Original Article

A Comparison between Methods Used to Extract Maximum and Minimum Myocardial Velocities by Spectral Pulsed-TDI

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Background: Tissue Doppler imaging is an echocardiographic useful method in the assessment of left ventricular myocardial function in the clinical condition. Pulsed Doppler interrogation measures the instantaneous velocities of the myocardium which passes through the sample volume during the cardiac cycle.
Objective: The present study attempts to verify a computerized method to determine myocardial maximum and minimum velocities throughout the cardiac cycles using spectral pulsed-tissue Doppler imaging. The data of curves might be used to calculate myocardial physical and mechanical parameters throughout the cardiac cycle.
Methods: Spectral pulsed-TDI was performed to evaluate longitudinal function in 23 healthy volunteers by using a sample volume placed in 170 left ventricular segments. The velocities were extracted automatically based on four common edge detection algorithms using Matlab software. Labeling of connected components in boundary of spectrum allowed comparing the methods. In addition to analysis of variance and t-test, linear correlation and Bland-Altman analysis were calculated to assess the relationships and agreements between the systolic and diastolic results of measurements before and after using the computed program.
Results: Comparison of the means of the four edge detection methods showed that there are statistically significant differences between methods (number of labels were 12±3 for Canny, 20±4 for Roberts, 31±4 for Sobel and 39±5 for Prewitt respectively, $P<0.05$). There were not significant differences between measured velocities in the segments; before and after application of the Canny method. There was significant correlations ($r=0.99$ and $r=0.96$, $P=0.01$) at the base and mid segments, respectively with Bland-Altman analysis significant agreements between the measurements.
Conclusion: It is concluded that the proposed method automatically extracts myocardial velocities using spectral pulsed images. Canny method showed relatively favorable results and seems to be a preferable option to extract velocities from the spectral images. Correlation study and Bland-Altman analysis confirmed a good agreement between the measurements.

Keywords: Echocardiography, Pulsed Doppler, Velocity, Software Verification

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Introduction

Tissue Doppler echocardiography (TDE) or tissue Doppler imaging (TDI) is an validated ultrasound technique that uses shifts in Doppler frequencies for quantifying myocardial motion.[1,2] Mechanical phases of the myocardium are composed of different periods and appropriate sampling rate in imaging need to extract correct myocardial velocity profile.[3] Pulsed-tissue Doppler (pulsed-TDE) and color-coded tissue Doppler (color-TDE) are two TDE methods. Color-TDE is an extension of the pulsed-TDE method. Both methods employ low-pass filter and low gain to isolate myocardial low velocity and high intensity tissue Doppler signals from blood flow signals that reflects from red blood

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cells.[4,5]

Color-TDE uses autocorrelation analysis and the computed velocity is the mean of all velocity component found within the sample volume.[6] Pulsed-TDE is available on most commercial echocardiography systems and in everyday practice most clinicians use spectral pulsed-TDI to assess left ventricular (LV) function. Pulsed-TDE provides a spectrum of myocardial tissue Doppler velocities within the sample volume.[7] Thus, the maximum and minimum velocities can be chosen by determining the outer and inner borders of the spectrum respectively. Alternatively, speckle tracking imaging (STI) technique based on measurement of speckles motion within the tissue on 2-dimensional ultrasound imaging was presented that typically works on lower temporal resolution data.[8-10] The present study suggests a computerized method with various edge detection algorithms to determine these myocardial velocities using pulsed-TDI. The data of curves might thus be used to calculate myocardial important parameters for example myocardium accelerations and displacements or myocardial mechanical parameters throughout the cardiac cycle.

