Heterogeneity of the Myocardial Strains as Revealed by High Resolution Measurement of Myocardial Velocities

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Abstract

Speckle tracking echocardiography is a tool for measuring myocardial velocities from echocardiography. Since the measured velocities are noisy, only global measures are obtained. The use of wavelet de-noising for filtering the raw velocities, allows processing the high spatial frequency components, and this may reveal new insight into cardiac mechanics.

Echocardiography was applied to 27 normal rats, and the myocardial velocities from 3 short axis levels were analyzed by a commercial speckle tracking program and by a wavelet de-noising process. Thereafter, the circumferential and radial strains were calculated for 6 segments. The circumferential strain was heterogeneous at the apical and basal levels ($P<0.001$); while it was homogeneous at the mid-ventricular level. The radial strain was heterogeneous at all scan levels ($P<0.01$). Wavelet de-noising of the myocardial velocities reveals heterogeneity of the circumferential and radial strains.

1. Introduction

Speckle tracking echocardiography (STE) is a technique for obtaining functional measurements of the left ventricular (LV) mechanics during its contraction and relaxation. It is based on tracking of stable natural acoustic scatterers, which reflect echoes from the myocardium during echocardiography [1]. The locations of these speckles change from frame to frame with the surrounding tissue motion, and the local movement of the myocardium can be measured, i.e. myocardial velocities. Consequently, strain and strain rate parameters may be calculated for the total wall thickness [1, 2]. These strain measurements were validated against tagged Magnetic-Resonance Imaging (MRI) [3-5] sonomicrometry [6], tissue Doppler imaging [2], histological analysis for fibrosis [7] and heart staining for infarct size [8].

The calculation of strain and strain rate parameters can be performed by using tissue Doppler imaging (TDI) method as well. However, the STE method is advantageous over the TDI since it is independent on the insonation angle, and thus the area of the analysis is not restricted to the areas along the ultrasound beam. Moreover, the STE method is easier to use and it is user independent in comparison to the TDI method. On the other hand, the STE method is dependent on the image quality, and in many cases the image quality is not sufficient for the whole myocardium that is seen in the ultrasound cine. Thus, it is vital to apply smoothing to the myocardial velocities, which are obtained from the speckle tracking algorithm. Recently, a layer-specific STE was developed, which employs wavelet de-noising algorithm for the smoothing of the myocardial velocities. It allows the measurement of myocardial function at high spatial resolutions. The layer-specific STE method was implemented and validated against computerized and mechanical phantoms [9].

The hypothesis in this study is that the myocardial strains are heterogeneous between the myocardial segments. This heterogeneity can be revealed by the layer-specific STE method for the smoothing of the myocardial velocities, instead of the built-in smoothing that exist in the commercial programs.

2. Materials and methods

Animal experiments were approved by the institutional animal ethical committee of the Technion – Israel institute of technology (ethics number: IL-101-10-2007).

In this study 27 adult male Sprague-Dawley rats (weighing 250-300 grams) were tested. LV function of the rats was normal according to the echocardiogram signal, the calculated ejection fraction and LV dimensions.

2.1. Protocol of rat echocardiography

Rats were sedated by an IP injection of 29 mg/kg Ketamine and 4.3 mg/kg Xylazine mixture, and their chest was shaved. The scan was performed, while the rats were laid in the left lateral decubitus position. A commercial echo-scanner was used - Vivid^{TM}i ultrasound cardiovascular system (GE Healthcare Inc. Haifa, Israel) with a 10S phased array paediatric transducer and a cardiac application. This transducer was utilized with a transmission frequency of 10 MHz, a depth of 2.5 cm and a frame rate of 225 frames per second. The echocardiography study consisted of acquiring cines at three short-axis levels: basal at the Mitral Valve, mid-ventricle at the Papillary Muscle tips, and the Apical cross-sections.

