Characterization of transmural strain gradients in canine myocardium

D. B. Ennis[1,2], J. A. Derbyshire[2], E. R. McVeigh[1,2]

[1]Biomedical Engineering, Johns Hopkins University, Baltimore, MD, United States, [2]National, Heart, Lung, and Blood Institute, National Institutes of Health, Bethesda, MD, United States

Introduction: Quantitative analysis of cardiac function using magnetic resonance tagging is typically limited in spatial and temporal resolution because of breath hold constraints. Attempts to increase the number of transmural tags by increasing the spatial resolution are generally hindered by concomitant and unacceptable decreases in SNR or unacceptable increases in breath hold duration in order to maintain SNR. The result is that nominal tag spacing resolutions and the associated breath hold constraints preclude analysis of transmural gradients in wall thickening. The use of high resolution magnetic resonance tagging techniques allow for characterization of transmural gradients and transmural events.

Methods: A three dimensional (3D) magnetic resonance tagging technique for acquiring high spatial and temporal resolution images of cardiac function was previously developed [1]. Briefly, a fast gradient echo, three dimensional pulse sequence was modified to support cardiac phase acquisition. This pulse sequence implements a combined respiratory and cardiac gated data acquisition scheme. The previous implementation was further improved through the addition of a BRISK-like spatial frequency dependent temporal sampling scheme in order to reduce acquisition time[2]. Two separate stripe tag experiments were performed to characterize each direction of tag plane deformation.

Right atrial pacing was synchronized to the respiratory cycle in order to improve the overall efficiency of the experiment. Timing of the experiment was precisely controlled using a digital stimulator that triggered the scanner and, with a controlled delay, paced the right atrium. This provided the ability play tagging RF pulses in late diastole, prior to systolic contraction, so that the entire systolic interval was tagged, thus avoiding delays associated with QRS detection. One third of all heartbeats were used for imaging. Imaging was performed on a General Electric CV/i 1.5T magnetic resonance scanner using a four-element phased array knee coil. Raw data was spooled to a local disk for off-line sorting and reconstruction. Image reconstruction used linear temporal interpolation for k-lines that were not acquired due to BRISK-like undersampling. The field of view was 180mm x 180mm with 5mm slice thickness. The three dimensional encoding resolution was 384 x 128 x 32. The tag spacing was 5 pixels resulting in a tag separation of 2.3mm. Acquisition bandwidth was ±62.5kHz and a TR/TE of 8ms/3.3ms. The central 32x8 k_Y-k_Z lines were acquired with 1 view per segment. Higher k_Y and k_Z phase encodes lines were acquired with 2, 4, or 8 views per segment. A single cardiac phase was reconstructed for each TR.

The images were segmented to isolate left ventricular myocardium and the tags were tracked using the FastTag software [3]. Short axis tag plane fitting was accomplished using high resolution B-spline tensor product fitting. Errors between measured and modeled tag lines were minimized when using a 12x12 array of short axis knots [4]. The analysis excluded the most epicardial and endocardial 10% of the wall due to the sparseness of edge data.

Results: 5 beagles (canines) were imaged with right atrial pacing at 120 beats per minute. Total experiment time for each short axis time resolved 3D volume was 32 minutes. The acquisition efficiency, defined as the number of heartbeats used for imaging divided by the total number of heartbeats during the experiment, was 33%. Continuous monitoring of left ventricular pressure confirmed hemodynamic stability over this duration. Total acquisition time was reduced by 3.2x through implementation of the BRISK-like acquisition. At a pacing rate of 120 beats per minute with a 2% trigger window a total of 61 cardiac phases were reconstructed. The image SNR was ~25 for all acquisitions and the CNR ranged from ~20 at end diastole to ~10 at end systole.

The average wall thickness was ~10mm, thus a minimum of 3 analyzable tags was visible across the transmural extent of the wall. Transmural gradients in circumferential and radial strain are shown in Table 1. Peak systolic strains are shown for four transmural segments at the mid-ventricular level that incorporate the middle 80% of the myocardial wall. Eight circumferential segments in five canines were used for analysis.

	Epicardium	Sub-Epicardium	Sub-Endocardium	Endocardium
E_{cc}	-0.09±0.02	−0.11±0.02	-0.14±0.02	-0.18±0.03
E_{rr}	0.21±0.05	0.29±0.05	0.31±0.06	0.25±0.04

Table 1. Peak systolic strains at four transmural locations. E_{CC} (circumferential strain), E_{RR} (radial strain). Results are expressed as mean±standard deviation.

Conclusions: The improvements in the high resolution 3D tagging sequence provided images of sufficient quality for accurate quantitative analysis. The tagging resolution was increased approximately two fold in each spatial dimension when compared to nominal tagging resolutions. The high spatial and temporal resolution MR tagging technique provides characterization of transmural strain gradients.

References:

[1] Ennis DB, Thompson RB, Derbyshire JA, McVeigh ER, *Proceedings 10th Annual ISMRM*, 2002
[2] Doyle M, Walsh EG, Blackwell GG, Pohost GM, 1995, MRM 33(2):p. 163-170
[3] LTS Denney, Gerber BL, and Yan , MRM, 2003. 49(4): p. 743-754
[4] Ozturk, C. and E.R. McVeigh, Phys Med Biol, 2000. 45(6): p. 1683-702.