Validation of Shape Averaging for Modeling Average Lung Deformation in 2-D Ventilator-Acquired Mouse MR Sequences

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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. We have previously demonstrated and validated a non-rigid image registration algorithm for computing the deformation between successive magnetic resonance (MR) images of the lung [2,3,6]. The resulting deformation field represents an estimate of the pulmonary motion between two sequential images. In recent work, we have employed a shape averaging algorithm to promote the development of dynamic atlases of the lung from free-breathing sequences of 2-D human MR data [1,5]. The algorithm uses symmetric (forward- and backward-) registrations to produce a shape and intensity average of two images based on the correspondence between their deformation energies, and accordingly allows the interpolation of intermediate images. Our previous hypothesis was that reparameterization of these free-breathing data via interpolation of images at specific normalized lung volumes would enable us to establish temporal correspondence between different subjects, in an effort to produce an average atlas of breathing lungs from multiple individuals. Here, we quantitatively evaluate the validity of the reparameterization by applying the algorithm to two sequences of ventilator-acquired 2-D MR coronal images of a healthy mouse.

Methods

A healthy mouse was mechanically ventilated at a frequency of 120 breaths/min and placed with a dorsal respiratory sensor in a 4.7 T MRI system (Biospec 47/40, Bruker BioSpin, Karlsruhe, Germany). After the localizer imaging, a gradient echo sequence was performed in a cine-mode where the TR was determined as 1/20 the duration of a respiration (25 ms) so that 20 MR images were obtained with respiratory triggering every 25 ms over one breath. Other imaging parameters were: TE = 1.9 ms, matrix size = 128x128, slice thickness = 1 mm, and FOV = 2.56 cm, which afforded 200 µm in-plane resolution. MR imaging was repeated at two different positive end-expiratory pressure (PEEP) settings of 0 and 4 cm H_2O.

Cross-sectional area (CSA) was used in our 2-D experiments as a surrogate measure for lung capacity (in 3-D, we would compute volume). The CSA in each image was measured using Insight-SNAP, an open-source implementation of semi-automated level-set segmentation [4]. The resulting segmentations were not post-processed in order to avoid paradoxical inclusion of non-parenchymal tissue. In each dataset, end-inspiration was identified as the time point with the largest CSA. The graph of capacity over time revealed a biphasic pattern during respiration (figure 2). As a result, we reconstructed the inspiratory and expiratory phases of respiration separately. Using the shape averaging algorithm, the average inspiratory and expiratory images were computed for both PEEP=0 and PEEP=4 datasets, and images were interpolated between end-expiration and end-inspiration at the same time points as the original data were acquired. This produced two new image sequences that were expected to correlate with the original data. We then measured the CSA in each of the interpolated images, and compared it to the CSA computed from the original data.

Results

Representative deformation fields from the PEEP=0 (figure 1a) and PEEP=4 (figure 1b) datasets are shown below. The mean error in computed CSA between the interpolated and original sequences was computed as the difference between the capacities on the two images divided by the original lung capacity. Error was computed to be 6.54±3.41% for the PEEP=0 data and 2.06±1.11% for the PEEP=4 sequence. Figure 2 shows the CSA trends for both datasets. CSA is measured in mm^2 and plotted over milliseconds of respiration.

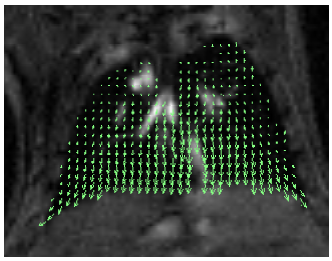

Figure 1a

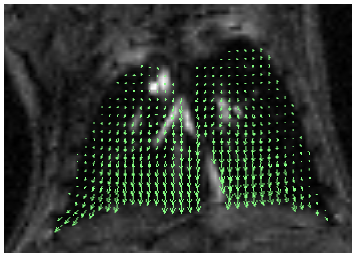

Figure 1b

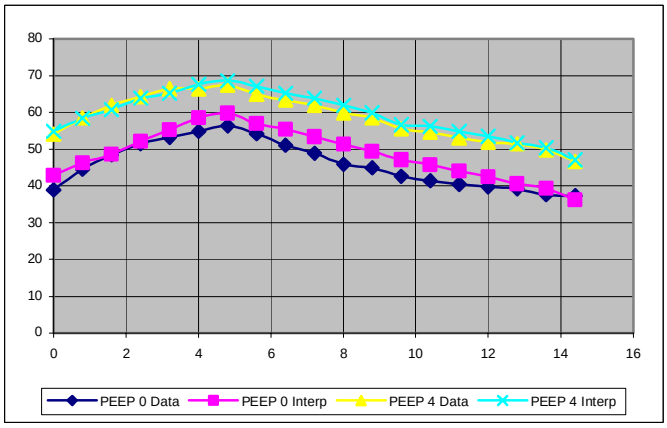

Figure 2

Discussion & Future Work

In both datasets, the biphasic trend of the lung capacity during a single breath was reproduced with an acceptable degree of error, which supports our application of shape averaging to the reparameterization of dynamic image sequences. We suspect that some of the observed error is related to the segmentation that is used to estimate lung capacity. Future work entails extending these experiments to 3-D image sequences, as well as the construction of dynamic atlases of normal lung motion from multiple individuals.

References:

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