The effect of through plane motion on left ventricular regional rotation: a study using slice-following harmonic phase (SF-HARP) imaging.

D. Brotman[1], Z. Zhang[2], and S. Sampath[2]
[1]Fairfield University, Fairfield, CT, United States, [2]Yale University

Introduction: There is a renewed interest in regional rotation quantification, as new studies reveal its importance in active contraction and relaxation, and in the creation of intraventricular pressure gradients to aid normal filling[1]. Current methods to evaluate regional rotation include magnetic resonance (MR) tagging, and echocardiography speckle tracking. These methods typically acquire data on a set of prescribed short-axis slices, and neglect effects due to through-plane myocardial motion. This is critical to the accuracy of measurements of rotation, as it is well known that a base-apex gradient in LV rotation exists. The goal of this study is to evaluate the effects of through-plane motion on measurements of regional rotation. We have developed imaging and post-processing methods that combine principles of slice-following[2] and harmonic phase[3] imaging (SF-HARP)[4] to account for through-plane motion effects in regional rotation measurements from tagged images. Results are compared to equivalent datasets that do not employ slice-following. **Methods:** Using the slice following technique, thin short axis slices were tagged, while a large slab that always encompasses the moving tagged slice was imaged (See Fig. 1). Two series of images A and B with complimentarily signed (1-1 SPAMM) tagging modulations were acquired at each short axis slice location within a single breath-hold. The complex CSPAMM subtraction operation $A - B$ was next applied to guarantee that the residual signal arises from the tagged slice rather than from tissues that might have entered the image plane as the result of through-plane motion. Using HARP, one of the harmonic peaks obtained from the Fourier transform of these images was isolated to compute a series of (complex-valued) harmonic images. The 2-D harmonic phase values, obtained from two series of orthogonally tagged harmonic images were then tracked to yield true 2-D pathlines (trajectories) of all material points on the image plane. Consider a material point located at a three-dimensional position $\mathbf{r}(t_0) = r_1(t_0)\mathbf{e}_1 + r_2(t_0)\mathbf{e}_2 + r_3(t_0)\mathbf{e}_3$ on a tag plane corresponding to an SA slice. At any later time t_n, the point $\mathbf{r}(t_n)$ lies on the deformed SA tag plane, and the HARP tracked point $\mathbf{x}^S = (r_1(t_n)\ r_2(t_n))$ is the orthogonal projection of $\mathbf{r}(t_n)$ onto the central cross-sectional plane of the SA imaged slab (see Fig. 1). Rotation of all material points on the image plane at any given time point was then calculated as the angle of rotation about the center of rotation (defined as the center of mass of all material points in the left ventricle at that time instant) from a given reference time point (set as the first time frame)[5]. A mesh defining the endo, mid and epicardial layers was superimposed on the myocardium, and the average rotation of points lying on these three layers was computed for each slice. Rotation measurements were calculated in 6 volunteers for six slices using the slice following scheme, and using conventional tagging sequences. Data was acquired on a 1.5T Siemens Sonata Scanner with the following imaging parameters: 8mm slice thickness, 192X192 matrix, 320mm FOV, 7mm tag separation. **Results:** Fig. 2. illustrates the mean rotation curves obtained from six volunteers for six slices from apex and base using SF-HARP and conventional tagging. We observe a difference in the curves between measurements, especially as it progresses towards the basal region. We find that without slice following, a flip in the rotation curves occur with a prominent negative peak slightly shifted from the positive peak observed in the apical slices. Using slice following this feature is absent. While the rotation, as expected, gradually shifts from a counter-clockwise to a clockwise rotation, the general shape of the curves remain similar across slices. The curves all appear to have a positive peak that occurs at the same time instant in the cardiac cycle for all slices. The averaged peak rotation (mean±SD for six volunteers) for the apical, mid and basal (negative peak) slices for each of the three layers are shown in Table 1. Fig. 3. illustrates the mean rotation-circumferential shortening loops from six volunteers obtained for the same six slices. We find that loops resemble a typical non-linear magnetic hysterisis loop. The spread in rotation values from base to apex is larger when using conventional tagging as opposed to SF-HARP. A characteristic feature observed is that during end systole (more prominent in apical and mid-ventricular slices) and early diastole, large changes in rotation (late twist and early untwist) occur with much smaller corresponding change in circumferential shortening. These loops provide insight into the role that rotation may play in early diastolic filling. **Conclusion:** SF-HARP is an excellent quantitative tool to accurately measure regional cardiac rotation. Overall, by taking into account through-plane motion, SF-HARP provides a more reliable analysis of the base-apex gradient in rotation that exists in the left ventricle.

