

Validation of 2D Ultrasound-based Strain Estimates with MR Tagging

W-N. Lee¹, Z. Qian², C. L. Tosti¹, S. V. Swaminathan^{3,4}, T. R. Brown^{1,4}, D. N. Metaxas², and E. E. Konofagou¹

¹Department of Biomedical Engineering, Columbia University, New York, NY, United States, ²Department of Biomedical Engineering, Rutgers University, Piscataway, NJ, United States, ³Philips Medical Systems, Cleveland, OH, United States, ⁴Department of Radiology, Columbia University, New York, NY, United States

Introduction

Echocardiography enjoys widespread availability in the clinic for qualitative detection and diagnosis of cardiovascular disease. However, Magnetic Resonance Imaging cardiac tagging (tMRI) [1] is currently considered as the gold standard for myocardial strain mapping *in vivo*. Ultrasound Myocardial Elastography (UME) is a radio-frequency (RF) based speckle tracking technique that has been previously validated using a 3D finite-element model [2, 3], reliably estimating in-plane myocardial deformation in both normal and abnormal cases. In this study, UME is applied in a clinical setting in order to evaluate the myocardial motion and strain estimates and to validate them against tMRI findings.

Methods

A clinical echocardiography ultrasound scanner (GE Vivid FiVe, GE Vingmed Ultrasound, Horten, Norway) with a phased array probe (FPA 2.5MHz 1C) was used to acquire cardiac ultrasound in-phase and quadrature (I/Q) data in 2D short-axis (SA) views at the medial papillary muscle level from two healthy volunteers and a frame rate of 136 fps. Tagged MR images were obtained on Philips Intera 1.5T scanner (Philips Medical Systems, Best, The Netherlands) equipped with a five-channel SENSE cardiac coil and Master gradients of strength 30 mT/m and slew rate 150 T/m/s. A Multi-slice and multi-phase true short axis tagged image was acquired under free-breathing with a combination of fast field echo excitation and a multi-shot echo-planar readout (EPI-FFE) technique [4] (FOV=350 mm, TE=4 ms, TR=30, NSA=4, resolution acquired/reconstructed=192/256, flip angle =13 degrees, EPI factor=3 and full ECG gating scan duration=2.96 min). Two dimensional grid tagging was performed yielding a 9 mm in-plane tag resolution.

The UME is an RF-based speckle tracking technique and consists of four steps [2, 3]. First, in-plane (lateral and axial) incremental displacements are iteratively estimated using 1D cross-correlation and recorelation techniques in a 2D search with a 1D matching kernel of 7.7 mm and 80% overlap. Second, all the estimated incremental 2D displacements from end-diastole (ED) to end-systole (ES) are then accumulated to acquire the cumulative 2D displacements. Third, 2D Lagrangian strains (i.e., lateral and axial) are calculated from cumulative 2D displacements. Fourth, radial and circumferential strains are further computed from the 2D finite strains based on coordinate transformation.

In tagged MRI, cardiac motion is obtained by a template matching based tracking algorithm on a 2D grid-shaped mesh [5-8]. Each crossing point (or, node) on the mesh is tracked by calculating the similarity between templates, which are modeled using two tunable Gabor filters and the underlying image. The crossing points on the mesh are driven iteratively by forces from the neighboring image patches, whose texture patterns are the most similar to a reference template. The coordinates of the crossing points in a time sequence are further smoothed by a cubic spline function, and the displacements are thus calculated through subtraction. Finally, a cubic B-spline-based method is used to obtain the entire displacement distribution within the myocardium [9]. The method for the estimation of the 2D finite strains as well as radial and circumferential strains in tMRI is the same as in UME.

Results

The in-plane (2D, radial and circumferential) systolic strains estimated from tMRI and UME on a SA view of a normal left ventricle at ES are shown in Figs. 1 and 2 (displayed on a scale of ± 0.5 , i.e., $\pm 50\%$). The anterior, lateral, posterior and septal walls are in the upper right, lower right, lower left and upper left regions, respectively. In 2D strains (Fig. 1), positive and negative strains indicate tension and compression, respectively. Figure 2 shows positive radial (myocardial thickening) and negative circumferential (myocardial shortening) strains. The difference between UME and tMRI strain estimates is calculated as $\bar{\epsilon}_{UME} - \bar{\epsilon}_{tMRI}$, where $\bar{\epsilon}_{UME}$ and $\bar{\epsilon}_{tMRI}$ are the mean strain values in a region of 7.5-by-7.5 mm² in the posterior wall for UME and tMRI, respectively. The mean and standard deviation of the estimation difference of the average strains over the two healthy subjects are shown in Fig. 3. The difference of strain estimates is below 0.04 (i.e., 4% strain) with the strain values ranging from -0.5 to 0.5 (Figs. 1 and 2). The strains obtained from UME are overestimated compared with those from tMRI.

