

## Myocardial Elastography – Comparison to Results Using MR Cardiac Tagging

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*Abstract* - MRI cardiac tagging has been established as the gold standard in assessing intramyocardial displacement and strain. Yet, despite the high imaging quality of cardiac MRI, tagging techniques are limited by low spatial and temporal resolution. It has been recently shown that axial displacement and strain could be estimated and utilizing B-scan ultrasonography [1]. We compared and correlated intramyocardial displacement data from B-scan ultrasound images and cardiac MRI in seven normal human subjects. Subjects were first imaged in a 4-chamber view using an Agilent/PMS 5500 system with a 1.8/3.6 MHz probe and at 38 Hz frame rate, and then scanned using a Philips 1.5T Intera system and a CSPAMM tagging sequence. A single-cardiac-cycle tagging loop was generated combining data from 15 cardiac cycles. Incremental axial and lateral, displacement and strain estimates along the interventricular septum between successive frames were obtained using 2D crosscorrelation with a 5 x 5 mm<sup>2</sup> kernel and 95% overlap. Ciné-loop and M-mode displacement images and elastograms and temporal plots depicted the high repeatability of all estimates over 2-5 cardiac cycles. Axial and lateral displacements both ranged between 0.04 mm at peak systole and -0.04 mm at peak diastole. Axial and lateral strains also had similar magnitudes with averages within 6% and -8% and 5% and -5%, respectively. Axial displacements and strains were also estimated from the MR cardiac tagging data using a simple zero-crossing algorithm to track the motion of the horizontally-placed tags. The peak systole and displacement estimates obtained from the ultrasonic and MR tagging data correlated well ( $r=0.81$ ;  $p<0.05$ ) as were the strain estimates ( $r=0.65$ ;  $p<0.05$ ). The correlation between elastographic and MR tagging results indicates that myocardial elastography could offer comparable quality estimates to those obtained with MR cardiac tagging; with the added advantage of higher temporal and spatial resolution representing thus a viable alternative to the quantitative assessment of myocardial function.

### I. INTRODUCTION

The heart is a continuously moving organ that is responsible for pumping blood through the body.

Disease, such as ischemia or infarction, alters the way the heart moves, contracts and relaxes during a cardiac cycle. Therefore, in order to detect disease early, its mechanical dysfunction needs to be rapidly and accurately assessed. Despite the progress with the use of imaging modalities such as echocardiography and MRI, identification of regions of myocardial dysfunction remains a challenge. In echocardiography, most current methods for assessment of regional myocardial dysfunction rely on visual tracking of the endocardial border and observation of myocardial thickening. These methods remain, thus, subjective and imprecise, and it can be difficult to distinguish endocardial motion due to translation and rotation of the heart from myocardial contraction. In more recent years, a series of techniques have been developed in order to monitor the velocity and strain rate of the myocardium based mainly on Doppler methods [2]. MRI cardiac tagging techniques have been proven to be more quantitative and robust in the characterization of myocardial deformation, normal or pathological, but remain highly costly and less widely available.

MR cardiac tagging has been shown capable of estimating all principal strains of the strain tensor by utilizing 'tags', i.e., deposition of planes of presaturation intersecting the myocardium prior to the ployout of the MRI imaging sequence itself [3]. Despite the fact that the MR cardiac tagging technique has permitted important new insights with regard to normal physiology and myocardial disease, it has been slowed by limitations of availability, speed and effort required. In addition, tag spacing is fundamentally limited to 5-7 mm and thereby motion and deformation information to a restricted number of sites across the myocardium. Finally, the low temporal resolution, i.e., frame rate, that assures tag setting and elimination of respiratory motion effects,

does not offer the possibility of obtaining displacement or strain estimates in the myocardium during the same cardiac cycle, but rather during a breath-hold (16-20 sec), which may not be an option for several patients [3].

In this study, two areas of myocardial elastography are investigated, i.e., whether:

- lateral strain can be estimated and imaged in an M-mode fashion using envelope-detected data.
- the axial displacement and strain are comparable to those estimated using MR cardiac tagging.