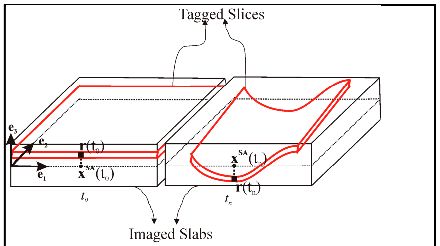

Fig. 1. Combining slice-following scheme with HARP 2D tracking results in the orthogonal projection of the material point on the central cross-sectional plane of the imaged slab.

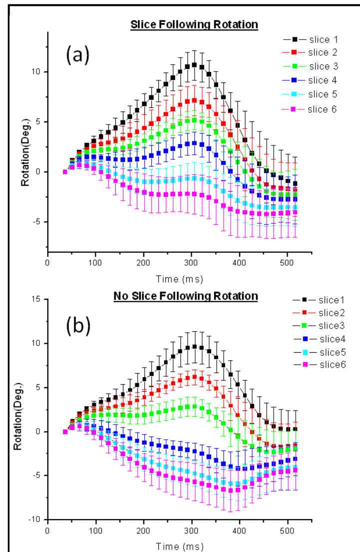

Fig. 2. Mid ventricular rotation curves in six slices with (a) slice following and (b) conventional tagging. Curves represent mean curves from six volunteers, and error bars denote standard deviation within population. All curves were normalized to a heart rate of 60bpm. Slice 1 = apical and Slice 6 = basal.

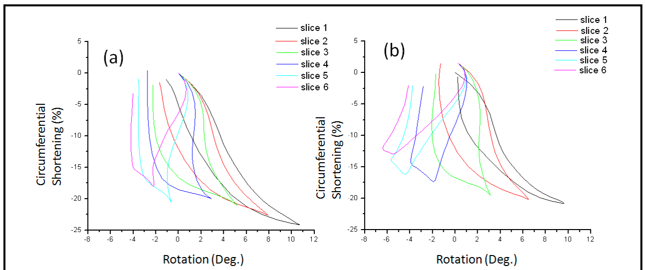

Fig. 3. Rotation-Cirmcumferential shortening loops for six slices with (a) slice following and (b) conventional tagging. Mean rotation and circumferential shortening values obtained from all six volunteers were used. Slice1=apical, Slice 6=basal.

		NSF Peak Rotation			SF Peak Rotation	
	Apical	Mid	Basal	Apical	Mid	Basal
Endo	11.22 ± 1.68	3.26 ± 1.27	-7.07 ± 2.70	11.74 ± 1.25	3.41 ±1.21	-4.21 ± 2.64
Mid	9.25 ± 1.22	2.82 ±1.09	-6.74 ± 2.52	10.68 ± 1.07	2.84 ± 1.08	-4.33 ± 2.74
Epi	8.41 ± 1.40	2.45 ± .90	-6.29 ± 2.30	9.44 ± 1.01	2.38 ± 1.04	-4.13 ± 2.31

Table 1: Peak regional rotation values (in degrees) expressed as mean±SD from six volunteers.

References: 1.Notomi Y et. al., AJP, 2007; 2.Stuber M et. al., MAGMA, 1999; 3.Osman NF et. al., MRM, 1999; 4.SampathS et. al., MRM, 2007; 5.Iris K et.al., MRM, 2008