate the motion of the lung during the imaged interval [1]. First, sequential image pairs within the original whole-lung image sequence are registered to characterize the expiratory phase of respiration. Next, sequential pairs within each of the five new 2-D image sequences are similarly registered to produce coronal and sagittal approximations of whole-lung expiratory motion.

The goal of our analysis is to determine if 2-D imaging effectively captures in-plane lung motion, even though through-plane motion is lost. The 2-D and whole-lung results are compared by extracting the planar displacements within the whole-lung fields that correspond to the coronal and sagittal slices used to create the 2-D sequences, and comparing these displacement fields to those obtained from the 2-D registrations (figure 1). Whole-lung motion is treated as ground truth in these experiments. The discrepancy of the 2-D estimated displacement fields with respect to this ground truth is computed as the mean endpoint error d between $\mathbf{u_3}$, the vector within a specified slice generated by registration of the whole-lung data, and $\mathbf{u_2}$, the vector computed via registration of the extracted slices: $d = |\mathbf{u_3}-\mathbf{u_2}|$.

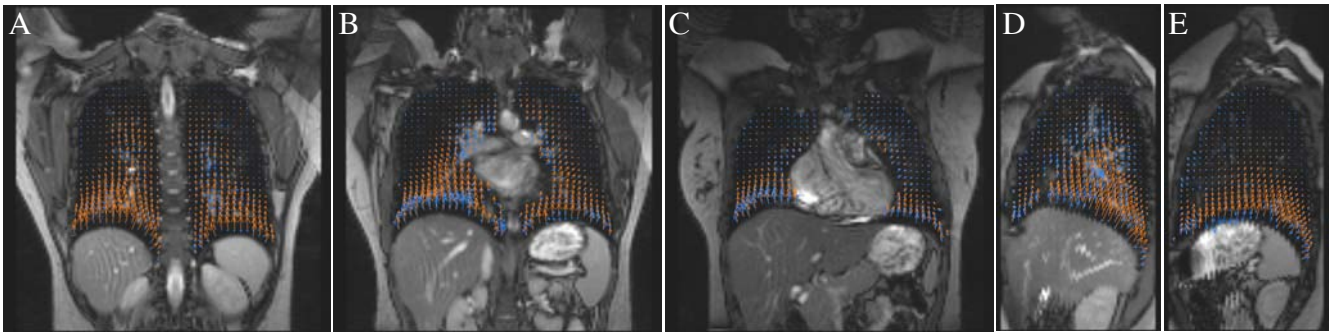

Figure 1: Comparison of 2-D derived (blue) and whole-lung derived (orange) sagittal displacement fields in one volunteer in each of the five locations during mid-expiration: (A) posterior coronal, (B) mid-coronal, (C) anterior coronal, (D) right mid-sagittal, (E) left mid-sagittal. Note that the fields derived from whole-lung analysis consistently capture more motion than the fields from the 2-D analysis.

Results: Overall, whole-lung motion estimation appears to quantify significantly more lung motion compared to the 2-D estimates in corresponding slices. This is also qualitatively evident in figure 1, which reveals a clear discrepancy in the magnitude of the captured displacements and some disagreement in vector orientation, particularly at the lung bases and costophrenic angles. Furthermore, the extent of lung deformation influences the accuracy of the 2-D estimates; mean endpoint errors range from 0.93±0.60 to 1.47±1.00 pixels when only 3% of instantaneous lung volume is expired to as much as 5.16±4.44 pixels when 25% is expired. In both subjects, the best correspondence between the two sets of displacements occurs when estimating motion using the posterior coronal slice; mean endpoint errors are consistently less than 1 pixel. This is potentially due to the fact that there is the least amount of through-plane motion in the posterior coronal slices, since patients are supine during image acquisition. Motion estimated from mid-coronal slices is generally more consistent with the extracted whole-lung displacements than motion from the anterior coronal slices. This is likely due to the greater degree of chest expansion anteriorly, particularly with the large changes in lung volume that occur with breathing that spans inspiratory and expiratory reserves. Neither sagittal slice seems to convey an advantage in terms of correspondence to the whole-lung measurements; this could be a result of selecting slices that do not contain the heart. Furthermore, endpoint errors in the sagittal slices were generally comparable to those in the mid-coronal slices.

Discussion & Future Work: We investigate the effect of through-plane motion on the estimation of lung motion using 2-D image sequences as compared to whole-lung images. Current technical limitations make 2-D imaging more practical than whole-lung imaging; however, motion information is sacrificed as a result. When acquiring 2-D images of the lungs, it is important to be cognizant of the inherent underestimation in the quantified motion and to select appropriate imaging planes. In future, we plan to extend this analysis to a larger population, and better quantify the error using landmark correspondences that provide better ground-truth displacement information. Additionally, we hope to explore the effects of positional variation during imaging on the accuracy of slice-based motion quantitation. Furthermore, it would be interesting to determine if there is a regional distribution of error longitudinally within the lung, and whether the information loss incurred with 2-D imaging is minimized by tidal respiration.

References: [1] B. Avants et al. *Neuroimage* Suppl. 1:S139-150, 2004. [2] J. C. Gee et al. *Acad. Rad.* 10: 1147-52, 2003. [3] H. Hatabu et al. *Proc. ISMRM 9th Mtg. 2001*, p. 2008. [4] C. Plathow et al. *Brit. J. Rad.* 78: 836-840, 2005.