

High-Resolution Transmural 3D Myocardial Strains using 3D Tissue Tagging with Optical Flow Tracking

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INTRODUCTION: Tissue tagged MRI has been applied to quantify regional myocardial function with limited in-plane and through-plane spatial resolution. This results in an inability to accurately quantify transmural deformation in the left ventricle. This study uses a novel high-resolution MR tagging and analysis tool to measure left ventricular (LV) function of a normal heart at high spatial resolution.

METHODS: To measure principal strain a pulse sequence was developed that applied the SPAMM tag prep pulse in three distinct planes in one acquisition. Two orthogonal sets of tags were oriented through-plane, while the third tag plane was applied at a defined angle relative to the through-plane tags. The normal of the in-plane tag orientation relative to the through-plane tags was optimized in a previous study and was set at 35, 66 and 66 degrees. Displacement of each pixel was tracked with sub-pixel resolution using an optimized 3-D Optical Flow Method (3-D OFM). Lagrangian strain tensor was derived from flow fields, and maximum and minimum principal strains (ϵ_1 and ϵ_3) from end-diastole to end-systole were computed. A normal sheep was scanned using a 3D fast gradient echo (FGRE) sequence with the optimized 3-D tag preparatory pulse on a 3 T Siemens Trio scanner (Siemens Medical Solutions, Malvern, PA, USA). Breath hold and ECG gating were performed to minimize respiratory and cardiac motion. Anterior and posterior phased array flex coils were placed on the animal and imaging was performed with the following parameters: TR/TE/FA=4ms/3.08ms/15°, Averages=4, views per segment= 6, slice thickness= 1 mm, raw data matrix 512x256, interpolated to 512x512, field of view 220mm x 220mm, resolution 0.4mm x 0.4mm x 1mm, 3D tag spacing 4mm, 20 slices.

RESULTS: Color-coded systolic strain maps reveal complex and detailed myocardial transmural deformation. Radial wall thickening (ϵ_1) was smallest at the septum and greatest in the free wall (anterior, posterior and lateral regions, Figure 1A), with orientation of maximum thickening aligned with in-plane radial direction (32 +/- 7.8°, Figure 1C). Representing maximum shortening, ϵ_3 was more homogeneous in the circumferential direction, with a decrease transmurally from subepicardium to subendocardium (increase in the shortening, Figure 1B). Direction of maximum shortening at mid-ventricular is aligned with the circumferential direction, and with components in longitudinal direction in the septal area (Figure 1D). Figure 2 demonstrates the time-course of magnitude (Figure 2A, 2B) and orientations relative to wall based coordinates (Figure 2C-E) of systolic principal strains. Both maximum transmural thickening and circumferential shortening demonstrate a linear trend throughout systole, with higher slope at the anterior region. The direction of principal strains is more consistent compared to the magnitude, with ϵ_1 deviating from the radial direction by 15° to 40° (Figure 2C) and ϵ_3 by between 60° to 80° from longitudinal (Figure 2D) and 20° to 40° (Figure 2E) from circumferential direction, respectively.

CONCLUSION This study has demonstrated an innovative method to estimate deformation with sufficient resolution to accurately measure transmural variation in 3D strains. Data processing required minimal user interface and the results are in agreement with those reported by other research groups [1], but required significantly shorter acquisition and analysis time.

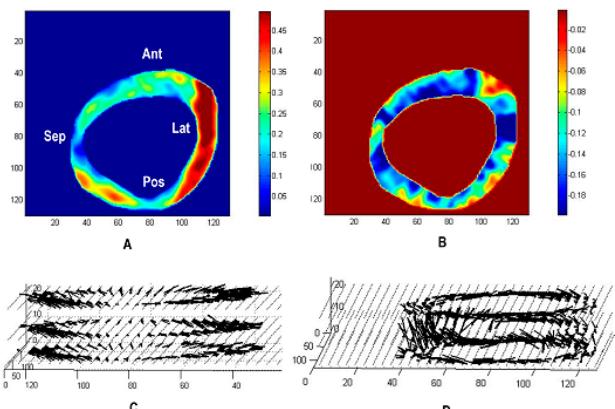


Figure 1. LV end-systolic maximum (ϵ_1 , A) and minimum (ϵ_3 , B) principal strain at one selective mid-ventricular level. Strain is color-coded by principal strain magnitude (positive for ϵ_1 and negative for ϵ_3). Direction of eigen vectors at three selective mid-ventricular levels are depicted by C (ϵ_1) and D (ϵ_3).

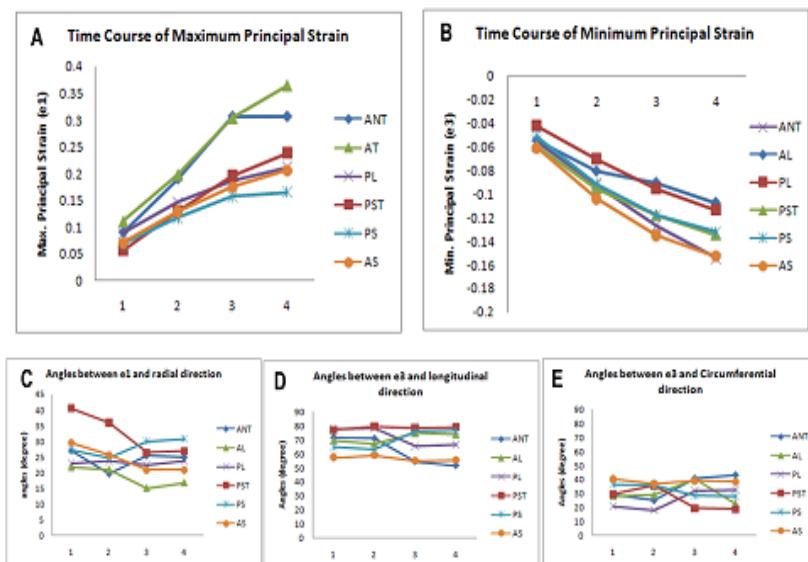


Figure 2. Time course of principal strain (ϵ_1 and ϵ_3) magnitude and orientation relative to wall based coordinate (r, c, l) on one selective mid-ventricular slice. The abscissa represents systole divided by 4.

1. Moore, C.C., et al., *Three-dimensional systolic strain patterns in the normal human left ventricle: characterization with tagged MR imaging*. Radiology, 2000. **214**(2): p. 453-66.