Fourier Analysis of STimulated echoes (FAST) for quantitative analysis of left ventricular torsion

M. Reyhan[1], D. B. Ennis[1], and Y. Natsuaki[2]

[1]Radiological Sciences, University of California, Los Angeles, CA, United States, [2]Siemens Medical Solutions USA, Inc., Los Angeles, CA, United States

Introduction: Alterations in left ventricular (LV) torsion are important in many pathophysiologic scenarios including myocardial infarction [1], dilated cardiomyopathy [2], mitral regurgitation [3], diastolic dysfunction [4] and aging [5]. LV torsion is a measure of the rotation of the apex relative to the base of the heart. Herein, we exploit the fact that object rotation can be measured directly in Fourier space. When SPAMM tagging is employed, stimulated echoes form dominant features in magnitude Fourier space. With appropriate image processing, quantitation of the rotation of the stimulated echo about the center of Fourier space corresponds to a rotation of the LV SPAMM tags. We have developed and validated a quantitative method termed Fourier Analysis of STimulated echoes (FAST) that requires limited user interaction for the quantitative analysis of LV torsion. The present study validates FAST and evaluates the intra- and interobserver variability in the assessment of torsion in six animals. Application of FAST is also demonstrated in six healthy volunteers.

Methods: Short-axis tagged images were acquired at 1.5T in six beagle dogs using a 3D fast gradient echo pulse sequence with the following parameters: 180x180x128-160mm field of view (FOV), 4-5mm slice thickness, 384x128x32 acquisition matrix, 12° imaging flip angle, 325Hz/pixel receiver bandwidth, TE/TR = 3.4/8.0 ms, five pixel tag spacing, 1 view-per-segment (VPS), and 58-60 cardiac phases. Tissue tags in two short axis slices were tracked semi-automatically using the FindTags[6] software to define "gold standard" results. For patient studies, a 1.5T cardiac MRI pulse sequence was modified to support 1-1 SPAMM line tags and used to acquire short-axis images in healthy volunteers at the base and apex with the following parameters: 300x300mm FOV, 5mm slice thickness, 192x96 acquisition matrix, 15° imaging flip angle, 250 Hz/pixel receiver bandwidth, TE/ TR = 5.2-5.4/9.2ms, 8mm tag spacing, 4 VPS, and 18-23 cardiac phases. _Tag Tracking_ – "Gold standard" estimates of LV rotation at basal and apical slice levels for the first forty frames (duration of trackable tag persistence) were obtained from the rotation of horizontal and vertical tag intersections about the LV centroid determined using FindTags. _Fourier Analysis of STimulated echoes (FAST)_ – The only user interaction needed for FAST processing is contouring of the LV epicardium and endocardium in an end-systolic frame. The epicardial contour was used to fit an ellipse to the LV epicardial boundary. The axes of the ellipse were used to define the full width half maximums of a 2D Gaussian mask. The endocardial contour was used for centering of the Gaussian mask. Masking was necessary to define the region of interest (i.e. LV myocardium), to eliminate tissues that did not rotate and to reduce ringing subsequent to 2D Fourier transformation. After the image was Fourier transformed, it was cropped depending on tag orientation to reduce image size and processing time and the center peak in Fourier image was nulled with a circular mask. The Fourier magnitude data for each frame was 2D cross-correlated with a rotated version (-1° to 1° with step-size of 0.2°/0.1° for apical/basal slices) of the frame immediately after it within the same slice. The maximum of the cross-correlation from all tested rotations defined the angle of rotation between those frames. _Statistical Analysis_ – The left ventricular epicardium and endocardium at end systole were each contoured twice by two investigators. Each trial consisted of contouring basal and apical slices for each of the six dogs. For each trial, the mean and standard deviation of peak systolic torsion were calculated and compared. The intra-observer coefficient of variation, CV_{INTRA}, was calculated for each investigator as the standard deviation of the peak systolic torsion from both trials times 100 divided by its mean. The inter-observer coefficient of variation, CV_{INTER}, was calculated for each trial as the standard deviation of the mean difference in peak systolic torsion times 100 divided by its mean. Linear regression analysis of the complete set of torsion values from the two investigators against the FindTags results was performed by calculation of Pearson's correlation coefficient. Peak systolic torsion for all trial combinations was compared using the Wilcoxon signed-rank test for paired non-parametric samples. The student t-test was used to compare the torsion values from each trial with the FindTags torsion values of each cardiac phase. P-values less than 0.05 were considered significant.

