Novel Time-Varying 3D Display of Wall Motion, Strain, Strain Rate and Torsion for LV Function Assessment

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Abstract

Advanced post processing of the standard acquisitions of echocardiographic data (i.e. 3 parallel short-axis views and 3 rotational long axis views) results in a total of 72 time-varying traces of segmental linear strains and 18 traces of segmental rotational data. If one separates the signal into endo, mid, and epicardial myocardial layers, a staggering 246 time-varying traces are available. The synthesis of this amount of data is extremely difficult. Our goal was to develop tools that can visualize this complex dataset in a single representation and use these tools to assess LV function in subjects to examine characteristic patterns.

1. Introduction

Advanced analysis of 2D echocardiographic data from various vendors is available to compute myocardial displacement, strain rate, strain, and torsion. Beyond basic dimensional measurements and calculations of area and volume, the ability to track the ultrasound speckle deformation provided by higher resolution acquisitions, both in terms spatial and temporal detail, permits computations of myocardial strain. Analysis generally begins with manual selection of a regional location at which the speckle pattern is tracked to obtain a regional myocardial velocity trace. Multiple selections of regions allow the investigator to compare different wall segments from the same echocardiographic view. A further step in automating this process has been shown where a set of locations is tracked, for example around the circumference of a short-axis LV image to obtain either a plot of strain as a function of location and time or a set of waveforms for each segmental region. While the m-mode plots of strain graphically show the distribution of strain over the cardiac cycle, they do so only for a single echocardiographic view.

The 2D speckle-tracking method used to compute strain is significantly different from prior tissue Doppler imaging techniques [1]. Speckles, or backscattered ultrasound patterns in the myocardium, create a unique pattern that can be tracked frame by frame to produce a 2D map of myocardial motion and deformation. This technique has been used to calculate global strain in myocardial infarction patients which demonstrated a close correlation to wall-motion score index [2]. Regional speckle tracking strain has also been used to differentiate infarct from normal myocardial segments [3] and to measure angular mechanics, or torsion, in short-axis views validated by tagged MRI [4].

LV wall motion and function are generally described in a segmental fashion using 16-18 myocardial segments. The bulls-eye plot is a common representation used in depicting regional function in a graphical manner. Three rings of the bulls-eye plot represent the longitudinal axis of the ventricle and generally show segments grouped from the base of the ventricle (in the outer ring) to the apex of the ventricle in the inner ring. Each ring of the bulls-eye is generally divided into 6 segments around the myocardium representing the circumferential axis of the ventricle. These 18 segments can be evaluated using 3 rotational views along the longitudinal axis of the ventricle, namely the 4-chamber, 2-chamber and 3-chamber view. These echocardiographic 2D views are obtained by rotation of the transducer in 60-degree steps. The two wall segments observed in each view are indicated on opposite sides of the bulls-eye or 180 degrees apart.

The main idea of this work was to create tools for the display of advanced regional measurements, such as longitudinal and circumferential strain in a bulls-eye representation.

2. Methods

Echocardiographic data used in this investigation was acquired from a GE Vivid ultrasound machine with capabilities enabled to store raw data in addition to DICOM data. This GE raw data format allows quantitative analysis in the GE EchoPac environment. Echocardiographic standard views (4-chamber, 2-chamber and 3-chamber) were utilized. EchoPac 2D Strain analysis was performed on each of these three views to quantify longitudinal and circumferential strain as shown in Figure 1. For each view this process allows the user to define the ventricular boundary as a starting condition to the speckle tracking algorithm. Following visual confirmation of the tracking results, the user is able to export an ASCII tab-delimited file with time-varying curves representing each of the six segments obtained from a particular view, along with the temporal resolution and the electrocardiographic waveform from the particular acquisition.

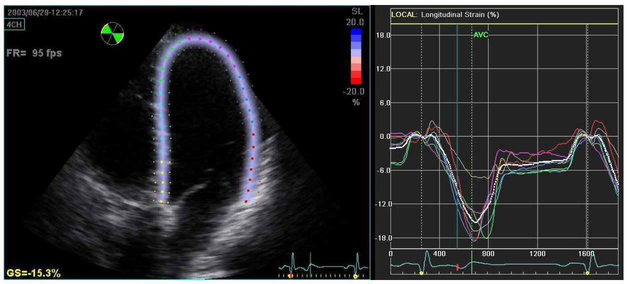

Figure 1: Example of GE Echopac display showing color strain map overlay (right) and segmental longitudinal strain waveforms (left) of a 4-chamber echocardiographic acquisition.

The first step of the tool developed reads sets of these files and reorganizes the data such that the parameter is a function of time and regional location such that electrocardiographic alignment from the three acquisitions is achieved. In general, each of the acquisitions has a slightly different heart rate and normalization is required. The user is able to see if the difference is too large and reject the subsequent processing.

The second step was to develop a bull's eye plot diagram showing the distribution of a parameter, for example longitudinal strain, at a single time point (e.g. end-systole). The regional distribution of the parameter was organized in a rectangular matrix array with x representing distance (apical, mid, basal) and y representing the counterclockwise rotational angle (anterior, antero-septal, septal, inferior, posterior, lateral). As the regional locations are sparse we selected to perform bilinear interpolation to achieve a smoother transition in these dimensions. The matrix was then warped onto a sphere to create a bull's eye plot.

Strain magnitude is represented by a color scale. Strain values at the boundaries of each segment are equivalent to the actual segmental value obtained by the trace while other values are interpolated. With the ability to create a pattern at on time point, the process can be repeated for each temporal sample to create a dynamic representation of strain development through the cardiac cycle.

The second step in development was an extension to show the time-varying changes in a dynamic display that demonstrates the evolution of strain.