## II. METHODS

Seven normal human subjects were first imaged using an Agilent/PMS 5500 system in a 4-chamber view with a 1.8/3.6 MHz probe and at 38 Hz frame rate, and then scanned using a Philips 1.5T Intera system and a CSPAMM tagging sequence. A single-cardiac-cycle tagging loop was generated combining data from 15 cardiac cycles. Incremental axial and lateral displacement estimates along the interventricular septum (Fig. 1(i)) between successive ultrasonic envelope-detected frames were obtained using 2D crosscorrelation with a  $5 \times 5 \text{ mm}^2$  kernel and 95% overlap. A least-squares estimator was applied in order to estimate the 2D strain components with a kernel equal to 6 points [1]. M-mode displacement images and elastograms were obtained over the range 2-5 cardiac cycles.

For the displacement estimates from the MR cardiac tagging images, a simple zero-crossing estimator was employed after removing the mean amplitude of each line of the image perpendicular to the tags (Fig. 2(i)) so as to make sure it varies around zero. The tag occurrence will thus force the amplitude to become negative. When the displacement measured between successive MR frames exceeded the tag spacing, that estimate was given a value out of the range of reliable estimates so as to identify it as 'unreliable'. The CSPAMM sequence used was only in one direction: perpendicular to the septum and thus only one motion and deformation component could be estimated: the axial one. In all cases shown, three cardiac cycles were considered and the plots were taken across from the corresponding M-mode image at  $\frac{3}{4}$  level starting from the top of the image.

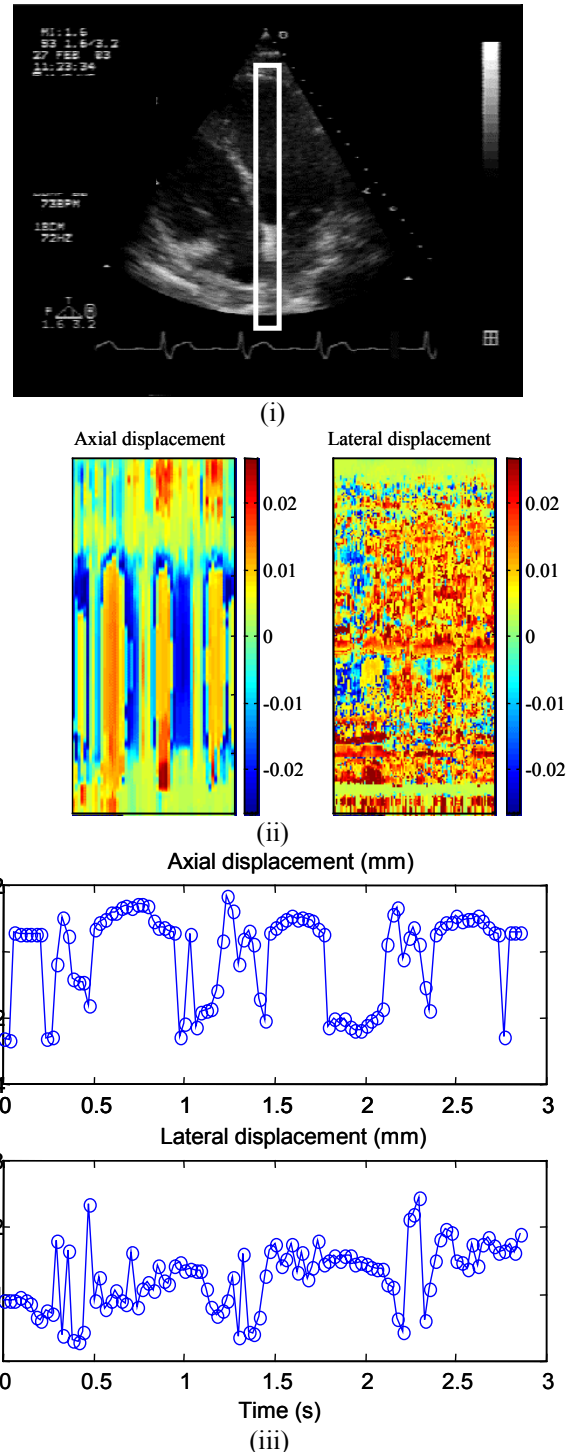


Figure 1 i) 4-chamber view of one subject; ii) M-mode and iii) plots of axial and lateral displacement estimated with time in the kernel shown in (i) over three cardiac cycles.