2.2. Global echocardiographic parameters

The outer diameter of the LV and the wall thickness were calculated from 2 dimension derived M-mode echocardiograms of the mid-vantricular level at end-diastolic phase as recommended [10, 11]. The LV wall thickness was calculated at the posterior wall. Thereafter, wall thickness to diastolic radius ratio was calculated. Fractional shortening and ejection fraction were calculated at the papillary muscle level by the Teichholz formula [11]. The heart rate was calculated from the ECG signal.

2.3. Speckle tracking echocardiography

The 2-dimensional ultrasound cines were post-processed by a commercial STE program called '2D-strain' (EchoPAC Dimension '08, GE Healthcare Inc., Norway). The program tracks the movement of the stable speckles that are observed in the B-mode images frame by frame [1]. The program requires the user to mark the endocardium and to choose the width of the myocardium. Thereafter, the program imposes a grid of points in the marked region, tracks the region of every point and evaluates the velocities at each frame [1]. Next, the velocities are de-noised by a 3-dimensional wavelet representation (MATLAB software, MathWorks Inc. USA), instead of being processed by the built-in smoothing of the commercial program. Thereby, the spatial resolution of the myocardial velocities is increased, and the calculation of strains at 3 myocardial layers and 6 segments is enabled, instead of averaging across the myocardium. Subsequently, the circumferential strain was evaluated from the circumferential velocities and the radial strain was evaluated form the radial velocities.

2.4. Statistical analysis

All values are presented as Mean±SE. For determining whether a parameter is heterogeneous or homogeneous among the different segments, one-way analysis of variance for unequal variance was used. P-values of less than 0.05 were considered statistically significant.

3. Results

3.1. Global left ventricular function

The values of the global echocardiographic parameters are summarized in Table 1. The results show that all rats were in a healthy condition.

Table 1. Global echocardiographic parameters.

Parameter	Value
End diastolic diameter, mm	10.3±0.2
End diastolic wall thickness, mm	1.6±0.04
Ejection fraction, %	77±1
Fractional shortening, %	41±1
Heart rate, beats per minute	271±6

The values are in Mean±SE.

3.2. Circumferential and radial strains

Typical circumferential and radial strain maps are seen in Fig. 1 and Fig. 2. The segmental heterogeneity is well noticed in both circumferential (Fig.1) and radial (Fig. 2) strain maps. Moreover, in the circumferential strain map the heterogeneity of the strain among the different layers is observed, as the circumferential strain is larger at the endocardium and smaller at the epicardium.

The results for 27 rats are depicted in Fig. 3 and Fig. 4. The heterogeneity of the circumferential strain among the different myocardial segments was observed at the apical and basal levels (P<0.001), while the circumferential strain at the mid-ventricle was homogeneous (Fig. 3). Furthermore, the radial strain was heterogeneous for all short axis levels (P<0.01).

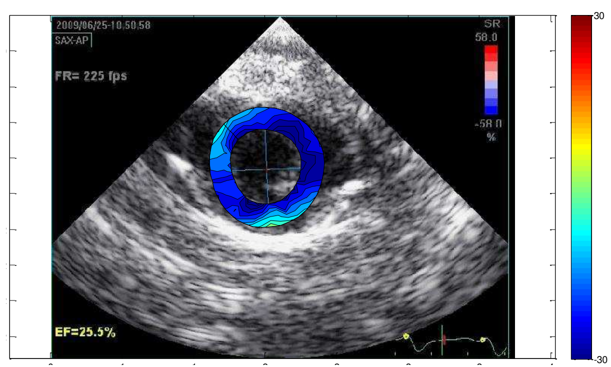

Figure 1. An example of a typical circumferential strain map during end systole. The map is depicted for an apical short axis scan. The values on the color-bar are in %.

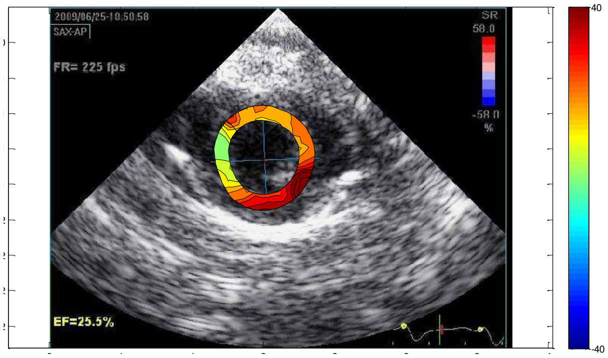

Figure 2. An example of a typical radial strain map at end systole. The map is depicted for an apical short axis scan. The values on the color-bar are in %.

