Automated Left Ventricular Twist Measurement with Complementary Radial Tags

Zhe Wang[1,2], Meral L. Reyhan[1,3], Abbas N. Moghaddam[1,4], J. Paul Finn[1], and Daniel B. Ennis[1,2]

[1]*Department of Radiological Sciences, University of California, Los Angeles, CA, United States,* [2]*Department of Bioengineering, University of California, Los Angeles, CA, United States,* [3]*Biomedical Physics Interdepartmental Program, University of California, Los Angeles, CA, United States,* [4]*Department of Biomedical Engineering, Amirkabir University of Technology(Tehran Polytechnic), Tehran, Iran*

INTRODUCTION – We have previously demonstrated an MRI sequence that generates a radial myocardial tagging pattern, which better fits the annular shape of the Left Ventricle (LV) in Short Axis (SA) images[1] [2]. Radial tagging may have an advantage as a non-invasive technique for estimates of LV twist, the difference in rotation between the apex and base of the heart. Current LV twist measurement methods require manual contouring of the LV epicardial and endocardial boundaries, which increases the total processing time and limits clinical adoption of the technique. The ***objective*** of this study was to utilize the unique contrast in complementary radial tagging for fully automated LV contouring and subsequent LV twist estimates.

THEORY – In radial tagging, the longitudinal magnetization (I_{total}) after the tag preparation pulse can be expressed as the summation of the tissue signal information I_{image} and the tag pattern I_{tag} [3] (Eqn.1). The combination of radial tag encoding with the idea of Complementary SPAtial Modulation of Magnetization (CSPAMM) [3] generates Complementary Radial Tags (CRT), which improves tag contrast throughout the cardiac cycle. Two sets of radial tags are acquired with the same I_{image}, but different I_{tag}. The subtraction of the two image sets generates images that only contain the tag information (Eqn.2), where r, θ and t stand for the radius, angle and time in the polar coordinate system respectively. Importantly, I_{tag} is a function of both θ (radial tags) and r (tagging pattern is less intense distant from the LV) as seen in Fig 1. The two tag patterns have a phase difference (π/N), where N is the number of tags in the imaging plane (Eqn. 3). Tag contrast is enhanced as a consequence of image subtraction (Eqn. 4). T_1 relaxation causes I_{tag} to fade. In practice, the amplitude and duration of RF pulse and gradients are designed deliberately to make pixels near the annulus of the LV (2.5cm to 3.5cm away from the tag center) have the highest contrast range. In later cardiac phases, pixels that are distant from the tag center have a tag pattern that is approximately zero (Eqn. 5), hence the two different image sets have very similar tag intensity at large radii and all tissue signal is significantly suppressed after subtraction (Eqn. 6) (Fig. 1). Variable flip angle imaging is used to maintain constant contrast throughout the cardiac cycle.

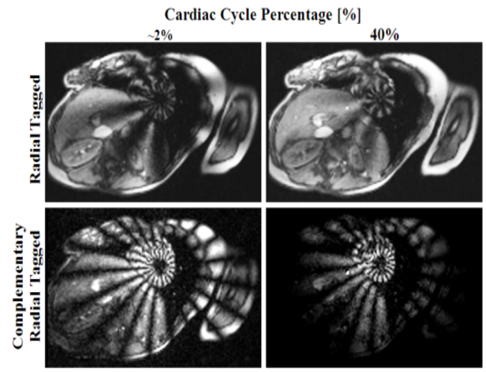

Figure 1. RT and CRT images at different cardiac phases. Note the contrast difference between myocardium and the chest wall.

$$I_{total} = I_{tag} + I_{image} \quad \text{Eqn. 1}$$

$$I_{total1} - I_{total2} = I_{tag1}(r,\theta,t) - I_{tag2}(r,\theta,t) \quad \text{Eqn. 2}$$

$$I_{tag2}(r,\theta,t) = I_{tag1}\left(r, \theta + \frac{\pi}{N}, t\right) \approx -I_{tag1}(r,\theta,t) \quad \text{Eqn. 3}$$

$$I_{total1} - I_{total2} \approx 2\, I_{tag1}(r,\theta,t) \quad \text{Eqn. 4}$$

$$\lim_{r,t\to\infty} I_{tag1}(r,\theta,t) = 0 \quad \text{Eqn. 5}$$

$$\lim_{r,t\to\infty} \left(I_{total1}(r,\theta,t) - I_{total2}(r,\theta,t)\right) = 0 \quad \text{Eqn. 6}$$