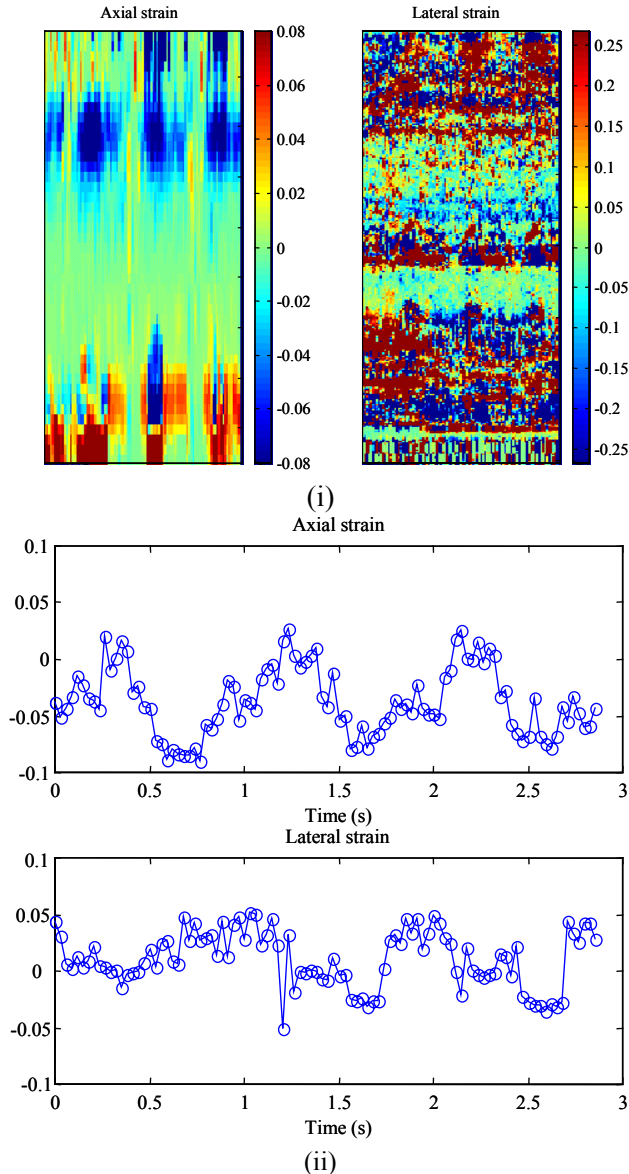


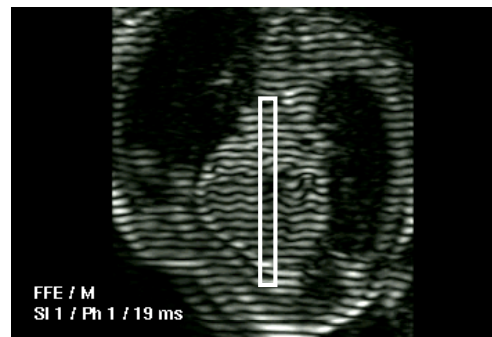
Figure 2: i) M-mode and ii) plots of axial and lateral strain estimated with time in the kernel shown in Fig. (i) over three cardiac cycles.

For the comparison between ultrasound-based and MRI-based displacement and strain estimates, the time values were adjusted in order to take into account the different frame rates.

