Assessment of Regional Myocardial Strain using Cardiac Elastography: Distinguishing Infarcted from Non-Infarcted Myocardium

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Abstract - Estimation of the regional mechanical properties of the cardiac muscle has been shown to play a crucial role in the detection of cardiovascular disease. Current echocardiography-based cardiac motion estimation techniques, such as Doppler Myocardial Imaging (DMI), are limited due to angle dependence. By contrast, elastography, a method designed and used for the detection of tumors, measures displacement and strain by comparing echoes *before* and *after* (not *during*) a deformation and thus is not angle-dependent. Therefore, the feasibility of cardiac elastography to provide reliable and reproducible displacement and strain estimates from multiple sonographic views was recently demonstrated utilizing RF data from a normal human heart in vivo [1]. In this paper, we demonstrate this technique utilizing 2D B-scan data in a patient with a known myocardial infarction. Envelope-detected sonographic data was used to estimate regional wall motion and deformation. Displacement and strain estimates were obtained in both non-infarcted, normally contracting and infarcted regions. By obtaining ciné-loop and M-Mode elastograms from both regions, the ischemic regions could be identified. In conclusion, elastography may be a clinically viable method for detection of abnormalities of regional wall motion throughout the cardiac cycle.

I. INTRODUCTION

Based on the principle of palpation, elastography has proven useful for the detection of abnormal pathology, such as tumors, by taking advantage of their distinct mechanical properties compared to normal tissues. In its noninvasive applications, an external compression is used to deform tissue and the resulting tissue strain is measured using time-delay estimation techniques. In contrast to most soft tissues, the heart undergoes constant deformation as it contracts and relaxes. Furthermore, the extent of cardiac contraction should directly influence the degree of strain observed, with reduced strain in regions that are less contractile regardless of translational motion. Because assessment of regional contraction is currently based on endocardial wall motion excursion, and not on any parameters that directly reflect the contractile state of the myocardium, there is a need for the development of novel methods to assess contractile state independent of non-contractile motion. Elastography thus represents a potential alternative for the study of cardiac motion as well as for the detection and mapping of cardiac ischemia or infarction. The feasibility of cardiac elastography in a normal patient using high frequency RF signals at a high frame rate has already been demonstrated [1].

In this study, two areas of cardiac elastography are explored:

- The use of video or envelope-detected data at a regular frame rate of 30 frames/sec in the estimation and imaging of strain.
- Its ability for detection of infracted myocardium.

It has previously been shown that the variance associated with strain estimates from envelope signals is twice higher than that using RF signals [2]. The lower bound on the variance in the displacement and strain estimation using envelope-detected data are given by

$$\sigma^2(\hat{d})_{CRLB} = \frac{3c}{2\pi^2 BT}\left[\frac{1}{\rho^2}\left(1+\frac{1}{SNR^2}\right)-1\right], \quad (1)$$

and

$$\sigma^2(\hat{\varepsilon})_{CRLB} = \frac{2}{T\Delta t}\sigma^2(\hat{d})_{CRLB}, \quad (2)$$

respectively, where $\hat{d}$ is the estimated displacement, $\hat{\varepsilon}$ is the estimated strain, T is the window size and Δt the window shift. Clearly, in order to be able to decrease the variance in both

estimates and obtain good quality elastograms, the window size needs to be high enough (Eqs. 1 and 2). This translates into loss of resolution in the resulting motion and strain images, but also renders cardiac elastography a clinically viable tool.

II. METHODS

Envelope-detected sonographic data from a Hewlett-Packard Sonos 5500 system using a harmonic imaging probe operating at 1.8/3.6 MHz was used to estimate regional wall motion and deformation. Short-axis, long-axis and apical views were obtained in real-time for two patients with documented myocardial infarction. Data were acquired and transferred to a workstation for off-line analysis. Crosscorrelation of segmented envelope-detected signals was applied using a window size of 4 mm and 90% overlap so as to assure high signal-to-noise ratio (Eq. 2). The frame rate was equal to 30 frames/s. A least-squares estimator was applied in order to estimate the strain with a kernel equal to 6 points [3]. In all cases shown, three cardiac cycles were considered.