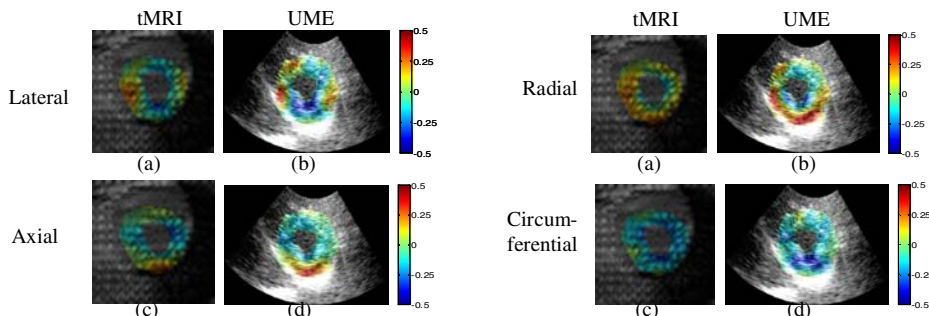


Figure 1: (a) and (c) are the lateral and axial strains from tMRI; (b) and (d) are the lateral and axial strains from UME. Strains are displayed on a scale of ± 0.5 .

Figure 2: (a) and (b) are the radial strains from tMRI and UME, respectively; (c) and (d) are the circumferential strains from tMRI and UME, respectively. Strains are displayed on a scale of ± 0.5 .

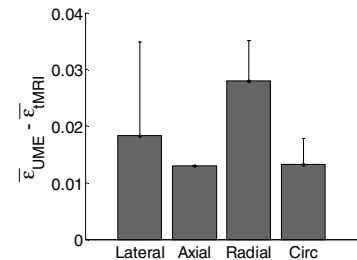


Figure 3: Variation of the UME-tMRI difference in the case of lateral, axial, radial and circumferential strains between UME and tMRI over two healthy volunteers. $\bar{\epsilon}_{UME}$ and $\bar{\epsilon}_{tMRI}$ are the mean strain values in a region of 7.5-by-7.5 mm² in the posterior wall for UME and tMRI, respectively.

Discussion and Conclusion

UME was able to assess myocardial deformation determining values highly comparable to the strain estimates from tMRI. However, overestimation of the strains with UME compared to tMRI was observed, possibly resulting from the fact that the ultrasound signals suffered from low SNR, the ultrasound and tagged MR images were not acquired at exactly the same short-axis slice and that the spatial resolutions of the strain estimates in both imaging modalities were not necessarily equivalent. Future work will focus on more accurate registration of ultrasound and tagged MR images, assessment of the role of the sonographic SNR on the UME strain estimates and study of the tradeoff between spatial resolution and strain accuracy for precise quantification.

Acknowledgement

This study was supported in part by the American Heart Association (SDG 0435444T) and NIH (R01EB006042-01). The authors would like to thank Hamed Mojahed for acquiring the tagged MR images, Kana Fujikura for acquiring ultrasound data, Simon D. Fung-Kee-Fung for developing the data acquisition protocol in ultrasound and Jianwen Luo for helpful discussion.

References

- [1] J. Declercq et al., *Phys. Med. Biol.*, vol. 45, pp. 1611-1632, 2000.
- [2] S. D. Fung-Kee-Fung et al., *Proc. of IEEE Ultrasonics Symp.*, pp. 516-519, 2005.
- [3] W-N. Lee and E. E. Konofagou, *Proc. of IEEE Ultrasonics Symp.*, 2006. (in press)
- [4] M. Stuber, et al., *Magn Reson. Med.*, vol. 41, pp. 639-643, 1999.
- [5] Z. Qian et al., *Proc. of CVIBA Workshop*, In Conjunction with ICCV, LNCS 3765, pp. 93-102, 2005.
- [6] Z. Qian, et al., *Proc. of MICCAI*, LNCS 4190, pp. 636-644, 2006.
- [7] J. Park, et al., *Int. J. Med. Inform.*, vol. 55, pp. 117-126, 1999.
- [8] I. Haber et al., *Comput. Sci. Eng.*, vol. 2, pp. 18-30, 2000.
- [9] D. T. Sandwell, *Geophys. Res. Lett.*, vol. 14, pp. 139-142, 1987.