# A fast and novel groupwise-non-rigid registration methodology for freezing motion in DCE-MRI

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**Target Audience:** Researchers & clinicians using motion correction with CE-MRI

**Introduction:** Dynamic contrast enhanced (DCE) MRI is used for understanding prostate tumor characteristics. The extended duration of DCE scan makes it vulnerable to patient motion artifacts. In prostate, motion is caused by patient breathing or muscle relaxation and hence demonstrates non-rigid deformation Traditional approaches for non-rigid registration (NRR) (e.g. optic flow) primarily assume intensity consistency for motion detection. Therefore, with DCE-MRI, NRR is confounded by temporal changes in contrast and can potentially introduce new artifacts or undesirable changes in signal intensity curves. Moreover, the use of pair-wise registration with one of the bolus phases as reference can get biased by the choice of reference phase **[1]**. In perfusion studies, contrast could peak at different time points at different spatial locations. Thus, one would see pronounced differences in registration results with different choice of the reference image. Further, if the reference image has anatomy exhibiting extreme motion, in pairwise NRR approaches, the other images have to undergo large deformation to register to the reference image. Thus there would be challenges both from standpoint of registration quality and from computational complexity. NRR when performed in a group-wise framework prevents the appearance of such artifacts. Previous efforts have used a group-wise NRR approach using B-splines based deformation model in **a**. non-contrast 3D+t data [1] and **b**. in DCE-MRI, but limited to post contrast data only **[2].** In this work, we demonstrate a ***dense*** group wise registration method, which allows the entire DCE data to be used and achieve good motion correction in-spite of presence of contrast & coil related shine-through related artifacts and completed in reasonable processing time (~ 5mins). We demonstrate its ability to maintain signal intensity consistency for reliable pharamco-kinetic (pK) modelling. Results are presented in prostate tumor cases along with impact on respective pK maps.


**Figure 1**. **(a).** DCE data, **(b).** N4 corrected DCE data **(c).** Bolus Normalization using Gaussian kernel ($\mathbf{I_{norm}}$) **(d).** Normalized temporal signal curves within ROI marked in (a) (black = DCE, red = DCE+N4, green= $\mathbf{I_{norm}}$).

**Methods and Materials:** ***Patient Data:*** Data for our study was acquired from three prostate tumor patients who exhibited significant motion. An appropriate IRB approved the study. ***Imaging:*** The datasets were obtained on a 1.5T / 3T GE Signa HDxt clinical scanners (GE Healthcare, Waukesha, WI). The protocol was: axial slices, 3D FSPGR with EIS TORSO coil, TE = 1.3 ms, TR = 3.4 ms, FA = 10°, TH = 6 mm, matrix size = 256 x 256, FOV = 260 x 260 $mm^2$, 55 to 80 bolus volumes (~4.5 to 6s s/ volume), in 5-6 mins. ***Image intensity normalization:*** Coil receive sensitivity correction was performed on the first bolus volume using the N4 filter in ITK **[3].** The bias map obtained was applied to all the remaining bolus volumes. Contrast related intensity variations were corrected as follows: $\mathbf{I_{norm} = I_{N4,phase} / (I_{N4,phase} \otimes Gaussian_\sigma)}$. The sigma of Gaussian filter was fixed to 5 mm since it provided the minimal coefficient of variation in normalized data. ***Registration Workflow:*** Registration was performed on intensity normalized ($\mathbf{I_{norm}}$) data and deformation field applied on the respective original bolus phases. Registration was performed as ***a. Affine registration*** with mutual information metric using functionality in ITK. ***b. Non-Rigid registration with group-wise registration:*** We implemented an optic flow based dense non-rigid registration where all phases were simultaneously registered to evolving group-wise median (which is the reference image), followed by Gaussian smoothing of updates. At each iteration, the updates for the deformation fields at each time point are smoothed using a Gaussian filter. As a post-processing step, a temporal median filter was applied on the co-registered phases to impart greater stability. The entire pipeline was implemented in ITK [4]. ***DCE data analysis:*** DCE pK model analysis was performed using automated in-house tool developed within the ITK framework. The DCE signal data was converted into concentration units using baseline images and fixed $T_1$ = 1317 ms (1.5T) and 1597 ms (3T). The DCE concentration data was fit to two-parameter Toft's model using a population based AIF [5] to obtain $K_{trans}$ and Ve estimates [6].