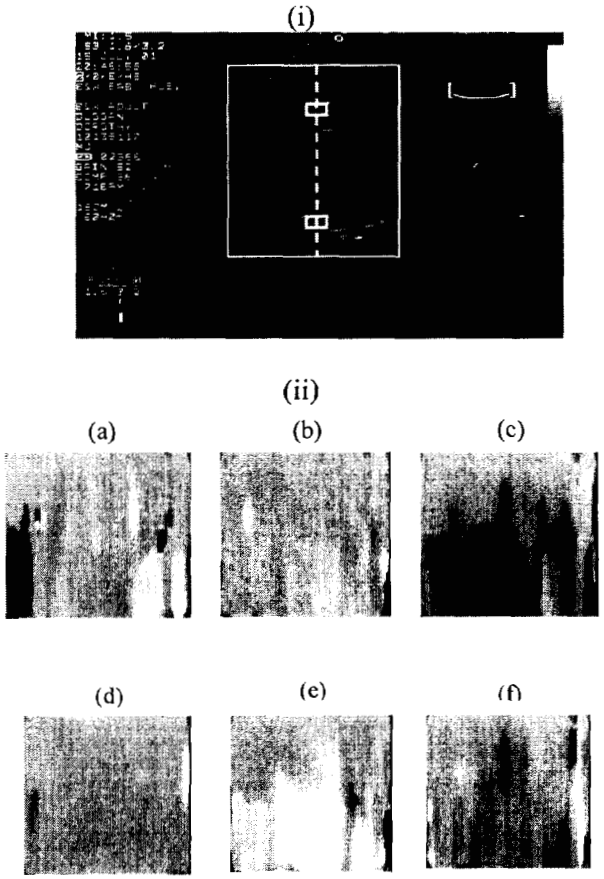


Figure 1: i) Sonogram and ROI of infracted case I (short-axis view), ii) Displacement images inside denoted ROI of (i) at a) 0%, b) 20%, c) 40%, d) 60%, e) 80%, f) 100% of the cardiac cycle (scale same as Fig. 3(i))

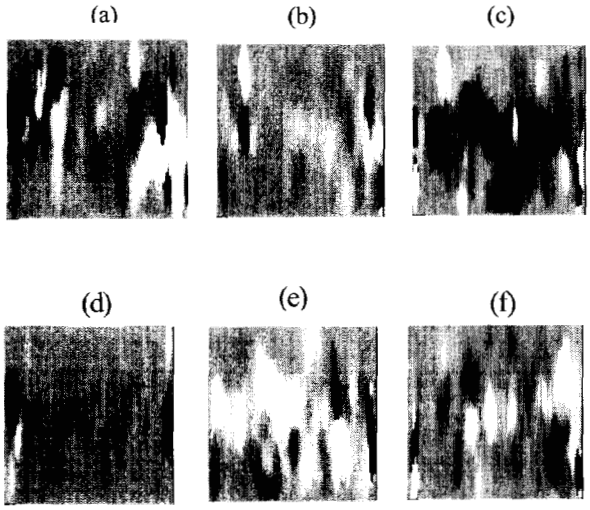
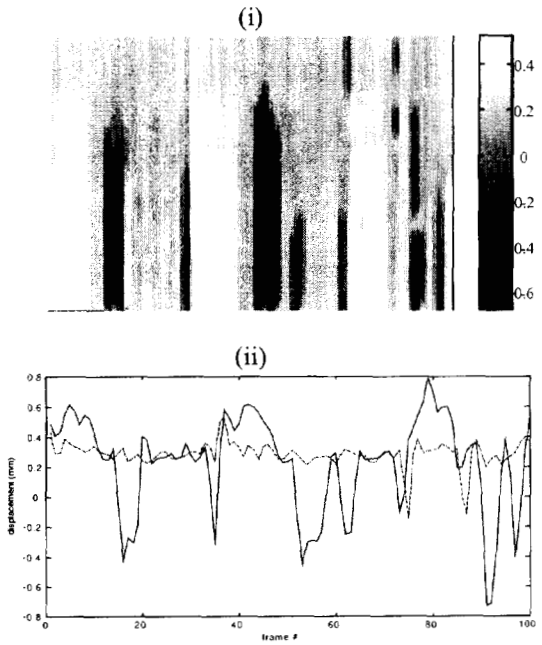


Figure 2: Elastograms inside denoted ROI of Fig. 1(i) at a) 0%, b) 20%, c) 40%, d) 60%, e) 80%, f) 100% of the cardiac cycle (scale same as Fig. 3(iii)).



