Unsupervised Computation of Left Ventricular Strain from Tagged Cardiac MR Images

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Introduction: Cardiac MR tagging is a promising technique for non-invasively measuring the regional mechanical function (strain) in the left ventricular wall, but existing image analysis techniques require user supervised identification of myocardial contours in each image in the study (typically 200 images). These contours are used both in the tag tracking process to define the region of interest and in the strain reconstruction process to define a coordinate system and model geometry tied to the specific heart under study.

The purpose of this study is to develop an unsupervised technique for computing regional 3-D strain in the left ventricular wall from tagged cardiac MR image data.

Methods: Our unsupervised strain reconstruction algorithm consisted of three steps. First, tag lines were identified in each image using an algorithm developed by our group called the ML/MAP algorithm [1], which does not require user defined myocardial contours. Second, a 3-D segmentation of the myocardium was computed solely from the tag points identified in the tag tracking step as follows: 1) for each short axis slice and time frame, a binary tag point image, *tag*, was constructed that is 1 where a tag point has been identified and 0 elsewhere. Another function, *g*, was then computed according to the formula $g=\exp\{-\alpha(tag*G)\}$, where $*G$ denotes convolution with a Gaussian kernel (variance σ^2) and α is a parameter. The image *g* is small where the tag density is high (which is the case inside the myocardium) and large where the tag density is low. 2) a 2-D myocardium segmentation was obtained by running a level set algorithm [2] on *g*. 3) A 3-D myocardium segmentation was obtained for each time frame by interpolating the 2-D segmentations for that time frame. Finally 3-D deformation and strain were computed for the LV wall from the tag line data and segmentation using the discrete model-free (DMF) algorithm [3], which does not require a specific coordinate system or model geometry.

To validate our unsupervised strain reconstruction algorithm, 10 normal human volunteers (NV1-10) were imaged using a cine, black blood, breath-hold, parallel planar tag imaging protocol [4]. Two short-axis sequences (5-7 slices) and one long-axis image sequence (6 slices) were acquired per study. Each short-axis slice was imaged with tag plane orientations of 0 and 90 degrees. Each long-axis slice was imaged once with tag planes oriented parallel to the short-axis image planes. The tag planes had a FWHM of 2 pixels and were separated at end-diastole by 5 pixels. Ten cardiac phases were imaged spaced 32.5ms apart through systole.

3-D strain was computed for each study using both the unsupervised algorithm and a user supervised algorithm [3] which requires user-defined myocardial contours in both the tag tracking and strain reconstruction steps. The amount of agreement between the unsupervised and user supervised strains was quantified by computing the correlation coefficient between the strains computed by the two methods at the same set of material points. The robustness of the level-set segmentation was studied by computing a 2-D segmentation for a mid-ventricular slice of NV1 for a range of parameter settings and comparing the resulting segmentation to a set of user-defined myocardial contours.

Results: The correlation coefficients between the unsupervised and user-supervised circumferential strain (Ecc) were all >0.9 with the exception of NV3 and NV6, which had a correlation of 0.85. The segmentations computed by the level set algorithm on average reconstructed the endocardial contour 0.5 pixels smaller that the user-defined contours and an epicardial contour 0.25 pixels larger than the user-defined contours with a standard deviation for both contours of ~2 pixels.

Discussion: We demonstrated that unsupervised computation of 3-D myocardial strain from tagged MR images is possible. While the unsupervised myocardial contours are less accurate than user supervised contours, our experimental results on normal human hearts show good correlation between unsupervised and user-supervised circumferential strains. A parameter robustness analysis showed that the level set segmentation is not sensitive to its parameters.

References

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4. McVeigh and Atalar, *Mag Res Med* **28**(2):318-327 1992

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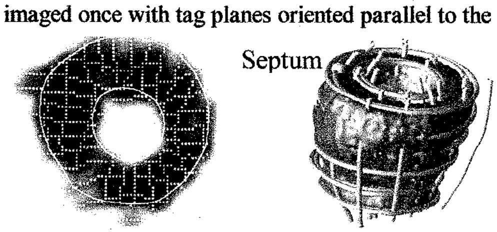

Figure 1: (left) myocardial contours from level set segmentation overlaid on tag points and the *g* image. (right) 3-D segmentation with user-defined contours for reference.

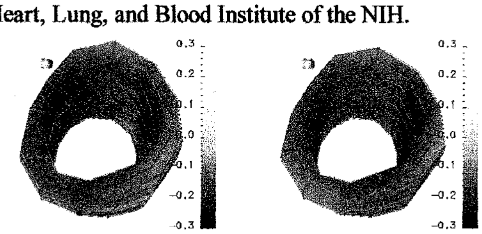

Fig. 2: (left) End-systolic Ecc computed by unsupervised algorithm. (right) Ecc computed by user-supervised algorithm. The balls are septal landmarks.