Non-Rigid-Registration of Breast Dynamic Contrast-Enhanced MRI Data: Comparison and Evaluation of B-splines and Symmetric Diffeomorphic Normalization based Methods

Venkata Veerendranadh Chebrolu¹, Dattesh D Shanbhag¹, Aurelie Le Deley¹, Sheshadri Thiruvenkadam¹, Uday Patil², Patrice Hervo², Sandeep N Gupta⁴, and Rakesh Mullick³

¹Medical Image Analysis Lab, GE Global Research, Bangalore, Karnataka, India, ²GE Healthcare, Buc, France, ³Manipul Health Enterprises Pvt. Ltd., Bangalore, Karnataka, India, ⁴Biomedical Image Processing Lab, GE Global Research, Niskayuna, NY, United States, ⁵Diagnostics and Biomedical Technologies, GE Global Research, Bangalore, Karnataka, India

Target Audience: Physicists and radiologists interested in non-rigid motion correction in breast dynamic contrast-enhanced (DCE)-MRI.

Purpose: DCE-MRI is increasingly being used in diagnosis and screening of breast tumors. Careful study of intensity changes over time between the pre-contrast and post-contrast images is critical to tumor biometry. Rigid and non-rigid motion may be caused by factors such as voluntary patient motion, cardiac pulsation, and breathing during image acquisition. A reduction of motion effects is important for valid morphological or dynamical image analysis [1]. Previous work [1] evaluated the efficacy of b-splines [2] based approaches in correcting for motion in breast DCE-MRI. In this work we compare and evaluate b-splines and symmetric diffeomorphic normalization [3, 4] based non-rigid registration (NRR) algorithms for their effectiveness in motion correction for breast DCE-MRI.

Methods: NRR in the breast DCE data was compared and evaluated for four different approaches. Method 1: 3D symmetric diffeomorphic normalization based NRR [3] between the 3D volumes (phases) of the DCE intensity data. Method 2: 3D symmetric diffeomorphic normalization based NRR [3] between different phases of the DCE intensity data with NRR localization using a mask which includes the breast and cardiac region. Method 3: 3D b-splines [5] based registration between the Laplacian transforms of different phases of the DCE data. A mask including the breast and cardiac region was used for localizing the motion correction. Laplacian was used to reduce the effect of contrast changes on NRR between different phases. Method 4: 3D b-splines [5] based NRR between all the Laplacian transforms of the different phases. Same mask as Method 1 was used. In all the four methods, mutual information was used as the similarity metric and last-phase of the 4D data was used as the “fixed” image volume and other phases were registered to the last-phase. A multi-resolution framework was used for all the four methods with processing at three different resolutions. The number of iterations of different resolutions is represented by $MxN\times P$ ($M$ iterations at 4 times lower resolution, $N$ iterations at 2 times lower resolution and $P$ iterations at the original data resolution). A grid-spacing of $15\times 15\times 15$ mm was used as the final grid-spacing in physical units [5] for the b-splines based deformation in the multi-resolution framework.

Results and Discussion: NRR Time Performance: Figure 1a shows the average processing time taken by Method 1 for NRR between two phases. The processing time of deformation normalization based approaches was directly proportional to the number of voxels per phase. Hence, the usage of mask in Method 2 reduced the NRR processing time by 40% on average. In contrast, independent of the number of voxels per phase, the average time that b-splines based methods took for NRR between two phases was 2min with or without use of mask or with use of different sized masks, at 250 iterations. For a given number of iterations, the final grid-spacing in physical units was the determining factor for NRR processing time with the b-splines based approaches. Since, a grid-spacing of $15\times 15\times 15$ mm was fixed when performing NRR using b-splines in our work, no difference in processing time was found at different sizes of the 3D phase volumes. NRR Accuracy: Figure 1b shows the experienced radiologist’s accuracy of the four methods for five cases using yes (Y) or no (N) rating on motion correction and new deformations. 3D symmetric b-splines (Methods 3 and 4) introduced new deformations in the chest wall in one of the five cases. The accuracy of the NRR with the exclusion of cardiac mask was better than with inclusion of cardiac mask for b-splines based approaches. In contrast, the NRR accuracy of diffeomorphic approaches (Methods 1 and 2) did not change with or without use of mask in the region of interest defined by the mask. Figure 2 shows an example of the impact of NRR on the time courses of NRR in a ROI (shown in red) for a representative case. Qualitative visual assessment shows better NRR accuracy with Diffeomorphic normalization based methods. Work on quantitative measures for assessment of the efficacy of motion correction by NRR methods in DCE-MRI has been submitted separately. Conclusions: B-splines based NRR approaches provided consistent time performance, but introduced new deformations in some cases. The time performance of diffeomorphic normalization based NRR approaches changed from case to case depending on the number of voxels processed for NRR. However, better NRR accuracy was achieved and no new deformations were introduced. References: [1] Melbourne A et al, Phys Med Biol. 2011;56(24):7693-708. [2] Modat M et al, Comp Meth Prog Biom. 2010;98: 278–84. [3] Avantis B et al, Penn Img Comp and Sci Lab. 2009. [4] Arno K et al, Neuroimage 2009;46(3):786–802. [5] Klein S et al, IEEE Trans on Med Img 2010;29(1):196–205. [6] Thiruvenkadam et.al. ICP 2006. [7] Samson et al. PAMI 2000; 22(5).