Optimization of 3-D Tag Sequence and OFM Using a Synthetic Tag Model

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INTRODUCTION Geometrical and motion abnormalities in the left ventricular (LV) myocardium have been linked to a variety of heart diseases. The ability to quantify full three-dimensional (3-D) myocardial motion will improve pathogenesis understanding and assist in developing therapeutic interventions. Tissue tagging has demonstrated great utility in estimating regional myocardial functions precisely and non-invasively. However, current tag analysis methods require significant effort and time to track the tag displacement and to reconstruct the myocardium motion, which makes them less desirable in the clinical arena. To address these limitations, we present a novel method of estimating high-resolution 3-D myocardial motion using 3-D tags combined with 3-D optical flow method (OFM), and optimized the technique utilizing a synthetic tag model.

METHODS Initially a synthetic 3-D tagged cardiac volume was constructed from an ex-vivo ovine heart which was imaged using a 1.5 T Siemens Sonata scanner (Siemens Medical Solutions, Malvern, PA, USA) with the following parameters: acquisition matrix = 256 x 256 x 27; FOV=24 cm; and slice thickness = 1.5 mm. A 3-D grid was generated and overlaid on the images to simulate MR tagging. Two orthogonal tag planes were fixed in space and the angles between the normal of the third plane ***n***, and ***x-, y-, z-*** axis were adjusted. From an independent data set, the 3-D flow fields were extracted, which were scaled and applied to the synthetic set to simulate LV systolic deformation. Tag fading through the cardiac cycle due to T_1 relaxation was simulated using $SI = M_0\left(1 - e^{-t/T_1}\right)$ where SI is the tag intensity and T_1=900ms. Phase-to-phase pixel displacement in the synthetic set was estimated using 3-D-OFM[1]. Orientation and spacing of the 3-D-tagging grid was adjusted so as to maximize the correlation coefficient (CC) between the known and estimated flow fields. OFM parameters (coarse-to-fine levels, iterations, filtering) were also optimized in a similar manner. Subsequent to model optimization, 3-D LV motion was estimated and integrated though out the systolic phase. Lastly, a series of experiments were performed to study the sensitivity of OFM to noise perturbation. The noise-free synthetic model with the optimized parameters was defined as the baseline model, and the zero mean Gaussian noise was applied with increasing magnitude. The error was defined as the mean difference between the flow fields computed from the baseline model and noise-added model over all pixels in the image set.

RESULTS From the simulation, OFM parameters that produced the highest correlation were: 3 coarse-to-fine levels, 8 iterations at each level, Gaussian filtering for the global estimations; and 1 level, 8 iterations and Laplacian filtering in the local stage. Tagging parameters were optimized at 2-pixel width and 8-pixel tag spacing. The optimal angle for CC in apex-base direction was found when the third tag plane was parallel to the short axis plane, however this configuration reduced CC in the in-plane direction. Overall optimization was achieved when the normal of the third tag plane ***n*** was 35, 66 and 66 degree with ***x, y*** and ***z***-axis, as observed for the third configuration in Table 1. Utilizing the optimized OFM parameters, the temporal deformation of a representative mid-left ventricular short-axis slice during systole is shown in Figure 1. The integration procedure of each individual flow field enhances CC significantly, producing CC values greater than 0.99 and RMS error less than 0.04 mm in all directions. Figure 2 shows the error (mean and standard deviation) of the derived integrated flow fields using the optimized configuration at different noise levels. RMS error increased as the noise perturbation increased. Flow fields in ***z***- (apex-base) direction showed higher bias and is more sensitive to noise.

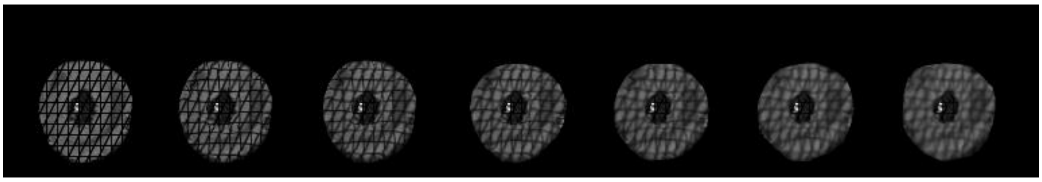

Figure 1. Representative mid-ventricular slice of the synthetic left ventricular volume from end-diastole (left) to end-systole (right). Note the tag fading through the cardiac cycle due to T_1 relaxation

Table 1.Cross Correlation of dx, dy, and dz at different configurations. The third tag plane orientation ***n*** is controlled by adjusting the angle between the planes normal *n* with x, y and z axis

Angle between **n** and x, y and z axis			Correlation (dx)	Correlation (dy)	Correlation (dz)
55	55	55	0.895	0.894	0.843
66	35	66	0.903	0.907	0.901
35	66	66	0.921	0.920	0.896
66	66	35	0.890	0.891	0.885
45	45	90	0.908	0.907	0.876
90	90	0	0.8	0.81	0.938
no third tag planes			0.890	0.898	0.798

DISCUSSION This study utilized a 3-D tagged synthetic volume data set with known displacements to optimize both 3-D OFM and 3-D tag parameters. Cross-correlation between the known and estimated flow fields demonstrated that this method produced accurate measures of pixel displacement from a 3-D tagged volume. Improved accuracy in the apex-base direction can be achieved by placing the tag plane parallel but it resulted in reduced in-plane accuracy and would obscure all signal in that plane which is typically larger than the in-plane pixel dimensions. Furthermore, inclusion of a third tag plane not only enables the detection of through plane motion, but improves precision of in-plane components measurements by 13% and 36% in x- and y- direction, respectively. Noise analysis demonstrated that this method is robust to random noise, and less sensitive to noise in the short-axis plane. In conclusion, this study demonstrates that optimized 3-D OFM combined with 3-D optimized tag sequence has the potential to generate in-vivo myocardial displacement rapidly and accurately directly from a 3-D tagged volume.

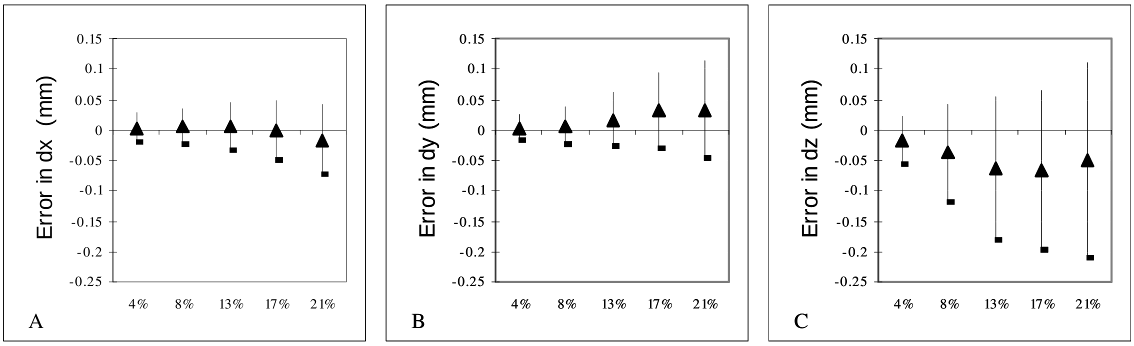

Figure 2. Mean and standard deviation of the errors of flows estimated from noise-added image set. The center of each error bar represents the mean value and the bar extends to one standard deviation above and below the mean.

REFERENCES

1. Dougherty, L., et al., *Use of an optical flow method for the analysis of serial CT lung images.* Acad Radiol., 2006. **13**(1): p. 14-23.