(iii)

(iv)

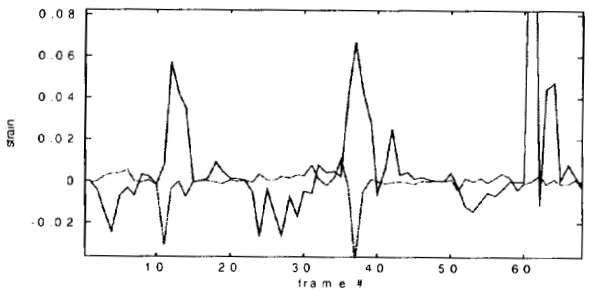
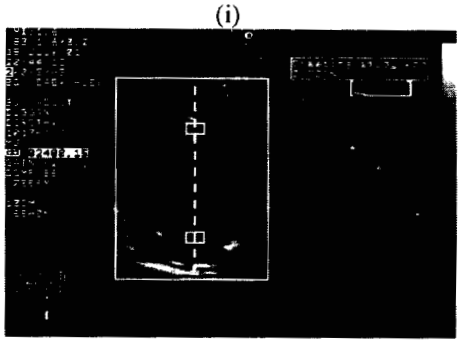
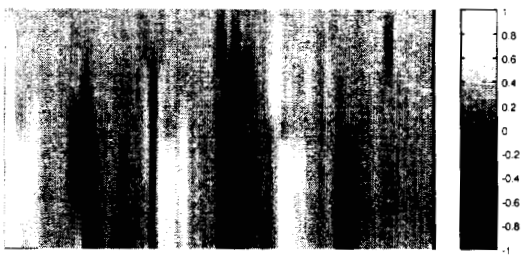


Figure 3: i) M-mode displacement image along the dotted line on the sonogram of Fig. 1(i); ii) Displacement profiles at the infracted (dotted) and non-infarcted (solid) regions, at top and bottom squares, respectively as noted on Fig. 1(i); iii) M-mode elastogram at the same region as (i) iv) Strain profile at the same regions as (ii).

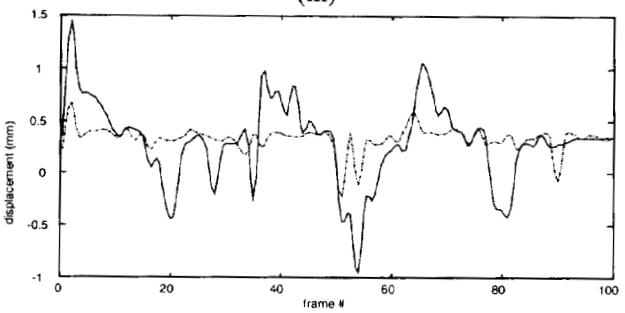
(i)



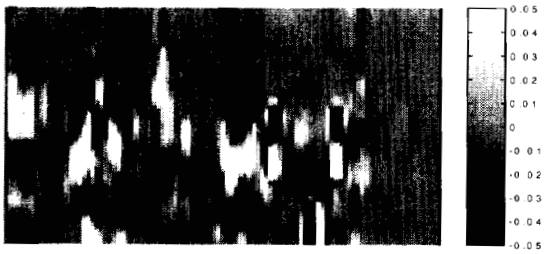
(ii)



(iii)



(iv)



(v)

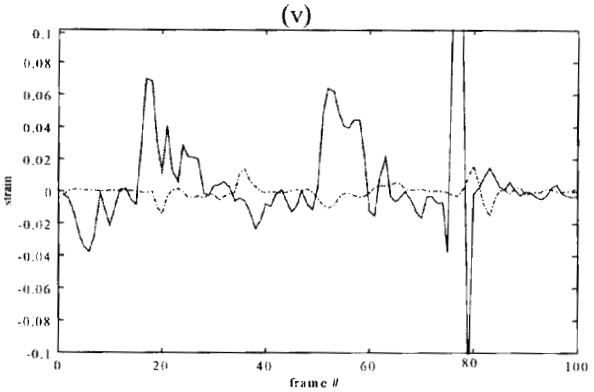


Figure 4 i) Sonogram and ROI of infracted case I (long-axis view), ii) M-mode displacement image along the dotted line on the sonogram of (i); iii) Displacement profiles at the infracted (dotted; top small square on (i)) and non-infarcted (solid; bottom small square on (i)) regions, as noted on (i); iv) M-mode elastogram at the same region as (ii) v) Strain profile at the same regions as (iii). Note that the top of (ii) and (iv) show low motion and deformation, respectively since they correspond to the infarcted.region.

