In-Vivo 3-D Left Ventricular Strain Estimation from a 3-D Tag Sequence Using Optical flow Method

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Abstract - Magnetic resonance tissue tagging has been proven a valuable tool in the quantification of myocardial motion. This study proposes a method to directly estimate motion and subsequently compute regional strain maps from left ventricle (LV) in a human volunteer , using a 3D MR tissue-tagging sequence combined with a 3D optical flow method (OFM).

Keywords: tagged MRI, optical flow method (OFM), cardiac mechanics

INTRODUCTION

- This study presents a method of obtaining and analyzing 3D tagged images to generate 3D strain maps in the heart wall directly with less post-processing time and higher spatial resolution in human subjects.
- Quantification of cardiac mechanics: Motion reconstruction from tagged MR images
- Available 3D methods:
  - Consists of pre-defined deformable models and sparse material points tracking
  - Use multiple orthogonal tag images acquisition sets
  - Long acquisition time, less than optimal spatial resolution

METHODOLOGY

- **Pulse Sequence:** composed of two orthogonal sets of tags that were oriented through-plane, while the normal of the third tag plane was applied at an optimized orientation: 35, 66 and 66 degrees relative to the through-plane tags
- **Pixel Motion Tracking:** Displacement of each pixel was tracked with sub-pixel resolution using an optimized 3D Optical Flow Method (3D OFM)
- **Regional Contractility:**
  - Lagrangian strain tensor
  - Maximum and minimum principal strains (ε_1 and ε_3)
- **Local Cardiac Function Quantification**
- **Imaging Parameters:** TR/TE/FA = 3.8ms/2.65ms/150, Averages = 2, views per segment= 6, slice thickness = 4 mm, raw data matrix 256 x 96, interpolated to 256 x 192, rectangular field of view 260mm x 195mm, 16 slices.

RESULTS and DISCUSSION

- Vector plots of in plane flow fields reveal complex and detailed myocardial displacement patterns (Figure 1).
- Color-coded vector plots of integrated systolic flow fields (Figure 2, A to D) indicate an increase in displacement from apex to base and from epicardium to endocardium.
- Significantly smaller longitudinal displacement was observed in the apical region (Figure 2, E and F), while the longitudinal strain was greatest between the mid-ventricular and apical sections.
- At each location radial wall thickening (ε_1) was smallest at the septum and greatest in the free wall (anterior, posterior and lateral regions). Representing maximum shortening, ε_3 was consistently aligned with the circumferential-longitudinal direction, and was greatest in the mid-ventricular section and significantly smaller in the basal region (Figure 3, Table 1).

CONCLUSIONS

This study has demonstrated an innovative method to estimate displacement and deformation in the LV wall of a human heart by combining a 3D tag sequence, 3D OFM and finite element analysis. Regional strains generated from this method are in agreement with results from other research groups [1, 2] but required significantly shorter acquisition and analysis time. In addition, we achieved greater in-plane and through-plane spatial resolution. The method presented in this paper has the potential to generate high-resolution LV regional 3D strain, which could lead to improved characterization of the mechanics in normal and diseased hearts.