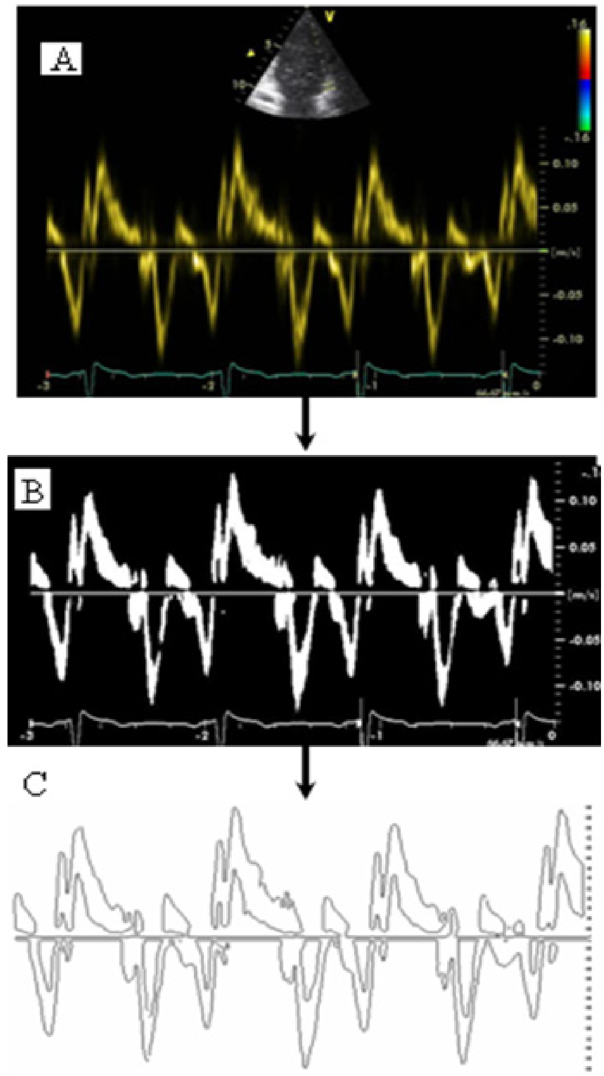

Figure 1. Three steps of the presented method to determine maximum and minimum myocardial velocities using spectral TDI throughout the cardiac cycle. A: Spectral pulsed-TDI; B: Binary image; C: maximum and minimum myocardial velocities.

Methods

The present analytical study carried out from December 2010 to May 2011. All echocardiography examinations were performed in the Department of echocardiography, Shaheed Rajaei Cardiovascular Medical and Research Center, Tehran University of Medical Sciences, Tehran, Iran and image processing and analysis were performed in Heshmat Cardiovascular Research Center, Guilan University of Medical Sciences, Rasht, Iran.

Study group:

The participants under study consisted of 23 healthy volunteers (14 men and 9 women, aged from 35 to 63 years (44±10 years), who had no cardiac abnormality on clinical, EEG, and Doppler echocardiographic examinations, and no history of cardiovascular disease, angina, diabetes and medication. This study was approved by the local Ethics Committee, with the participants giving written informed consent.

Acquisition of Echocardiographic images

Echocardiography studies were performed using a Vivid7 GE echocardiography system (GE, Milwaukee, Wisconsin, USA) with an ergonomically designed M3S transthoracic sector multi-frequency transducer (2.5-4 MHz). In the left lateral position, TDI was performed using real-time pulsed-TDI in the apical two and four-chamber views for accessing myocardial velocities at the end of expiration, according to guidelines of the American Society of Echocardiography. The sector angle was adjusted and care was taken to obtain the data by limiting the angle of interrogation in an attempt to align at as low degrees as possible with longitudinal motion. An 8 mm sample gate was placed in the middle of LV base and mid segments. Appropriate scale, sweep speed and low-gain settings were used for optimizing the spectral display. Isovolumic contraction, ejection phase, isovolumic relaxation, early and late atrial contraction velocities were identified in the spectrum of myocardial velocities, respectively (Fig. 1A) and the images stored at least in three cardiac cycles.

Off-line Analysis

The spectral pulsed-TD images transferred to a personal computer for off-line analysis via a program written in the Matlab software version 7.08 to automate the extraction of maximum and minimum myocardial regional velocities throughout the cardiac cycles. In this program, a full-color image converts to binary image before the edge detection to enhance the edges (Fig. 1B). The velocities were extracted automatically via this program based on four common edge detection methods/algorithms separately that propounded in the image processing (Sobel, Canny, Roberts and Prewitt methods, Fig 1C). The Sobel operator acts locally on the image and detects edges at small scales and is sensitive to regions of high spatial frequency that correspond to edges and will generate local edge data instead of recovering the global structure of a boundary.[11] By the Canny operator, an image is smoothed by Gaussian convolution and then a simple first derivative operator is applied to the smoothed image to highlight regions of the image with high first spatial derivatives.

Edges in images often are areas with high gradient magnitude. Canny's algorithm determines high gradient values on an image and creates a thin line.[12,13] Roberts's algorithm uses a simple and fast algorithm to calculate the spatial gradient on an image. In this method, areas with high spatial frequencies are determined, thus the values of pixels will be an estimate of the spatial gradient of the input image. Prewitt's algorithm uses a set of matrixes or masks which are sensitive to edge orientation and magnitude. In this method, the edge orientation and magnitude are determined by convolving the image with the masks and finding the maximum responses.[11,13]

Labeling of connected components in boundary of the binary images was used in our program, allowing for a comparison between the methods. The edge detection method that leads to fewer numbers of labels or more connectivity, means that the edge detector has better performance

Verification Study and Statistical Analysis

The accuracy of the program was verified by using two methods; linear correlation and Bland-Altman analysis.[14] For this reason, we measured systolic and diastolic peaks using original spectral pulsed-TD images. The program was then applied on the same images and the velocities were determined again. The linear correlation was calculated to assess the relationships between the results of the two measurements. In addition, Bland-Altman analysis was calculated to evaluate agreements between the two measurements, before and after using the computed program.