3. Results

Figure 2 shows an example of the regional longitudinal and circumferential strain curves from a normal subject. Figure 3 demonstrates the bull's eye plots of the strain data shown in the previous figure. These plots are at the point in the cardiac cycle with peak negative strain.

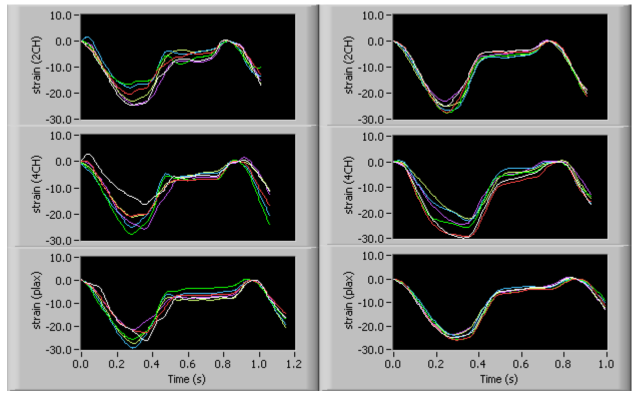

Figure 2: Regional longitudinal strain curves for a normal subject are show in the left column and circumferential curves are shown in the column to the right. Six segments for each echocardiographic view are show; 2-chamber in the top row, 4-chamber in the middle row, and 3-chamber on the bottom row).

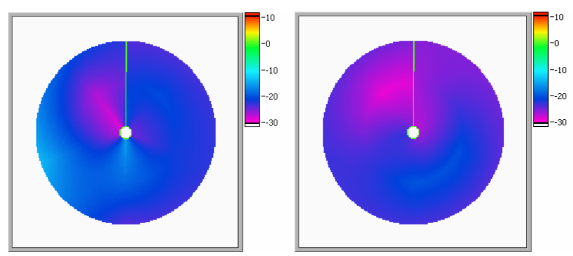

Figure 3: Bull's eye plots of the normal longitudinal (left) and circumferential (right) strain data shown in the previous figure.

Figure 4 shows a comparison of segmental longitudinal strain waveforms and bull's eye plots at the time indicated by vertical bar (yellow) in the waveform plots. Four subjects are shown and these are from top to bottom – normal, hypertrophic cardiomyopathy (HCM), dilated cardiomyopathy with left bundle branch block (DCM w/ LBBB), and a subject with a posterior scar. In this figure you can observer the degree of confusion in interpreting the large about of data available, even though this is only longitudinal strain information.

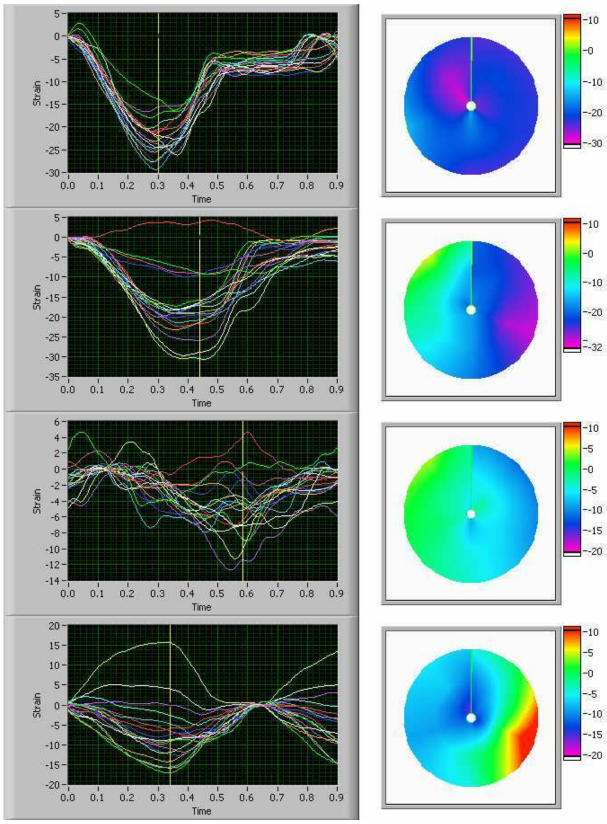

Figure 4: Comparison of segmental longitudinal strain waveforms and bull's eye plots at the time indicated by vertical bar (yellow) in 4 subjects: top to bottom – normal, HCM, DCM w/ LBBB, and scar.

In the normal example shown above, the strain at peak systole is rather uniform and has a value of approx -25. This illustration shows a patient with hypertrophic cardiomyopathy, a disease of segmental thickening of the ventricular wall. In HCM, the hypertrophic segments don't contract as well and there is less development of strain. Note the "green" basal anterior septal wall segment in HCM example vs normal control. The next raw shows a patient with dilated cardiomyopathy and left bundle branch block. This disease affects the conduction systems and makes the contract weaker and less synchronous. In DCM parametric bull's eye image, the segmental strain is of lower amplitude and very dysynchronous. The bottom row shows data from a patient that has had a previous myocardial infarction. From the plot, you can see that the effected region is the basal posterior segment that is scarred.

4. Discussion and conclusions

While parametric images have been previously shown for time-to-peak strain development, this display does not incorporate amplitude of strain data. Timing and amplitude is displayed in our parametric presentation in a manner that may allow improved clinical decision support.

Further development of a four-dimensional representation wire-frame mesh that contains both circumferential and longitudinal elements is being explored where wire-frame coordinates would be based on actual x, y, z coordinates obtained from the speckle tracking data. Regional "bricks" would be constructed and temporal deformation would be imposed using three components of linear strain and rotational data.

Acknowledgements

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