A model-based approach for deformable registration of ungated cardiac perfusion MRI

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Introduction: The standard approach in MR for myocardial perfusion assessment is to acquire three to four short-axis slices each heartbeat using an ECG gated sequence. Recently there has been interest in continuously acquiring slices without waiting for an ECG trigger [1]. This approach can be efficient for patients with Atrial Fibrillation who have irregular heartbeats and also for imaging at higher field strengths where obtaining good gating can be difficult. Self-gating techniques [1] can be used to bin ungated images into different cardiac phases. However respiratory motion can still be present in the binned images and also cardiac phases may not be perfectly resolved. Here we propose a model-based approach for deformable registration of perfusion images . A similar idea was proposed for correcting rigid body respiratory motion in ECG gated images [2]. Here we formulate a new multi-step model-based procedure that uses multiple reference images and a deformable framework. The method corrects for cardiac as well as respiratory motion in ungated studies.

Methods: Figure 1 shows a flow chart of the proposed processing framework.

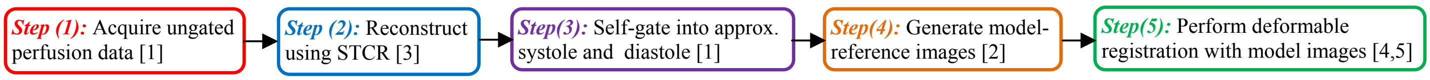

Figure 1. Flow chart of the proposed framework

Step(1): Radial perfusion data was acquired on a Siemens 3T scanner using a saturation recovery turboFLASH sequence. The acquisition parameters were TR=2.2 ms, TE=1.3 ms, acquisition matrix=288x24, FOV=280 mm^2. 5 slices were acquired continuously every ~240msec, without a gating signal. ***Step(2):*** Images were reconstructed using a spatio-temporally constrained reconstruction (STCR) method [3] with total variation constraints. ***Step(3):*** The self-gating technique described in [1] was used to bin ungated images into approximate systole and approximate diastole. Navigator signal was obtained by summing a region around the heart and local maxima in the signal were identified as diastole while local minima in the signal were identified as systole. Each bin was then processed separately in a deformable registration framework. ***Step(4):*** In order to take into account contrast variation in the images and avoid mis-registrations from using a single reference image, multiple model reference images were generated using a two-compartmental model as described in [2]. The arterial input function was computed from the mean signal intensity of a region in the right ventricular (RV) blood pool. Each pixel time curve was then fit to a two-compartment model with four parameters K^{trans}, k^{ep}, v_p and τ [2]. Model reference images were generated by replacing the original time curves with fitted ones. Contrast variation in model images is similar to that in original images except that cardiac and respiratory motion is suppressed. ***Step(5):*** For the final step in the registration each original image was registered to its corresponding model reference image using a finite element (FEM) method [4,5].

Results: Figures 2 and 3 show representative results of deformable registration using the model-based approach from one of the four patients that were processed. Cardiac and respiratory variations in the ventricular blood pools and the myocardium present in Figure 2 A1-A4 are reduced in B1-B4. Motion of the intensity profiles of vertical and horizontal lines over time seen in C1 and C2 are drastically reduced in D1 and D2. Motion suppression after registration is also corroborated by reduced fluctuations in the mean intensity time curves in Figure 3. Total processing time after reconstruction was under five minutes with parallel processing on an 8-core machine for one slice with 116 self-gated time frames.

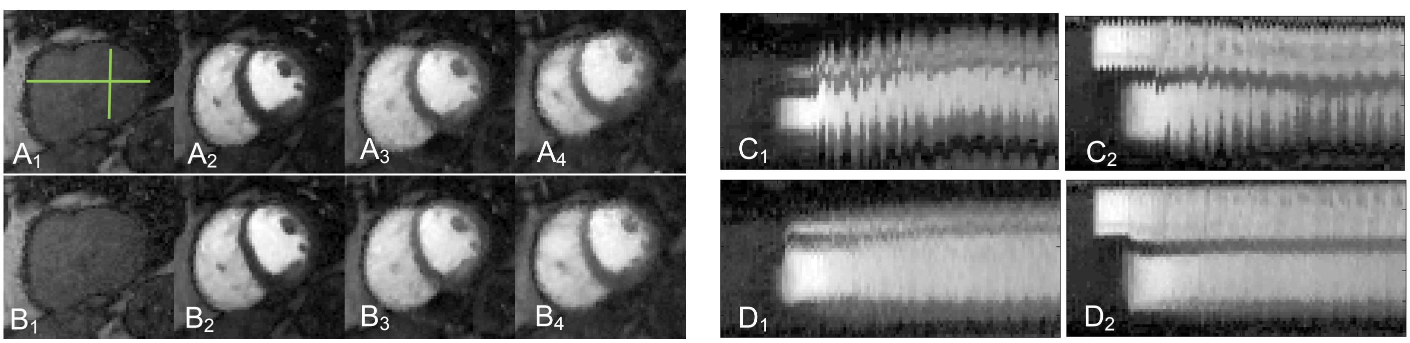

Figure 2. Results of deformable model based registration. Images in the top row represent diastolic phase after self-gating and the bottom row images are obtained after registration. Four different time frames from the dynamic sequence before and after registration are shown in A1-A4 and in B1-B4 respectively. Horizontal and vertical green lines on the pre-contrast image (A1) are used for registration evaluation. C1 and D1 show vertical line intensity profile over time before and after registration respectively. Horizontal line intensity profile over time before and after registration are shown in C2 and D2 respectively.

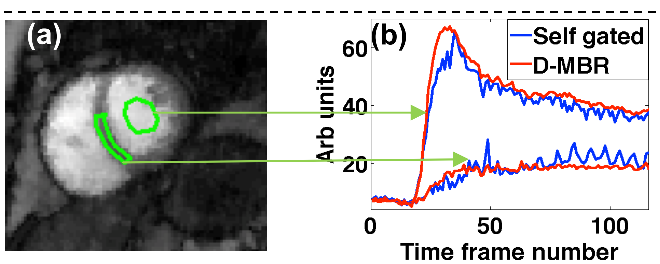

Figure 3: Comparison of time curves before and after registration. **(a)** Regions of interest in the left ventricular blood pool and myocardial septum on a time frame. **(b)** Corresponding mean intensity time curves for self-gated and deformable model based registered images (D-MBR).

Discussion and Conclusion: Here we applied deformable registration on self-gated images as opposed to directly applying on ungated images in order to share the burden of binning and registering the images, and because we seek perfusion estimates at both systole and diastole since these have been reported to differ [6] Blurring in deformable registration was alleviated by using a b-spline interpolator in the FEM based method. We note that more sophisticated diffeomorphic registration methods [7] may also be promising alternatives for blur reduction.

In summary model based deformable registration is a promising way to reduce motion in ungated perfusion images and may allow improved quantification.

References: [1] DiBella et al. #222, Proc. ISMRM 2011. [2] Adluru et al. 24:1062-70, JMRI 2006. [3] Adluru et al. 29:466-473, JMRI 2009. [4] Gee et al. In: Toga, Brain Warping. Acad. Press, pp. 183-198, 1999. [5] www.ITK.org [6] Radjenovic et al. 64:1696-1703, MRM, 2010. [7] http://www.picsl.upenn.edu/ANTS/