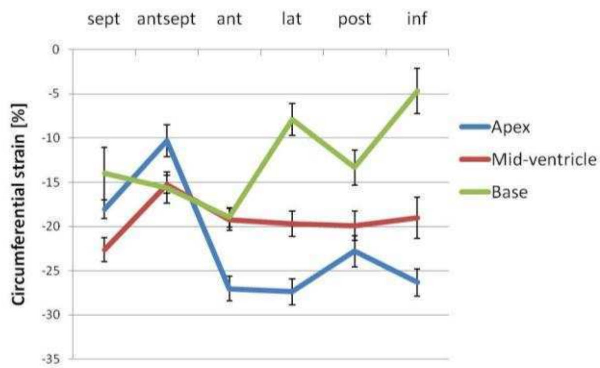

Figure 3. Circumferential strain results for 27 rats (mean±SE). The results are depicted for 3 levels of short axis: apical (blue), Mid-ventricular (red) and basal (green) and for 6 myocardial segments: septum (sept), anterior septum (antsept), anterior (ant), lateral (lat), posterior (post) and inferior (inf).

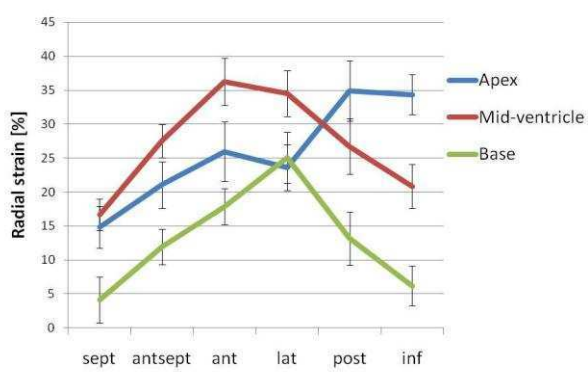

Figure 4. Radial strain results for 27 rats (mean±SE). The results are depicted for 3 levels of short axis: apical (blue), Mid-ventricular (red) and basal (green) and for 6 myocardial segments: septum (sept), anterior septum (antsept), anterior (ant), lateral (lat), posterior (post) and inferior (inf).

4. Discussion

When the myocardial velocities are smoothed, so as to reduce the effects of noisy data after the speckle tracking is performed, the high frequency components of the signal may be lost. Hence, the myocardial deformations may possibly look homogeneous by mistake. In this study a 3-dimensional wavelet de-noising algorithm was employed for the smoothing of the myocardial velocities. This kind of de-noising is able to remove noise and maintain the high frequency components of the myocardial velocities [9].

In the present study the hypothesis was tested whether the myocardial strains are heterogeneous between the myocardial segments. The main findings were: 1) in normal rats, the peak systolic circumferential strain is heterogeneous among the different myocardial segments at the apical and basal levels, while it is homogeneous at the mid-ventricular level; 2) in normal rats, the peak systolic radial strain is heterogeneous at all levels of short axis.

Previous reports used a commercial program that contains a different kind of smoothing algorithm than used here. The strain results on a rat model, which can be seen in the study of Popovic et al. in Fig. 2B and Fig. 2C [7, 12] and in the study of Migrino et al., in normal state, appear homogeneous and smooth in comparison with the results reported here. The difference between the results of this study and of the studies of Popovic et al. and Migrino et al is larger for the radial strain than for the circumferential strain. The radial strain of the myocardial segments, as reported in those studies, appears as a horizontal line, while the radial strain found in this study was heterogeneous within the various segments ($P<0.01$).