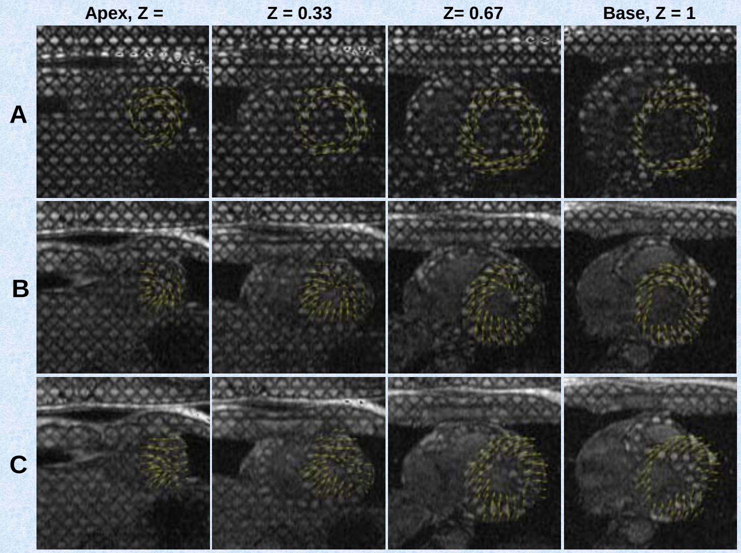

FIGURE 1: Viewed from apex, in-plane flow field in the short-axis view of a healthy volunteer during three cardiac frames: early-systole (A), mid-systole (B), and end-systole (C) at 4 locations from apical (z = 0.07), middle (z = 0.34, z = 0.67) to basal left ventricle (z = 1). The longitudinal position of each slice was normalized by the distance between the most apical and basal slices. In the early-systole stage, LV demonstrates pure twisting and counterclockwise rotation at all locations. During mid-systole, apex and its neighboring regions show contraction in septal and inferior areas, with mainly counter clock-wise rotation at lateral wall. At base and its neighboring regions, clockwise rotation was shown in septal and anterior areas, with contractions at lateral and inferior wall. In the end-systole, all locations show the onset of expansion in lateral walls, with continuous contraction demonstrated on septal-inferior wall. Clockwise rotation was also observed in middle and basal anterior wall.

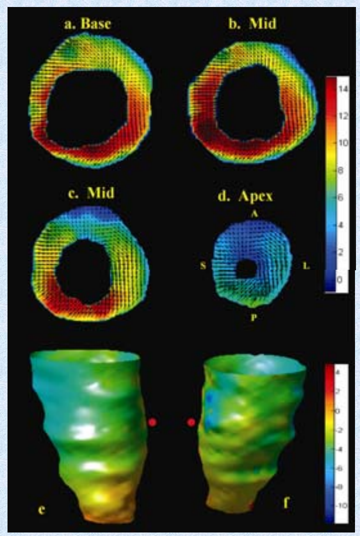

FIGURE 2. Integrated systolic LV displacement in the heart of a normal human volunteer. Four representative short axis planes, base (a), mid-ventricle (b-c), apex (d), were color-coded for 3-D displacement magnitude (mm), and overlaid on the projection of 3-D displacement vectors. Anterior (e) and posterior (f) views of the LV mid-wall surface are shown with color-coded through-plane motion.

TABLE 1. Principal strains (ε_1 and ε_3) during systole evaluated from a healthy volunteer, measured as mean +/- SD

		ε1		ε3	
Apex	Septal	0.1	0.1	- 0.2	0.1
	Posterior	0.2	0.1	- 0.2	0.1
	Lateral	0.2	0.1	- 0.2	0.1
	Anterior	0.2	0.1	- 0.2	0.1
Mid	Septal	0.1	0.1	- 0.3	0.1
	Posterior	0.3	0.2	- 0.3	0.1
	Lateral	0.3	0.1	- 0.3	0.1
	Anterior	0.2	0.1	- 0.3	0.1
Base	Septal	0.1	0.0	- 0.1	0.1
	Posterior	0.3	0.2	- 0.1	0.0
	Lateral	0.3	0.1	- 0.1	0.1
	Anterior	0.2	0.1	- 0.2	0.1

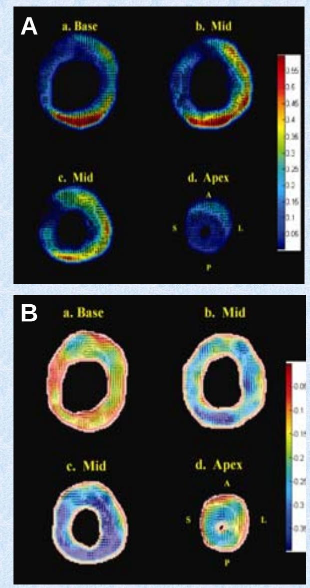

FIGURE 3. LV end-systolic deformation of a normal volunteer. The LV is segmented as in Figure 2. In plots A and B, a-d show maximum principal strain (ε_1) and minimum principal strain (ε_3) at 4 representative short axis slices. Color represents the through-plane component of ε_1 (A) and ε_3 (B), while the length represents the in-plane component.

REFERENCES

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