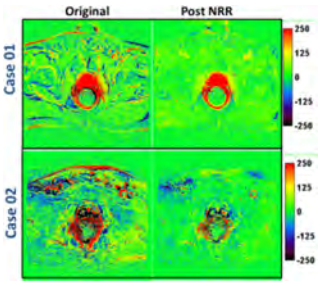


**Figure 2.** Diff. image between bolus phases before & post NRR.

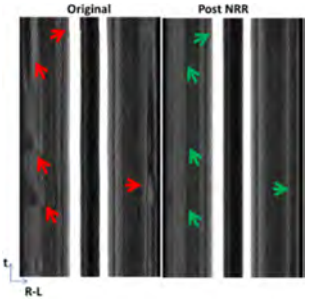


**Figure 3.** Spatio-temporal slice shows how NRR (green arrows) aligns tissue misplaced due to motion (red arrows).

**Results and Discussion:** Fig.1 shows that contrast neutralization scheme makes DCE data compatible with intensity requirements for optic flow algorithm. Overall, the group-wise registration took anywhere between 200s (55 phases) to 330s (80 phases), making it very practicable for clinical use. The difference images (Fig.2) and spatio-temporal slice (Fig.3) demonstrate significant improvement in spatially varying mis-alignment obtained by group-wise NRR algorithm. Fig.4 shows that the current approach while correcting for motion has not introduced any significant corruption either in AIF or tissue signal curve characteristics (arrival time, wash-in or wash-out). Fig.5 demonstrates the improved fidelity of pK map after NRR correction; especially in region most affected by motion (femoral arteries and tissue surrounding the prostate region).

**Conclusion:** We have introduced a fast group-wise registration scheme for correction of non-rigid motion in prostate DCE exams, within a reasonable time of 3-5 mins. We demonstrate the effectiveness in correcting motion even in presence of coil shine through artifacts, while retaining signal characteristics. Overall, motion correction allows improved confidence in interpretation of DCE and pK model data.

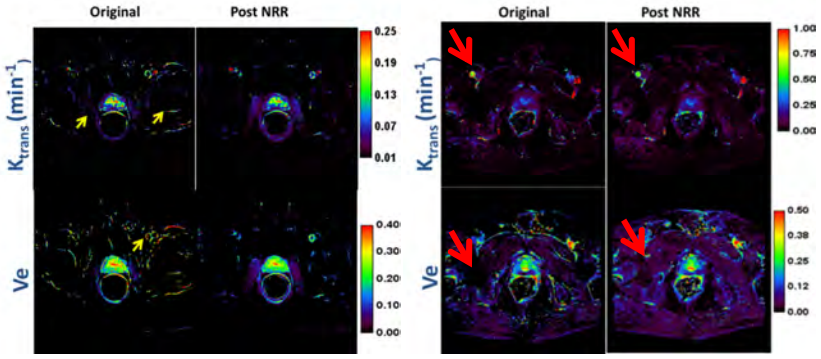


**Figure 5**. $K_{trans}$ ($min^{-1}$) & Ve maps in two cases (left = Case-01, right = Case-02) Notice that iliac vessels are well defined post NRR and regions of muscle surrounding the prostate region are well recovered and false enhancements removed (arrows). Since most of motion is in wash-out phase (see: Fig 4), improvement in Ve maps is more pronounced.

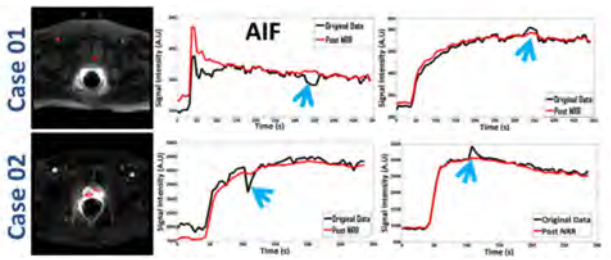


**Figure 4.** Signal intensity curves in original images (black) retain their characteristics even after NRR correction (red), while motion related fluctuations (arrows) are removed

**References:**

**[1].** C.T. Metz et.al. Med.Img.Anal, 15(2): 238–249 **[2].** Kim M., Med. Phys. 39 (1), p.353 **[3].** Tustison et.al. IEEE Trans. Med.Img, 29:1310-1320, 2010 **[4].** www.itk.org **[5].** Morgan et al., Br. J Cancer 2006; 94: 1420-1427 **[6].** Tofts PS, 1997, JMRI, 7(1), 91-101