The main limitation of the wavelet de-noising process used here is its sensitivity to artifacts in the B-mode cines. The commercial program compensates for artifacts, such as areas in which the myocardium is shaded by the ribs (black area), by imposing there the averaged values. The wavelet de-noising shows no movement in these areas while the commercial program depicts normal movement. Thus, when applying the wavelet de-noising algorithm used here, it is important to include the whole annulus of the short axis within the echo scan.

5. Conclusion

The circumferential and radial strains, measured in a rat model, are heterogeneous among the various myocardial segments. This heterogeneity can be seen by applying 3-dimensional wavelet de-noising algorithm to the myocardial velocities instead of the built-in smoothing process of the commercial program.

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References

[1] Rappaport D, Adam D, Lysyansky P, Riesner S. Assessment of myocardial regional strain and strain rate by tissue tracking in B-mode echocardiograms. Ultrasound Med Biol. 2006 Aug;32(8):1181-92.

[2] Leitman M, Lysyansky P, Sidenko S, Shir V, Peleg E, Binenbaum M, et al. Two-dimensional strain-a novel software for real-time quantitative echocardiographic assessment of myocardial function. J Am Soc Echocardiogr. 2004 Oct;17(10):1021-9.

[3] Cho GY, Chan J, Leano R, Strudwick M, Marwick TH. Comparison of two-dimensional speckle and tissue velocity based strain and validation with harmonic phase magnetic resonance imaging. Am J Cardiol. 2006 Jun 1;97(11):1661-6.

[4] Helle-Valle T, Crosby J, Edvardsen T, Lyseggen E, Amundsen BH, Smith HJ, et al. New noninvasive method for assessment of left ventricular rotation: speckle tracking echocardiography. Circulation. 2005 Nov 15;112(20):3149-56.

[5] Notomi Y, Lysyansky P, Setser RM, Shiota T, Popovic ZB, Martin-Miklovic MG, et al. Measurement of ventricular torsion by two-dimensional ultrasound speckle tracking imaging. J Am Coll Cardiol. 2005 Jun 21;45(12):2034-41.

[6] Amundsen BH, Helle-Valle T, Edvardsen T, Torp H, Crosby J, Lyseggen E, et al. Noninvasive myocardial strain measurement by speckle tracking echocardiography: validation against sonomicrometry and tagged magnetic resonance imaging. J Am Coll Cardiol. 2006 Feb 21;47(4):789-93.

[7] Popovic ZB, Benejam C, Bian J, Mal N, Drinko J, Lee K, et al. Speckle-tracking echocardiography correctly identifies segmental left ventricular dysfunction induced by scarring in a rat model of myocardial infarction. Am J Physiol Heart Circ Physiol. 2007 Jun;292(6):H2809-16.

[8] Treguer F, Donal E, Tamareille S, Ghaboura N, Derumeaux G, Furber A, et al. Speckle tracking imaging improves in vivo assessment of EPO-induced myocardial salvage early after ischemia-reperfusion in rats. Am J Physiol Heart Circ Physiol. 2010 Jun;298(6):H1679-86.

[9] Bachner-Hinenzon N, Ertracht O, Lysiansky M, Binah O, Adam D. Layer-specific assessment of left ventricular function by utilizing wavelet de-noising: a validation study. Med Biol Eng Comput. 2010 Jul 20.

[10] Sahn DJ, DeMaria A, Kisslo J, Weyman A. Recommendations regarding quantitation in M-mode echocardiography: results of a survey of echocardiographic measurements. Circulation. 1978 Dec;58(6):1072-83.

[11] MacMahon SW, Hickey AJ, Wilcken DE. M-mode echocardiography: reproducibility of serial left ventricular measurements in subjects with normal ventricles and patients with congestive cardiomyopathy. Aust N Z J Med. 1983 Oct;13(5):457-62.

[12] Migrino RQ, Zhu X, Pajewski N, Brahmbhatt T, Hoffmann R, Zhao M. Assessment of segmental myocardial viability using regional 2-dimensional strain echocardiography. J Am Soc Echocardiogr. 2007 Apr;20(4):342-51.

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