All the statistical analyses were performed using the SPSS software package (SPSS Inc. Chicago, IL, USA). The data were expressed as mean±SD, and the comparisons between the differenc¬es were made using the analysis of variance (ANOVA) and paired samples t-test. Results were considered significant when the p-value was <0.05.

Results

In 23 healthy volunteers that participated in our study, mean systolic blood pressure was 116±8 mmHg and mean diastolic blood pressure was 72±7 mmHg. All were in sinus rhythm and mean heart rate was 75±8 beats per minute, left ventricular ejection fraction 56±9% and body mass index 21±3).

In this study we analyzed a total of 184 segments in the healthy population. Although great care was taken to ensure the quality of the data, 14 (8%) segments were excluded from the final analysis because of mostly either the presence of artifact or higher noise effect. Among the 170 segments included in the study; 91 base segments and 79 mid segments from LV inferior, anterior, septum and lateral walls were evaluated in this study.

All edge identifying methods showed relatively favorable results in detecting maximum and minimum velocity data (visual assessment). Based on labeling results calculated from average of three cardiac cycles (quantitative assessment), Canny method (12±3) had better results compared to other methods. Using ANOVA, the comparison of the means of four edge detection techniques showed statistically significant differences between methods (12±3 for Canny, 20±4 for Roberts, 31±4 for Sobel and 39±5 for Prewitt, P<0.05) and multiple comparisons showed no statistically significant differences between the methods (P<0.05).

The verification was evaluated and presented only for the method of Canny because it was superior to other methods. The results of the peak systolic, early and late diastolic velocities from the longitudinal assessment at the LV base and mid segments are presented in Table 1. The first measurement was directly related to using spectral imag-

Table 1. Comparison of the peak systolic, early and late diastolic velocities from the LV base and mid segments (m/s), before and after using the Canny edge detection method

LV Segments	spectral TD (m/s)	Canny (m/s)	P-value
Basal (n=91):			
Peak systole	0.114±0.026	0.110±0.025	0.676
Peak early diastole	0.116±0.020	0.115±0.020	0.782
Peak late diastole	0.071±0.015	0.069±0.016	0.706
Middle (n=79):			
Peak systole	0.074±0.026	0.070±0.025	0.606
Peak early diastole	0.077±0.020	0.074±0.019	0.650
Peak late diastole	0.041±0.015	0.039±0.016	0.710

Spectral TD: measured velocities from original spectral TD images; Canny: measured velocities after using Canny method on spectral TD images

es and the second was to check the efficacy of the edge detection method after using Canny method. There was not statistically significant differences between the two methods at 95% confidence level in all the segments (P>0.05).

Figure 2 shows significant correlations between velocity measurements in base segments before and after use of the Canny method in 23 healthy volunteers (Y=0.9653*X-0.0013, r=0.99; P=0.01). Almost similar results were obtained for mid segments (r= 0.96; P=0.01). For Bland-Altman analysis (Fig. 3), the difference between two measurements before and after applying the program plotted against the average of both observations. The mean difference between the two measurements was 0.004±0.009 mmHg. The middle line indicates the average difference between the two methods, whereas the outer lines represent ±1.96SD or the 95% limits of agreement (LOA).

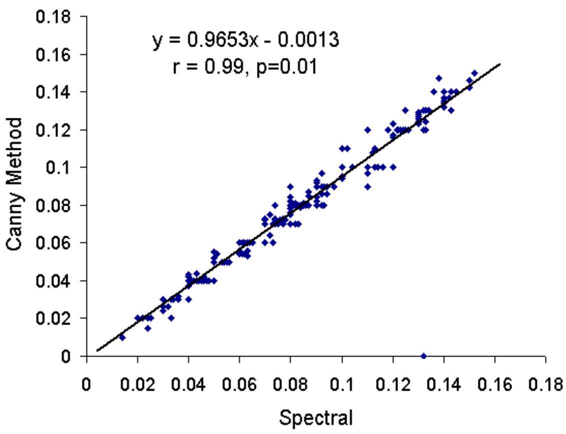

Figure 2. The correlation of the two peak-systolic, early and late diastolic velocities (m/s) measured from original spectral pulsed-TD images and after using the Canny method at the LV base and mid segments combined.

