Nonrigid Registration for Motion Correction in Contrast-Enhanced MR Breast Imaging: Comparison between Finite Element and Free Form Deformation Method

A. W. Magri[1], A. Krol[2], M. Unlu[3], J. Mandel[4], G. Tillapaugh-Fay[2], W. Lee[2], E. Lipson[1], and D. Feiglin[2]

[1]Department of Physics, Syracuse University, Syracuse, NY, United States, [2]Department of Radiology, SUNY Upstate Medical University, Syracuse, NY, United States, [3]Department of Electrical Engineering, Syracuse University, Syracuse, NY, United States, [4]Department of Civil and Environmental Engineering, Syracuse University, Syracuse, NY, United States

Aims:

In order to improve diagnostic accuracy for evaluation of breast tissue lesions detected in contrast-enhanced MR imaging one needs to perform nonrigid registration of consecutive time frames. The objective of this study was to compare the quality of registration accomplished by two different approaches: Finite Element Method (FEM) with fiducial skin markers and a Free Form Deformation (FFD) method.

Materials and Methods:

Twelve patients, each with up to nine fiducial skin markers (FSMs) taped to each breast, were positioned prone with both breasts suspended into a single well that housed the receiver coil of 1.5 T Intera MR scanner (Siemens). An IV line was established in a distal antecubital vein with a 22- or 24-gauge angiocatheter insertion for Gd-DTPA (Magnevist; Berlex Imaging) injection. After scan acquisition of the pre-Gd scan the contrast (0.15 mmol/kg) was delivered with a constant flow of 10 ml/15s and followed directly by 20 ml of physiologic saline solution. The field of view (360 mm × 360 mm) was centered over the breasts. We used a gradient recalled echo (GRE) technique with TR/TE = 5.4/2.1 for pre-Gd baseline reference, followed by five more measurements at 60 s intervals (in a 256 × 256 matrix). First, locations of centroids of corresponding FSMs visible on pre-Gd and post-Gd images were estimated thus providing the observed surface displacement vectors. This was followed by segmentation of breast surfaces in all dynamic-series images, and meshing all post-Gd breast volumes. Tetrahedral volume and triangular surface elements were used to construct a finite element model. An analogy between orthogonal components of the displacement field and the temperature differences in steady-state heat transfer (SSHT) in solids was utilized to calculate dense displacement field within the breast volume using the FEM ANSYS package. The floating images (post-Gd) were warped to the target image (pre-Gd) using an appropriate shape function for interpolation from mesh nodes to voxels. To reduce any residual misregistration, surface matching between the previously warped floating image and the target image was performed. A FFD method was implemented using the Image Registration Toolkit software package. The normalized mutual information was used to drive the FFD nonrigid registration.

Results:

Similarity measurements performed on four Volumes Of Interest (VOI) were used to quantitatively evaluate the registration quality. They included: Normalized Mutual Information (maximum value of 2); Normalized Correlation Coefficient (NCC, maximum value of 1), and the Sum of Absolute Value Differences (SAVD; smaller values indicate better registration). The results are collected in Table I. Figure 1 shows an example of nonrigidly registered breast dynamic MR images obtained using the two methods. We observe that FFD outperforms FEM.

Conclusions:

The registration accuracy for FEM is worse than achieved using FFD method. The FEM method is significantly faster than FFD registration: processing time was 2 hours for FEM vs. 48 hours for FFD using a dual core, 3.6 GHz workstation. However, FEM requires fiducial markers placement on the patients' breast surface and therefore can only be applied prospectively. The FFD approach does not require any additional patient preparation, therefore can be used retrospectively and results in better registration quality. The only drawback is the processing time. Consequently, we conclude that FFD plus dedicated hardware and software that would reduce execution time is a method of choice for nonrigid registration of consecutive time frames in dynamic MR breast imaging.

TABLE I
CALCULATED IMAGE SIMILARITY MEASURES FOR FOUR SELECTED STRUCTURES, ESTIMATED USING FINITE ELEMENT METHOD AND FREE-FORM DEFORMATION NONRIGID REGISTRATION OF CONTRAST-ENHANCED MR IMAGING

Similarity Measurements					
		Volume of Interest			
		1	2	3	4
Normalized Mutual Information	FEM	1.05	1.14	1.11	1.08
	FFD	1.15	1.21	1.19	1.17
Normalized Correlation Coefficient	FEM	0.57	0.56	0.79	0.81
	FFD	0.96	0.98	0.96	0.97
Sum of Absolute Value Differences	FEM	8.5×10^6	3.1×10^6	2.2×10^6	3.7×10^6
	FFD	3.1×10^6	1.1×10^6	1.3×10^6	1.6×10^6

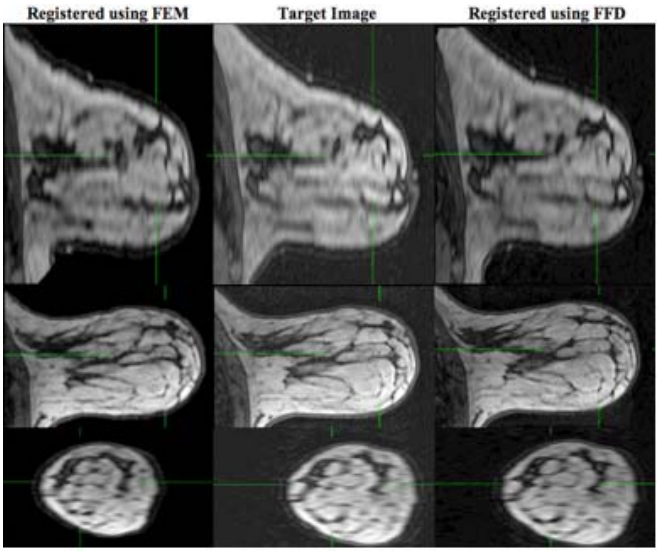

Fig. 1. Qualitative comparison of pre-Gd source image registered with post-Gd target image using Finite Element Method (FEM) and Free Form Deformation (FFD) method. First column: FEM registered images. Second column: pre-GD MRI target images. Third column: FFD registered images. Top row: sagittal views. Middle row: axial views. Bottom row: coronal views.