Results: _Validation_ - The mean peak systolic torsion for Investigator 1 was 10.0°±1.9° and 9.6°±2.3° (Trial #1 and #2 respectively). The mean peak systolic torsion for Investigator 2 was 10.0°±2.6° and 9.8°±2.4° (Trial #1 and #2 respectively). CV_{INTRA} for peak systolic torsion for Investigator 1 and 2 were 4.2% and 2.3% respectively. CV_{INTER} for peak systolic torsion for Trial #1 and #2 were 8.4% and 5.4% respectively. The mean difference in peak systolic torsion for Trial #1 and Trial #2 were 0.0°±0.8°and -0.2°±0.5° respectively. The Wilcoxon signed-rank test did not reveal any significant differences between the peak systolic torsion for any combination of trials. Linear regression analysis of the complete set of FAST torsion values and the FindTags results from the two investigators yielded a Pearson's correlation coefficient of R=0.99 and the equation y=1.02x+0.004 – indicating excellent linearity with negligible bias. No significant differences were detected by the student t-test for FAST torsion values from each trial compared to the FindTags torsion values in each cardiac phase. Figure 1, compares the FAST torsion and FindTags results (mean±SD) for six canine studies. Figure 2, shows a Bland-Altman analysis for the first two-thirds of the cardiac cycle (before tag rotation becomes undetectable by either method), which compares all of the FAST torsion data collected by both investigators and the FindTags data. There is excellent agreement between FAST and FindTags for calculating LV torsion with a bias (FAST-FindTags) of -0.02° and 95% confidence intervals of (-3.3°, 3.3°). The average user interaction time for the FAST method was 2.6 minutes; this time includes study selection and contouring of the epicardium and endocardium for the basal and apical slices for both horizontal and vertical tags. The average computational time for the FAST algorithm was a total of 27 minutes for the horizontal and vertical tags at the basal and apical slice level (4 separate sets of images containing 40 frames each with an image size of 256x256). _Healthy Subjects_ - The mean peak LV torsion from the healthy volunteers using FAST was 10.5± 2.1° with an average user interaction time of 2.7 minutes. Peak systolic torsion and early diastolic untwisting are clearly visible in all cases (Figure 3). Figure 3 shows incomplete untwisting because the tags have faded too much for quantitative analysis.
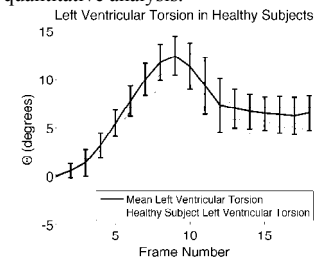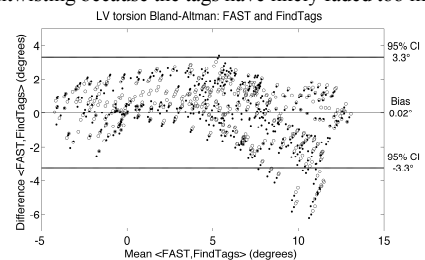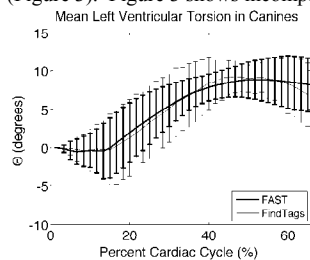
Figure 1   Figure 2   Figure 3

Discussion: The FAST algorithm for quantifying LV torsion is a fast, reliable, and reproducible method. Furthermore, the quantitative results from FAST LV torsion analysis compare very favorably (no statistical differences, negligible bias) with the FindTags ("gold standard") results and the user analysis times were short (<3 minutes per study). The mean LV peak systolic torsion for each investigator and each trial were not significantly different indicating excellent user agreement and highly reproducible analysis. The mean peak systolic torsion values from the healthy human subjects were in good agreement with previously reported value of 12.7±1.7°[7]. Compared to FindTags, for which the user interaction time requires many tens of minutes, the FAST processing significantly reduces the analysis time and produces comparable results. Future improvements in the tagging sequence[8] may improve the ability to quantify LV untwisting during diastole, thereby further extending the utility of the FAST method.

Conclusion: The FAST method for quantifying LV torsion produces quantitative results that are equivalent to "gold standard" in a fraction of the user interaction time.

References: 1. Bansal, M. J Am Soc Echocardiogr, 2008. **21**(8). 2. Meluzin, J. J Am Soc Echocardiogr, 2009. **22**(5). 3. Borg, A.N. Heart, 2008. **94**(5). 4. Burns, A.T. JACC Cardiovasc Imaging, 2009. **2**(6). 5. van Dalen, B.M. Am J Physiol Heart Circ Physiol, 2008. **295**(4). 6. Guttman, M.A. IEEE Comp. Graph. Appl., 1997. **17**(1) 7. Henson, R.E. Am J Physiol Heart Circ Physiol, 2000. **278**(4). 8. Ennis, D.B. Magn Reson Med, 2003. **50**(3).