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

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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-mm slice thickness, 384x128x32 acquisition matrix, 12° imaging flip angle, 325Hz/pixel receiver bandwidth, TE/TR = 3.4/8.0 ms, 5 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 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 maximum of a 2D Gaussian mask. The endocardial contour was used for centering of the Gaussian mask. Masking was necessary to define a 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 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 mean difference in peak systolic torsion 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 10.9±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 #2 were 0°±0.8° and 0°±0.8° respectively. CV.INTER for peak systolic torsion for Investigator 1 and 2 were 1.4% and 1.4% respectively. The mean difference in 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.

Discussion: The FAST method 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.

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