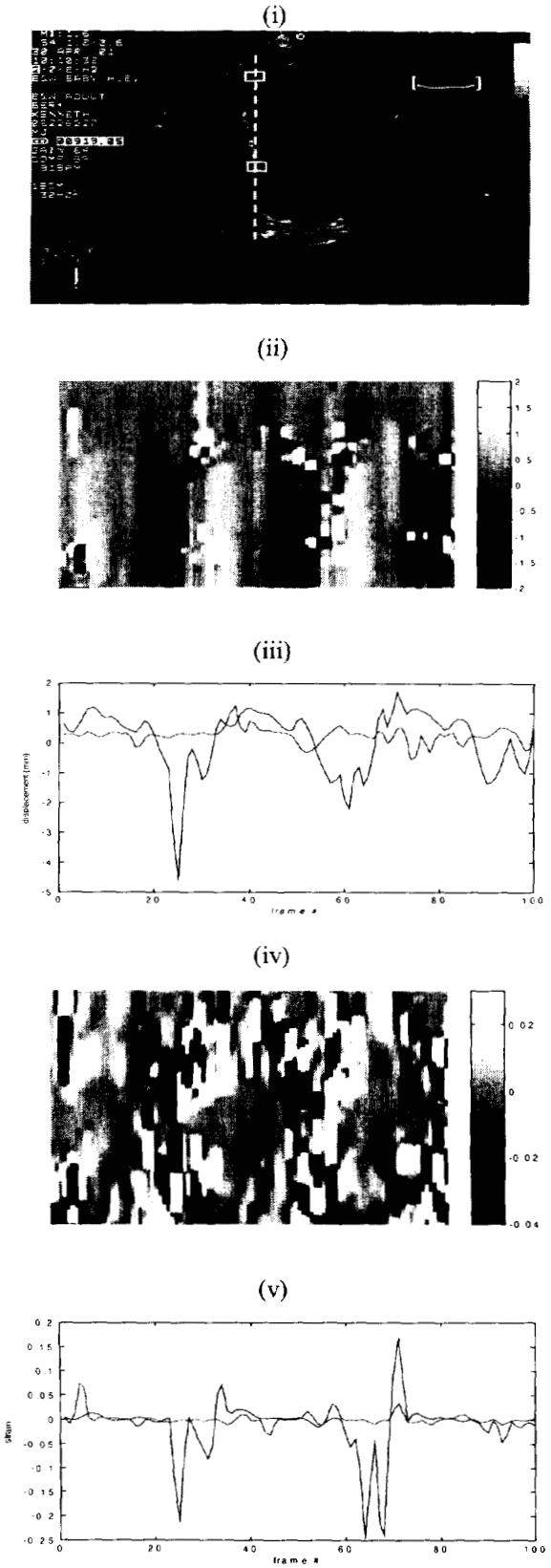


Figure 5 i) Sonogram and ROI of infracted case II (apical view), ii) M-mode displacement image along the dotted line on the sonogram of (i); iii) Displacement profiles at the infracted (dotted) and non-infarcted (solid) regions, as noted on (i); iv) M-mode elastogram at the same region as (i) v) Strain profile at the same regions as (iii). Note that the top of (ii) and (iv) show low motion and deformation, respectively since they correspond to the infarcted.(apical) region.

III. RESULTS AND DISCUSSION

Envelope-detected data was used to obtain ciné-loop displacement images (Fig. 1(ii)) and elastograms (Fig. 2) as well as M-Mode displacement images (Fig. 3(i), Fig. 4 (ii) and Fig. 5(ii)) and elastograms (Fig. 3(iii), Fig. 4 (iv) and Fig. 5(iv)) across myocardial structures in three different sonographic views and the infarct regions could be identified and differentiated from the non-infarcted ones. An extensive clinical study should further define the promising and clinically viable role of elastography in the detection of cardiovascular disease.

Current assessment of cardiac wall motion by echocardiography, relying on qualitative estimation of endocardial wall motion excursion, is both insensitive and subject to low inter- and intra-observer reproducibility. Furthermore, the sensitivity of this assessment is further reduced by the fact that translational and rotational movements of the heart that are independent of myocardial contraction contribute to endocardial wall motion excursion. Estimation of the mechanical strain within the myocardial signal therefore represents a potential improvement over current methods for assessing contractility. Finally, given the strains measured within the different regions in the cardiac muscle, the incremental elastic moduli can be simulated using adaptive finite-element methods. The combination of motion, deformation and mechanical property estimation may represent a unique and easily accessible tool for noninvasive cardiac diagnosis

IV. REFERENCES

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