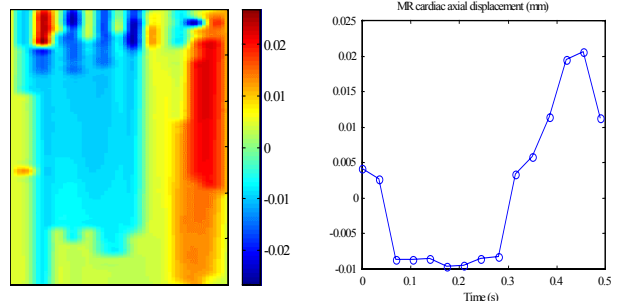
### III. RESULTS AND DISCUSSION

Ultrasound envelope-detected data were used to obtain M-mode axial and lateral displacement images and plots (Fig. 1(ii) and (iii)) and elastograms (Fig. 2(i) and (ii)) along the interventricular septum in 4-chamber views over three cardiac cycles. Both the

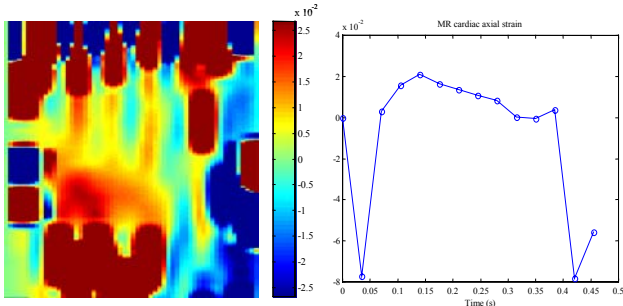
displacements and strains were shown to be highly repeatable over three cardiac cycles. The lateral displacement and strain estimates were noisier than the axial estimates (Figs. 1 and 2), as predicted from theory. Axial displacement (Fig. 3(ii)) and strain (Fig. 3(iii)) estimates were also obtained from 1D tagged MR cardiac images of the same subject using a zero-crossing estimator. The displacements and strains were shown to vary within the same range as those obtained using elastographic techniques. Finally, in order to evaluate the accuracy of the ultrasound-based estimates, a comparison with the MR-based ones was performed at peak systole and peak diastole. Figure 4 shows the results of the study over all seven subjects. In all cases, the elastographic estimates were well correlated with MR ones with the displacement and peak systole showing the highest correlation. These results are very promising in the sense that they clearly show that elastography-based results can be as accurate as those obtained using MR cardiac tagging. With the additional advantage of higher temporal and spatial resolution, myocardial elastography could be established as a viable alternative or complementary to the MR cardiac tagging techniques. A larger study over a higher number of subjects as well as 2D and 3D motion estimation and comparison are under way.



(i)

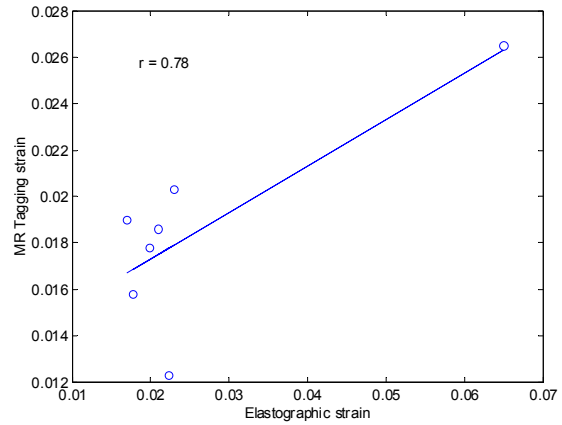


(ii)



(iii)

Figure 3: i) CSPAMM image of the same subject as in Figs. 1 and 2; M-mode and temporal plot of axial displacement and iii) strain estimated with time in the kernel shown in (i) over three cardiac cycles. The sign of the strain is reversed compared to Figs. 1 and 2: negative strain denotes contraction while positive denotes tension.



(iii)

(iv)

Figure 4: Average axial i) peak systolic and ii) peak diastolic displacement, iii) peak systolic and iv) peak diastolic strain measured at the interventricular septum in all seven subjects. The correlation coefficient is shown on the upper left of each plot ( $p < 0.05$ ).

## V. ACKNOWLEDGMENTS

This study was supported by a fellowship grant from the American Society of Echocardiography.

## VI. REFERENCES

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