METHODS – A GRE sequence is modified to generate radial tags on the base of LV SA planes in 5 healthy human subjects with the following parameters: 350x350 mm FOV, 6mm slice thickness, TE/TR=4.52/5.25ms, 20° imaging flip angle, 160x160 acquisition matrix, 396 Hz/pixel bandwidth and with GRAPPA2 on a Siemens Trio 3.0T scanner. The acquisition duration was adjusted to acquire images to mid-diastole (~800ms). An automated region growth method was applied to segment the LV myocardium (Fig. 2). Briefly, CRT LV SA images are transformed into the polar coordinate system and the image area with the highest mean pixel value was chosen as a seed point. A region growth algorithm that combined pixel intensity with geometric position was used to determine the LV boundaries. Epicardial and endocardial boundaries of the tagged area were calculated by interpolation of the adjacent untagged boundary. The automated segmentation results were then used to calculate the LV twist by Fourier Analysis of STimulated echoes (FAST) method [4]. Post-processing work was performed in MATLAB (The Mathworks, Natick, MA). Additionally, manual contouring of the LV was performed for all subjects at an end-systolic frame. LV twist derived from manual contouring was compared against values derived from the fully automated method using a paired t-test of peak LV twist, linear regression with Pearson correlation coefficient on temporally decorrelated (decimated) data for all subjects. Mean Peak LV twist is reported as the mean ± standard deviation.

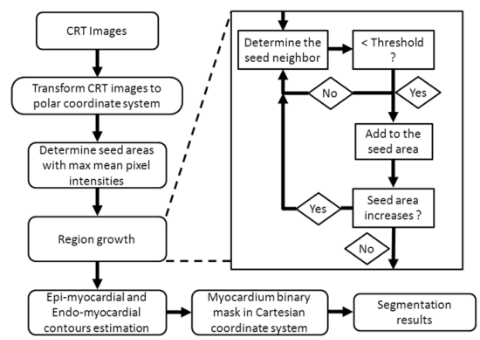

Figure 2. Image segmentation flow chart

RESULTS – Mean peak LV twist from the automatic method was 16.32° ± 2.82° and 16.32° ± 2.83° from the manual method. Fig. 3 shows mean the LV twist measurements based on manually segmentation (blue) and automated segmentation (red). Linear regression of the decorrelated twist data shows a relationship of AUTOMATIC=0.95*MANUAL+0.5, r=0.99. No significant difference was found between in peak LV twist derived by the two methods, p=0.2.

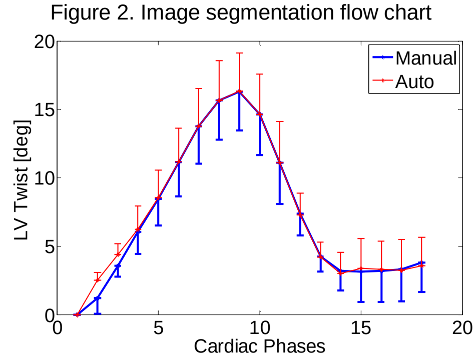

Figure 3. LV twist results from 5 healthy subjects. Note the coherence of the twist results between manual segmentation and automated segmentation.

DISSCUSSION AND CONCLUSION – In this study we demonstrate a unique contrast property of CRT images. The radial tagging sequence parameters were deliberately designed to maintain high constant tag contrast in the LV myocardium. Based on the unique contrast properties of CRT, the automated segmentation method determined the contours of the epicardial and endocardial LV wall favorably compared to manual contouring. This study has demonstrated that a fully automated and accurate LV twist measurement is feasible using CRT and FAST.

REFERENCE – 1. A. N. Moghaddam, *et al.* JCMR 2008.10 (Suppl 1):A199 **2.** Z. Wang, *et al* ISMRM 2010 1327. **3**. S. E. Fischer, *et al.* MRM 30:191-200. **4.** M. Reyhan *et al.*JMRI DOI: 10.1002**.**