A Novel Non-Rigid Registration Approach for Accurate Quantification of Dynamic Contrast Enhanced MR Imaging (DCE-MRI) in Ovary Employing Residual Complexity Framework

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Target Audience: Engineers and physicists interested in artifact correction in DCE-MRI

Introduction: One of the major assumptions in quantification of dynamic contrast enhanced MR Imaging (DCE-MRI) in abdominal organs, such as ovary, is spatially fixed region of interest over the time course of contrast agent passage. However, this assumption becomes essentially invalid when motion artifacts occur **[1]**. Thus, accurate quantification of DCE-MRI image series highly depends on minimization of motion artifacts. Two types of motion occur in DCE-MR images of abdominal organs: 1) complex motion resulting from breathing, pulsation, and the natural movement of the organ of interest or its surrounding organs; 2) motion of contrast agent in the tissue **[2]**. Motion correction of DCE-MR image series becomes a challenging issue in the sense that the proposed registration algorithm for rectifying the first type of motion must be unaffected by signal intensity changes during the bolus passage **[3]**. Apart from intensity variations caused by motion, spatially varying intensity distortions induced by bias fields in high-field MRI, increase the complexity of the interrelationships of pixel intensities, which compromise the performance of registration procedures. The complexity resulting from the aforementioned artifacts cannot be resolved by the commonly used image registration similarity measures, which assume independence and stationarity of pixel intensities. Recently, residual complexity (RC) has been introduced as a new similarity measure for non-rigid registration, which can capture non-stationarity and complex spatially-varying pixel intensities **[4]**. The idea of exploiting RC is to minimize the complexity of the residual of images in the Discrete Cosine Transformation (DCT) domain rather than in pixel domain. Here, we proposed a registration approach for accurate quantification of DCE-MRI in ovary employing RC to account for spatially-varying intensity changes within the registration framework.

Materials and Methods: Data Acquisition: DCE-MR images of eight patients diagnosed with solid or solid/cystic ovarian masses were acquired on a 3T MR scanner (Siemens MAGNETOM Tim TRIO) using a surface phased array coil, *TE*/*TR* = 1.74/5*ms*, flip angle = 60°, image matrix = 156×192, FOV = 23×23cm^2, slice thickness = 5*mm*, number of measurements = 52 at 6 sec/volume, number of slices = 16. The acquisition was performed before and immediately after injection of 0.2*mL*/kg of Gadolinium (DOTAREM; Guerbet, Aulnay, France) followed by injection of 20cc normal saline solution with 3*mL*/min injection rate. **Image Registration:** The proposed registration approach is composed of two steps: (1) Rigid registration employs normalized mutual information (NMI) as the similarity measure. The first image in the sequence of images is used as the reference and the consequent images are aligned with the first image. (2) Non-rigid registration is performed using RC similarity measure along with 2D Free Form Deformation (FFD) Bspline transformation, and the gradient descent optimization method. Since proper test data does not exist for evaluation of the registration of DCE-MR images, the assessment of the registration quality is not straightforward. Here, the performance of the proposed framework is assessed by comparing this method with an alternative method, employing normalized MI similarity measure in the non-rigid registration step. **Quantification:** It has been proposed that parameters such as SI_{max}, SI_{max} (tumor)/SI_{max}(psoas) and the area under the signal intensity curve can be used to distinguish between benign and malignant ovarian masses **[5]**.

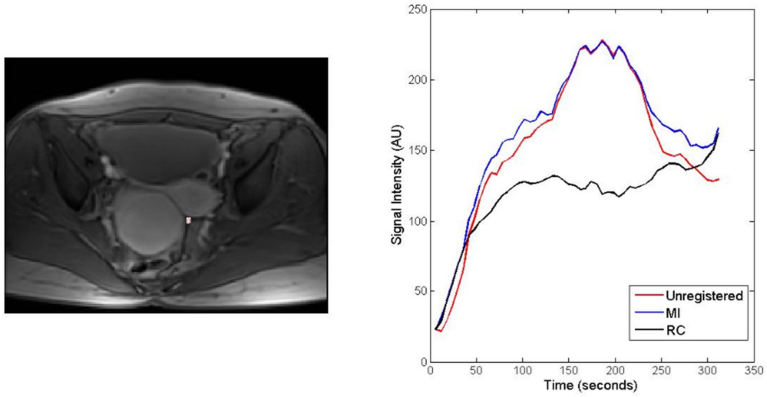

Fig. 1 Signal Intensity-Time curve from unregistered images, and registered by MI, RC in a benign mass.

Results and Conclusions: **Fig. 1** illustrates the mean signal intensity time courses for the selected ROI obtained from unregistered image sequence and the images registered by MI and RC similarity measures in one of the patients with benign tumor. RC significantly improved the signal intensity time courses. In the cases with solid malignant masses, the MI and RC returned almost similar results. In addition, the mean and the median of standard deviation in two ROIs (Tumor and Psoas) were computed (**Table 1**), which suggest that MI and RC methods significantly improve the signal intensity-time courses in contrast to the unregistered method. It can be inferred from **Table 2**. that the quantification parameters obtained after RC registration method can better discriminate Benign from Malignant ovarian masses in comparison with unregistered and MI techniques. In conclusion, the results show that RC can be used conveniently as a proper similarity measure for non-rigid registration of DCE-MR images of ovary, and consequently for accurate quantification of ovarian masses.

Table 2. Evaluation of unregistered, MI and RC methods

		Patient 4 (Benign)		Patient 7 (Malignant)	
		Psoas	**Tumor**	**Psoas**	**Tumor**
Unregistered	**mean**	7.32	45.01	5.13	5.85
	median	7.8	43.11	4.97	5.43
Mutual Information (MI)	**mean**	5.98	47.44	4.86	5.23
	median	6.1	49.35	4.73	4.96
Residual Complexity (RC)	**mean**	5.88	21.24	3.94	4.12
	median	5.88	19.77	4.04	3.86

Table 1. Parameter calculations for Benign and Malignant ovarian masses

		Benign (n=4)		Malignant (n=4)	
		Mean	**Standard Deviation**	**Mean**	**Standard Deviation**
SI_max (tumor)	**Unregistered**	340	97	329	22
	MI	264	184	326	17
	RC	246	158	321	17
SI_max (tumor)/ SI_max (Psoas)	**Unregistered**	1.4	0.62	2.35	0.4
	MI	1.4	0.66	2.36	0.4
	RC	1.28	0.67	2.88	0.93
Area under the curve	**Unregistered**	622	358	846	379
	MI	445	377	784	477
	RC	390	303	751	474

References: **[1]** Dilks P *et al.*, *EUR Radiol* 20, 2176 (2010). **[2]** Zöllner F *et al*, *CMIG* 33, 171 (2009). **[3]** Li X *et al*, *Magn Reson Imaging* 27(9), 1258(2009) **[4]** Myronenko A *et al.*, *TMI* 29, 1882 (2010). **[5]** Bernardin L *et al.*, *EUR Radiol* 22, 880 (2012).