Rapid 3D LV Strain Reconstruction from Tagged Cardiac MR Images

X. Deng[1], T. S. Denney Jr[1]
[1]Auburn University, Auburn, Alabama, United States

Synopsis

We present a rapid unsupervised method, called rapid UNTETHER, for computing three-dimensional (3D) myocardial strain from planar tagged cardiac MR images. Our method consisted of two steps: tag line tracking and strain reconstruction. The tag line tracking algorithm is based on a spatial tag detector and a modified 1D harmonic phase (HARP) π isocontour tracking algorithm. 3D myocardial strains are reconstructed using a cylindrical B-spline deformation model. Experimental results from ten human imaging studies (5 normal volunteers, 5 patients) demonstrate that our method is reproducible and can reconstruct 3D end-systolic circumferential shortening strain from tagged images accurately in 90 seconds.

Introduction

Cardiac MR tagging is an established technique for imaging the deformation of the left ventricular (LV) wall. The regional myocardial mechanical function (strain) can be quantitatively computed from the movement of tag lines in a tagged image sequence. The major drawbacks of existing tagged cardiac image analysis techniques are that they either require user-defined myocardial contours [1] or are limited to 2D approaches [2]. In previous work [3][4], we presented an unsupervised technique, called UNTETHER, for computing 3D strain from tagged images. In this paper, we present and validate a rapid version of the UNTETHER algorithm.

Methods

Imaging: Ten human imaging studies (five normal volunteers, five patients with myocardial infarction) were imaged with a parallel tagged protocol with either black blood (n=6) or white blood (n=4) contrast.

Tag Line Tracking: The tag line tracking algorithm consisted of four steps. First, the user selected a region of interest (ROI) and initial tag line positions for each stack of short-axis images and an ROI and initial tag positions for each long-axis image. Second, for each image in the sequence, the π isocontours inside the ROI were identified in the corresponding HARP [2] images. The π isocontours theoretically coincide with tag line intensity minimums in tagged images [2]. Instead of searching for HARP phase of π in every pixel, the sharp intensity transition points in the HARP phase images were used as starting points for a modified 1D HARP tracking algorithm, which determined the position of the π HARP phase with sub-pixel accuracy. Third, a spatial tag detector [3] was applied to determine the identified tag centers that were actually part of a tag line. Fourth, the tag points were grouped into tag lines by finding the tag points closest to each tag line in the previous time frame. In the first time frame, the initial tag alignment was used to group the tag points. Steps 2-4 were repeated for all time frames in the sequence.

Strain reconstruction: 3D strain was computed by fitting a 3D deformation model to the identified tag lines in three time frames around end-systole. The deformation model was composed of B-spline functions parameterized by cylindrical coordinates [6], which enforces smoothing in the nominal fiber and cross-fiber directions. Lagrangian LV strain was computed on a 3 radial × 12 circumferential × 6 longitudinal material point mesh by analytically differentiating the B-spline deformation model. At each mesh point, the end-systolic strain was computed by determining the minimum circumferential shortening at that point over the three time frames. For comparison purposes, strain was also computed on the same mesh from the same image data using a user-supervised technique [1].

Results

The total processing time for a 3D imaging study composed of 12 time frames was 90 seconds on a cluster of 12 440MHz SUN Ultra 10 (SUN Micro systems, Palo Alto, CA). On single processor 450MHz SUN Ultra 80, the processing time was 11 minutes (10 minutes for tag tracking, 1 minute for strain reconstruction).

Fig. 1 shows tag lines identified in 2 mid-ventricular short-axis slices and 1 long axis slice near end-systole in a patient with myocardial infarction. The root-mean-square (RMS) differences between the tags detected using our method and expert-edited tags at end-systole for 10 studies was 0.39 mm, which is comparable to the accuracy with which tag lines can be tracked (roughly 0.3-0.4 mm [5]). Approximately 10% of the tag points were located more than 2 mm away from the expert-edited tag lines. These points were removed from the RMS difference computation, but used in the strain computation. The tag detection rate, defined as the ratio of number of detected tags to total number of tags inside the myocardium, of our tag tracking algorithm is 91%.

For pooled data from both normal volunteers and patients, the rapid UNTETHER method showed good correlation with the user-supervised technique in circumferential shortening strains (r=0.74, P<0.0005 see Fig. 2), but less agreement in longitudinal shortening (r=0.48, P<0.0005) and radial thickening (r=0.24, P<0.005). If points outside ± three standard deviations in the Bland-Altman plots are thrown out, the correlation improves to r=0.80, P<0.0005; r=0.57, P<0.0005; and r=0.24, P<0.0005 for circumferential, longitudinal, and radial strains, respectively.

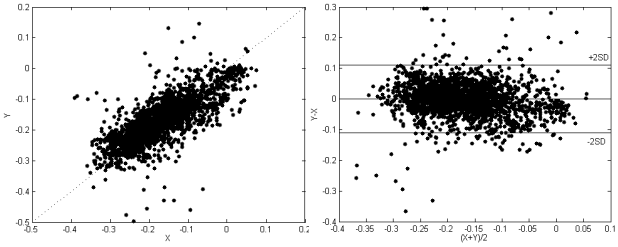


Fig 2. Scatter (left) and Bland-Altman (right) plots comparing circumferential shortening computed by rapid UNTETHER (Y) and a user-supervised technique (X).

For pooled data from both normal volunteers and patients, the rapid UNTETHER strains were highly reproducible. The correlation coefficient between strains computed by two independent observers were r=0.93, P<0.0005; r=0.98, P<0.0005; r=0.87, P<0.0005 for radial, circumferential, and longitudinal strains respectively.

Discussion

The rapid UNTETHER algorithm can reconstruct 3D strains from tagged cardiac MR images in 90 seconds, which is fast enough to allow the attending physician to view the results after a scan. Rapid UNTETHER circumferential shortening was highly reproducible and correlated well with user-supervised analysis that requires from 4-8 hours per study.

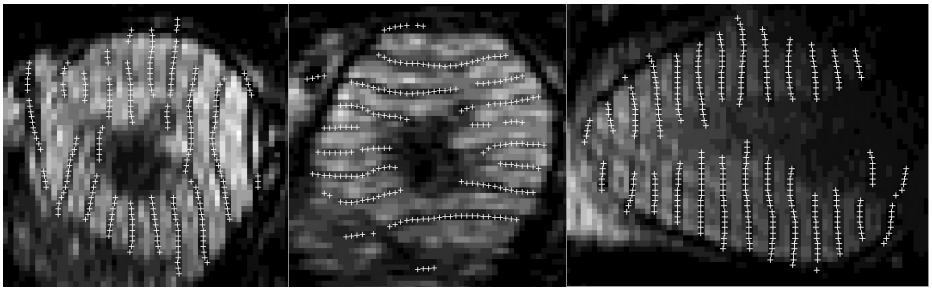


Fig 1. End-systolic images of a mid-ventricular short-axis slice (left) and a long-axis slice overlaid with rapid UNTETHER tag lines.

References

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