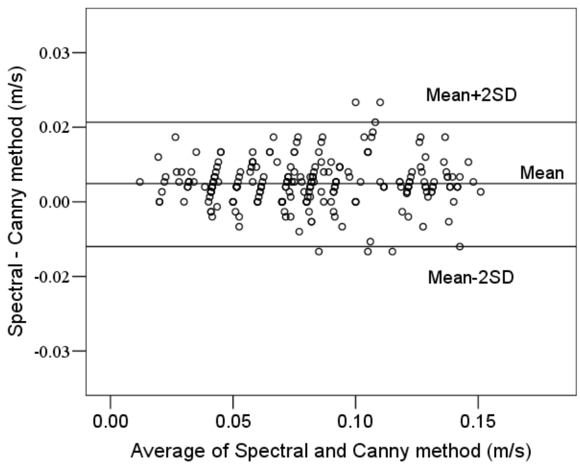

Figure 3. The Bland-Altman diagrams with 95% limit of agreement.

Discussion

Today, quantification of myocardial function is one of the major issues discussed in clicical cardiology. Traditional methods for evaluation of regional myocardial function using echocardiography are subjective, tedious, time-consuming and only partially quantitative. On the other hand, because of echocardiographic low quality and high image noises, automatic analysis is challenging.[15] New ultrasound techniques such as TDE/TDI is able to detect myocardial tissue velocities in very brief events and displays a spectral Doppler waveform or in a color-coded manner reveal potential application in assessing regional myocardium in various pathologic conditions. An advantage of pulsed-TDI is an improved temporal resolution and the ability to quantify maximum and minimum rather than mean myocardial velocities.[2,16-20]

Several studies show that ultrasound images can be used to evaluate the properties of tissue by calculating physical and mechanical parameters. In order to determine the interface location, for example the measuring of intima-media thickness and internal diameter of arteries, computer-based boundary detection algorithms are commonly used. The important goal of these studies was introducing automated procedures to make the measurements objective and less time-consuming.[21-29] This study presents a fully automated procedure to extract myocardial velocities throughout the systolic and diastolic phases from echocardiographic pulsed-TDI using various edge detection methods. In an image, edges are places with strong intensity contrast and representing object boundaries. The edge detection methods are commonly used in the image processing. Since edges consist of mainly high frequencies, nowadays it is possible to detect edges by applying a high-pass frequency filter in the Fourier domain or by convolving the image in the spatial domain.[30] In this study, we applied edge detection in the spatial domain, because it often yields computationally better results. The method is fast and leads to objective result which does not suffer from a considerable variability. Verification study showed excellent result with linear correlation (Fig. 2) and Bland-Altman analysis (Fig. 3). The coefficients of correlation were 0.99 and 0.96 at base and mid segments respectively, which statistical analysis of Bland-Altman with the mean difference and limits of agreement confirmed this correlation. In other words, Bland-Altman analysis showed limits of agreement to be small enough to ascertain that the applied method can be used for clinical purposes.

Using these data, additional parameters can be derived to further evaluate myocardial function. For example, integrating the velocities throughout cardiac cycle yields tissue displacement or total amount of tissue movement[31,32] and derivation of the velocities throughout cardiac cycle yields myocardial acceleration.[33,34] Thus, the tissue Doppler image provides a way to measure the segmental myocardial velocity, displacement and acceleration, which are valuable parameters in clinical practice. Alternatively, one may calculate the spatial derivative of the velocity data to obtain strain rate and strain, a fundamental measure of tissue contraction and relaxation that avoids many limitation of tissue velocity alone.[35]

Several limitations are to be noted in this study. Edge function in Matlab's image processing toolbox supports six different edge detection methods. In this study we investigated the most commonly used edge detection methods; therefore the reported data are limited to these techniques. Laplacian of Gaussian and Zero-Cross methods were not utilized in this study because these templates implements second order differentiation and have a major drawback of being highly sensitive to noise.[11,30]

Pulsed-TDI can compute velocities only for one sample volume. Therefore, to make measurements in a few segments, the operator has to examine each segment separately during any scan and different cardiac cycles. In addition, in this study we did not consider apical segments because it is shown that due to difficulty in analysis and angle dependency of the Doppler method, most of these segments have to be ignored.[36]

It can be concluded from our experience that the proposed method has the ability to automatically extract minimum and maximum myocardial velocities using spectral tissue Doppler images. In this study, four edge visual detection methods showed relatively favorable results used for fully automated estimation of myocardium accelerations and which might thus be displacements throughout the cardiac cycle. Given that Canny method provides statistically significant result of fewer labels, it seems to be a superior option. A practical application of the presented method is its ability to measure physical and mechanical parameters of the myocardium by using the echo systems equipped with spectral pulsed-TDI that can be used on a wide range of equipments.

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